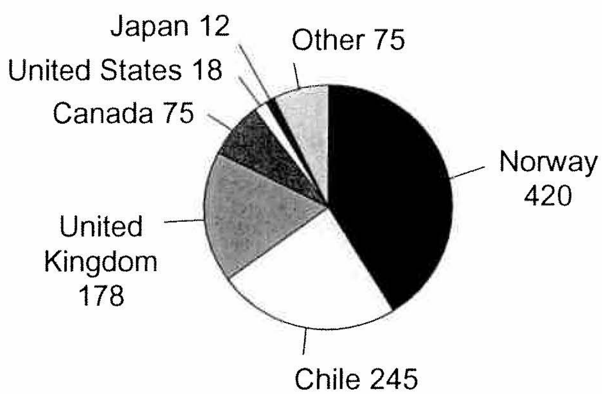
Salmon *Salmo salar*

Production	
Area Under Cultivation	Not applicable, production in net pens
Global Production	1 million MT
Average Productivity	Not applicable
International Trade	
Share of World Production	95% (estimate)
Exports	950,000 MT
Average Price	$2,000 per MT
Value	$2 billion
Principal Producing Countries/Blocs (by weight)	Norway, Chile, United Kingdom, Canada
Principal Exporting Countries/Blocs	Norway, Chile, United Kingdom, Canada
Principal Importing Countries/Blocs	European Union, Japan, United States
Major Environmental Impacts	Escapes and introduction of exotics Disease Waste and nutrient loading Pressure on wild fisheries for feed Use of chemical inputs
Potential to Improve	Poor Expensive to close the system either in the ocean or on-shore Without closed systems disease, escapes and wastes will be key issues The use of wild fish for feed per kg of production is decreasing but still an issue Consumer interest could push the industry

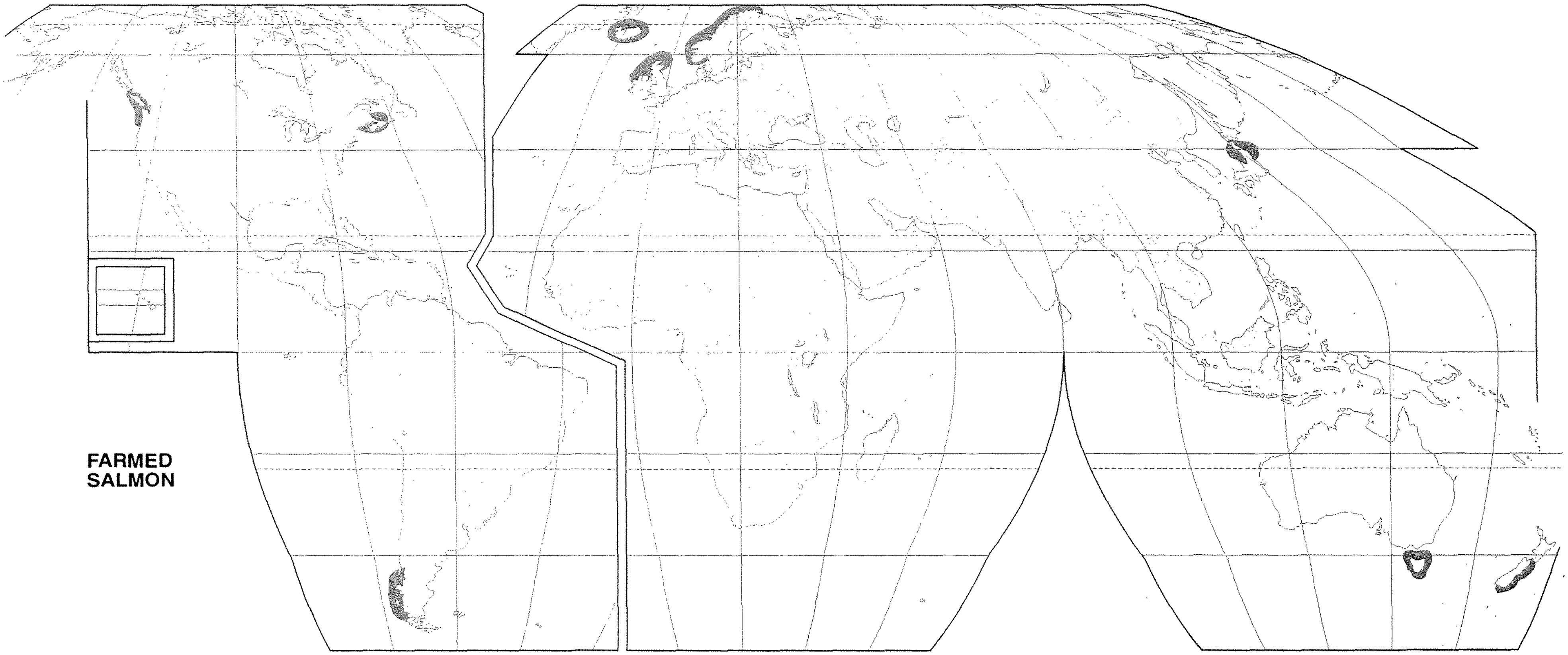
Source: FAO 2002; Johnson and Associates 2002. All data for 2000.

Salmon

Total Production (MMT)



FARMED SALMON



Main areas of production

Adapted from *Seafood Handbook*
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Chapter 23

Salmon

Overview

The first evidence connecting humans to salmon is found in southwestern France and northern Spain in caves that were occupied during the Upper Paleolithic period. Salmon vertebrae, salmon images carved onto reindeer antlers and other implements, and meter-long paintings on the walls were found in these caves. Salmon fish traps from around 6000 B.C. have been found in Sweden, and salmon fish nets from around 6250 B.C. have been found in Danish bogs.

Atlantic salmon, once abundant throughout the North Atlantic, were prized food by Gauls, Romans, and Native Americans alike. In Europe salmon fishing was done from small boats such as those made of skin stretched on wooden frames seen by Julius Caesar when he invaded Britain in 55 B.C. Salmon were so common in some areas that they were fed to pigs, and laws were written to limit the number of days a week that laborers could be fed salmon so that they would have more variety in their diets.

The *Domesday Book* (1085–86), written at the request of William the Conqueror to determine the wealth of the British Isles, inventoried a number of salmon fisheries. In one instance, a thousand fish per year were paid as tribute to the lord of the manor. From the twelfth century A.D. onward, salmon fishing rights were mentioned in property grants by kings and religious houses, royal boroughs, and the landed nobility.

For most of the Middle Ages, salmon was caught for local subsistence. However, by the thirteenth century there were records of salmon exports from Scotland. In 1488 the Scottish government's revenue from taxing salmon exports amounted to £310, a huge sum for the time. After the Reformation, when religious groups lost their title to rivers, ownership was turned over to friends of the King who worked the fisheries for profit. By 1669 some £200,000 of Scottish salmon were exported annually (Netboy 1974). After the union of Scotland and England in 1707, the trade in salmon increased even more, aided by improved transportation links.

In the seventeenth century, the Dee and Don rivers in the United Kingdom produced 170 metric tons of salmon annually, with exports going to Germany, Spain, Portugal, Holland, and even as far away as Venice. The local price for salmon was 2 pence, but in London they sold for 6 shillings and 6 pence, a 36-fold increase. By the early eighteenth century, the annual rental fee for the salmon and eel fishers of the lower River Don alone amounted to £30,000 (Netboy 1974).

There have long been efforts to maintain salmon production. In the Middle Ages, river managers developed wise-use practices to protect salmon runs. Kings in England and Scotland forbade blocking migratory routes and even taking fish in what they believed (usually erroneously) to be the spawning season. In 1030 King Malcolm II of Scotland established a closed season for salmon from the end of August to Martinmas (November 11). Richard the Lionhearted made a statute that all rivers must have a free-flowing gap in the middle of at least the length of a three-year-old pig (Netboy 1974).

Under Edward XIII in 1285 salmon were in decline in some areas, and the idea of closed seasons was introduced in England. By 1376, only authorized nets were allowed to take salmon. Under Elizabeth I, only fish longer than 41 centimeters (16 inches) were legal catch. Even so, by the early 1800s excessive netting in estuaries, damming of waterways to provide power to mills, pollution from the industrial revolution, and raw sewage dumped by pipes from growing cities all took a toll on the salmon population. Off seasons, weekly closings, mesh and net size regulations, and even water bailiffs could not prevent the demise of the fishery from these larger environmental impacts. The last salmon was caught on the Thames River in England in 1833.

Even in more remote Scotland, pollution was a problem. By 1850 there were eleven distilleries on the Spey River that consumed 2,270 barrels of malt in addition to grain and other organic material to make whiskey; the waste from this whiskey production was subsequently released into the river. By 1900 twenty-seven distilleries consumed 50,000 barrels of malt a week as well as all the other organic ingredients used in whiskey. As early as 1861 the situation for salmon was so bad that Charles Dickens wrote "Salmon in Danger" in his weekly magazine *All the Year Round* (Netboy 1974).

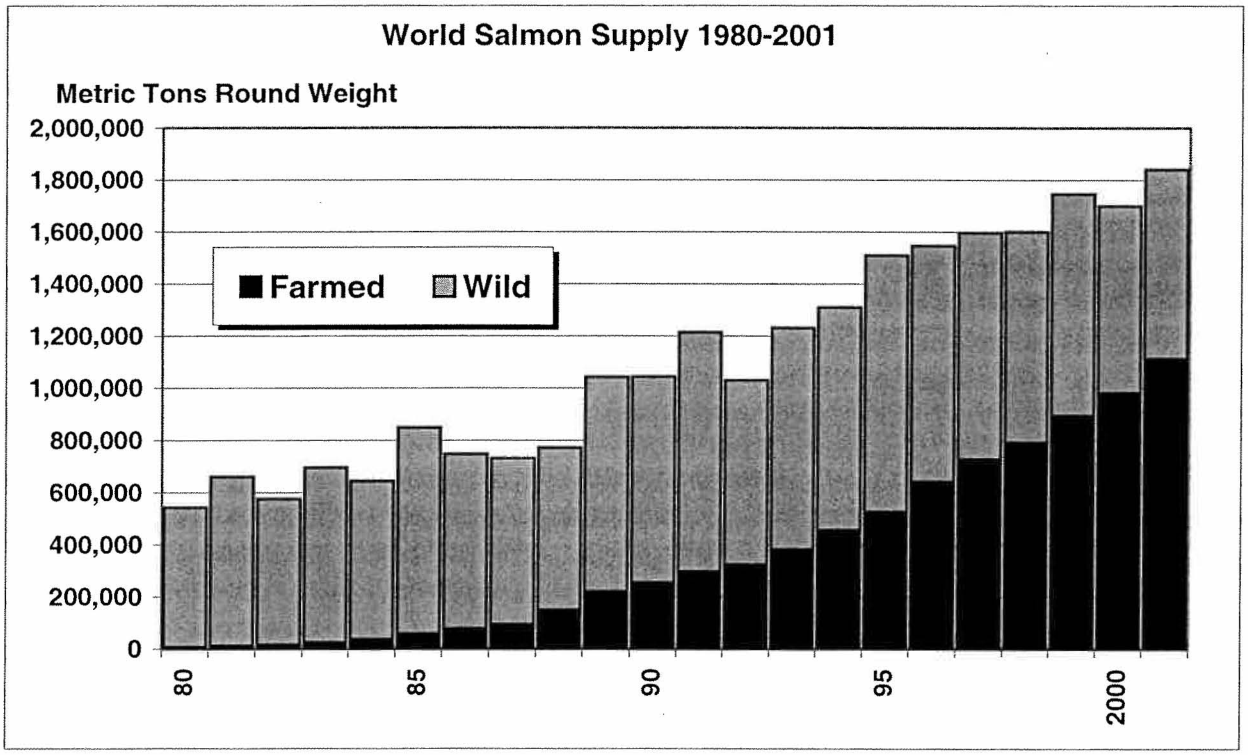
Salmon felt the impact of environmental degradation in North America as well. By 1900 Atlantic salmon populations in the United States ran afoul of industrial and sewage pollution and damming, as had affected England and Scotland, as well as agricultural expansion and soil erosion. At that time, salmon had become extinct in both the Salmon River and Lake Ontario, and the Hudson River no longer had a viable commercial salmon fishery.

In only a short time, salmon have gone from abundance to depleted stocks to abundance again. What has made this possible is aquaculture and the ability of humans to farm the seas. In only a generation, salmon has become semi-domesticated through intensive breeding programs. While farming took some 6,000 years of learning to get where it is today, salmon aquaculture has been created in only 30! And a food once affordable only by kings is now available to most families at home or in restaurants every night of the week.

Making salmon a commodity has not come without costs. There have been steep learning curves, and many believe that salmon production is not sustainable as it is now practiced. Even so, vast improvements in production techniques have been made. More importantly, what has been learned from salmon aquaculture (and the problems it raises) is relevant to most other over-fished or depleted fish stocks whose status is now similar to salmon when it first started being produced through aquaculture.

Today nearly one-third of fish eaten in the world is produced by aquaculture. During the 1990s aquaculture production increased by 150 percent (Johnson and Associates 2001). The performance of salmon aquaculture was similar. In 1980 farmed salmon made up a negligible percentage of world salmon supply, but by 2000 more than 1 million metric tons of total production and more than 50 percent of global salmon supply was farmed (Johnson and Associates 2001) (see Figure 23.1). Atlantic salmon is the fastest growing high-value farmed species, with annual production exceeding 1 million metric tons (Packard Foundation 2001).

Figure 23.1



Source: Johnson and Associates 2001.

Producing Countries

In 1999 farmed salmon production surpassed wild salmon catch for the first time ever. In 2000 farmed salmon production exceeded 453 million kilograms (1 billion pounds), and by 2002 farmed salmon were expected to account for more than two thirds of total salmon production. In other words, two farmed salmon would be produced for every one caught in the wild.

Aquaculture production of Atlantic salmon has long been dominated by Europe, where it was invented. Total farmed salmon production reached 668,601 metric tons in 2001 (Aquamedia 2002). Norway was by far the largest producer at 460,000 metric tons, followed by Scotland (140,000 metric tons), the Faroe Islands (40,000 metric tons), Ireland (23,000 metric tons), and Iceland (5,600 metric tons). Other important global producers included Chile with 245,000 metric tons and Canada with 75,000 metric tons

(Johnson and Associates 2001). In Chile production has grown at some 9 percent per year for a decade or more, while prices have dropped a total of 30 percent. In 2002 Chile surpassed Norway as the world's leading producer of farmed salmon.

Consuming Countries

In 2001 sales of farmed salmon amounted to more than $2 billion (Packard Foundation 2001). The European Union, Japan, and the United States are the three biggest markets for the product. In 1998, for example, the United States imported more salmon than it exported for the first time in history. In the United States, per capita salmon consumption increased 285 percent from 1987 to 2000, rising from 0.2 kilogram per capita to 0.73 kilogram per capita. Salmon ranks behind shrimp and tuna as the third most commonly consumed seafood in the United States (Anderson 2001). Although per capita consumption of all seafood remains relatively stable in developed countries, total consumption is increasing as a function of population growth (Packard Foundation 2001).

Production Systems

The biggest challenge for salmon aquaculture is that producers have had to find ways to produce a wild species in captivity. This includes not only growing fingerlings, but also producing them in hatcheries from captive brood stock. It also means finding the right feed formulations to insure growth, flavor, and color and still be financially viable; identifying ways to treat diseases as they arise from confining animals; and doing all this while reducing or mitigating impacts on the environment and other species. Salmon aquaculture falls into two categories: hatchery production and grow-out operations. Wild salmon are also discussed to provide context.

Wild Salmon

Wild Atlantic salmon spend most of their adult life in the ocean but return to fresh water to reproduce. In fact, 99 percent return to the river where they were spawned and reared. Each female produces about 800 eggs per pound of body weight so an average salmon of 9 to 10 pounds produces some 7,000 to 8,000 eggs. Unlike Pacific salmon that die after spawning, Atlantic salmon can spawn as many as four or five times and live eleven years.

Once hatched, the majority of wild Atlantic salmon stay in fresh water for two years (a smaller number stay three or more years in fresh water) before migrating to the estuaries and open oceans. Salmon must undergo profound physical changes to adapt from a fresh- to a salt-water habitat, at which stage they are known as smolts. Size, rather than age, appears to be key to this transition. How long they stay in fresh water depends entirely on how fast they grow, and how fast they grow depends on how far north they are spawned and how abundant food is. In some cases, the small smolt will remain in freshwater streams for as much as seven to eight years until they grow to the size at which their bodies change to live in salt water.

Hatcheries

Salmon aquaculture production mimics, but compresses, the life cycle of wild salmon. As Fred Whoriskey (2000) describes it, salmon production starts in freshwater hatcheries. The development of fertilized eggs is typically accelerated by the use of heated water so that the fish hatch in February. Salmon are carnivores. As young hatchlings they eat plankton, insects, and eventually sand lice, herring, capelin, shrimp, and other fish. In captivity salmon must be fed a balanced diet starting as soon as they absorb their yolk sacs. The fish are reared at high densities in tanks. Larger tanks are used as the fish grow. Liquid oxygen is often injected into the water until the young fish reach smolt size (60 to 125 grams or larger). As juveniles, salmon are vaccinated against a variety of diseases. Each fish is injected individually, by hand, and vaccine formulations often carry antigens for four or more major diseases. Though it usually takes two years for salmon to reach the size at which they adapt to salt water, that length of time is not feasible for hatchery-produced fish. Given the costs of producing salmon in aquaculture and the current market price, the goal of breeding salmon is that the offspring can make this transition at one year or even less.

In general, smaller producers buy their product when it is time to stock their net cages. Large companies tend to maintain adult brood stock and sell eggs or recently hatched animals. The sales from hatcheries are more profitable than producing mature salmon. Moreover, well-run hatchery operations offset the cost of stock through profits from the sale of excess production.

Breeding programs have been publicly supported to create salmon with genetic characteristics that make them perform better within standard aquaculture operations. The artificial selection of salmon has begun to change their genetic characteristics. Genetic work has been undertaken in Norway, the United Kingdom, and Canada.

Different countries have instituted different laws regulating imports of eggs, sperm, and live fish. Some countries allow the import of eggs, sperm, and stock, usually from Europe. The United States used to import eggs, sperm, and stock; however, since most such imports were banned ten years ago, these items are now produced domestically.

To date, there have been no controlled scientific trials, in North America at least, to compare the performance in culture of domesticated North American salmon lines versus wild salmon, hybrids, or European lines. This issue is important because European lines have tended to dominate the aquaculture industry. However, because of the Gulf Stream, European growing conditions are far milder during the winter than in many other salmon-producing regions. For this reason, researchers have been experimenting with genetically modifying salmon. To allow salmon to grow in the winter in less favorable climates than Europe, DNA from the Arctic char has been put into salmon as a kind of "antifreeze". To date, no country has allowed transgenic salmon to be produced commercially. Some industry players are interested because transgenic salmon would not only grow faster and have a shorter time to market, but also they could be grown on farms in far less hospitable areas near the poles.

Grow-out Production Cages

When the smolts have made the transition to salt water, they can be stocked into containment areas in the ocean. Farmed salmon are most commonly grown in cages or pens in sheltered coastal areas such as bays or sea lochs. The cages are designed to hold salmon but are open to the marine environment. These tend to be large, floating mesh cages. While a wide variety of brands and sizes exist, the trend historically was for cages to get bigger. Now just the opposite is true; cages are getting smaller so that operations can become more efficient. Mesh size generally starts at 1.9 centimeters (0.75 inch) stretched net and is changed periodically as the fish grow (to 2.54-centimeter or 1-inch and then 3.81-centimeter or 1.5-inch mesh) to improve water circulation. The water circulation improves oxygen levels and washes away feces, uneaten feed, and other waste. At this time, waste disposal costs farmers nothing.

Large steel cages with mesh nylon nets are usually laid out in double rows. A typical salmon farm in British Columbia has between eight and twenty cages. Cages are usually 30 meters square by 20 meters deep.

Smolts are used to stock the cages. The cages are stocked at high densities. The number of fish that are stocked in a net cage varies depending on the age of the fish and the size of the net cage. In many operations 180,000 to 250,000 animals per cage are stocked initially. Formerly, harvests from single net cages were often on the order of 160,000 8-kilogram (9-pound) animals. Now the overall size of net cages has peaked and is decreasing.

A site includes all the net cages that are supported with a common structure and feeding system. Multiple sites are often owned by a single farm or company. Some countries even limit the total biomass per site. Norway, for example, does not allow more than 300 metric tons of fish at any site. In Canada, however, sites have nearly 800 metric tons of fish (Ellis and Associates 1996). The size of operations at sites in Chile can be considerably larger.

Farmed salmon are raised in high densities, which results in rapidly spreading diseases and severe problems with parasites such as sea lice. Sea lice were once controlled by pouring toxic substances into pens. They can now be suppressed through special additives in salmon food or by co-stocking fish species that eat lice. Other diseases are also common. For example, furunculosis is a bacterial disease against which salmon are vaccinated. Infectious salmon anemia (ISA) is a viral disease for which there is no treatment other than culling infected and exposed fish.

In addition to the grow-out operations, most farms also have a two-story float house that serves as a lab and storage area on the bottom floor with worker accommodations above. If farms have electricity, a generator is usually housed in the float house. Most operations have separate storage facilities for their feed. Feed deliveries take place every week or two, and feeding systems are nearly all automated at this time. Increasingly, feeding operations have photo sensors at the bottom of the net cages to determine when salmon have stopped feeding so that the feed system shuts down automatically to avoid wasting food.

Galvanized steel gangways typically provide access to all net cages so that it is easier to observe operations and to make any necessary repairs or adjustments. The walkways tend to be built on plastic barrels and located about 0.5 meters above the water level (Ellis and Associates 1996). The pens have upright supports around the edge that extend 1.5 meters and form a safety barrier. Nets also extend over the cage to prevent fish from jumping out of the cages.

All net cages are anchored to the bottom, to beaches (when near land), or to both. Anchor lines may extend more than 100 meters, depending on the depth of the water at the site. Buoys are used to mark the location of anchors and lines.

Algal blooms can affect salmon aquaculture production systems. In the wild, fish can swim away from potentially toxic algal blooms. When confined in net cages, however, that is not possible. Some production areas with more moderate summer temperatures are more susceptible to blooms. In salmon-producing areas susceptibility can increase due to the nutrient-rich environment around net cages that is created from the feces and feed waste. Producers in areas where this is a consistent problem must monitor the situation closely in order not to lose their entire crop.

A number of wild animals including seals, river otters, sea lions, herons, and kingfishers commonly attempt to take salmon from net cages. Most operations have developed various defenses to convince animals that it would be easier to eat elsewhere, and these often work. However, some individual animals will become persistent problems when they simply choose to live off of the fish in the salmon operations rather than continue their normal seasonal migrations. These animals are destroyed. Depending on the animal and the country, permits may be required before this can happen. Of course, if operations are built in or near areas that are traditionally used by specific species, then conflicts will be more intense. It is not clear what the impact of salmon aquaculture production is on other wild animal species.

Production Trends

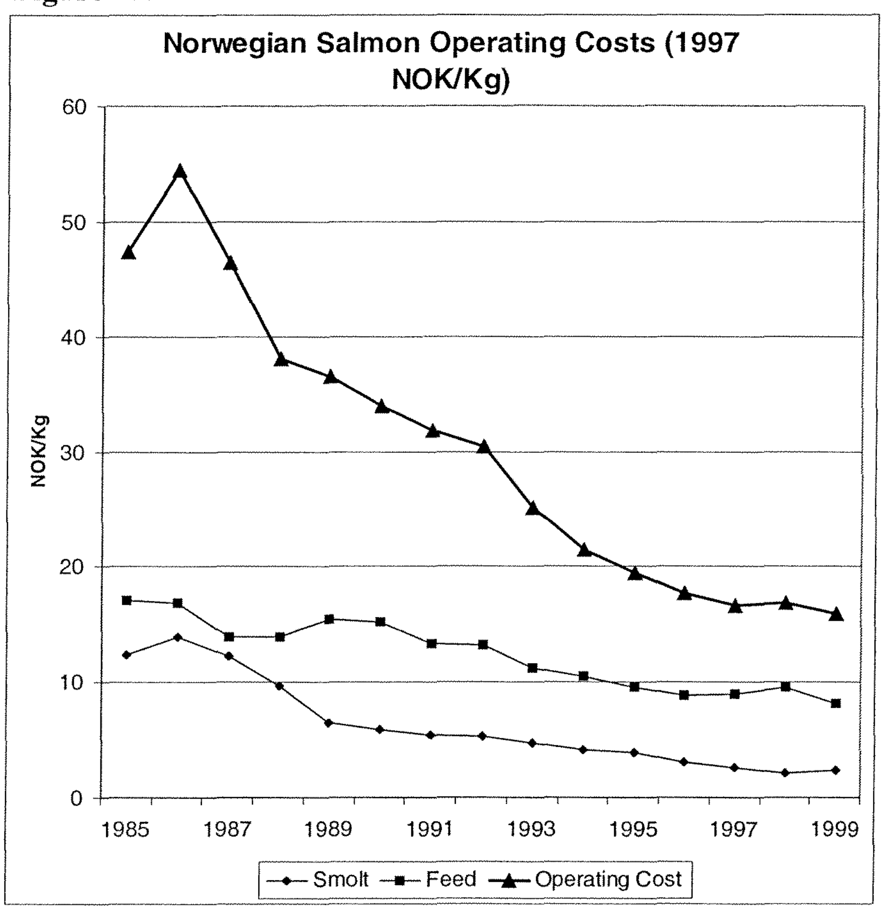
The number of salmon farming operators in some countries has increased, but the average size of operation has increased far more dramatically. If anything the trend is toward a smaller number of much larger producers. Scotland exemplifies this trend. In 1994 only 19 percent of farms produced more than 1,000 metric tons of salmon. By 1999 the figure had risen to 59 percent. During the same period the number of farming operations declined by 29 percent. Even more consolidation is likely given that by 1996, 106 of the firms operating had a combined production of only 4 percent of the total. Another trend represented by Scotland is that 47 percent of output of Scottish salmon was produced by foreign-owned companies (Berry and Davison 2001). In 2000 William Crowe, general secretary of the Scottish Salmon Growers, remarked that "the fundamental economics of this industry mean that one can envisage that there would [eventually] be five or six large global companies" (Berry and Davison 2001).

There are other production trends of note as well. In Scotland, as elsewhere, productivity has increased from 39.8 metric tons per worker in 1993 to 97.2 metric tons in 1999 (Berry and Davison 2001). Production has also become more intensive. However, the size of individual net cages has not been increasing. If anything, after some initial attempts to increase their size the average size has decreased so that each unit can be managed more efficiently.

Production Costs

The operating costs for salmon farming, while variable, generally fall into the following proportions. Feed is the largest single expense at about 34 percent of total costs. The smolts for stocking represent about 23 percent of the cost with wages, overhead, and depreciation amounting to 13 to 15 percent each. It is these latter three costs that give Chile a comparative advantage over Norway and other producers in developed countries. Efficiency of feed manufacture and use as well as hatchery operations are what have allowed Norway to remain competitive with Chile. In Norway, operating costs fell significantly between 1985 and 1999 (Figure 23.2).

Figure 23.2



Source: Norwegian Directorate of Fisheries 1999, as cited in Anderson n.d.

Labor is a significant expense of salmon farming. Over time producers have automated their production as a way to avoid high labor costs. In addition, they have shifted from full-time employees to part-time employees. By 2000, for example, Chile employed 15,000 full-time workers directly in the salmon industry and another 8,000 as seasonal employees (Claude and Oporto 2000). In Chile some twenty-one people were originally employed per production center (a cluster of net cages), whereas today only eleven are. The main changes have come about from the use of automated feeding systems and the use of prefabricated PVC (polyvinyl chloride) cages instead of plastic and wood ones that had been made by hand on the farms. What this means is that in Chile some 40 percent fewer people are employed by the industry than in 1998. From 1990–95 salaries decreased as a percentage of total costs of production by 8.4 percent, and taxes decreased by 3.6 percent. Profits, by contrast, increased by 11.9 percent during the same period (Claude and Oporto 2000).

The cost of raising salmon, of course, depends on the size of the operation. Over the years, costs have declined. By the late 1990s production costs in the United States were about $4.40 per kilogram, while they were only $3.28 in Norway. Since that time costs have continued to decline.

Net-cage culture is vulnerable to storms that can break anchors or mooring lines. This can result in damage to equipment or crops and even in escapes. Insurance for crop, plant, equipment, and liability ranges from 2.5 to 5 percent of fish inventory values at any time (Ellis and Associates 1996).

Processing

For five days before harvest, salmon are not fed. This is done to empty the gut, reduce the fat on the animal, and firm the flesh. The fish are collected in baskets or pumped out of the net cages with fish pumps. Fish are killed by tranquilizing them with carbon dioxide or salt brine and then bled through a cut near the gill arch. In Chile only 12 percent of processors treat their blood-laden discharge water.

Farmed salmon are usually sold fresh with the heads still on; they are shipped on ice in 27-kilogram (60-pound) Styrofoam boxes with ice or gel packs. All net-cage salmon are graded based on texture, color, and factors such as oil content, according to grading standards developed by the salmon farming industry (Ellis and Associates 1996). Depending on the size and the location of the production facility, salmon may be processed nearby or at some distance from the farms. Once processed, it is common for salmon to be repackaged at larger distribution centers. Since salmon are sold fresh, they are often shipped by air from more distant production areas, and this of course increases producer/processor prices. Most of the larger salmon producers also have their own processing plants. Smaller producers are forced to sell into the processing plants of larger companies. Processors have the ability to trace salmon back to specific farms and often to specific net cages.

Farmed salmon processors have developed value-added products such as boneless and skinless fillets, salmon burgers, complete dinners, premarinated steaks and fillets, precooked portions, and breaded steaks. Some of the products can be made with trimmings or other "waste" products with far less market value than whole fish. Only salmon burgers have gained a tiny foothold (a quarter to half a million kilograms sold per year). The production of value-added products is hampered by the fact that salmon flesh is difficult to stabilize, and the cost of new frozen brand products at retail is prohibitive for most companies.

Substitutes

Any fish or even meat protein is, at some level, a substitute for aquaculture salmon. However, even with the price of salmon falling considerably, most terrestrially produced meats are cheaper. The main substitute for aquaculture salmon is wild salmon. Aquaculture salmon is nearly always cheaper. Blind taste tests, however, suggest that most consumers prefer wild salmon to aquaculture salmon. The significant advantages of aquaculture product are convenience, uniformity, and price.

The market share of seafood in the United States remains relatively stable at 7.7 percent of the protein market share (Johnson and Associates 2001). This shows that the increase in seafood consumption is due to population increase rather than a per capita change in eating habits, and that increase in salmon consumption is potentially accompanied by a decrease in consumption of other seafood, especially because of the high substitutability of other fish. Seafood is price elastic, which means an increase in price leads to a decrease in demand.

In the early days of the industry, aquaculture salmon were harvested during the off-season, when wild-caught salmon was not available in the market to depress prices. At that time, the two did not compete directly in the fresh category. This has changed in recent years as aquaculture salmon production has increased and as dedicated markets have come to rely on farmed salmon.

Wild salmon is not losing out just because of price, either. Wild-caught salmon is not keeping pace with consumer preferences. The short harvest season (eight weeks), the small airfreight shipping capacity, and the lower prices for all salmon as a result of farming have contributed to the decline of wild salmon in many markets. More than 90 percent of Alaskan salmon, the largest source of wild salmon in the world, was sold as lower-priced frozen or canned product in 2001 (Alaska Department of Revenue, as cited in Johnson and Associates 2001). Most Alaskan processors have stopped trying to increase fillet production to compete with aquaculture producers. In Alaska, labor and production costs are higher than on farms. In 2001 only 357,000 pounds of frozen fillets were produced from a harvest of 765 million pounds; in fact, 1 percent of all Alaskan fillets were exported and reprocessed in China and Thailand in 2001.

Market Chain

The farmed salmon industry has consolidated. Over half of aquaculture salmon is produced by five companies: Nutreco Holding N.V. (165,000 metric tons in 2001), Fjord Seafood ASA (102,000 metric tons), Pan Fish ASA (97,000 metric tons), Stolt Sea Farm SA (55,000 metric tons), and Statkorn Holding ASA (53,000 metric tons) (Packard Foundation 2001). All of these companies have operations in one or more of the following regions: Canada, the United Kingdom, Chile, the United States, and Norway. Production figures for these companies for 2000 are shown in Table 23.1.

Table 23.1 The World's Main Salmon-Producing Companies

Company (Headquarters)	Production (MT)	2000 Sales (million U.S.$)	Production Locations
Nutreco Holding N.V. (Netherlands)	141,500	$855	Canada, United Kingdom, Chile
Pan Fish ASA (Norway)	64,200	$527	Norway, Faroe Islands, British Columbia, Scotland, United States (Washington)
Stolt Sea Farm SA (Luxembourg)	47,000	$310	Canada, Chile, United Kingdom, United States (Maine)
Fjord Seafood ASA (Norway)	39,120	$258	Norway, Chile, United States
Statkorn Holding ASA (Norway)	35,000	$150	Norway
Salmones Pacifico Sur SA (Chile)	27,000	$69	Chile
George Weston Ltd. Connors Bros. (Canada)	27,000	$560	Canada, Chile, United States
Modnor Group AS (Norway)	19,300	$56	Norway
Camanchaca SA (Chile)	19,000	$70	Chile
Multiexport SA (Chile)	18,000	$85	Chile

Source: Johnson and Associates 2001.

Many large producer/processor companies attempt to distribute their own product, but so much salmon is consumed in so many types of markets that this is not really possible. The top seafood distributor in the United States is SYSCO with $1.3 billion in seafood sales (out of total sales of $21 billion). SYSCO has 400,000 customers. They sell eleven types of shrimp and six salmon products. Ahold-owned US Foodservice is a distant second with $760 million in seafood sales. Performance Food Group has $250 million in sales, and the next seven distributors (Morey's Seafood International, Inland Seafood, East Coast Seafood, Supreme Lobster & Seafood Co., Gordon Food Service, Ipswich Shellfish Group, and Reinhart Food Service) have $140 million or less in sales.

There are 25,000 supermarkets in the United States alone, and some 10,000 have full-service seafood sections. Fresh, farmed salmon is the second largest seafood item on a dollar basis (after shrimp) in most seafood departments. Large supermarket chains negotiate six month, fixed price contracts with farmed salmon suppliers.

In the large club stores such as Costco and Sam's Club/Wal-Mart, annual fresh farmed salmon fillet sales grew 30 percent in 2001 to 30 million pounds. Costco purchases most of its salmon through Marine Harvest, the aquaculture division of Nutreco Holding N.V. that operates farms in Chile, Norway and Canada. Costco sells 9 to 12 million pounds of farmed salmon per year. Recently, the average Costco sale price was $8.35 to $11.00 per kilogram ($3.79 to $4.99 per pound) for salmon, for which they paid $6.17 to $6.61 per kilogram ($2.80 to $3.00 per pound). This 50 to 60 percent markup is higher than the norm for other seafood; the typical markup is 10 to 12 percent. In short, the decrease in salmon prices has generated higher revenues for retailers rather than savings for consumers. Wal-Mart has total sales of $57 billion with stores in nine countries. It has a total of 1,600 seafood departments with annual sales of more than $800 million.

Salmon is the most popular finfish on menus in the United States and Europe. In the United States, it is on 39 percent of the food service establishment menus and on 71 percent of the menus of fine dining establishments (Restaurant and Institution Menu Census, as cited in Johnson and Associates 2002). Outback Steakhouse uses an estimated 1.4 million kilograms of 283-gram (10-ounce) Chilean farmed salmon portions per year. Applebee's has introduced honey-grilled salmon on its menu, and Bennigan's has introduced "O'Cajun" salmon, 198-gram (7-ounce) fillets.

The top casual dining establishment in the United States for seafood sales is Darden's, which owns 660 Red Lobster restaurants, 490 Olive Garden restaurants, 24 Bahama Breeze restaurants, and 9 Smokey Bones BBQ sports bars. Darden's has more sales than most of its competitors combined. This company operates another 37 locations in Canada. In all, its restaurants serve 140 million guests per year. Red Lobster's sales are $2.1 billion. Another major seafood chain is Landry's, which owns 215 full-service restaurants (including Joe's Crab Shack, Landry's Seafood House, The Crab House, Rainforest Café®, Willie G's Oyster Bar, and Muer Seafood Restaurants) in 22 states with total sales of $750 million (Packard Foundation 2001).

Market Trends

Consumption of salmon in the United States increased nearly 270 percent from 1988 to 2000. Salmon aquaculture makes fresh salmon available year-round, rather than just May through September when it was linked to wild salmon runs. Salmon has nearly completely penetrated the U.S. market. What has facilitated the rapid expansion of salmon consumption in restaurants has been the move to process salmon into ready-to-use forms known in the trade as "case-ready" and "cross-dock," which do not require additional processing. Once salmon farms began to produce large quantities of fish on a continuous basis, they could afford to establish very efficient processing plants. The fillets from these plants make it possible to bring boneless fish into so many family restaurants.

During the initial rise of the salmon farming industry, farmed salmon commanded premium market prices because for the first time ever fresh product was available year-round. This high return on investment encouraged rapid growth, but like all commodities an oversupply on the world market followed. Market saturation, greater competition, and lower prices result in higher investments in efficiency and new developments such as biotechnology. Continued expansion is constrained by low profit margins. Over time, smaller enterprises become nonviable, as they are replaced by foreign-owned factories (Berry and Davison 2001). For example, seventeen companies produce over 75 percent of Scotland's salmon production (Staniford 2001).

Over the past decade, farmed salmon prices have been declining due to both decreases in production costs and oversupply (Johnson and Associates 2001). Salmon farming pushes down prices and forces those who harvest wild fish to increase their yields to sustain economic viability. If this trend continues, wild salmon fisheries will go out of business unless even higher levels of subsidies are given to the industry. This picture is only going to worsen.

By 2010 Atlantic farmed salmon production is expected to exceed 1.9 million metric tons, and other farmed salmon species, 0.3 million metric tons. This would more than double the global production of farmed salmon since 2000, when it was approximately 1 million metric tons (Johnson and Associates 2000; 2001). Corresponding to the increases in production is a general decline in salmon prices. No one knows exactly how far the price would decline (and how many producers would remain in business) if production doubled in the next eight years. For the sake of comparison, in 1998 the price of salmon fillets (pin bone out) averaged just over \$8.38 per kilogram (\$3.80 per pound). By 2001 the price had dropped to nearly \$5.29 per kilogram and was still declining (Johnson and Associates 2001).

In 2000 more than 40 percent of American consumers said they never eat salmon. So there is still some room for further market penetration (SeaWeb 2001). Recent surveys suggest that consumers are inclined to believe that farmed salmon are better for the environment and healthier for people, with human health being the single most important issue for most consumers. In general, consumers are aware that many fish species are being overfished and that many bodies of water are polluted and therefore the fish taken from them may be harmful to one's health. Even environmentalists believe that farmed salmon is "better" (SeaWeb 2001).

Environmental Impacts of Production

Many involved in the salmon aquaculture industry believed that its growth would help take pressure off wild stocks of over-harvested fish such as cod, which had once been an economic mainstay of the North Atlantic fishery where salmon aquaculture began. While the industry clearly helps to provide consumers with fish while taking some pressure off of comparable wild stocks in the ocean, it has a number of other detrimental impacts that, on the whole, may actually endanger wild stocks. These impacts occur at the level of individual salmon farms, but due to the open nature of oceans many can have much more far-reaching impacts as well.

Ecological Footprint

A recent report by Michael Weber (1999) suggests that for every metric ton of Atlantic salmon from aquaculture, 10.6 hectares of marine area and 3.0 hectares of terrestrial area were required to support or provide the inputs to make it possible. For example, some 99 percent of the marine requirement for production of salmon is dedicated to the production of organisms that are caught and made into salmon feed. On the terrestrial side, some two-thirds of the land required was actually to assimilate the 7 metric tons of carbon dioxide created during the production of a metric ton of salmon from aquaculture. Most of the remaining terrestrial impacts resulted from the production of crops that were converted to salmon feed.

Waste and Nutrient Loading

Salmon produced from aquaculture are efficient at converting feed to flesh. For example, 1 kilogram of salmon can be produced with as little as 0.9 to 1.1 kilograms of feed and only 0.27 to 1.1 kilograms of waste. Even so, because salmon are produced in a water column that can be up to 20 meters deep, wastes can accumulate and degrade water quality. This in turn can smother plant and animal communities living beneath the net cages (Weber 1997).

Waste from feces and uneaten food results in increased nitrogen and phosphorus released into marine environments. In 1998 Scotland produced 115,000 metric tons of Atlantic salmon. Nutrient inputs to the marine environment for that year were 6,900 metric tons of nitrogen and 1,140 metric tons of phosphorus (i.e. 1 metric ton of salmon released 60 kilograms of nitrogen and 10 kilograms of phosphorus). Ellis and Associates (1996) found that each metric ton of salmon production resulted in waste equivalent to that from nine to twenty people. So for nitrogen, the total nutrient input for 1998 was equivalent to the sewage from 3.2 million people, and for phosphorus, 9.4 million people. In 1997 Scotland's human population was 5.1 million people (MacGarvin 2000).

Nutrient pollution leads to eutrophication, which often results in increased plant growth. Even small changes in nutrients can have major impacts on phytoplankton communities. Increased phytoplankton populations reduce light availability below the surface, and as a result, threaten seaweed and eelgrass communities. Elevated nutrient concentrations, along with climatic conditions, can contribute to blooms of plankton and toxic algae (MacGarvin 2000).

Blooms can have devastating effects on farmed fish. Some plankton species have sharp spicules (needlelike pointed structures) that can damage gill tissue, making fish more susceptible to disease. Depending on cage depth, salmon raised in net cages may not be able to evade the surface plankton (Ellis and Associates 1996). The frequency of mortalities due to algal blooms around salmon farms is increasing. When these mortalities occur, salmon farmers suffer huge financial losses but can also make compensation claims. In certain areas, the evidence suggests that salmon farm pollution is the main, or at least a contributing, cause of toxic algal blooms (Staniford 2002).

Algal toxins can also be transmitted via plankton-feeding fish up the food web to other marine species including birds and marine mammals (MacGarvin 2000). In Scotland, fecal waste from fish farms has been linked to toxic algal blooms and outbreaks of the algal toxins that cause diseases in humans, most notably amnesiac shellfish disease (ASD). Both diarrhetic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP) are also of concern in the region. Such blooms have severely depressed the shellfish farming industry in Scotland.

Fish farm sediments are deposited on the ocean floor, disrupting and altering the community of macrofauna that live there. Benthic communities play important roles in sediment nutrient cycling. The structure of the community can change as species with low tolerance to pollution, or species that are no longer suited to the organically enriched environment, die or move to other areas. The rapid deposition of waste can overwhelm organisms that promote aerobic decomposition on the ocean floor. Anaerobic decomposition by a different community is then favored, causing a drastic shift in the ability of the original benthic community to survive in the area (Ellis and Associates 1996).

Incorporating seaweed and/or shellfish into the salmon farming system can help to solve the waste problem, since these organisms filter and utilize waste products. An integrated system of, for example, salmon and seaweed or salmon and shellfish could reduce nutrients significantly. There is some question, however, as to whether such systems could reduce significantly the overall impact of having so much organic matter concentrated in one place. In addition, such a system does not help solve the problem of toxic chemicals entering the marine environment (Staniford 2002).

Increased Pressure on Wild Fisheries

Salmon aquaculture is often touted as a precursor of aquaculture production systems that could relieve pressure on other wild fisheries. However, because salmon are carnivorous, they require a diet high in fish meal and fish oil. Fish oil use is now dominated by aquaculture, which takes 60 percent of total production (FAO 2000). Salmon aquaculture is by far the largest user. Analysts have suggested that aquaculture will use more than 90 percent of fish oil by 2010.

At this time, some 20 to 25 percent of annual global seafood supply is converted to fish meal and fish oil (Packard Foundation 2001). Though a relatively new industry in 1994, the carnivorous aquaculture farms used approximately 15 percent of the global fish meal output (Ellis and Associates 1996). By 1997 aquaculture used 33 percent of fish meal supplies (Jacobs, Covaci and Schepens 2002). Changes in feed formulation have focused on oil to provide energy for fish to swim and meal to result in weight gain. Salmon feed can contain up to 40 percent fish oil. This has increased from 8 percent in 1979 (Staniford 2002). Net-cage rearing of 1 kilogram of salmon is estimated to use anywhere from 4 to 5.5 kilograms of wild fish. While this is probably a far better ratio than salmon in the wild (where the ratio could easily be 8 to 1, 10 to 1, or even higher), responsible businesses must strive to use finite resources more efficiently. Finally, the tradeoffs for this issue are further compounded if the fish used to make fish meal could be consumed directly by people rather than converted to more high value products for wealthier consumers.

Feed accounts for 30 to 50 percent of a salmon producer's annual expenses. Because of the high quantities of fish meal and fish oil used, farmers look for low prices for these products, putting pressure on the South American fish meal industry. Japan, Chile, Peru, and the Commonwealth of Independent States (former Soviet constituent states) account for approximately two thirds of all fish meal production. Three species of fish (anchoveta, sardine, and jack mackerel) constitute 85 percent of South American fish meal production, and they are susceptible to large fluctuations in population due to El Niño. The anchoveta population collapsed in the 1970s, 1980s, and 1990s. When this happens, it puts more pressure on other species to make up the difference for industries that are dependent on feeds based on fish meal.

Interactions Between Wild and Farmed Fish

Caged salmon escape virtually everywhere that salmon are farmed. The introduction of a species to an area inevitably has unforeseen consequences. Salmon that escape from aquaculture operations can cause a wide range of impacts including competition for food and spawning habitat with both wild salmon and other species. Escapes can interbreed and cause genetic pollution that reduces the hardiness of wild salmon. Also, they can spread diseases that either did not previously exist in the area or were not previously a problem for wild populations.

There are large numbers of escapes. In Norway as many as 1.3 million salmon escape each year, and a full third of the salmon spawning in coastal rivers are of escaped origin. In 1997 300,000 salmon escaped in Puget Sound in a single instance when net cages were ripped open accidentally (Weber 1997). In 2000 an estimated 500,000 fish escaped in Scotland (Berry and Davison 2001). The year before, there were sixteen reported escape incidents involving 440,000 farmed fish. Often the escapes involve much smaller numbers (only 10,000 or so might escape as a result of a single accident), but the cumulative impact on an ecosystem over the course of a year can be quite large.

There is considerable evidence that in some areas the escapes are becoming significant populations in their own right. The number of escapes in Scotland has increased more than threefold since 1998, but less than 60,000 wild salmon were caught in 1999. On the west coast of Scotland, an estimated 22 percent of the "wild" catch is, in fact, escaped farmed salmon (Staniford 2001). In some of Norway's rivers, there are as many as four escaped farmed salmon for every wild one (Ellis and Associates 1996).

With an estimated half a million escapes in 2000 off the Scottish coast, farmed fish and wild fish may be interbreeding. As farmed fish are selectively bred for characteristics favorable for aquaculture, breeding between the two populations could alter the genetic makeup of wild fish and decrease their fitness to survive in the wild environment.

The significance of escapes can be demonstrated by the example of New Brunswick, Canada, where the first salmon farms were built in 1979. Within four years, 5 percent of the salmon in the nearby Magaguadavic River were escaped salmon from the farming operation. By 1995, 90 percent of the salmon in the river were escaped (Weber 1997). When escapes are an insignificant portion of the population in the wild, they probably pose a rather limited risk. However, when they dominate the numbers in the wild, they can very quickly become one of the major reasons for the demise of wild populations.

Farmers have every incentive to eliminate escapes because escapes represent significant costs for buying and feeding animals. However, in some instances the releases are not accidental. Some 4 million salmon are estimated to have escaped in Chile since the industry started (Claude and Oporto 2000). In 2002 when salmon prices declined, Chilean producers actually released hundreds of thousands of salmon rather than pay to harvest them.

There is another important issue, however, when discussing the issue of escapes. This is the impact of deliberate releases from hatcheries that are intended to increase or even create salmon runs in specific river systems. For more than a century, salmon species have been released throughout the world into a wide range of river systems that did not include salmon previously. In the Eastern United States, Alaskan salmon were released more than a hundred years ago in an attempt to reintroduce salmon in rivers where Atlantic salmon were extinct. In the case of Chile, salmon were released into the wild in 1905, 1914, 1946, and 1952 in an attempt to colonize river systems thought to be suitable but with no comparable fish populations. None of the Chilean releases were successful (Claude and Oporto 2000). The implications of this for wild species are not clear.

Sea lice and other diseases spread by farmed salmon can have a devastating effect on wild salmon and other fish. Researchers found that 86 percent of wild migrating juvenile salmon in two Norwegian fjords died as a direct result of sea lice infestations that they contracted while migrating past salmon farms (Pearson and Black 2001, as cited in Berry and Davison 2001). This contributes to the continuing decline of wild salmon, which in turn upsets the ecological balance in marine and freshwater systems. It also reduces revenue from commercial harvesting and sport fishing.

The application of biological engineering to salmon has resulted in the creation and patenting of transgenic, or genetically altered salmon. There has been pressure on the U.S. Food and Drug Administration to consider a petition to farm and sell the salmon within the United States. The farming of such fish further increases the likelihood of salmon aquaculture affecting wild salmon populations as well as other organisms within the environment (Kay 2002).

Contamination with Toxic Compounds

The farming of fish high up the food chain can tend to concentrate contaminants (Staniford 2002). The artificial food chain built by feeding oil-rich and animal-derived diets to salmon has resulted in elevated levels of such contaminants as dioxins and polychlorinated biphenyls (PCBs) in farmed salmon compared to their wild counterparts.

The term *dioxins* refers to over 200 different polychlorinated dibenzo-*para*-dioxins and dibenzofurans, seventeen of which are considered toxic. Dioxins are produced as unwanted by-products, while PCBs are manufactured for use in transformers and insulators (CFIA 2002). Chlorinated hydrocarbon compounds can accumulate in the fatty tissues of fish, so fish oil has relatively high levels of these compounds (especially if derived from fish from contaminated areas). Any of these toxins can pose serious risks to human health.

PCBs and many organochlorine pesticides (which have been found in aquaculture salmon) have been banned in most of the world, but they still affect humans through their diet. European farmed salmon can be a significant source of these toxins in the diet (Jacobs, Covaci and Schepens 2002). The European Union's Scientific Committee on Food found that fish can represent up to 63 percent of the average daily exposure to dioxins. The Food Standards Agency of the United Kingdom recommends that people consume only one portion of oily fish per week (Staniford 2002).

A recent study of PCB concentration in salmon showed that some farmed salmon had relatively high concentrations of the compound. However, wild salmon captured from polluted water had even higher levels of PCBs. Variation in farmed salmon PCB levels is attributed to the variation in the level of contamination in fish meal. Fish meal from Peru had PCB concentrations ten to twenty times lower than those from Denmark and the Faroe Islands (Jacobs, Covaci and Schepens 2002). Farmed salmon in Scotland were shown to have relatively high concentrations of dioxins and PCBs, presumably due to the sources of the fish meal and oil used for feed. Concentrations of the compounds in salmon were higher than those of other species such as cod, because salmon have a higher fat content than other species. Thus, salmon retain more toxins per pound of fish than do fish with lower fat levels since the compounds accumulate in the fatty tissues of the fish (Jacobs, Ferriaro and Byrne 2002). In addition, farmed salmon have four to five times more fat content than wild salmon (Staniford 2002).

In addition to these contaminants, toxic heavy metals can also accumulate in the fatty tissues of fish. These metals can be concentrated further through the rendering of fish meal and fish oil and further still in the animals that eat feed made from them. Mercury is a good example; once consumed by humans, it is readily absorbed into the gastrointestinal tract. Symptoms associated with the consumption of low levels of heavy metals may not appear until later in life (Quig 2002).

Many studies have examined the concentrations of toxins in fish, fish meal, and fish oil. Results vary considerably. One study in Canada showed that fish meal and fish oil do not contain high levels of dioxins, PCBs, DDT, or mercury (CFIA 2002), while the authors of a study in Scotland recommend that measures be taken to lower these levels because they are too high. An analysis of dioxin toxicity of thirteen categories of food (such as beef, chicken, ocean fish, freshwater fish, butter, eggs, etc.) found that the freshwater fish (in which the study included many farmed species and salmon) had the highest dioxin toxicity. In fact, freshwater fish toxicity was 50 percent higher than butter, which had the second highest toxicity. All of the other products had less than half the toxicity of butter (Schecter et al. 2001).

Use of Antifoulants

Salmon net-cage operations generally have steel cage superstructures with knotless nylon nets suspended within. While the net cages can vary considerably by area, they tend to be some 20 meters deep. One of the main problems that the net cages pose is the potential for fouling. Shellfish and marine algae grow on the nets and can make them extremely heavy. This makes the lifting and cleaning of the nets very difficult, and it shortens the lifetime of the investment (Ellis and Associates 1996).

To avoid fouling and to prolong the life of the cage, growers often use antifouling paints. Such paints, by definition, are highly toxic given that that is how they prevent organisms from growing on painted structures. The most commonly used antifoulants (organotin or copper-based compounds) are toxic to bivalves and could be harmful to fish species as well (Cripps and Kumar 2003). Titanium, copper, and tributylin (TBT) have been used in marine paints, and are known to be harmful to shellfish. However, some of these paints are also known to accumulate in the tissues of fatty fish such as salmon and are therefore inappropriate for use around fish intended for human consumption. Tributylin has been shown to be highly toxic to marine life, causing reproductive failure and growth abnormalities in molluscs. In addition, paints containing oxytetracycline should be prohibited from salmon aquaculture operations because they are known to result in increased antibiotic resistance (Ellis and Associates 1996).

Use of Chemical Inputs

In addition to the antifoulants discussed earlier, chemical inputs in salmon farming include antibiotics and insecticides such as organophosphates and synthetic pyrethroids. Therapeutic chemicals may be applied as a bath treatment or administered in feed, but in both cases the chemicals eventually make their way outside the salmon cage into the larger marine environment. The effects of chemicals on the greater marine environment are not well known. The ecological impacts resulting from the use of antibiotics in salmon farming have not been studied. It is conceivable that antibiotics could accumulate in the tissue of wild fish and invertebrates, while also leading to resistance in target pathogens and other microbial species. Scotland is known for being the strictest country when giving out permits to salmon farmers. Their typical discharge consent, however, allows the use of over fifty different chemicals. The number of drugs permitted for use by the Veterinary Medicines Directorate has increased from three to forty from 1989 to 2002 (Staniford 2002). In short, "the global advance of intensive salmon farming has meant that farmed fish have become agents of pollution rather than biological indicators of pollution" (Staniford 2002).

Several different drugs and chemicals are used to combat diseases and parasites in the production of salmon. Over time the industry has learned how to produce more salmon using fewer drugs and chemicals. However, the learning curve has tended to be repeated in each new area of culture. For example, from 1985–87, antibiotic use in salmon farms in Norway increased from 17 to 48 metric tons per year, more than the combined use of all antibiotics for humans and terrestrial animals in the country (Weber 1997). In 1999 in the United Kingdom, 4 metric tons of antibiotics were used in salmon farming compared to 11 metric tons in cattle rearing and less than 1 metric ton with sheep (Berry and Davison 1999). As vaccines have been developed and as management systems have been improved, these levels have declined drastically.

In Chile, however, the reduction in the use of antibiotics has been slower, even though most of the major investors are Norwegian. In 1990 the salmon industry used 13 metric tons of antibiotics, by 1995 usage had increased to 65 metric tons, and by 1998 it was 100 metric tons. In 1993 Chile used seventy-five times more antibiotics per kilogram of salmon produced than Norway (Claude and Oporto 2000).

In the early years, most antibiotics were put in the manufactured feed, and as late as 1999 medicated feed was still common in Chile (Claude and Oporto 2000). At least three-quarters of antibiotics in feed are lost to the environment, whether the feed is eaten or not (Weber 1997). Little is known about the impact of these drugs on ecosystems in general or on individual species in particular.

The prophylactic use of drugs can lead to growth of drug-resistant strains of pathogens in both wild and cultivated fish populations. The abuse of antibiotics through prophylactic use can also build up pathogenic resistance in humans. In 1991, 50 percent of the bacteria responsible for the fish disease furunculosis were resistant to two compounds used to treat the disease. Scientists disagree about the extent to which resistance has developed, but they agree that resistance will increase as antibiotic use increases—and that this resistance can be passed on to human pathogens. In addition, there are a limited number of compounds that are effective on aquatic pathogens, which means there will be even graver consequences if resistance develops.

The chemicals are not always even appropriate. For example, the chemicals used to treat sea lice have largely been developed for terrestrial use, and little research has been done on their use in the marine environment. In Scotland salmon producers used a chemical delousing agent called dichlorvos to reduce infection of salmon by sea lice. Later research suggested that this chemical killed oysters, mussels, and other shellfish and crustaceans within 75 meters of the salmon cages (Weber 1997).

Mort Disposal

The disposal of salmon that die before harvest (morts) has both environmental and health implications. Approximately 20 percent of salmon die during grow-out, some of them from diseases that could potentially be spread from the improper disposal of morts. A variety of disposal methods is used; the principal ones are landfilling, composting, and ensilage (a liquification of the morts that is then used in animal feed or fertilizer). Some companies dump morts into the ocean, where the chemicals ingested by the salmon before death, as well as any diseases that may be present, are released into the environment.

Impact on Predators

Salmon in net cages attract predators such as seals, river otters, sharks, kingfishers, eagles, cormorants, and great blue herons. The effect on these animals of consuming salmon that have antibiotics and other chemicals in them is not known. Nor is it clear how greatly they have been impacted by various methods salmon farmers employ to keep them away. One of the methods is simply to kill them. Seals, for example, can be shot by salmon farmers in British Columbia, though the farmers must obtain permits to do so. It is estimated that at least 500 are shot by salmon farmers each year in British Columbia, where harbor seals are estimated to cost the industry $10 million a year (Weber 1997). In Scotland the industry estimates that 350 seals are shot each year, while environmentalists put the figure at 5,000 (Weber 1997).

From the 1980s to the mid-1990s, some 5,000 to 6,000 sea lions were killed in Chile by salmon farmers. In addition, an unknown number of dolphins and even an occasional minke whale were killed (Claude and Oporto 2000). According to one study (Brunetti et al. 1998, as cited in Claude and Oporto 2000), sea lions cost the Chilean salmon industry about $21 million in damage annually (in direct costs as well as the cost of security, etc.). This amount was some 3 percent of sales.

Farmers also use predator nets, or nets above and around the salmon cage, to prevent predators from getting too close to the cage. Netting used to exclude marine mammals and birds can entangle and drown animals. Some producers leave the dead animals there as a way to scare away others. Acoustic devices that emit a high-pitched sound can be used to scare away seals and sea lions. In some instances these devices have been so successful that they have also caused the withdrawal of resident populations of harbor porpoise and whales. The extent of the impact of any of these methods on bird and mammal populations is unclear, but potentially they could have a great impact, especially in areas where salmon farms are highly concentrated.

Poorly Run Hatcheries

Well-run hatcheries should not have environmental impacts. Unfortunately, not all hatcheries are well run. In many parts of the world, hatcheries are allowed to dispose of waste without treatment. This damages the environment not only by causing nutrient overloading, but also by introducing diseases into the marine or freshwater environment that can affect both wild salmon and salmon farming operations.

In Chile hatcheries were established in large freshwater lakes rather than in closed systems as in most other parts of the world. In Southern Chile, where most salmon are produced, five of eight lakes are polluted, and the salmon aquaculture industry appears to be the main cause (Claude and Oporto 2000).

Better Management Practices

There are BMPs for salmon aquaculture at both the site and the landscape level. Clearly, making sure that net cages are put in the least damaging places and that they are operated in ways to reduce their impacts are both important strategies to reduce the overall environmental impact of the industry.

Other factors are also important. For example, salmon aquaculture has received rather less public resources than might be expected given the phenomenal growth of the industry. This suggests that there may be some room to negotiate with governments to help fund some of the transition costs to more sustainable production. To date, technologies have been developed and deployed around the world faster than the understanding of their consequences or unintended impacts on nontarget organisms or ecosystem functions (Whoriskey 2000).

Improve Siting of Operations

The salmon aquaculture industry is centered in areas where many wild salmon populations are in crisis. While the industry may not have been the primary cause for the decline of wild salmon populations, the first step to their effective recovery will have to be to eliminate, or at least reduce substantially, the impacts of the aquaculture industry (Whoriskey 2000). One way to do this at both the farm and the landscape level is to integrate risk analysis into the review process for siting hatcheries and farms.

Use Closed Production Systems

Some have suggested that in the final analysis, completely closed systems for the containment of contaminated wastes is the only sustainable solution for salmon production (Staniford 2002). Enclosed, land based salmon farming can reduce or eliminate many of the problems specific to net-cage production systems. Salmon farmed in net cages escape into the wild. This impact, and the genetic and disease issues that it raises, would be eliminated with on-shore closed systems. Similarly, wastes that are discharged into the ocean in the net-cage system would be captured as the water leaving the land based tank is filtered. These nutrient-rich wastes could potentially be recycled for agricultural use. The industry, and ultimately the consumer rather than the environment or the "public" more broadly, would pay for the cost of waste disposal.

AgriMarine Industries Inc. in Canada recently made the first sale of Pacific salmon raised in a land based, closed containment system (Smyth 2002). The company raises salmon in concrete tanks, in which seawater is pumped in and oxygenated and outgoing water is filtered. This system produces healthy salmon but is far more expensive to operate than the standard cage production system. While AgriMarine's salmon was sold at a higher price and marketed as "eco-friendly," it is not clear that such a system is economically viable over the long term (Smyth 2002).

The most complete study, to date, on the viability of land based salmon aquaculture was undertaken in the Bay of Fundy (ADI Ltd. et al. 1998). The large tides in the region were seen as an asset because they could move water into reservoirs from which it could flow by gravity into salmon tanks with no pumping costs. Pumping water is a very large expenditure for land based aquaculture systems.

The study assumed that production would follow standard industry practices (e.g. stocking densities, feeding and growth rates, etc.). It was also assumed that the factors that would most affect such operations were the price of salmon, the rate of return, the up front capital costs (e.g. investing in dams and seawalls to hold and move the water), the growth of the fish, and the cost of money. The only scenarios modeled that showed a positive cash flow in five years were those that grew transgenic salmon. These salmon grow faster and far bigger than the animals used today. Even with transgenic animals the scale of operations would have to be increased considerably to make the operations profitable. While such systems may not work for salmon unless the price increases (which is unlikely), it may work for other, higher-valued species. In fact, this system might well have worked for salmon early on when prices were much higher than they are today. What this means is that with the current level of environmental subsidies for salmon aquaculture in many parts of the world, it may be impossible to go back to more sustainable production systems.

Another important issue is that the proposed closed system has some unique implications. It must be located in areas with severe tides, and these areas must, in turn, be located near rather flat terrestrial areas where land based farms can be established. More importantly, the land based systems require production units and large tracts of land that would be rarely available in coastal areas anywhere in the world without considerable conflict with existing residents.

Norway is reported to have considered land based systems, but the country eventually abandoned the idea based on the belief that sufficient land was not available. As a consequence it was assumed that producers using closed systems would be forced to stock at higher densities. Such densities, it was felt, would lead to very real risks of disease outbreaks (Whoriskey 2000).

Another closed system that may offer more hope is the use of closed containment systems in the open water. These systems amount to little more than large plastic bags in the water column. Water is pumped into and out of the bag to provide oxygen for the fish. The shape is maintained by the force created by a small hydraulic head pumped into the bag. Such bags offer a number of environmental benefits. Seals and other predator attacks are reduced because animals no longer see the fish through the opaque bags. Waste can be collected and removed from the bottom of the bag rather than released into the water. Finally, fish raised in bags have fewer sea lice problems than those raised in open net cages (Whoriskey 2000). Closed-bag systems have been experimented with in both eastern and western Canada. To date, this system of production appears to be expensive to install and operate. This is a deadly combination given the overall decline in salmon prices.

Reduce Escapes

Escapes can have a huge impact on wild salmon populations, particularly where those populations have been depressed. For example, if a river has a salmon run of 5,000 animals a year, then a 5 percent level of escapes within that run (say twenty-five animals) would not be a large impact. If, however, a river only has twenty-five animals in its annual run, then the twenty-five escapes would have a much larger impact. To date, there is no science available to define what impact levels would be "acceptable" for what reasons.

Similarly, moving the industry away from the mouth of rivers with major runs of salmon or other species would help to reduce contact between wild and caged fish and, consequently, the spread of disease from either. Norway has adopted a much more thoughtful approach to the siting of operations as well as to the size of operations allowed in any one site since the early days of the industry when it developed with less planning and fewer controls. Even so, at this time the majority of streams and rivers in Norway no longer have salmon runs. While aquaculture was not the only or even the primary cause of the demise of these runs, it did have an effect on at least some of them.

One way to address the issue of escapes is through a code of conduct. A code could address such issues as improved cage engineering, better operating regimes, education of workers on their roles regarding this issue, improved monitoring, enforced and prompt reporting, contingency planning, and more effective recovery programs. Specific targets could be set and monitored. Whoriskey (2000) has suggested an overall escape reduction target of 10 percent per year for five years. Once the goal is set, let the industry find the best ways to meet it. Proper siting could reduce the chance that escapes would happen at all, much less enter rivers with salmon runs.

Another way to reduce the impact of escapes from salmon aquaculture is to stock only sterile fish. Sterile fish programs are not foolproof; there is no way to guarantee that the organisms are always sterile. However, as long as escapes persist, and perhaps even after they cease, sterile fish should be stocked to help to insure that escapes do not cause genetic pollution of wild salmon runs. Such programs will at least reduce the overall risk of interbreeding from escapes.

Encourage Organic Net-Cage Production

No chemicals are used in organic net-cage production, including no medication for the animals or chemical treatment of the cages to prevent "fouling". An organic net-cage operation in Canada had 30 percent losses of salmon during the grow-out phase of production compared to the industry average of 20 percent. Despite these high mortalities, the operation also had lower-than-normal production costs since it was not buying chemicals. More importantly, the product fetched a higher market price. Product on the farm is harvested each week so as not to saturate markets; some 100 metric tons are sold each year. A non-organic producer operating on the same site could produce some 700 metric tons and still not have the same net profit. While such an operation does not eliminate the dangers and impacts of escaped fish or the fish meal issue, the low density production and lack of chemicals cause the system to have considerably lower environmental impacts than the standard net-cage production system. Total production by volume, however, is only about 15 percent of the standard system operating on the same area (Ellis and Associates 1996).

Encourage Fallowing in Net-Cage Production Systems

Fallowing can reduce, but not eliminate, the overall impact of net-cage production systems. Fallowing does not mean leaving net cages unused, but rather moving them from one area of recent production to another area. This practice spreads the impacts of production over a wider area and gives the ecosystem time to flush and disburse the wastes that accumulate below the net cage. In general, it is not advisable to produce fish in the same location over long periods of time, as there is an increasing chance of disease.

This practice is equivalent to agricultural fallow systems. An area is not used for production for a number of years (up to five for salmon aquaculture) in order to let nature recover from the effects of production (Ellis and Associates 1996). Provided there is sufficient area for moving net cages, fallowing does not have to reduce overall production, although there would be downtime while moving and setting up net cages in new locations.

Reduce Use of Fish Oil and Fish Meal

Considerable work has been done to achieve truly phenomenal results in improving the feed conversion ratios for salmon production. The industry norm at this time is nearly one to one: one kilogram of feed produces one kilogram of product. Work still needs to be done, however, to change the formulation of the feed to reduce the total quantities of wild fish needed to supply the oil and meal. Today, it takes four or five kilograms of wild fish to make one kilogram of farmed salmon. In order to reduce overall environmental impacts and use resources more efficiently, this proportion needs to be changed. Given that salmon are carnivorous, it is not clear how much progress can be made.

Replacing part of the fish oil component of fish feed with vegetable-based oils would be a good start and could have a number of benefits. It could decrease the toxins from fish oil that farmed salmon currently consume. Ultimately, this means that humans would consume fewer of these harmful toxins as well. While the accumulation of residues from vegetable-based oils is possible, it is much less of a problem than from fish oil (Jacobs, Ferriaro and Byrne 2002).

The use of fish meal and fish oil in salmon diets has also been linked to eutrophication and pollution problems. A vegetable-based diet results in lower levels of pollution, even though there is still considerable organic matter. Because salmon raised on a vegetable-based diet have a different flavor, a lot of work will need to be done to maintain the flavor profile consumers have come to expect (Staniford 2002).

Alitec, a leading Chilean feed producer, says that it will begin to reformulate its feed so that it will contain significant quantities of vegetable oil by 2004, thus reducing the amount of fish oil used. Though some salmon farmers are skeptical, the company believes that the reformulation will have benefits, one of which will be a lower priced feed.

Implement Measures to Reduce Diseases

Disease is one of the main threats to salmon aquaculture operations. The development and widespread adoption of a code of conduct could help producers both prevent diseases and contain them if they occur. Producers need their own systems for quarantining animals before introduction if countries do not have their own rules or if such rules are inadequate or are not enforced. The point here, however, is not simply to obey the law.

Diseases can wipe out operations, so there is too much at stake to hide behind laws. Producers must develop their own programs that exceed those of most countries because producers stand to lose if things go wrong. Once procedures are established, workers need to understand their role in containment and disease transference issues, whether they work in hatcheries or net-cage operations. Vaccination programs should be mandatory, as should the quarantine of sick animals. Fish that are untreatable should be killed and properly disposed of so there is no chance that they will infect other fish, either within the aquaculture production system or in the wild.

Diseases in salmon operations are also a threat to wild fish populations. Consequently, diseases should be addressed quickly and effectively both to maintain the economic viability of the producer and to avoid the potential impact of disease outbreaks on wild populations (Whoriskey 2000). Diseases should be monitored systematically on all farms as well as within the proximity of farms to better identify and understand the role that farms play in maintaining or extending disease vectors. If disease issues cannot be addressed through management, medication, and vaccines, then they may have to be addressed through a total reduction of net cages in any given area.

Operate Systems for Continuous Improvement

A process of continuous environmental improvement, similar to the management systems that are endorsed by the ISO certification and standards processes, would help to make sustainable salmon aquaculture a concern (Whoriskey 2000). Such systems, however, require written procedures, measurement of impacts, and ongoing monitoring. Thus systematic, timely, and effective monitoring is required not only for each net cage or even each farming operation, but also for larger ecoregions where cumulative impacts of the entire industry may be significant.

Outlook

In the space of three decades, salmon aquaculture has found ways to take a seasonal, high value wild species and produce a year-round product at half the price. The growth of the salmon aquaculture industry has been remarkable. Currently, it threatens the viability of the wild salmon fishery in most parts of the world, especially Alaska. However, it also offers insights into the opportunities and problems with the intensive aquaculture production of other high value, carnivorous wild fish species.

Since the founding of the salmon aquaculture industry, its environmental impacts have been tremendous. There have also been tremendous efforts and accomplishments in reducing those impacts. Norway, more than all the other producing countries combined, has taken the lead in these efforts. In 2002, for the first time ever, Norwegian production was eclipsed by that of Chile. While Chile has benefited historically from Norwegian investments and expertise, it is not clear that at this time either Chile's government or its salmon aquaculture industry have the same financial and human resources to invest in continuing the efforts to make the industry more sustainable. If anything, Chile has been lax in monitoring issues such as siting and carrying capacity. That country has also been willing to let producers cut corners such as overlooking the improper disposal of wastes and excessive use of antibiotics, both of which cause unacceptable impacts on both fresh- and salt-water ecosystems. Cutting these corners (in effect, subsidizing production through damage to the environment) has allowed Chile to be the lowest cost producer of salmon. Cutting corners has also put the industry at greater risk in a place where neither the government nor the industry is prepared to address, much less anticipate, future crises as they arise. This is an explosive situation for any industry, but it is especially so in aquaculture where disaster can strike quickly and thoroughly.

For its part, Norway is still a very large producer of salmon, but the lessons being learned in Norway today are less relevant to the direction the industry has taken in Chile, i.e. larger scale, more intensive, growth-led production. Furthermore, in Norway the industry and government are both diversifying their interests. As they experiment with other high value fish species in aquaculture, hopefully they will be able to avoid many of the problems associated with salmon farming today. Ideally, however, because of the value of many of the new species, both Norway and its producers will have the resources, as well as the inclination, to identify better ways to produce such fish in aquacultural systems, ways that can also be applied to salmon aquaculture. Getting salmon aquaculture right will be the litmus test for whether humans will be able to take pressure off wild, carnivorous finfish fisheries while reducing environmental and social impacts to acceptable levels.

Resources

Web Resources

Aquaculture in general:

www.seaweb.org/resources/sac/
www.fao.org/sof/sofia/index_en.htm
www.fao.org/fi/default_all.asp
www.aquamedia.org/
www.was.org
www.gaalliance.org/
aquanic.org/

Salmon:

www.davidsuzuki.org/Oceans/Fish_Farming/Salmon
www.salmonfarmers.org
www.watershed-watch.org/ww/salmon_farming.html
www.sectionz.info/Issue_1/
www.fishupdate.com
www.panda.org/downloads/marine/osloresprogfinal3.pdf

Additional resources can be obtained by searching on "salmon" or "aquaculture" on the WWF International Intranet:
http://intranet.panda.org/documents/index.cfm

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