The World Salmon Farming Industry

Key Points

- ✔ The origins of salmon farming can be traced back to fertilization trials in Europe in the second half of the eighteenth century. Hatcheries were established one century later in both Europe and North America. Hatchery-based enhancement programs were introduced at a significant scale only after the 1950s in Japan, the USSR, United States and Canada. The modern techniques of salmon culture in floating sea cages were initiated in Norway in the late 1960s.
- ✔ By the 1980s and 1990s, commercial salmon farming was well established in many temperate countries around the world (Norway, Scotland, Chile, Canada, etc.). In 1996, salmon aquaculture overcame the salmon fishing industry as the most important supplier of salmon products worldwide. By 2004, global production of farmed salmon exceeded wild harvests by more than one million metric tons (mt).
- ✔ There is little potential for further growth in countries such as Scotland and Ireland. Excessive regulatory pressure and conflicts with user groups also limit development in the United States and Canada. Salmon farming appears to have the brightest future in Chile due to ideal environmental conditions and a favorable business climate. Average annual growth rate of the industry between 1984 and 2004 was 42 percent (FAO 2006).
- ✔ The United States has developed advanced hatchery and marine growout technologies but ocean-pen production accounts for less than 1 percent of global supply. Alaska placed a permanent moratorium on private, for-profit farmed salmon and salmon trout in 1988, but still allows enhancement programs, which account for a large share of its harvest.
- ✔ Increased supplies have generally resulted in falling prices. These low prices appear to have created more problems for the traditional fisheries than for farmed producers since the latter have managed to reduce production costs and improve marketing while the traditional salmon sector has been slow to adjust.
- ✔ Transgenic technologies offer new opportunities and new challenges for expansion of the industry.

Introduction

The culture of salmonids (particularly Atlantic salmon, *Salmo salar* and salmon trout (*Oncorhynchus mykiss*) is one of the most important examples of commercially successful intensive aquaculture in the world. It is a demonstration of what can be achieved through conscious investment, innovative research, technological advances and creative marketing strategies. At the same time, it has served to illustrate the dangers of rapid development and depressed prices that result when market capacity to absorb increasing supplies is exceeded.

Of the several salmonid species (including all salmon species and salmon trout) cultured for commercial purposes worldwide, Atlantic salmon is by far the most important. Its native range is the North Atlantic, from New England to Ungava Bay in Canada in the west, Iceland, Greenland and from northern Portugal to the Kara Sea off Russia on the east (Laird, 1996). Its potential for farming is excellent since it is relatively easy to handle, it grows well under culture conditions, it has a relatively high commercial value and it adapts well to farming conditions outside its native range.

Of the five Pacific salmon species that are commercially caught in North America —pink, chum, sockeye, coho and chinook —only coho and chinook are valuable enough for salmon farming. Pink and chum are low value and thus not attractive to salmon farmers. Sockeye salmon is less adaptable for farming because it has lower growth and survival rates, it has a lower fillet yield and it is more susceptible to stress leading to poor product quality. In addition, much less research has been conducted on sockeye salmon aquaculture as compared to species such as Atlantic salmon. Salmon trout (*Oncorhynchus mykiss*) is also commercially important, can be farmed in freshwater or seawater installations and is often also referred to as "steelhead trout" or "rainbow trout."

The preliminary sections of this chapter will provide a brief review of the major steps involved in modern salmon aquaculture (primarily based on Willoughby 1999). For the rest of the report, farmed salmon will be considered as including both salmon and salmon trout.

Subsequently, an historical account of salmon ranching and net-pen culture development in different regions of the world is provided. Production trends will be reviewed for each major producing country and the industry as a whole as well as potential for further expansion.

The chapter ends with a brief summary of the major factors that have contributed to the remarkable growth of the industry, some of the major issues surrounding the use of commercial salmon feeds and the potential role of biotechnology in the future of salmon farming.

From egg to market size

The production of salmon in intensive aquaculture recreates the life cycle of the species in a protected environment. As such salmon farming consists of both a freshwater and a marine phase. The freshwater phase encompasses the spawning cycle, egg production, hatching and first-feeding stages. As the fry develop, they turn into fingerlings and finally grow to become *smolts*. At this point the fish have become physiologically adapted to seawater conditions. Hatchery fish are released from the hatcheries at or slightly before this stage, as discussed in Chapter IV.

In the second phase, smolts are transferred to the marine environment, reared to market size and harvested. If the fish develop into sexually mature adults in their first year at sea, they are known as *grilse*. Grilse are graded out and harvested before maturity because their flesh is of inferior quality. The remaining salmon are allowed to grow to market size, generally 3-5 kg and above.

Adult fish with outstanding features are selected and managed as the broodstock—stock from which eggs and milt are taken. The general goal of the breeding programs is to transmit the desirable traits of the broodstock to the offspring generation.

Broodstock management: In contrast to managing hatcheries for enhancement purposes, broodstock management for fish farms has different objectives. Broodstock are subject to two types of selection, depending on the characteristics of the desirable trait. Individual (or phenotypic) selection is conducted when emphasis is placed on external characteristics (size and skin color) or performance (growth rate). For this type of selection, the number of broodstock should be kept fairly high, with a minimum of 50 or more for each sex (Gjerde 1993). Selection of desirable traits such as disease resistance or harvest quality is done through a more difficult method known as family selection, which requires careful monitoring and marking. To maximize reproductive success, broodstock should always be maintained under carefully controlled conditions and fed a special diet with vitamins and minerals.

The hatchery: The hatchery phase is probably the most technically demanding, requiring a high degree of organization and planning. The objective of this portion of the cycle is to maximize the yield of quality fry for rearing to smolts with a survival rate of more than 90 percent. Survival under natural conditions is considerably lower (around 0.12 percent for Atlantic salmon), because predation by larger animals occurs at much higher rates. After hatching, the young fish feed on the contents of their yolk sac for several weeks and are called yolk-sac fry or alevins. On a dry-weight basis, the yolk makes up about 75 percent of the alevins' weight. At about four to six weeks after hatching, the yolk-sac has been almost totally consumed and the alevins are generally developed enough to start feeding. Starter diets formulated with feed ingredients, such as freeze-dried fishmeals and fish oils, give rapid growth.

Fry and fingerling development: When the alevins begin to feed they are known as fry. During this phase, growth is rapid and the fish can increase body weight by five to seven percent each day. As they develop, fry become more accustomed to solid feed and increase their activity. When the fry are sufficiently developed, they are transferred into larger tanks. Once fry reach an average weight of about five grams, they are known as *fingerlings*. Fingerlings display characteristic ovoid stripes along their flanks.

Smolt production: Once the larger fingerlings are sufficiently developed, they will undergo major physical and physiological changes to become smolts. These changes mark the transformation from freshwater fingerlings to seawater fish (Fitzgerald et al. 2002). The smoltification process involves changes in most organ systems, both morphological (silvery color), physiological (ATPase activity) and behavioral (swimming with the current), which will allow the fish to survive, grow and develop normally in the marine environment.

Growout phase: Smolts are transported from the smolt production facility to the growout site in specialized tanker trucks or well boats. Growout is primarily conducted in the sea in nets, which are supported by some type of floating structure. If cages are placed in sheltered fjords and bays, designs do not need to be particularly strong. However, expansion of the industry in most countries will involve installation of farms in more exposed sites with stronger currents, which obviously requires cages of a more solid construction. Today, most marine salmon cages have galvanized steel or plastic frames. Cage size has increased over the decades as a result of health and financial considerations. Volumes are now likely to be several thousands of cubic meters, compared with less than 100 in the early days of the industry (Myrseth 1993).

Use of Antibiotics in Fish Feed

There has been a significant amount of discussion concerning the use of antibiotics in salmon feed. There are several concerns, including the concerns of antibiotic residues in the salmon flesh that might affect consumers' health as well as antibiotics that are either passed through the fish into the environment or go directly into the environment through uneaten feed. Figure V-1 shows the antibiotic use in Norwegian salmon and salmon trout aquaculture from 1980 through 2001. The levels of use were highest in the late 1980s, and have dropped precipitously since then. We do not have similar data for Chilean or Canadian aquaculture.

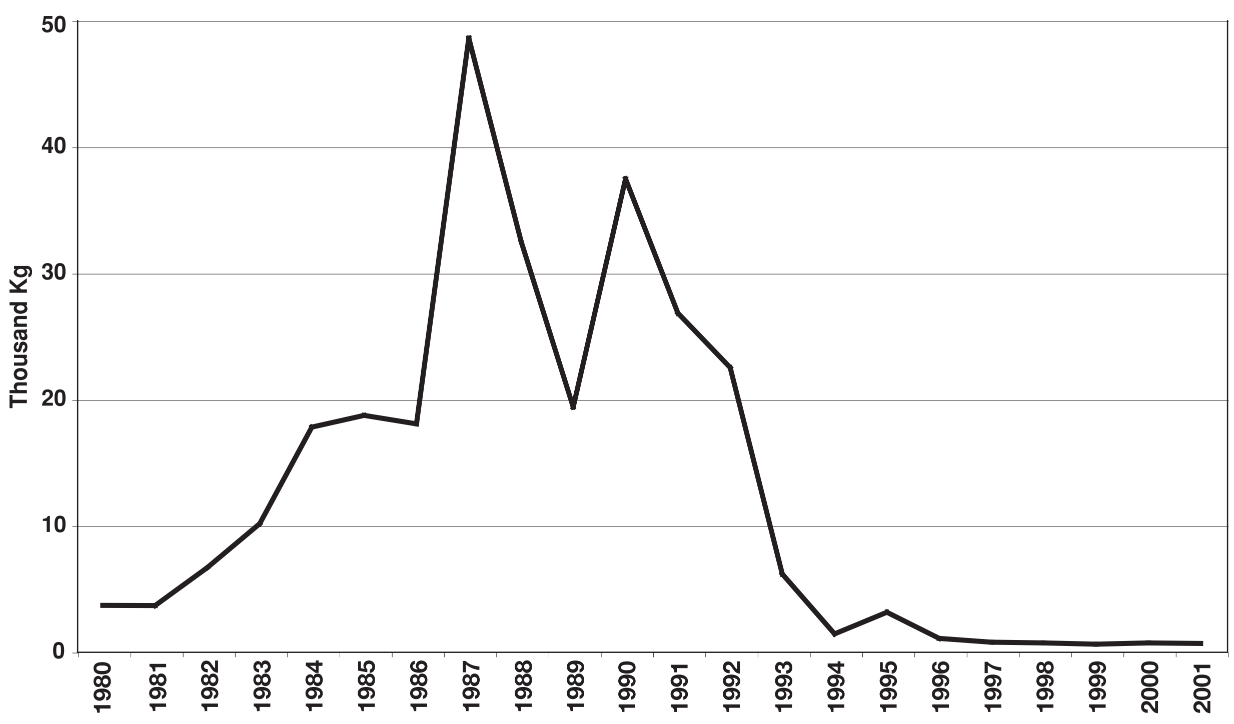
Historical development of salmon farming

The general life history of the Atlantic salmon was first described by Hector Boece, the first Principal of the University of Aberdeen (UK) in 1527 (Laird 1996). The first fertilization trials for Atlantic salmon took place in Germany in 1763 (Francis 1865) and were later refined by biologists in Scotland and France.

In the second part of the nineteenth century the techniques of artificial fertilization and incubation of salmon eggs were well developed and soon thereafter hatcheries were established in both Europe and North America. This development was motivated by the recognition that natural stocks of salmon were in decline (Thorpe 1980) and the desire to introduce salmon and trout outside their native ranges.

The history of salmon aquaculture is shown in Table V-1. Beginning in 1976, with the enactment of the 200-mile-limit fishing zones and other constraints to high seas salmon fishing, Japan began promoting hatchery programs and aquaculture development. By the late 1990s the hatchery-based salmon harvest represented approximately 80 percent of Japan's total salmon production.

Figure V-1 **Use of Antibiotics in Norwegian Salmon and Salmon Trout Aquaculture**



Source: Norwegian Institute of Public Health; data provided by Sigbjørn Tveterås, University of Stavanger, Norway.

Table V-1	Milestones in the salmon aquaculture industry
1857	First hatchery propagation of Pacific salmon.
1950s-1960s	USSR, Japan, United States and Canada begin enhancement programs.
1960s	Norwegian salmon aquaculture emerged.
1974	Private, for-profit salmon ranching starts in Oregon.
After 1976	Japan chum hatchery increases rapidly.
1979	Norway, United States, Canada, Chile, Japan and Scotland have emerging salmon farming industries.
Late 1970s-1980s	North American and Japanese hatchery programs grow significantly.
1980	World farmed salmon production accounts for about 1% of world salmon supply.
1983	World farmed salmon production exceeds world wild chinook salmon harvest.
1986	World farmed salmon production exceeds combined world wild chinook and coho salmon harvest.
1990	World farmed salmon production exceeds combined world wild chinook, coho and sockeye salmon harvest.
1991	World farmed salmon production exceeds Alaskan salmon harvest (all species).
1992	World farmed salmon production accounts for ~ 46% of world salmon supply; all U.S. private, for-profit salmon ranching has failed.
1994-1995	Chileans introduce the chef-ready pin-bone out (PBO) fillet. U.S. imports escalate.
1996	World farmed salmon production exceeds combined harvest of all wild salmon species. Atlantic salmon dominates pen-raised production.
1996- 2004	Increasing market development with farmed salmon as the leader. International prices and production costs continuously decline. Increasing criticism of salmon enhancement programs. Chile and Norway establish record production levels in 2004 with a joint production of nearly 1.2 million mt (round weight). Gap between world aquaculture production and wild combined harvests widens.

Source: Anderson 1997

In the United States, private salmon ranching was attempted in California (only one salmon ranch received a permit) and Oregon. Salmon ranching is essentially private stock enhancement where the ranch attempts to make profits from the returning salmon which escape the fishery and natural mortality. Anadromous, Inc. (started in 1974; controlling interest purchased by British Petroleum) and Oregon Aqua-Foods (started in 1974; purchased by Weyerhauser in 1975) were the most significant operations in Oregon under way by 1980 (R. Mayo and C. Brown, The Mayo Associates, Seattle, Washington, unpublished manuscript). All private salmon ranching in the United States was discontinued by the early 1990s.

While public salmon enhancement programs were growing, private pen-raised salmon began to emerge throughout the world. Salmon aquaculture was originally devised by Danish farmers as a system of earthen ponds for the rearing of the freshwater rainbow trout during the 1890s. The technique was quickly adapted in neighboring Norway but the system failed because of the lower water temperatures that resulted in a shorter growing season (Willoughby 1999).

However, it was soon realized that the seas around Norway, warmed by the influence of the Gulf Stream, would be more suitable than freshwater. This warm oceanic current allows year-round growth of fish as far north as 70º latitude.

Rainbow trout was first reared in seawater in Norway in 1912 but production at a commercial scale did not occur until the 1960s and early 1970s. Production peaked in 1974 at 2,200 mt but quickly declined thereafter due to low prices. Farmers then turned to Atlantic salmon, which was fetching a much higher price at the time (around 27-32 Norwegian kroner (NOK) per pound or US$4-4.5 per pound) (Willoughby 1999).

By 1969, the Grønvedt brothers had already begun growing Atlantic salmon on the Island of Hitra, Norway, in floating net pens (Edwards 1978). Systems of sea enclosures and floating sea cages were refined in the early 1970s and the industry soon began to be profitable. By 1972, there were five farms producing a total of 46 mt in Norway and by 1980, there were 173 farms producing a total of 4,300 mt (Heen et al. 1993).

The Norwegian industry began a period of impressive growth but license restrictions on farm size imposed by the government in subsequent years effectively drove investment and expansion overseas. As a consequence, net-pen salmon farming is today also well-established in Scotland, Ireland, Chile, Iceland, Canada, the United States and Australia.

The combination of suitable environmental conditions and pro-business governments in these locations, as well as the expansion of international trade during the 1980s and 1990s, made salmon farming the most important source of salmon products in the world today.

Global farmed salmon production exceeded the world's total commercial harvest of wild and ranched coho and chinook salmon by the mid-1980s; it exceeded the world's combined production of coho, chinook and sockeye salmon by 1990; and it exceeded all commercial harvests of wild salmon by 1996 (Table V-1). Global production of farmed salmon and salmon trout exceeded wild harvests of salmon by more than one million mt in 2004 and the gap is expected to widen in forthcoming years (Figure V-2).[1] The development of the pen-reared salmon industry in the major producing countries is further discussed below.

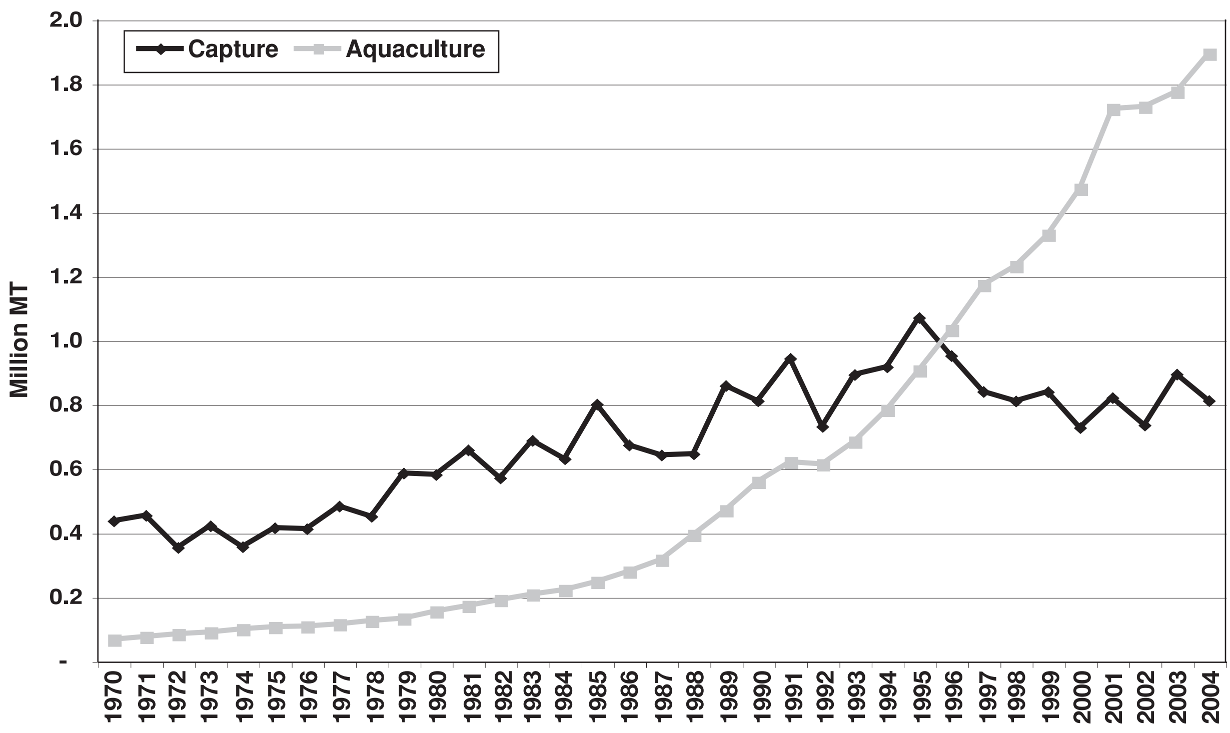
Development in Europe

Norway

The salmon industry developed rapidly in Norway in the last three decades, reaching a total value of over US$1.5 billion in 2004 (FAO 2006). Instrumental to this success was the decisive support of the government in terms of research and development programs, particularly in the early years of the industry's development. More recently, research and development by the private sector, especially the feed and pharmaceutical firms, has been essential to continued productivity gains.

Figure V-3 shows the contribution of Norway to the global supply of farmed salmon. Leading world production of Atlantic salmon since the late 1960s, Norway became the most important producer of farmed salmon in 1984. Reaching more than 600,000 mt in 2004, production has grown at annual average rate of 17 percent between 1984 and 2004 (FAO 2006).

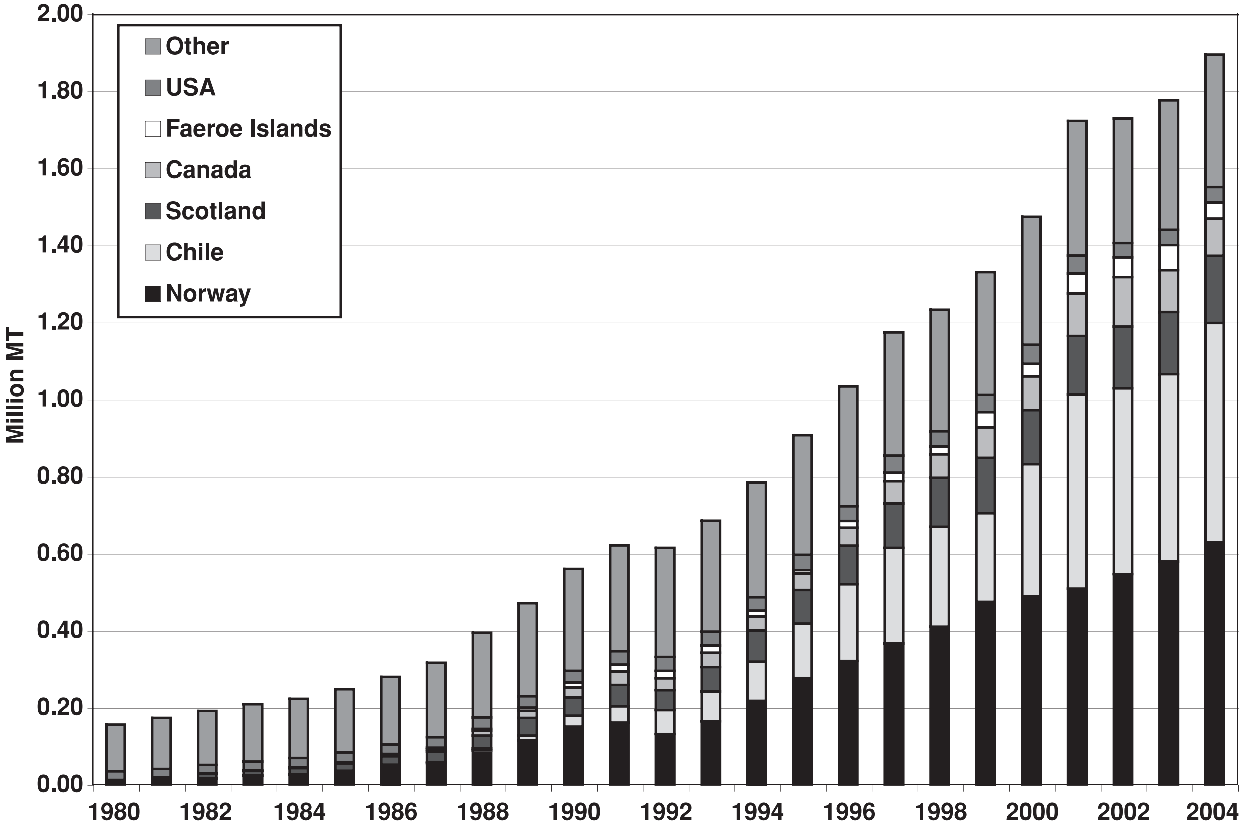
Figure V-2 **World Production of Salmon and Trout: Capture Fisheries vs. Aquaculture**



Source: FAO (2006)

[1] Figures V-2 and V-3 include all species of salmon and trout reared in marine and freshwater environments.

Figure V-3 **World Aquaculture Production of Salmon and Trout**



Source: FAO (2006)

The sheltered fjords and islands along the Norwegian coast provide excellent hydrographical conditions for the rearing of Atlantic salmon. The industry also benefited from substantial governmental investment in the development of a complex infrastructure of roads and rail links along the coast.

In 1970, production of Atlantic salmon was only 480 mt but it rose to 49,000 mt by 1986. Fearing that a few large companies would dominate the industry, the government set up a licensing program that limited farm size to a maximum of 8,000 m^3 of rearing volume. This limit was increased to 12,000 m^3 in 1989, with a maximum fish density of 25 kg/m^3 (Willoughby 1999).

The industry suffered the consequences of its own success in the early 1990s as overproduction led to a sudden downfall in prices. Many small farmers went bankrupt and the industry had to be reorganized in order to cope with the new market conditions (Hjelt 2000). New laws introduced in 1991 relaxed local ownership and made it possible for a farmer to own several farms.

This was the first indication of consolidation in the industry, marking the beginning of vertically integrated production, i.e., the control and/or ownership over the various production stages: hatchery, smolt production, growout and processing.

The new aquaculture laws and market pressure led to a tremendous decrease in the number of salmon and trout farming companies in the country, from approximately 1,100 in 1990 to 270 in 1998. It is now recognized that this consolidation process has allowed the Norwegian farming industry to retain its highly competitive profile in today's global market (Forster 2002).

Scotland

Salmon farming began in Scotland in 1966 with the experimental culture of sea-caged rainbow trout by Marine Harvest Ltd. Development was slow during the initial years but it accelerated during the latter half of the 1980s thanks to the financial support programs from the European Community (Integrated Development Program) and the Highlands and Islands Enterprise Council (Willoughby 1999). Development was more rapid in the Western Isles (Shetland) because of the exceptional growing conditions, similar to those found in Norway.

Although there was always a transfer of culture technologies, managerial skills and genetic material from Norway to Scotland, the Scottish industry did not evolve in the same way as did its counterpart in Norway. To operate within a certain area, Scottish farmers are required to obtain leases from the Crown Estate Commissioners, the government entity that regulates use of coastal zones in most of the UK.

However, there are not licensing systems restricting farm size or multiple ownership of farms. As a result, for many years the average Scottish farm was larger than the corresponding Norwegian farm. Also, vertical integration occurred much earlier in Scotland and by the early 1990s most of the Scottish farms were owned by multinational corporations (Hjul 1994).

Production has been increasing steadily over time (Figure V-3), reaching nearly 175,000 mt in 2004 (FAO 2006). However, the industry has suffered its share of setbacks, particularly in the early 1990s. Overproduction during these years led to bankruptcy for several farms because of very low salmon prices.

By the time prices recovered and the industry found itself again in the doorsteps of expansion, the oil tanker *Braer* spilled over 85,000 tons of crude oil off the coasts of Shetland. Because of the resulting pollution, the Shetland Salmon Farmers Association and the International Oil Pollution Compensation Fund agreed to destroy the entire smolt generations of 1991 and 1992. Disease problems (sea lice and furunculosis) as well the shortage of suitable sites have constrained further development of the industry in recent years.

The first farm in Scotland, Marine Harvest Ltd., founded by the Anglo Dutch multinational Unilever, was for many years the leading farmed salmon producer in the world. Because of financial difficulties it was sold first to the minerals conglomerate Hanson, then to Booker McConnell's salmon farming company, to be finally bought by the multinational Dutch feed supplier Nutreco in 1999 (Roberts 2000). In April 2005, MHM-Nutreco merged with Stolt Sea Farm (a Norwegian fish farming group). The resulting company, Marine Harvest, was bid for by Pan Fish, another Norwegian fish farming company, in March 2006. If allowed to go forward by the Norwegian government, Pan Fish-Marine Harvest would be the largest salmon farming conglomerate in the world.

Ireland

The salmon farming industry started with experimental culture in sea cages around 1975. As in Scotland, the industry developed in the 1980s due to heavy investment from the European Community and Norwegian entrepreneurs. The local government has also been very supportive, providing funding for a myriad of research and grant-aid programs (Willoughby 1999).

Production increased from 600 mt in 1980 to 25,000 mt in 2002; however, production declines were recorded in 2003 and 2004 (FAO 2006). The industry is mostly concentrated in the west and south-west coastlines; however, sheltered sites are not as numerous as in Norway and Scotland. The only direction for further expansion of the industry appears to be offshore but this will require continued development in cages that can withstand extreme hydrographic conditions.

Decimation of the native sea trout population (*Salmo trutta*) by sea lice perceived to be associated with salmon farms has resulted in strong opposition to further industry development by local fishermen and environmental groups, including sabotage of farm installations.

Faroe Islands

The self-governing administrative division of Denmark, the Faroe Islands, are located in the heart of the Gulf Stream in the North Atlantic, northwest of Scotland and halfway between Iceland and Norway. Salmon culture developed in the archipelago around the mid-1980s with the assistance of Norwegian technology and broodfish stocks.

Production reached a record level in 2003 with 65,500 mt (FAO 2006) but potential for further expansion is limited due to a scarcity of sheltered sites. As in Scotland and Ireland, farmers are being pushed offshore but further development will depend on advances in cage construction. The value of farmed salmon in 2003 was approximately US$188 million, exceeding by far the value of traditional marine fisheries.

Development in North America

Despite the enormous amount of research conducted on hatchery-based enhancement programs for Pacific salmon, the pen-reared salmon industry did not develop in the United States and Canada at the same pace as it did in Norway for a number of reasons.

In the first place, Pacific salmon does not lend itself to culture conditions as easily as Atlantic salmon. On the other hand, winters can be extremely cold in the Eastern coast of North America and the regulatory pressure exerted by environmental groups has effectively slowed industry growth (Anderson and Bettencourt 1992).

Canada

Salmon farming in Canada takes place primarily in British Columbia and New Brunswick. The British Columbia net-pen salmon industry started in 1972 with the production of small coho salmon using surplus eggs from a government hatchery (Folsom et al. 1992). Because coho salmon matures early in the year, it needs to be harvested from the net-pens in the summer, coinciding with the wild salmon harvest. Therefore, low prices always resulted for the farmed coho salmon and the industry remained undeveloped for more than one decade (Willoughby 1999).

In 1985-86 Norwegian investors were attracted to British Columbia by its favorable environmental conditions and proximity to the U.S. market. Initially they attempted to culture chinook salmon instead of Atlantic salmon because government regulations prohibited the introduction of non-native fishes. However, chinook salmon is not as easily domesticated as Atlantic salmon because it requires warmer ocean temperatures (>8ºC) to achieve optimal growth; however, warm temperatures also favor plankton blooms that may die off, resulting in eutrophication. Chinook salmon is also more susceptible to diseases.

Import restrictions on Atlantic salmon roe (ova), which had been imposed out of concern for the introduction of non-native species, were eventually lifted in 1985 and within a few years production levels of Atlantic salmon exceeded those of farmed Pacific salmon in British Columbia.

Reportedly, there were 75 companies operating by 1989 (Willoughby 1999) but lower prices caused by global oversupply of salmon led to a major restructuring of the industry, and by 1994 only 17 companies were operating.

Growth in recent years has been hampered by conflicts with commercial and recreational salmon fisheries as well as First Nations members and environmental groups. It has been claimed that escaped fish from farm installations may spread diseases and negatively affect the genetic integrity of the native fish populations. The industry is heavily regulated and a moratorium on further expansion was imposed in 1995. The ban on new salmon farms was lifted in 2002.

In New Brunswick, along Canada's Atlantic coast, experiments conducted in the early 1970s demonstrated that salmon could survive the very low winter temperatures. The first commercially viable operation started in 1978 near Deer Island (Sylvia et al. 2000) and further development took place along the protected coasts of the Bay of Fundy.

The industry has not been nearly as regulated as in British Columbia, and there have been fewer conflicts with First Nations, environmental groups and other special interest groups. A main advantage to firms in this area is the proximity to the large eastern U.S. markets; however, expansion is limited by a shortage of suitable sites for the farms and low ocean temperatures in the winter (Wray 1996a).

Despite constraints to development and the industry shakeout in the early 1990s, farmed salmon production has been steadily increasing on both West and East coasts. Overall production was 700 mt in 1980, exceeded 25,000 mt by 1990, and achieved a record level in 2002, with nearly 130,000 mt (Figure V-3). Government regulation and conflicts with other interest groups remain as the major obstacles to growth.

United States

The development of salmon farming in Washington and Maine has paralleled that in the Canadian provinces of British Columbia and New Brunswick. The National Marine Fisheries Service (NMFS) conducted the first experiments with pen-reared salmon at the Manchester Field Station in Puget Sound, Washington, in 1969.

The first private operation (Ocean Systems, Inc., later Domsea, a subsidiary of Campbell Soup Co.) established coho and chinook cage systems in Puget Sound and harvested their first fish in 1971 (Sylvia 1989). By 1980, western U.S. salmon production had reached an estimated 391 mt.

Atlantic salmon arrived in 1986 and since then there has been a move from Pacific to Atlantic salmon production. By 1994, Washington's salmon production was about 5,000 mt, of which 95 percent was Atlantic salmon (Willoughby 1999). The state industry underwent a period of consolidation in 1996-97, and all former companies are now consolidated into one holding company, The Omega Group, which also has holdings in British Columbia. The Omega Group is a subsidiary of Pan Fish Incorporated (Norway), one of the largest Atlantic salmon rearing companies in the world.

Commercial salmon farming was also attempted in the Northeastern United States in the early 1970s. The first company, Maine Salmon Farms, started producing coho at a pen site in an estuary of the Kennebec River in 1970, but the company failed in the late 1970s.

The first large-scale operation, Fox Island Fisheries, began production in 1973 in Vinelhaven, Maine but it also went out of business in 1979 (Bettencourt and Anderson 1990). Despite these initial failures, the high unemployment rate and the decline of the herring fishery provided additional impetus for aquaculture development in the Eastport-Lubec region in Maine.

Ocean Products, Inc. (OPI) began operations in 1982 in Cobscook Bay with smolts provided by Canadian hatcheries and the U.S. Fish and Wildlife Service. After developing its own hatcheries, OPI became the largest private salmon operation in the United States by 1988.

In 1987, the Norwegian seafood multinational Fjord Seafoods founded Atlantic Salmon of Maine (ASM) by converting a former state hatchery in a modern commercial rearing facility. The company grew continuously over the years through the acquisition of hatcheries and leasing of marine sites.

At the same time, consolidation within Canadian-based firms and the acquisition of OPI led to the creation of Heritage Salmon Company (HSC) in 1991. Both foreign-based companies are the largest salmon producers in Maine.

On both East and West coasts salmon aquaculture has found strong opposition by environmentalists, local property owners and fishermen (Sylvia et al. 2000). For example, in June 1987, Alaska imposed a temporary moratorium on private, for-profit, farmed salmon and trout, which became permanent in 1988 (Anderson 1997). Although reasons given for this included environmental concerns, spread of disease, pollution issues and genetic degradation of native stocks, other prominent motivating factors for the permanent moratorium were economic, such as market competition and concern about multinational corporations controlling the industry.

Currently, the salmon farming industry in Washington and Maine is facing considerable constraints related to environmental issues and profitability. In a recent report from the Stanford Fisheries Policy Project, the salmon farming industries in British Columbia and Washington are portrayed as posing a clear ecological risk to wild salmon populations in the Pacific Northwest, which led the authors to suggest an international moratorium on the industry (Naylor et al. 2003).

In Maine, there are also concerns related to the potentially negative impact of farmed salmon practices on the recovery of threatened native Atlantic salmon stocks. In May 2003, a lawsuit filed by two Maine residents and the U.S. Public Interest Research Group (an environment and consumer advocate organization) against the two largest salmon farms in the state, Heritage Salmon and Atlantic Salmon of Maine, resulted in the imposition of hefty fines and strict guidelines for the operation of farms in the state.

Under the new regulations, companies must rotate fish to allow some pens to go fallow for up to three years to prevent salmon waste from degrading sensitive seabeds. In addition, companies are forbidden to raise European stocks of Atlantic salmon, which grow faster and resist disease better than native fish. The court ruling forced the sale of Norwegian-owned Atlantic Salmon of Maine to New Brunswick-based Cooke Aquaculture in April 2004 (*Portland Press Herald* 2004).

As shown in Table V-2, U.S. ocean pen-raised salmon and trout production generally increased until 2000. However, production dropped precipitously from a high of 22,511 mt in 2000 to only 10,249 mt in 2004. At this point, there is little opportunity for growth.

Competitiveness of U.S. farmed salmon producers has been seriously eroded in recent years by the escalating cost of regulatory compliance covering almost all

Table V-2 **Farmed salmon and salmon trout raised in ocean net pens in Maine and Washington (metric tons)**

Year	Total: Maine & Washington	MAINE Total Maine	MAINE Atlantic Salmon	MAINE Trout	WASHINGTON Total Washington	WASHINGTON Pacific Salmon	WASHINGTON Atlantic Salmon
1990	3,438	2,082	N/E	N/E	1,356	706	650
1991	6,979	4,707	4,552	155	2,272	412	1,860
1992	10,401	6,120	5,839	281	4,281	67	4,215
1993	11,074	7,024	6,688	337	4,050	41	4,010
1994	11,224	6,396	6,130	266	4,828	38	4,790
1995	14,176	10,095	9,982	113	4,081	33	4,048
1996	13,965	10,024	9,991	33	3,941	23	3,918
1997	18,026	12,235	12,117	117	5,791	16	5,775
1998	15,798	13,226	13,142	84	2,572	3	2,569
1999	17,750	12,250	12,172	78	5,500	0	5,500
2000	22,511	16,466	16,356	109	6,045	0	6,045
2001	20,775	13,206	13,206	0	7,569	0	7,569
2002	12,735	6,800	6,800	0	5,935	0	5,935
2003	16,314	6,007	6,007	0	10,307	0	10,307
2004	10,249	8,515	8,515	0	1,734	0	1,734

Sources: Washington: 1990-2002 data are from the Washington Agricultural Statistics, 2003. http://www.nass.usda.gov/wa/annual03/aqua03.pdf. See Appendix C for 2003-2004 estimates.

Maine: Maine Department of Marine Resources, 2005. http://www.maine.gov/dmr/aquaculture/finfishharvestchart.htm. Data compiled by Laurice Churchill and Tracey Riggens; 1998-2004 data compiled by Jon Lewis and Marcy Nelson.

N/E: Non specified.

aspects of production: disease control, feed additives, effluent discharges, marine mammals, navigation, control of predatory birds and endangered species.

Despite having developed much of the hatchery technology and the most advanced research on health and nutrition, the U.S. salmon farming industry currently accounts for less than 1 percent of world farmed salmon production. This market share is likely to continue to decline.

Protecting wild Atlantic salmon from impacts of salmon aquaculture in the North Atlantic

In 1994, seven member countries of the North Atlantic Salmon Conservation (NASCO) signed an agreement called the "Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimize Impacts from Salmon Aquaculture on the Wild Salmon Stocks." The agreement recommended specific actions for nations to control impacts of salmon farming, including the development of standards for fish husbandry practices, guidelines for siting of pen structures and the demarcation of exclusion zones.

In 2003, the Atlantic Salmon Federation (ASF) and the World Wildlife Fund (WWF) conducted a country-by-country evaluation of the steps taken by each government to adopt legislation aimed at reducing harmful impacts of aquaculture on the wild salmon populations (Porter 2003).

The evaluation panel found relatively little progress on the adoption of this legislation (no private sector initiatives were evaluated). The greatest progress was made by Norway, followed by Scotland, Canada, Ireland, Iceland, United States and Faroe Islands, in that order. The evaluation panel recommended that significant changes be implemented in the regulatory framework for salmon aquaculture in each of the member countries.

Development in South America

Chile

Farming of salmon is a relatively new industry in Chile and it began with the commercial cage rearing of rainbow trout and coho salmon in 1978. The industry expanded very rapidly beginning in the mid-1980s (Figure V-3).

From a modest production of 500 mt in 1984, Chile moved on to become the second largest producer of salmon in the world in 1992 with 62,200 mt. Chilean production almost equaled that of Norway in 2001 with a little over 500,000 mt. Aquaculture output decreased slightly in 2002 and 2003, but a new record was reached in 2004, with a production of nearly 570,000 mt (FAO 2006). Some industry reports indicate that Chile will likely displace Norway as the world's largest salmon producer in the near future (*The Wave News Network, March* 25, 2004). The average growth rate of the industry for the period 1984-2004 was 42 percent per year.

Coho was initially the predominant species, but Atlantic salmon (imported from Norway in 1982) became the leading species in 1992, with about 20,000 mt. The production of salmon trout accelerated in the 1990s and exceeded coho production in 1997 (Bjørndal 2002). In recent years most of the production of coho in Chile is sold frozen to Japan and the bulk of the Atlantic salmon is sold fresh (pin-bone-out fillets) to the United States.

Chile is divided into 13 main regions, of which Regions X, XI and XII, in the southern part of the country, are most suitable for salmon farming. The industry is mostly concentrated around Puerto Montt and the Chiloé Island in Region X, about 1,000 km south of Santiago. The long coastline from Puerto Montt to Cape Horn offers many sheltered sites with ideal water temperatures (10-14ºC) and salinity. Additionally, unpolluted freshwater sources are numerous and most lakes do not freeze in winter, thereby providing favorable conditions for smolt production throughout the year.

There are other factors that explain the success of the Chilean salmon farming industry. Chief among these are easy access to fishmeal for feed, low-cost skilled labor, minimum interference from commercial and recreational fishermen, favorable regulatory climate and little pressure from environmental groups (Hicks 1995).

Moreover, as Chile is located in the Southern Hemisphere, its seasons are opposite to those of the Northern Hemisphere, meaning that Chilean farmers can supply fresh markets during the off-season in the northern hemisphere. However, Bjørndal (2002) argues that the importance of this competitive advantage has been reduced as Atlantic salmon and salmon trout have gained importance in the Chilean salmon industry. Atlantic salmon is harvested throughout the year and is generally marketed fresh primarily in the United States while the Chilean-grown coho and rainbow trout are largely exported frozen to Japan.

The Chilean industry has benefited from investment and joint ventures with Norway, Japan, the U.K. and other countries. Foreigners own the dominant share of many of the large farms but Chilean ownership is increasing (Willoughby 1999). Establishment of a farm is a much more expedited process than in other countries, with project approval taking no more than four months (Wray 1996b). Nevertheless, enforcement of new regulations in the future is expected.

Despite this positive outlook, Chilean aquaculture has also some problems of its own. There is still much room for improvement with respect to health management and disease control. While only small viral outbreaks have occurred thus far, the risk of a large outbreak in the lakes used for smolt production, where mortality among juvenile fish often ranges from 30 to 50 percent, is not negligible. Currently no health certificates or controls are required when transferring fish into and out of the lakes.

Similarly, antibiotics are used extensively, but the total amount is unknown and there are few government controls (Willoughby 1999). Nevertheless, Chileans have taken significant steps towards ensuring the sustainability of the industry. For example, a large portion of the salmon growing region is covered under a strict program of environmental control, which runs 16 monitoring stations from Puerto Montt to Chiloé.

Because per-capita consumption of fish is low in Chile, the salmon industry has been export-oriented from its beginnings. The main markets are the United States and Japan, representing 36.7 percent and 49 percent, respectively, of Chilean salmon exports in 2000 (Bjørndal 2002).

The Japanese market is mainly supplied with coho and salmon trout while most farmed Atlantic salmon is shipped to the United States. However, their extreme dependency on these two markets makes Chilean exporters vulnerable to the swings of international economic trends, exchange rates and trade policies.

Chileans have tried to develop new markets and products in recent years. In particular, the pin-bone-out (PBO) fillet has been extremely successful in the U.S. market. A long-term goal has been to obtain a third of the European salmon market. Although still accounting for a minor fraction of Chilean exports, those to Brazil have increased considerably since 1993. There is significant potential for expansion in this market, as well as other Latin American countries.

Development in Asia

Japan

The domestic industry started with the culture of sockeye, chinook, chum and pink salmon in the bays of north-east Honshu Island by the Nichiro Fisheries Company. By 1973, Nichiro had focused on pen-raised coho salmon, modeled after Norway's use of eggs imported from Washington and Oregon (Nasaka 1988). Since then, coho has been the species of choice for Japanese producers.

Domestic production peaked in 1991 with approximately 41,000 mt but has been declining since then. In 2004 only 18,500 mt were produced (FAO 2006). Recently, offshore fish farming installations have been promoted by the government in an attempt to bring the industry to more exposed locations (Willoughby 1999); however, the true potential of offshore farming has not yet been fully assessed.

Important Factors Contributing to the Success of Salmon Farming

Forster (2002) provided a comprehensive review of the various factors that have made salmon farming one of the most successful aquaculture enterprises worldwide. A summary of these factors follows:

A. <u>Easily replicated technology</u>: Salmon are raised in cages or net pens. Cages are a relatively simple technology for culturing fish under intensive conditions. If cages are placed in locations with good tidal flow, water exchange rates are many times greater than would be possible in land-based facilities. Although designs and materials can vary widely, all cages adhere to the same basic principles. This simplicity is what allowed Norwegian and Chilean farmers to set up their farms with minimum investment on fixed capital assets and develop their industries in a relatively short period of time.

B. <u>Access to a huge resource</u>: Successful cage culture requires coastlines with the right set of topographic conditions. Candidate sites must provide protection from heavy seas, have at least 15m of depth, an adequate regime of water flow to facilitate water exchange in the cages and optimal seawater temperature and salinity. Of all the countries that provide these conditions for salmon farming, Norway and Chile possess the most extensive coastlines. It is then not a surprise that these two countries are the most important producers in the world. Other countries such as Scotland, Canada, the United States (other than Alaska) and Ireland also provide good topographic conditions but to a lesser extent.

C. <u>Atlantic salmon is a good farm fish</u>: Atlantic salmon is a species with exceptional characteristics for intensive culture. The hatchery rearing is a relatively straightforward process. Eggs are easy to extract and incubate and the young fry are large and capable of feeding directly on dry feed. During growout in cages, they easily tolerate moderate crowding and careful handling. They are also moderately resistant to diseases and quickly grow to market size in less than 18 months after the 50-100 gram juveniles are put in net-pens. The meat quality is excellent and appealing to millions of consumers worldwide. The fillet yield is high, up to 60 percent of edible meat. A high fillet yield is critical for the creation of value-added products. This is an advantage over other mass-market species such as tilapia, which have a much lower yield (30-35 percent).

D. <u>Low cost of production and improvements in productivity</u>: After almost 30 years of uninterrupted progress, salmon farming has achieved a very high degree of efficiency. Production costs have been declining continuously in the major-producing nations. Modern, well-run farms can produce salmon today at around $2/kg, and in some cases even lower. Table V-3 presents a typical cost breakdown in a modern salmon farm. The largest cost is feed, making up over half of the total cost. This is so partly because salmon feed is rich in high-quality protein (fishmeal) and fat as compared to many other animal feeds. However, research is continuously aimed at reducing the dependence on fishmeal sources of protein. Advances are expected in the near future as similar breakthroughs have been achieved in other industries.

In addition to technological advances, costs of production have also declined because farms have grown bigger and captured economies of scale. At current production levels (about 15-20 kg per cubic meter of cage volume per year) the cost contribution of capital replacement is very low (Table V-3). Also, labor productivity has boosted in many farms (often exceeding 200 mt per man-year) while management and overhead expenses have been minimized.

E. Corporate ownership: The Norwegian government initially encouraged an industry model of small-scale operators and individual farm ownership. However, like any agricultural commodity sold in the world today, salmon is vulnerable to overproduction. The price crisis of the early 1990s made it clear that the initial policies adopted by the Norwegian government hampered its competitiveness in the global marketplace.

More recently, seafood buyers tend to be large food service operations or retail chains which demand from suppliers an absolute assurance of quality, year round availability and the ability to supply large volumes. In addition, prices must be internationally competitive.

Corporations also find it easier to finance research and development and update equipment and technology because they are able to spread these costs over a larger production volume. Ultimately, corporations are much more resilient and are better equipped to survive through commodity pricing cycles.

It is precisely the cyclical oscillation between profit and losses which contributed to consolidation of the salmon industry (Roberts 2002a; 2002b). The Dutch conglomerate Nutreco became the largest salmon producer in the world, integrated from egg to table, after acquiring the Scottish Marine Harvest and the Norwegian Norsk Hydro farming companies in 2000. Further consolidation occurred in 2005 when Nutreco merged with Stolt Sea Farm from Norway to form the multinational conglomerate Marine Harvest. In March 2006, Pan Fish, another Norwegian fish company, bid to purchase Marine Harvest from Nutreco and Stolt. If the purchase is allowed by the Norwegian government, which is concerned about too much industry consolidation, the combined Pan Fish – Marine Harvest company would become the world's largest producer of farmed salmon, with an expected production of 346,000 MT in 2006, accounting for over 20 percent of global farmed supplies.

The Norwegian government has also been directly involved in the consolidation of the industry. By the late 1990s, the Norwegian government owned 51 percent of the Norsk-Hydro farming company and had farms and processing plants in Norway, Scotland, Ireland and Chile. With the sale of Norsk-Hydro to Nutreco in 2000, the Norwegian Government was expected to make an exit from state sponsored aquaculture as it only kept Statkorn Holdings, a relatively minor conglomerate compared to Nutreco. However, in a series of maneuvers that took place in 2001 and 2002, Statkorn purchased Sweden-based Ewos, the world's biggest fish feed manufacturer at the time. Following the acquisition of Ewos, Statkorn engaged in acquisition of assets in all major producing regions in the world. The Statkorn company is now called Cermaq and it is currently

Table V-3 **Production costs of an efficiently run Atlantic salmon farm in 2000**

Cost item	$ per kg produced	% of total cost
Juveniles	0.33	16.5
Feed	1.10	55.0
Labor	0.16	8.0
Other cost + overhead	0.29	14.5
Depreciation	0.12	6.0
TOTAL	**2.00**	**100.0**

Source: Forster (2002)

one of the major salmon feed producers and the second largest farmed salmon producer in the world.

With a successful bid by Pan Fish for Marine Harvest, according to industry estimates (Pan Fish 2006), nearly 40 percent of global farmed salmon production in 2006 would be controlled by only three Norwegian companies (Pan Fish-Marine Harvest, Cermaq, Fjord Seafood) and one Chilean company (AquaChile). Further consolidation is expected to continue in the coming years.

F. Marketing: Salmon farmers have been particularly successful at understanding the market's need a for high-quality seafood product. Over the last two decades there has been a growing public awareness of the health benefits of eating fish as compared to other meats, and an increased demand for fresh products.

Salmon farmers responded by developing the ability to supply a consistent high-quality, fresh product year round, and by supporting these efforts with various generic marketing programs. As a result, Atlantic salmon can be found in almost all supermarkets and restaurants of economically developed countries (Forster 1999).

G. Government support: As with other types of aquaculture, salmon farming has succeeded wherever it receives support and legitimacy from government. That has been the case in Norway, Chile and Scotland, the three major salmon producers in the world.

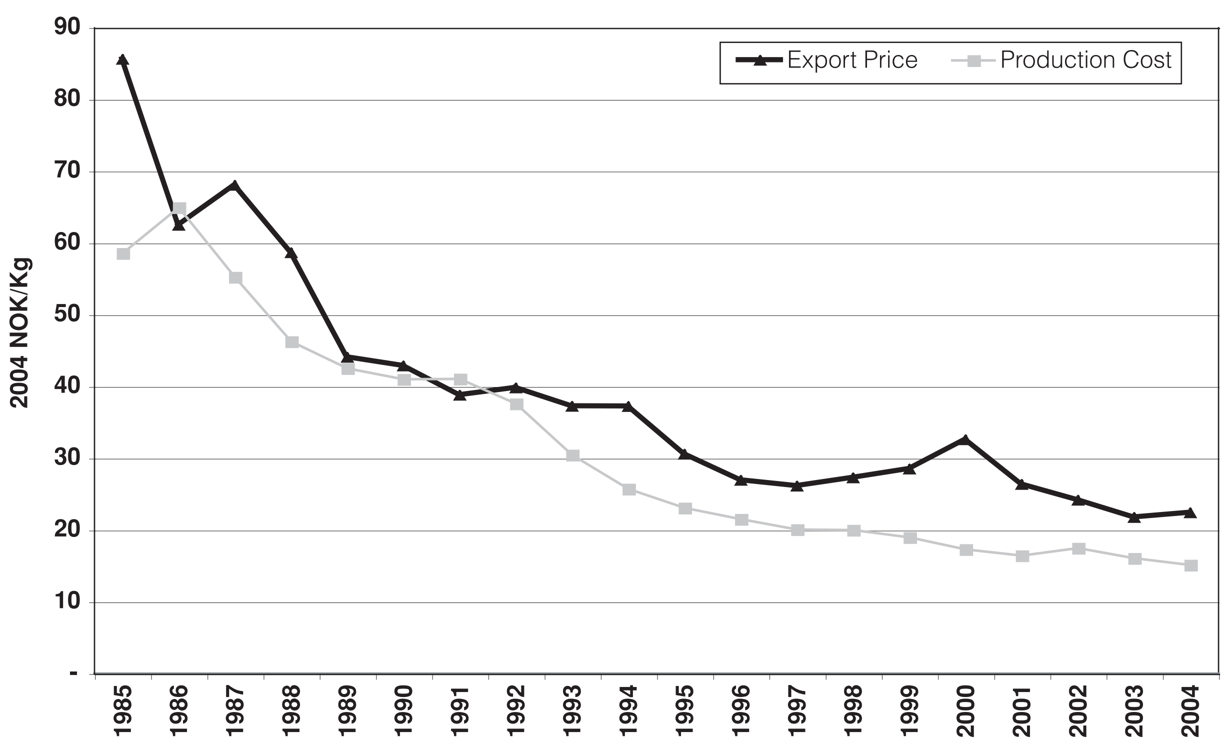
Although many governments can provide adequate support in research and development, few of them succeed at creating space in public waters and developing a straightforward regulatory framework supportive of the industry. One major problem lies in the public nature of the seawater resource.

For the aquaculture sector to operate efficiently it is important that farmers have secure and reasonably transferable property rights. This is frequently in conflict with the views of existing user groups and other interests.

Evolution of Prices and Production Costs

Increased supplies of an agricultural commodity generally result in falling prices. Farmed salmon is no exception. Figure V-4 displays the annual inflation-adjusted export price and production cost (in 2004 Norwegian Kroner) of farmed Atlantic salmon from Norway during the period 1985 – 2004 (NDF 2006). Prices of Norwegian salmon consistently declined over this time period, from 86 NOK/kg to 22 NOK/kg. The fall in prices was steeper during 1985-1989. Similar trends have also been experienced in Chile and the United States.

Figure V-4 **Export Price and Production Cost of Norwegian Atlantic Salmon (1985-2004)**



Source: Norwegian Directorate of Fisheries 2006 (provided by Frank Asche, University of Stavanger, Norway).

The years 1988 and 1989 were particularly remarkable for the salmon industry. Beginning in 1988, the farmed salmon industry increased production substantially. Falling prices were first observed in Europe late in 1987 and in the United States by mid-1988. In 1989, record supplies of farmed salmon (19 percent higher than 1988 levels), in conjunction with a record wild and ranched salmon harvest, led to an all-time record supply of salmon of more than one million mt (Figure V-2).

By 1989, aquaculture production already contributed 36 percent of the total world supply of salmon. As a consequence, prices declined precipitously. The bankruptcies, divestitures and producer concentration that had been commonplace in the salmon industry, reached a maximum in this period.

In the United States, price declines in 1989 prompted a petition from the Coalition for Fair Atlantic Salmon Trade (FAST), which alleged that Norwegian producers had received countervailing subsidies and were dumping salmon in the Unite States, materially damaging the domestic industry. This is discussed in more detail in Chapter XV.

Despite falling prices, there was still tremendous growth in the farmed salmon industry in the 1990s due largely to tremendous gains in productivity from innovations in disease control, nutrition, improved brood stocks and more efficient farm systems. The record low U.S. prices in the late 1990s and early 2000s were related to rapid growth in farmed salmon supply, particularly from Chile.

It is now clear that salmon farming operations have been able to remain profitable only by lowering production costs through technological and management innovations as prices have fallen. While average export price/kg in Norway decreased from 86 NOK/kg to 22 NOK/kg, production costs were lowered from 59 NOK/kg to 15 NOK/kg (2004 prices).

A key component of production costs is feed. In the 1980s, feed conversion ratios (FCR) in Norway were around 3 kilograms of feed per kilogram of salmon. In 1999, the average feed conversion ratio was 1.19 kilograms of feed per kilogram of salmon (Guttormsen 2002).

The reduction in production costs and FCR was made possible through consolidation and vertical integration of the industry, better broodstock, technology and improvements in nutrition, disease management and farm production systems (Asche et al. 2003). Undoubtedly, the many efforts conducted by the industry since 1989 to expand and broaden the market have been instrumental in dealing with the downward pressure on prices.

Commercial feeds in salmon farming: a controversial topic

Sustainability of Fish Meal and Oil

Salmon is a carnivore and requires a diet with a high protein content to promote and sustain growth rates throughout the entire life cycle. The dependence of salmon farming on the availability of high-quality proteins such as fishmeal and fish oil has raised some concern among environmental groups about potentially negative effects on wild fish stocks (Naylor et al. 2000).

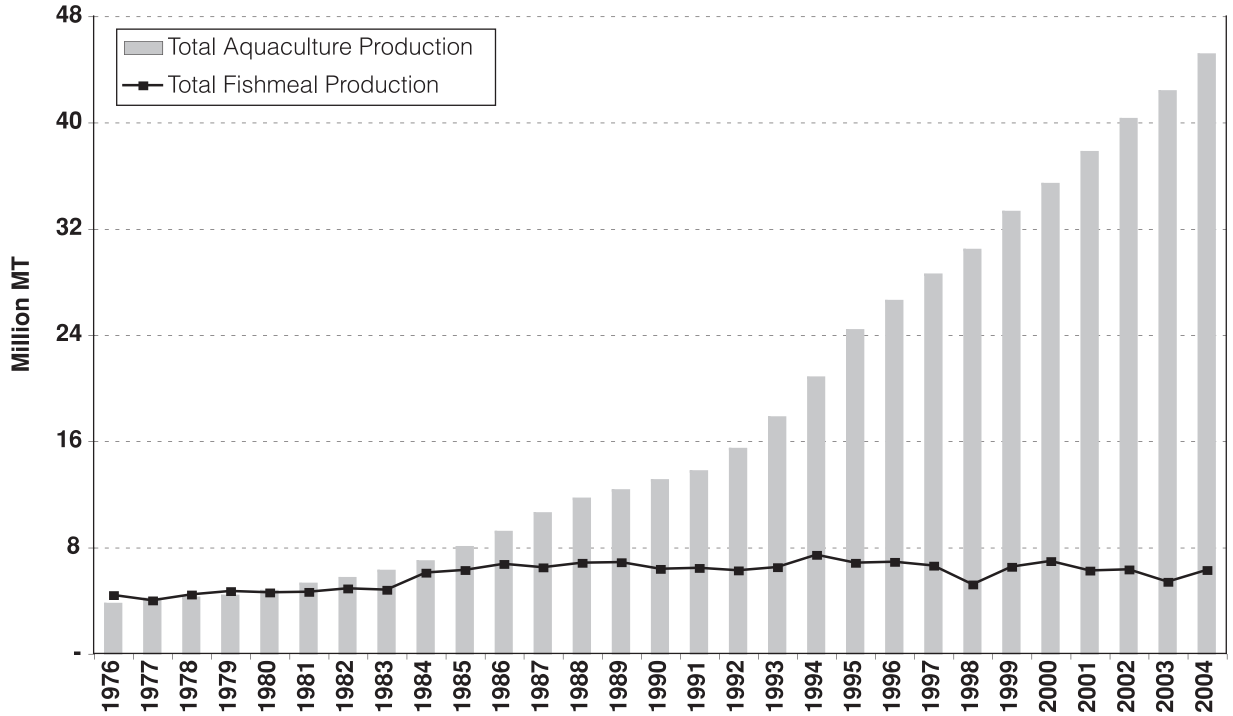
The concern over the sustainability of the stocks of fish from which fishmeal are derived is partly based on a concern that as aquaculture production grows, there is increased pressure on these stocks. However, as Figure V-5 below shows, as worldwide production in aquaculture of fish and shellfish (including all carnivorous fish and shellfish) have increased over the years, the level of fishmeal production has remained roughly the same. One might have expected catches of fish bound for fishmeal production to increase as aquaculture production has increased, however, that has not been the case. Although the share of fishmeal going to aquaculture is increasing (Delgado et al. 2003), the majority of the fishmeal produced worldwide goes to developing nations and is used as feed for livestock, primarily poultry and pigs. In 1986 only 8 percent of fishmeal produced worldwide was going to aquaculture production (Wijkstrom and New 1989). By 1995, 25 percent was going to aquaculture (Tacon 1998) and in 2002 it was up to an estimated 34 percent (Barlow 2002).

Thus, the implication of this is that the cost of fishmeal is generally increasing. As a result, a significant amount of research is currently underway to reduce the dependence of salmon feeds on fishmeal and fish oil (Hardy 1998). Vegetable ingredients such as soybean meal already provide most protein requirements in poultry and swine feeds as well as in catfish diets in the United States. Soybean meal and other low-phosphorus ingredients are currently being examined for their use in commercial salmon feeds (Opstvedt et al. 2003; Bell et al. 2003). This search for alternative feedstuffs is on-going for 2 reasons: 1) to address concerns related to sustainability of the stock of fish from which fishmeal and fish oil are derived; and, 2) because feed is the largest component of the costs of producing farmed salmon and it is in the industry's best interest to find ways to reduce those costs.

PCBs in Fish Feed

A recent report published in *Science* claims that farmed salmon contain higher levels of PCBs than their wild counterparts, that 8 ounces of farmed salmon should not be consumed more than once per month and the source of the PCB contamination is the fish feed (Hites et al. 2004). The study also indicated that farmed salmon from northern Europe had higher

Figure V-5 **Worldwide Total Aquaculture Production of Fish and Shellfish Relative to Total Fish Meal Production**



Sources: FAO (2006); IFFO (2005).

concentrations of contamination than farmed salmon from South America. The study was based on salmon taken from the water in 2001.

This study was highly controversial. The study has been challenged by the medical community, food scientists and the farmed salmon industry on the health implications of PCBs, which concluded that the benefits of eating fish rich in fatty acids are more clearly proven than the risk of PCB exposure (SOTA 2004; Santerre 2004; Willett 2005). At the heart of one of the controversies is that the study's authors use the approach of the U.S. Environmental Protection Agency (EPA) to assess comparative health risks of consuming wild and farmed salmon, which bases risks on animal testing. Other scientists feel the approach of the U.S. Food and Drug Administration (FDA) or the World Health Organization (WHO) is the more appropriate approach. Their limits are significantly higher. Referring to the assumed similar affects on humans as on animals of PCBs, Willett (2005) writes in the *American Journal of Preventative Medicine* about the Hites et al. study, "that report is particularly troublesome, perhaps even irresponsible, because the implied health consequences were based on hypothetical calculations and very small (lifetime risks of 1:10,000). In contrast, the benefits of eating salmon are based on human data at the doses actually consumed, …, and are likely to be at least 100-fold greater than the estimates of harm, which may not exist at all."

The study generated a significant amount of media coverage, with varying levels of responsible reporting. In a study by an affiliate of the Center for Media and Public Affairs, the Statistical Assessment Service investigated the news reporting of this study to determine if the media accurately reported this controversy and provided the key scientific data the public needed to make sense of the study (Butterworth 2004). For our purposes, what is more interesting is to what extent the media distinguished between farmed and wild salmon. Many of the newspaper headlines were quite clear that the study pointed to farmed salmon as being higher in contaminants than others. However, other headlines did not. For example, *USA Today*, on January 9, 2004 ran a headline that said "Study: Some Salmon are Highly Toxic." Similarly, that same day the *St. Paul Pioneer Press* ran the headline "Limit on Eating Salmon is Urged." While the *Washington Post* on that date did point out that farmed salmon were 'toxic,' its headline would not exactly create confidence in wild salmon either — "Toxins cited in farmed salmon. Cancer risk is lower in wild fish, study reports."

The study evaluated raw skin-on salmon. Since PCBs reside in the fat, 30-50 percent of the PCBs are carried away in the cooking processed in the dissolved fat. Therefore, if one does not eat the skin or the grey tissue, a lower concentration of PCBs are consumed than what would be implied by the study, independent of whether one uses the FDA/WHO approach or the EPA approach to assessing risk.

There are 2 critical issues in this controversy: a) public health and b) impact on the farmed and wild salmon industries. The above addresses the issue related to public health. The second issue is often assumed to be a positive impact on the wild salmon industry and a negative impact on the farmed salmon industry. However, as headlines above which fail to distinguish between farmed and wild salmon appear, the negative effects can easily be felt by both industries. In addition, as the PCB stories are intermingled and added to the media attention to mercury in tuna and swordfish and other health warnings concerning seafood, there is increasing concern among health professionals that consumers simply get confused about which species to eat and confused or frustrated consumers simply stop eating all seafood.

Use of Colorants in Salmon Feed

Some concerns have also been expressed with regard to the addition of synthetic pigments to salmon feeds. The characteristic pink color of salmon flesh is a result of deposition of naturally occurring carotenoid pigments, which are synthesized primarily by phytoplankton and subsequently stored in algae and zooplankton. Higher organisms, including salmon, cannot synthesize carotenoids and therefore rely on a dietary intake. Currently, commercial diets for farmed salmon contain either or both of the synthetic pigments commercially available, astaxanthin and cantaxanthin (Buttle et al. 2001). Current research is directed towards developing natural sources of the color enhancement pigments at a commercial scale. In particular, certain species of microalgae and yeast are being examined as potential sources of astaxanthin in salmon feeds (Muller-Feuga 2000; Harrell et al. 1998).

Plant-based Feeds

As feed shifts toward plant ingredients, there is the possibility that genetically modified soybeans or other meal-type products will be considered as fish feed, with the addition of fish oils. This will probably create a controversy of another type, one which is shared with industries that extend far beyond fish farming.

Genetically modified organisms: The next breakthrough or backbreaker in salmon aquaculture?

Recent advances in biotechnology may hold the key for future expansion of the salmon aquaculture industry. Transgenic technology in particular could provide the means for the development of genetically superior broodstocks exhibiting faster growth rates, improved feed conversion efficiencies, disease resistance, the ability to utilize vegetable protein diets and tolerance to low oxygen levels and water temperatures.

Transgenic technology, i.e., the identification, isolation, reconstruction and transfer to broodstock of genes associated with desirable culture traits, offers a powerful method of genetic/phenotypic improvement that would be difficult to achieve using traditional selection and breeding techniques (Fletcher et al. 2001).

During the last 20 years, Aqua Bounty Technologies, a company headquartered in Waltham, MA (United States), has conducted state-of-the-art research leading to the development of stable lines of transgenic Atlantic salmon with economically desirable traits such as cold tolerance and disease resistance. This has been achieved with a gene construct composed of the chinook salmon gene sequence for growth hormone, linked to the promoter sequence that controls antifreeze production in the ocean pout. By incorporating this all-fish gene construct into the Atlantic salmon genome at the egg stage, fish that are theoretically capable of producing the salmon growth hormone all year round have been developed. These fish are capable of growing four to six times faster than standard salmon grown under the same conditions (Aquabounty 2006). The company has recently applied to the U.S. Food and Drug Administration (FDA) for permission to market its transgenic salmon.

Research on transgenic technologies started in the early 1980s in response to problems faced by the aquaculture industry along the east coast of Canada. Most of these coastal waters are characterized by sub-zero temperatures that are lethal to most fishes, including salmon. Therefore, sea cage aquaculture of salmon is almost entirely restricted to a relatively small area in the most southerly part of the region (Hew et al. 1995). The production of faster-growing, freeze resistant salmon would facilitate the expansion of the aquaculture industry in the entire Atlantic coastal region and other areas currently deemed unsuitable for salmon farming.

Successful introduction of genetically modified organisms into the aquaculture industry will involve not only overcoming technological obstacles, but also addressing food safety, environmental safety, animal welfare and consumer acceptance issues.

Environmental organizations and consumer groups have already expressed their concerns on the potential deleterious effect of escaped transgenic salmon on wild salmon populations (Reichhardt 2000). Some members of the salmon farming industry have also expressed an unwillingness to pursue transgenic salmon production. The controversy surrounding genetically modified salmon will likely continue well into the foreseeable future.

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