

# FARMING SALMON: A BRIEFING BOOK

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Consultative Group on Biological Diversity

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## FOREWARD

It is an old, enticing dream: To farm the seas as we farm the land. The decline of many fisheries around the world, together with growing demand for fish and shellfish, has combined in recent decades to give new life to the dream. Perhaps we can feed the world and reduce hunger by growing fish, the dream urges.

Now, many people are asking about environmental and social costs of growing food as we do on land or in the sea. This booklet looks at the farming of one kind of food: salmon.

Salmon production and consumption have increased dramatically in the last two decades. By 1995, fishing and farming around the world were producing 1.4 million tonnes<sup>1</sup> of salmon. Of this, 440,000 tonnes, or nearly one third, was produced on salmon farms.

Salmon farming isn't just about making food. It's about making money, big money. In British Columbia, 90 farms alone produced \$165 million worth of salmon in 1995, compared with the \$140 million worth of salmon caught by commercial fishers there. Salmon farming also attracts some big players in the business world: In November 1994, Booker-McConnell PLC, a U.K.-based agricultural conglomerate with salmon farms in Scotland, acquired Marine Harvest Ltd., the world's largest producer of farmed salmon with farms in Scotland and Chile. The annual production of the new company is expected to reach 27,000 tonnes, or about 5 percent of the world total.

While salmon from capture fisheries and from aquaculture have flooded markets and driven prices down, salmon consumption has been increasing in the three principal markets: Japan, the United States, and the European Union. Just between 1990 and 1995, per capita consumption of salmon in the United States nearly doubled to 1.4 pounds. Salmon now ranks fourth behind canned tuna, shrimp, and Alaska pollock, according to the National Fisheries Institute. Nearly all of this increased consumption has been supplied by imported farmed salmon.

As salmon farming has expanded from Norway to Scotland, Ireland, Canada, the United States, Chile, Tasmania, Faeroe Islands, among other places, some costs of the young industry's way of doing business have become clear. Salmon farming in these areas often has been associated with water pollution, the spread of disease among farmed and wild salmon, birds and marine mammals entangled in nets, algal blooms, boom-and-bust economies, and other impacts.

Perhaps because many of these costs were out of sight, they were out of mind. But in recent years, salmon farming has come under criticism, not simply from environmentalists, but from fishers, Native Peoples, coastal inhabitants, tourist businesses, and others. In British Columbia (B.C.) public pressure caused the provincial government to undertake a salmon aquaculture review, which soon will be completed.

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<sup>1</sup> Tonne = metric ton. There are 2,204 pounds in a metric ton.

The review has triggered several nongovernmental studies of salmon farming in British Columbia. The David Suzuki Foundation recently released a report it commissioned called "Net Loss: the Salmon Netcage Industry in British Columbia." This report provoked a critique from the B.C. Salmon Farmers Association called "Net Gain: The Salmon Farming Industry in B.C." Dr. Ian Fleming prepared a critique of the latter paper for The David Suzuki Foundation.

This sample of the growing controversy over salmon farming suggests a principal reason for this booklet: Salmon farming is a complex, emerging topic of public discussion. Some people have been in the middle of the controversy for years. Most of us are new to the issue and will soon find ourselves overwhelmed, quite possibly confused, by terminology and references to this or that problem or this or that country. It is our hope that this booklet will help orient you to salmon farming and to the concerns it should raise in everyone's mind.

Much of the concern about salmon farming arises from its explosive growth. Between 1990 and 1991, farmed salmon production grew from about 7,149 metric tons to nearly 325,563 tonnes—an increase of 4,600 percent. With the enormous financial boom that accompanied early salmon farming in Norway, a kind of "gold rush" was sparked. Wherever cool, sheltered waters could be found, governments and industry invested in salmon farms. Neither government nor industry paid much attention to possible environmental and social impacts. Nor did governments address larger questions, such as whether it makes sense to feed fish to fish or the impacts of salmon farming on biological diversity. Instead, until recently, governments and industries have been far more eager to expand farming.

Nearly two decades of almost uninterrupted growth in salmon farming have shown many of the environment problems caused by this way of growing fish. These include the following:

**Escapes of Farmed Salmon from Pens:** Just this year, 300,000 Atlantic salmon were released into Puget Sound when their pens were accidentally ripped open. In Norway, where as many as 1.3 million salmon escape from farms each year, one third of the salmon spawning in coastal rivers are not wild, but escaped salmon. Besides competing for food and spawning habitat, escaped salmon may interbreed with wild salmon, reducing the latter's fitness. Likewise, the expansion of salmon farming has been associated with epidemics of diseases that otherwise play a minor role in wild salmon populations.

**Wastes:** Although salmon are relatively efficient in converting feed to flesh, producing 1,000 tonnes of salmon produces between 270 and 1,080 tonnes of wastes. These wastes degrade water quality and smother communities of plants and animals beneath salmon cages. Available techniques for reducing water pollution often are not used.

**Drugs and Chemicals:** Crowding animals together as salmon are crowded together in pens creates conditions that encourage the spread of disease. To counter this threat

salmon farmers employ antibiotics, vaccines, and other chemicals, much of which can enter the water. There has been little to no research on the impacts of this heavy use of chemicals upon marine life and human health.

**Marine Wildlife:** Salmon farms are a sitting target for marine mammals and sea birds looking for a meal. In British Columbia, an estimated 500 harbor seals are shot each year. Netting used to exclude marine mammals and birds can entangle and drown hapless animals. Acoustic-devices used to scare away seals and sea lions have been too successful in some places, leading to the withdrawal of resident populations of harbor porpoise and whales.

Although governments and industry now are addressing some of these problems, we believe more dramatic steps are required toward promoting the maturation of salmon farming into an ecologically sustainable and economically viable activity. In this spirit, we offer the following recommendations:

**1) Halt the expansion of salmon aquaculture:** The world does not need more salmon in the market. If anything, we need to better distribute the salmon that both wild and farmed sources produce. Rather than emphasizing quantity, we should support quality.

**2) Change the focus of research and development from production to integration:** For the most part, research now is focused on producing more salmon more quickly and with less feed. This could promote ecological and economic sustainability if, contrary to what history suggests, these technological developments would not simply lead to more production. Salmon farming is enormously wasteful of resources already. Developing new models and methods for capturing and reusing wasted resources are key.

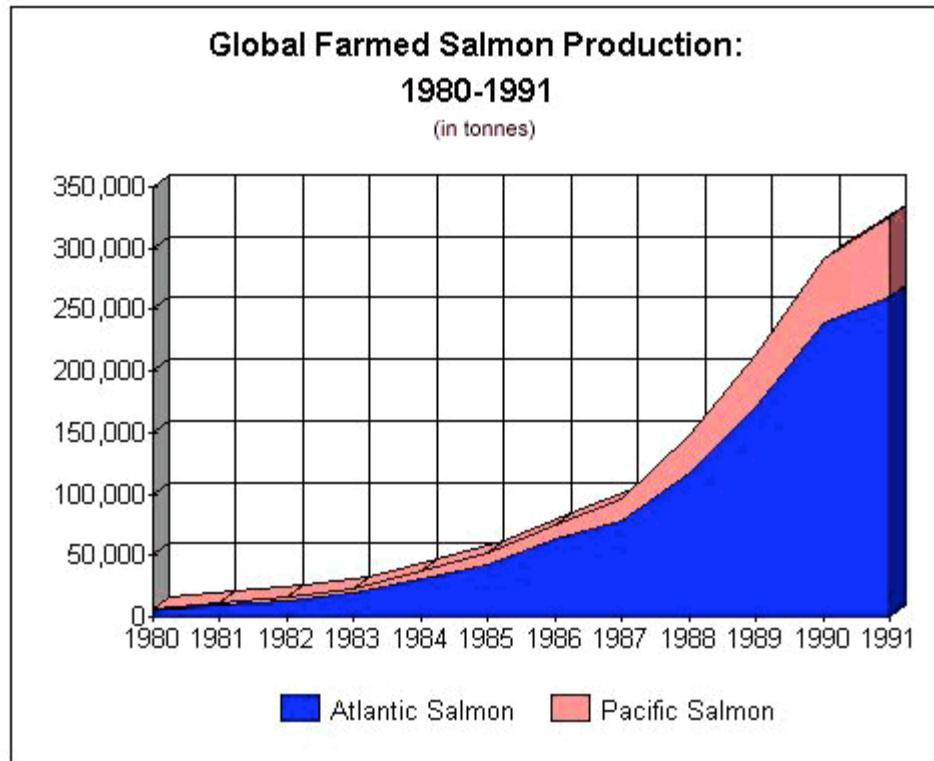
**3) Halt the expansion of salmon stocks out of their native watersheds:** The cavalier fashion in which salmon eggs and smolts have been traded in the past has no place in the future. As it is, the routine, though unintended release of salmon from farms continues to threaten wild runs, many of which already are threatened by other human activities such as water diversions and logging. Besides the risks to wild salmon from disease and parasites, farmed salmon also force wild salmon into a game of genetic roulette.

**4) Require salmon farms to be good neighbors:** Salmon netpens not only generate pollution that can damage water quality and the sea bottom in the immediate area, but also disrupt the patterns of marine wildlife, including marine mammals and seabirds. In some areas, night lights, acoustic devices aimed at scaring off marine mammals, odors, and pollution of traditional food sources have disrupted the lives of local people. Salmon farms should eliminate all such impositions on local communities.

**5) Make salmon farming compatible with salmon fishing:** The policies of governments regarding the promotion of salmon farming and the enhancement of wild salmon runs through hatcheries has produced a worldwide glut of salmon. Besides the damage to coastal environments and to the genetic integrity of wild salmon runs, these policies have reduced the economic viability of small-scale fishing communities and

small-scale salmon farms. Whether explicit targets are set, governments should ensure, at a minimum, that their own policies and programs on fish farming and fishing are coordinated and promote fishing and farming at levels that are ecologically and economically sustainable.

Consultative Group on Biological Diversity



## AQUACULTURE

People have been growing fish and aquatic plants for thousands of years. As worldwide catches of fish and shellfish from lakes, streams, bays, and the oceans have leveled off, farming aquatic plants and animals has attracted more attention internationally. At current rates of fish consumption and of population growth, demand for fish will increase by 16 million tonnes by the year 2010. In May 1995, the Consultative Group on International Agricultural Research (CGIAR) predicted that within 15 years, aquaculture could produce nearly 40 percent of all fish for human consumption. CGIAR recognized the need for ensuring that growth in aquaculture be sustainable and environmentally sound, but did not present specific means for doing so.

Aquacultural production has been growing faster than most types of agriculture: Worldwide, freshwater and marine aquaculture more than doubled production, from 6.9 million tonnes in 1984 to 16.3 million tonnes in 1993. In 1993, aquaculture accounted for 22 percent of food fish, up from 12 percent in 1984. By 1994, fish farmers around the world were producing 18.6 million tonnes of fish and shellfish worth more than \$33.5 billion.

China dominates all other countries in fish farming. In 1994, China produced 57 percent of the world's farmed fish and shellfish-six times the second-ranking producer, India. The United States ranked sixth, accounting for about 2.2 percent of the world total. Fish

farmers in the United States received more than \$750 million for their harvests in 1994.

Perhaps 186 genera and species of animals and plants are grown in water. Of these, 102 are finfishes, 32 crustaceans, 44 mollusks, and 8 seaweeds. Freshwater carps, raised mostly in China, account for more than one third of the total aquaculture production of fish and shellfish. In contrast, Atlantic salmon contributed just under two percent of the total in 1993. Still, only the farming of scallops produced more spectacular growth than that of salmon, which increased more than 1,100 percent from 27,000 tonnes in 1984 to 304,000 tonnes in 1993.

Aquaculture enjoys some advantages over raising stock or poultry. First, fish and shellfish are more efficient in converting food to flesh, since as cold-blooded animals, they do not have to expend energy to maintain their body temperature. Nor do they have to expend energy supporting themselves. Some breeds of salmon have been developed that convert protein in feed at a rate of 1.1 or 1.2 pounds of feed for every pound of flesh. By comparison, cattle require 8.0 pounds of feed to produce one pound of flesh, pigs 3.0 pounds, poultry 2.0 pounds, shrimp 1.7-1.8 pounds, and catfish 1.5-2.0 pounds.

### **Methods of Growing Fish and shellfish**

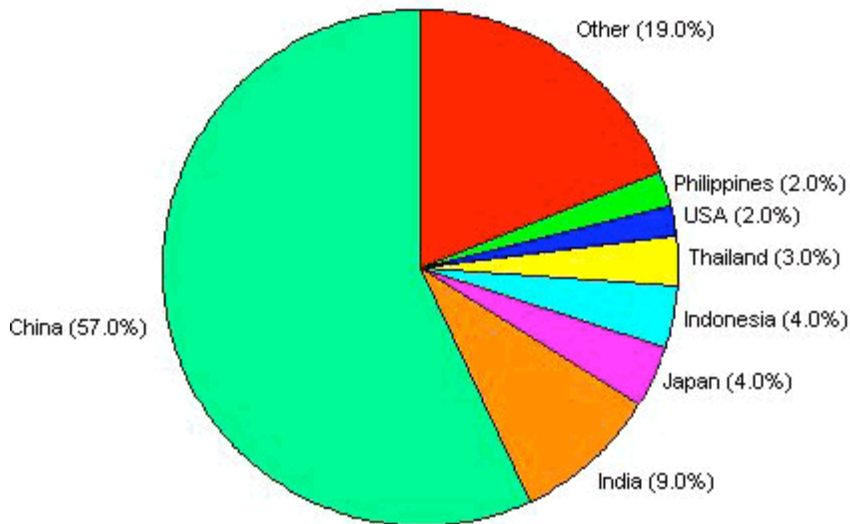
Most of the world's farming of fish and shellfish takes place in ponds on land. Carp grown in ponds, mostly in China, accounts for one third of the world's aquacultural production. In 1994, catfish grown in ponds accounted for two-thirds of the weight and 46 percent of the value of all aquaculture production the United States.

From the canals of Saigon to the fjords of Norway, finfish have been raised in suspended baskets or cages. A variant of this system is the farming of oysters or mussels on lines suspended from the surface. In these systems, animals feed on plankton and other naturally occurring food.

Some traditional systems culture several species at once, allowing individual species to exploit a particular niche in a pond. For instance, a polyculture system might have mussels feeding directly on plankton, each of several species of carp feeding on different plants or animals at different levels in the pond, and crawfish feeding on detritus. In India and Israel, these systems have produced as much as 4.4 tonnes per acre per year. Similarly, fish and shellfish may be raised on agricultural wastes. In Louisiana, crawfish are allowed to feed in rice fields after harvest. In 1990, 140,000 acres of fields produced 32,000 tonnes of crawfish, worth \$34 million.

In North America especially, trout and other coldwater species are grown in raceways—shallow, rectangular pools tilted to create streamlike conditions. In recent years, fish and shellfish have been grown in closed systems that recirculate water after wastes have been removed. Some of these systems can be quite elaborate, relying on computerized monitoring and mechanization. Other systems, which have been used for centuries in Asia particularly, are part of a larger system that also may produce rice, vegetables, poultry, and livestock.

1994



Modern aquaculture such as is practiced for raising salmon, shrimp, or catfish emphasizes quantity: the more, the better. Traditional aquaculture, which is being renewed now under the banner of ecological engineering, uses aquaculture not simply to produce food, but to process wastes from other production activities from farming to brewing beer, and to generate wastes and materials that can be used to produce other things.

### **Aquaculture Rhetoric and Aquaculture Reality**

Commonly, aquaculture is offered for achieving several objectives: to raise food to meet growing need and demand; reduce pressure on wild fish populations through substitution; and promote economic development in rural areas.

Most farmed fish and shellfish is grown for local markets, especially in China and other developing countries with a tradition of aquaculture. Clearly, this type of local aquaculture will continue to play an important role in meeting the dietary needs of people, especially where there are few alternatives. In Asia, where most of the world's fish farming already occurs, fish provides 28 percent of total protein intake, four times the share in North America. Africa gets three times as much of its animal protein from fish as we do in North America.

In recent years, however, there has been a much greater investment in the production of seafood, especially, for markets principally in Japan, the United States, and western Europe. The farming of shrimp in Asia and South America, and of salmon in Norway, Scotland, Canada, Chile, and the United States has grown dramatically since 1980, as has consumption of shrimp and salmon in the principal markets mentioned above. Whatever its other benefits, this type of aquaculture has little claim to ending world hunger, particularly as it relies on the use of large amounts of fish meal manufactured from fish caught elsewhere in the world.

Aquaculture boosters also claim that production of fish and shellfish on farms will reduce pressure on wild populations by replacing them in the marketplace. This is a pleasing thought, but it oversimplifies. If anything, cases of declining fishing effort due to substitution by farmed products are difficult to find

Another response to the availability of farmed products is lower prices and increased consumption. Around the world, fishing for shrimp remains very intense although farmed

shrimp production grew from 49,000 tonnes in 1980 to nearly 681,000 tonnes in 1994. Shrimp consumption in key markets, including Japan, the United States, and western Europe has grown. Similarly, while salmon farming increased 30-fold in the 1980s, salmon consumption in the destination countries increased as well. In the United States, consumption of salmon rose 27 percent just in 1994-1995.

Fish farming hasn't reduced fishing effort partly because farmers and processors have sponsored marketing campaigns, sometimes with government financial and technical support, aimed at boosting consumption. So, one part of the aquaculture process - marketing - is frustrating another aim of aquaculture - substitution for wild fish. Shrimp and salmon farming, as well as farming of catfish and oysters, shores this schizophrenia with much of the food producing and marketing industry.

Aquaculture has a role to play in the future and can secure some important benefits beyond food production. Aquaculture can be a clean form of economic development. It can provide food that is low in fat and a healthful source of protein. Farming aquatic plants or filter-feeding animals can cleanse waters. Aquaculture also can provide jobs in areas where there are few alternatives.

But as with many things, the important questions are what kind of farming of what kind of fish and where.

## **SALMON MARKETING**

A wide variety of factors have boosted markets and demand for farmed salmon, and other seafood, around the world. These include greater demand for convenience food, health concerns, the growth of supermarkets, developments in food technology including packaging and processing, and increased dining in restaurants. Developed countries account for 85% of total fish imports worldwide, led by Japan with 30% of the total, then the United States and the European Union. International trade in salmon also focuses on these three major markets.

While salmon traditionally was sold smoked or canned for the most part, most salmon now is sold frozen or fresh. Most smoked salmon is sold in Europe, and most frozen salmon is sold in Japan. The last decade has seen a dramatic growth in markets for fresh salmon in the United States, Japan, and western Europe

At first, fresh farmed salmon filled a seasonal gap in the availability of salmon from wild sources. However, with year-round production of high volumes of Atlantic salmon particularly, farmed salmon began competing with wild salmon throughout the year. Although wild salmon still dominates the worldwide market, farmed salmon has made inroads, particularly in the three major salmon markets, largely because it is available year-round and is of a more or less consistent size and quality. Until 1989, when an explosion in production of salmon by Norway led to gluts, the world market for salmon was a seller's market. Since 1989, prices have plummeted.

As supplies have overwhelmed markets, the industry has sought to build demand by offering new products. For instance, the Norwegian salmon industry promoted individually frozen salmon fillets as "Norwegian Salmon Singles" to restaurant and catering cooks in Illinois, Wisconsin, and Michigan. Some processors have tried to build a market for salmon by developing new products for restaurant and fast food chains such as Denny's and Red Lobster. The Alaska Seafood Marketing Institute has worked with Weber grills, California Wines, and Reynolds Wrap in promoting home salmon consumption. Chilean salmon farmers developed technology that debones salmon, producing fillets that are attractive to restaurants and supermarket fish counters.

Increasingly, salmon farmers issue competing claims. In its advertising, the Scottish Salmon Board promotes high quality:

Even in those lochs sheltered from the sea and placid on the surface, Scottish Salmon are challenged by stiff breezes and powerful currents, working off any trace of extra fat daily. So when they come to market, Scottish Salmon are deliciously fit, an irresistibly even, deep red.

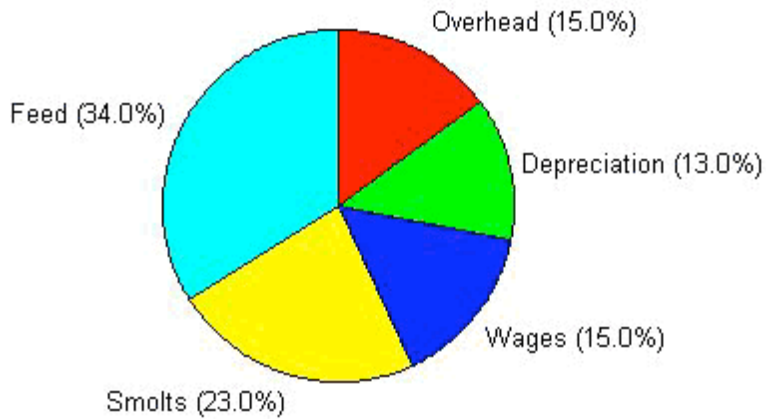
No doubt, this campaign has contributed to the dramatic increases in salmon consumption in Britain, the principal market for Scottish salmon.

Industry associations complain that they cannot compete with media spending by the National Pork Producers or the National Cattlemen's Association, which spends as much as \$80 million annually in promotion. Still, marketing has been credited with increasing salmon consumption in the United States only 27 percent to 1.411 pounds of salmon per person between 1994 and 1995. Between 1987 and 1995, per capita salmon consumption in the United States increased 170 percent, many times faster than other popular seafoods such as shrimp.

## **FARMING SALMON**

Raising salmon falls into two phases: a hatchery or freshwater stage, which lasts from six months to two years, and a smolting stage, which lasts until the fish are harvested. The freshwater phase begins with extracting milt and roe from adult salmon that have been bred for certain characteristics. Once fertilized with the milt, eggs are placed in hatcheries filled with oxygenated freshwater. Water temperature and oxygen levels play a major role in determining how quickly eggs hatch and their rate of survival. Generally, eggs are kept in water between 4° C and 8° C. To speed hatching, hatchery operators may raise temperatures to 10° C for eyed eggs. Water must be filtered to prevent accumulation of silt on eggs and gill damage to young fish.

Once hatched, alevins are exposed only to dim light. Bright light cause alevins to use energy for burrowing away from light, rather than for growth. Once alevins emerge as parr, they are moved to freshwater tanks and feeding must begin. Producing as many smolt as possible requires carefully controlling water temperature, oxygen levels, and



purity.

Parr and smolts generally are raised in circular tanks of various size in which water is circulated. Standard tanks in Norway and Scotland measure 3-4 meters in diameter and one meter in depth for yearling fish. At about 18 months and five inches in length, the parr undergo smoltification and are moved to saltwater pens, which generally are in coastal waters, and increasingly in offshore waters. There they are given special feed to promote rapid growth, which

is most rapid during the summer months. The smolts also are inoculated with vaccines or fed antibiotics to prevent disease.

Generally, pens are square and measure 30 meters by 30 meters with a depth of about 20 meters. Netting is stretched over the frames of these pens, which may be made of PVC pipe or steel, in order to confine the fish. The net of the pen generally extends above the surface in order to prevent fish from jumping out. Another net may be strung over the surface to prevent birds from diving for fish, while a stronger net may be strung beneath the pen to prevent marine mammals from feeding on the fish.

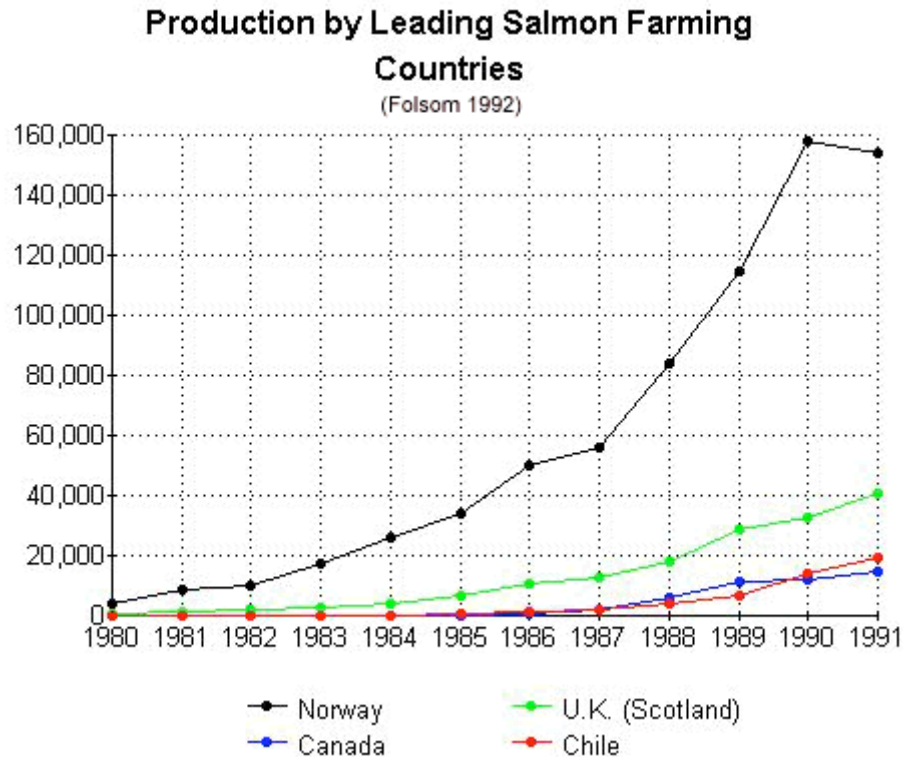
The pens are anchored to the seafloor and/or clustered together in groups of 8, 12, or 20 cages to form a site serviced by a platform for storage of feed and supplies. Recently, a salmon farming company in British Columbia installed four plastic salmon cages measuring 50 meters square - the world's largest such pens ever installed. Large cages are more difficult to handle, of course, when they are lifted to be cleared of shellfish and marine algae that may foul them.

Within 24 months after smoltification, the fish are harvested at 2-5kg. Once salmon reach sexual maturity, the quality of their flesh deteriorates so that it is no longer considered fit for human consumption. Five days before slaughter, salmon are starved in order to empty the gut, reduce fat, and firm the flesh. The fish are collected in large baskets or pumped out with fish pumps. Fish are killed by tranquilizing with carbon dioxide or soft brine, then are bled through a cut near the gill arch, gutted, and put in iced boxes.

The costs of raising salmon vary with the size of the operation. Feed accounts for a third of operating costs over the years, the costs of raising salmon have declined greatly. Production costs now average about \$2.00 per pound in the United States, but were as low as \$1.49 per pound in Norway in 1993. Fishermen supplying the fresh-fish market cannot compete head-to-head with these costs. In 1995, the average price paid to Oregon fishers for salmon averaged \$1.70 (compared to \$3.00 per pound in 1990) as the farmed salmon flooded into the market.

Although visual appearance, particularly red-colored flesh, has traditionally been a

demand of the Japanese market, recent studies indicate that consumers elsewhere also prefer salmon with darker flesh. Indeed, consumers will pay more for darker salmon, associating color with age, flavor, texture, and origin. Wild salmon acquire a reddish tint in their flesh from carotenoids that occur naturally in the zooplankton they feed upon. To produce the same effect, salmon farmers must add pigmentation compounds to their feed.



## THE CONSEQUENCES OF BEING CARNIVOROUS

Most species of farmed fish and shellfish eat plants. Indeed 85 percent of fish farmed around the world are fed on plants or feed manufactured from plants. Most of these fish feed directly on plants that occur naturally in the ponds, lakes, rivers, and bays where they grow or on other organisms that eat the plants. When these species are raised in large numbers in ponds, fish farmers may boost plant growth with fertilizers, sewage, or waste from other activities such as agriculture or brewing of beer.

In contrast, fish farmers raising carnivorous fish such as salmon must add feed with high percentages of fish meal and oil. In 1994, it is estimated, 4.25 million tonnes of fish meal – 15% of global production – was devoted to feeding carnivorous fish and shellfish. Salmon farms, which consumed roughly 27% of the meal used in aquaculture, were among the leading consumers, together with farms for shrimp, eel, and trout. Unlike shrimp and eels, which can use groundfish meal, salmon and trout require a meal that is

high in protein and low in ash, such as anchovies and sardines. Fish meal and oil make up about half of the content of the feed for salmon.

Of the 110 million tonnes of fish landed from the world's oceans, lakes, and streams in 1994, 33 million tonnes were used for fish meal and fish oil. All of the fish used for fish meal and oil were marine. The largest source for fish meal are the fisheries for anchovy, sardine, and mackerel in the Pacific Ocean off South America. These fisheries regularly undergo dramatic fluctuations in catch. When on El Nino prevents the upwelling of nutrient rich water and the production of food for anchovies, the catch of anchovies collapses.

Although salmon are relatively efficient in converting feed to flesh, feeding salmon with fish meal still has high costs. On average, it takes five pounds of fish to produce one pound of fish meal. Generally, fish meal accounts for about half of the elements in feed, and the balance is provided by vegetable meal, minerals, vitamins, and any drugs. One estimate for European salmon farming concluded that the production of 180,000 tonnes fish would require the capture and conversion of 585,000 tonnes of fish to fish meal and oil.

If the future brings greater demand for fish meal and periodic declines in the abundance of pelagic fish used in fish meal production, uses of fish meal may change. Higher prices may lead growers of chickens, pigs, and turkeys to move toward less expensive feeds based on soybeans. The United Nations Food and Agriculture Organization now is investigating the substitution of vegetable protein for fish protein in feeds. Recently, soybean meal has been used to replace some of the fish protein in feed for several species, including salmon. Vegetable meal, however, often includes elements that can be harmful or counter-productive. For instance, soybean meal includes trypsin inhibitors, which can limit growth rate. Other researchers are experimenting with feeding salmon a meal based on a protein concentrate made from canola.

## **THE IMPACTS OF SALMON FARMING**

Like most intensive forms of producing food, salmon farming has environmental and social costs that often are understated or ignored. Here is a brief review of several commonly discussed environmental impacts.

### **Escapes of Farmed Salmon from Pens**

Wildlife communities in many of the world's bays, estuaries, rivers, and lakes have been disrupted by the intentional and unintentional introduction of exotic species. Among many examples, the importation of Japanese oysters for oyster farming has introduced plants, animals, and diseases that have greatly changed habitats and reduced the diversity of plants and animals in areas as far apart as the State of Washington and Norway. Often ignoring recommended guidelines for avoiding these problems, governments still allow, even encourage the importation of alien species.

While the commonest causes of extinction in salmon runs have been destruction or degradation of habitat by logging, agriculture, dams, and water diversions, salmon runs are vulnerable as well to the intentional or unintentional release of salmon raised for commercial purposes or to "enhance" wild populations. Salmon that have escaped from farms can threaten wild runs by competing for food and habitat, spreading diseases, and breeding with wild runs of salmon.

There is no doubt that large numbers of salmon escape from sea pens both routinely and in severe weather. An estimated 1.3 million salmon escape from Norwegian farms each year - a level of escape unequalled in other forms of agriculture. In 1990, one third of the salmon populations spawning in Norwegian rivers were escaped farmed salmon. In some Norwegian rivers, escaped farmed salmon now outnumber wild salmon. The parasite *Gyrodactylus salaris*, which generally is dormant in the wild, wiped out wild salmon populations in some streams after escaped farmed salmon took up residence. Indeed, the parasite spread to wild populations with the expansion of salmon farming.

Species level distinctions are only a crude measure of the genetic diversity of salmon. Pacific and Atlantic salmon have adopted hundreds of streams and rivers for spawning grounds and nurseries. Over the generations, salmon from individual streams have developed genetic traits distinct from those of salmon of the same species but from different streams or from different runs in the same stream. These differences can have a profound effect on the fitness of salmon. For instance, some runs of salmon are more resistant to certain diseases than others.

Interbreeding of escaped or released salmon may undermine the genetic robustness of wild salmon for a simple reason. Farmed salmon are selected to do well in the confined, artificial conditions of a farm, where they are regularly fed and their eggs are artificially fertilized and hatched in plastic trays. Wild salmon, on the other hand, must find their own mates and natal rivers, lay eggs in gravel, and find their own food. When farmed salmon spawn with wild salmon, the genes that suited life on the farm dilute genes developed to exploit and survive in the wild. Within a few generations, wild fish may be eliminated from a stream. Hilborn's concerns about salmon hatcheries in the Pacific Northwest are worth repeating when considering escapes from salmon farms:

The net result may be that after a few generations there are no more wild fish - we will, and indeed in many places we now do have, mongrel fish not well adapted to any particular river. The great genetic diversity of the Northwest of 100 years ago is being lost at a horrifying rate, and hatcheries are accelerating this loss.

As salmon farmers in Washington State and British Columbia have moved from Pacific to Atlantic salmon, concerns have grown about potential interbreeding of exotic Atlantic salmon with wild Pacific salmon and about the displacement of Pacific salmon from their spawning grounds. By 1995, Atlantic salmon that had escaped from farms in B.C. had been found in 18 rivers. In 1996, the B.C. salmon fishery experienced a tenfold increase in the number of Atlantic salmon they caught, presumably from an accidental release from a farm in Washington State.

Typically, the industry in the Pacific counters this concern by saying that there has yet to be any report of such interbreeding, nor has there been any record of spawning by Atlantic salmon in Pacific rivers. The industry also points to the failure of past efforts by the Department of Fisheries to introduce Atlantic salmon into streams in order to promote recreational fisheries. But, some scientists believe that it is only a matter of time before Atlantic salmon colonize and establish self-sustaining populations that compete with wild Pacific salmon.

### **Spread of Disease and Parasites**

Governments generally impose very strict limitations on the introduction of potentially diseased animals or plants that may affect agricultural production. By comparison, current government policy is extraordinarily lax regarding the introduction of diseased animals that may affect wild salmon and other wildlife. Successful invasions of marine and terrestrial ecosystems by exotic species from zebra mussels to starlings have proved largely irreversible.

The transfer of salmon and salmon eggs between farms in different countries regularly has introduced disease into farm operations and exotic species into new areas. Twenty Norwegian salmon farms closed for two years in 1988 as the result of a disease called furunculosis that was accidentally introduced with imported salmon smolts in 1984. The disease caused more than \$100 million in damages. By 1989, 182 farms in Norway were infected, as well as wild runs of salmon in 18 rivers. Vaccines have eliminated disease from salmon farms in Norway, but clearly cannot help infected wild populations.

Salmon that have escaped from farms have exposed wild salmon to other diseases and parasites. For instance, enhancement of wild runs of salmon with hatcheries has been implicated in the spread of a deadly disease *Gyrodactylus salaris* that has spread to wild salmon in Norway. Despite radical and costly treatment, infected rivers in Norway have become re-infected.

Similarly, sea lice, which previously had been rarely observed on wild salmon, now are regularly found on wild salmon in Ireland, Scotland, and Norway. Heavy infestations of sea lice appear to cause higher mortality of smolts at sea.

Salmon farmers in Tasmania take the threat of introduced pathogens seriously enough that they have waged a campaign to prevent the importation of fresh Atlantic salmon meat into Australia. The farmers do not object to the importation of canned and smoked salmon, since these have been treated, but they argue that importation of fresh salmon risks introducing some of the 24 diseases found in North American salmon.

### **Wastes**

Wastes in any production system indicate inefficient use of resources. In this sense, the wastes generated by salmon farms and released to the environment squander resources. In some circumstances, these wastes can harm other wildlife and habitats.

Uneaten feed as well as feces from salmon can accumulate beneath salmon pens, affecting water quality in the immediate area at a minimum. Depending on how strong the tides in an area are, wastes may remain within an area immediately under a pen or as far away as 150 meters. Where wastes do accumulate on the sea bottom, they can deplete oxygen levels, release noxious gasses in decomposition, and smother benthic animals. In some cases, this has led to dramatic changes in the community of animals that live beneath salmon pens, including the reduction of species diversity, leaving only a few species that thrive in polluted conditions

Whether caused by nutrients from salmon farms or from other sources, blooms of algae can damage salmon operations in several ways. First, algal blooms may deplete waters of oxygen upon which salmon and other animals depend. Oxygen depletion may occur when the remains of dead algae decompose.

Even low concentrations of some kinds of algae can trigger the production of mucus that covers the gills of salmon, ultimately causing infections, hemorrhaging of gills, and suffocation. In response to such problems, insurers raised rates for salmon farms in the Sechart Inlet area of British Columbia, leading to a two-thirds reduction in salmon farming. Algal blooms also may produce toxins, such as heptatoxin and microcystin, that can cause disease among farmed salmon and other animals in an area. Studies have shown that the spread of parasites and other pathogenic organisms increases with continuous use of a site for culturing salmon.

Industry representatives generally dismiss concerns about wastes from fish farms. First, salmon farmers claim that they would avoid pollution since they would be the first to suffer. Second, salmon farmers argue that overfeeding makes no economic sense and that they are trying to reduce the amount of feed they apply. Third, impacts from farms generally are confined to the immediate area and are reversible once a farm has been moved.

Finally, government proponents of farming and the industry itself argue that proper placement of cages in areas that are well-flushed prevents accumulation of feed and feces beneath and around cages. But identifying and using such sites has been spotty.

Given a rest or fallowing period, damaged benthic communities beneath salmon pens areas may recover, some think. Fallowing salmon farms for a year is the most effective method of prevention against furunculosis since it deprives the responsible parasite of a host. However, the practice of fallowing is not a common practice in the salmon farming industry. A review of salmon farming in British Columbia found few sites fallowing, for instance. Salmon farmers give various reasons for not fallowing, including the lack of sites to which they might move their cages while allowing a site to lay fallow. In the short term, at least, it also is cheaper not to fallow, since the public cost associated with discharging pollutants into the environment from salmon pens is not borne by the salmon farmer.

## **Drugs and Chemicals**

To combat diseases and parasites, salmon farmers have relied on various chemicals and drugs, including antibiotics. Between 1985 and 1987 alone, antibiotic use on salmon farms in Norway increased from 17 to 48 tonnes, or more than the combined use in human and veterinary medicine there. These levels have declined greatly in the last decade, as vaccines have been developed and incorporated into feeds.

At least three quarters of most antibiotics in feed is lost to the environment, whether the feed is eaten or not. Little is known about the fate and effects of these drugs, although it is clear that they do escape to immediately surrounding waters and can accumulate in sediments and animals. High levels of some drugs have been detected in wild animals several hundred meters from salmon farms during treatment, but had nearly vanished within several weeks. Antibiotics and other chemical agents that accumulate beneath cages during treatment also can change bacteria in sediments and alter the degradation of other wastes.

There has not been significant research on the degree to which the use of antibiotics in salmon farming may lead to the evolution of resistant bacteria. Whether or not resistant bacteria present a threat to human health and to wildlife, they already have caused problems for salmon farmers. For instance, Scottish salmon farmers found that more than half of the bacteria that cause furunculosis had developed resistance to treatment with oxolinic acid, a commonly used antibiotic.

## **Salmon Farms and Marine Wildlife**

Salmon confined to pens invite predation by marine mammals and seabirds. Farmers attempt to reduce predation by a variety of means. Some of these, such as netting, sometimes entangle and kill marine mammals and seabirds. Estimates vary on the number of seals shot and killed by salmon farmers. In British Columbia, an estimated 500 harbor seals were killed each year. On the other side, B.C. industry sources estimate that harbor seals cause the loss of \$10 million worth of salmon each year. Efforts to reduce conflicts by moving cages to new areas have been futile, since harbor seals simply have relocated their rookeries.

Due to public objections to killing marine mammals, salmon farmers have sought to develop other methods of deterring marine mammals from salmon netcages. In Scotland, for instance, olfactory deterrents that induce vomiting have been used, as well as acoustic deterrent devices, and predator nets. The last method, predator nets, involves tightly fitting net completely around a cage to deter not only marine mammals, but such birds as bald eagles and areas blue herons. Nets on top of cages do seem to deter birds, but diving birds such as cormorants become entangled in underwater nets. One investigation of the B.C. salmon farming industry found that few farm sites use underwater predator nets due to high purchase and maintenance costs.

So-called acoustic deterrent devices (ADDs) emit a high-pitched, audible sound. Salmon

farmers report some success with these devices in deterring seals and sea lions. At the same time, the devices clearly affect not only seals and sea lions, but other marine mammals. Recent studies have found that harbor porpoises declined greatly in number in a wide area around netcage operations that had installed ADDs.

## **PROBLEMS DOWN ON THE FARM**

The release of captive-raised salmon to enhance wild runs has been implicated in the spread of a deadly disease *Gyrodactylus salaris* to wild salmon in Norway. Despite radical and costly treatment, infected rivers in Norway have become re-infected.

In 1989, the United Kingdom banned the importation of ungutted salmon from Norway to protect British salmon runs against Laxanaemia, a highly infectious disease that had killed large numbers of fish on Norwegian salmon farms.

Until recently, there had been few reports of infection of wild salmon by sea lice in Norway, although such infections were common among farmed salmon. Since 1989, however, wild salmon infected with sea lice have regularly been reported. Heavy infections increase mortality in juvenile fish and cause salmon to return for spawning prematurely.

In Norway, farms were placed in areas with little tidal flushing. As a result, fish feces and uneaten feed accumulated under the pens, releasing ammonia, hydrogen sulfide, and methane as they decomposed. This created unhealthy conditions for salmon and damaged other animals and plants.

In 1989, a disease caused by a previously unknown strain of the Rickettsia bacterium broke out among farmed chinook salmon in Chile. (Some kinds of Rickettsia cause human illnesses such as typhus.) The disease has caused up to 90 percent losses among farmed salmon, and was found to infect both Pacific and Atlantic salmon.

Salmon farmers sometimes shoot seals that attempt to feed on salmon in pens. In Scotland, estimates for the number of seals shot and killed each year range from 350 according to industry sources to 5,000 according to conservation groups.

Rather than carefully assessing the environmental impact of chemicals before their use, many Scottish salmon farmers used a chemical delousing agent called dichlorvos to reduce infection of salmon by sea lice. Later research found that this chemical also killed oysters, mussels, and other shellfish and crustaceans within 75 meters of salmon cages.

In June 1997, the Washington State Pollution Control Hearings Board ruled that Atlantic salmon are a living pollutant when they escape from salmon pens. Since 1991, half a million Atlantic salmon have escaped into the waters of Puget Sound.

In January 1992, a large storm struck the Norwegian coast, destroying many salmon

cages and releasing millions of Atlantic salmon. The same occurred in the Faeroe Islands during a brutal 1988 storm.

Blood tests of wild fish caught within 400 meters of salmon cages in Norway found high levels of drug residues two weeks after antibiotics were fed to the farmed fish.

Twelve years of monitoring found that the number of Orca whales in the Broughton Archipelago of British Columbia declined by 75 percent after the introduction of salmon farms in the area.

By 1995, Atlantic salmon that had escaped from salmon cages were reported in 18 rivers in British Columbia. Commercial fishermen in this part of the Pacific Ocean reported a tenfold increase in their catch of Atlantic salmon.

In producing 32,000 tonnes of farmed salmon in 1995, B.C. salmon farmers used fish meal produced from 118,000 tonnes of fish from the Pacific Ocean off South America, generating as much sewage as a city of 500,000 people.

In a typical salmon farm, roughly one-third of moist feed falls through the netpen to the water column and sea bottom. Another 20 percent of the food becomes feces. Altogether, as much as 1,080 tonnes of waste are generated in producing 1,000 tonnes of fish.

Four years after the first salmon farms appeared in New Brunswick in 1979, farmed salmon escapees accounted for 5.5 percent of the salmon in the Magaguadavic River. By 1995, farmed salmon made up 90 percent of the salmon in this river.

In the summer of 1997, 300,000 Atlantic salmon escaped from several net pens in Puget Sound, when the nets were torn during a move to avoid an algal bloom.

Despite assurances that salmon cages in New Brunswick were placed in highly flushed areas, a 1991 survey found 37 of 48 sites showed moderate to high environmental impact. A later study found that the area under eight sites was heavily degraded with thick bacterial mats, and much reduced populations of animals.

## **SUSTAINABLE AQUACULTURE**

As the environmental and social costs of industrial-scale aquaculture, particularly of shrimp and salmon, have become clearer, discussions about principles and methods for sustainable aquaculture have grown. These discussions have yielded some valuable guidance already.

Scientists attending a 1994 conference in Norway developed The Holmenkollen Guidelines for Sustainable Industrial Fish Farming. These guidelines place aquaculture within a larger framework of integrated coastal zone management and call for taking a precautionary approach. The guidelines also call for reducing waste and pollution,

moving from the use of fish meal to other sources for feed, conserving genetic diversity, and increasing integrated polyculture, especially for the purposes of cleaning up organic pollution. The guidelines also call for the use of genetically manipulated fish only after internationally agreed safety and ethical criteria have been established.

In 1995, after several years of negotiations, more than 100 countries developed a Code of Conduct for Responsible Fisheries under the auspices of the Food and Agriculture Organization of the United Nations. Although this Code is not binding, a number of countries, including the United States, have adopted it. Because it represents the points of view and experience of so many countries, it represents a global view about minimum standards for both capture fisheries and fish farming, which is addressed in Article 9.

Several provisions of the Code of Conduct for Responsible Fisheries are relevant to salmon farming, and set standards that are not being met in many areas. Besides calling for environmental and social assessments before fish farming begins, as well as monitoring of effluents, the use of drugs, and other activities, the Code of Conduct calls upon countries to consult with neighboring countries when introducing non-indigenous species. The Code specifically calls for conserving genetic diversity:

In particular, efforts should be undertaken to minimize the harmful effects of introducing non-native species or genetically altered stocks into waters, especially where there is a significant potential for the spread of such non-native species or genetically altered stocks....

More broadly, the precautionary approach mentioned above has been adopted by some governments and international organizations as a basis for management of fisheries and fish farming. This principle has particular relevance to the use of non-native stocks of salmon as well as the use of chemicals and drugs in raising salmon. In 1995, an FAO scientific meeting recommended the following regarding both wild fish management and aquaculture:

Because of the high probability of the irreversibility and unpredicted impacts, many species introductions are not precautionary. Therefore a strict precautionary approach would not permit deliberate introductions... in relation to aquaculture, experience has shown that animals usually escape the confines of a facility. As a consequence, the introduction of aquatic organisms for aquaculture should be considered as a purposeful introduction into the wild.

Scientists in Sweden have proposed borrowing principles from Chinese aquaculture for integrating salmon farming in coastal areas as Chinese farmers have integrated pond culture of fish and plants into agricultural production. In general, the aim is to use the wastes from one type of cultivation as a resource in others "The more a cultivation system resembles and fits with the processes and functions of ecosystems, the less environmental effects can be expected, these scientists concluded."

In a simple design for a salmon farm based on this principle mussels would be grown around salmon cages. By feeding on remnants of pellets fed to salmon, among other things, the mussels would tend to maintain water quality and reduce sedimentation. The mussels themselves might be recycled as fish feed. The higher the proportion of mussels used in the feed, the lower the need to introduce nutrients in the form of fish feed from

outside.

Other methods of salmon farming either are being used already or are being developed. In British Columbia, for instance, Yellow Island Aquaculture, Ltd., uses no chemicals to medicate fish or to prevent fouling on the netcages. The farm experiences higher mortality early in grow-out of chinook (about 30 percent), and incurs additional costs from maintaining low densities in its cages. Compared with 700 tonnes of Atlantic salmon that would be produced with conventional technology, this farm produces 100 tonnes of chinook each year. On the positive economic side, the farm's medication costs are nil and their organic salmon fetches a higher price in the market.

Another farm, recently restarted after several years of dormancy, raises salmon in tanks on land in British Columbia. This farm has the capacity of producing 600 tonnes of salmon every two years. An enclosed bag, sea-rearing system is being developed as well in British Columbia; this system will be used initially to raise smolts in freshwater.

The virtues of land-based and enclosed-bag systems are that they eliminate escapes and allow the capture, recovery, and recycling of wastes. They also reduce conflicts with marine mammals and other wildlife. If salmon farmers had to reckon with the public costs associated with uncontrolled discharge of wastes and exotic species into coastal waters and with damage to wildlife, these alternative systems would be viable.

## **THE FUTURE**

In promoting the expansion of aquaculture, industry, and government representatives often cite the need to meet the growing demand for protein of growing human population. In 1991, Michael New, the new President of the World Aquaculture Society, predicted that the demand for fish and shellfish would increase from 119.6 million tonnes in the year 2000 to 162.4 million tonnes in 2025, while world populations would grow from 6.26 billion to 8.5 billion. New foresaw landings from marine and freshwater capture fisheries stabilizing at 100 million tonnes, while aquaculture production would grow at an annual rate of 4.75 percent to 62.4 million tonnes in 2025. Similarly, the FAO recently estimated that aquaculture's share of worldwide fish production would grow from 8 percent in 1984 and 15 percent in 1994 to 27 percent in 2010.

Where will all this fish come from? In promoting a new research initiative in aquaculture, the Consultative Group on International Agricultural Research (CGIAR) emphasized growth in several areas of aquaculture. For instance, CGIAR pressed for more research into breeding fish and shellfish. The agency cited the example of Nile tilapia, a widely grown freshwater fish, whose growth and survival rates have been greatly increased through breeding. Attractive features of tilapia are that it is very productive, thrives on agricultural wastes, and can be grown in backyards or large farms.

Promoters of salmon farming expect to share in this dramatic growth, partly by developing strains of salmon through breeding that grow faster, more efficiently convert

food to flesh, resist disease, and tolerate crowded conditions.

Aquaculture of many organisms appears poised for revolutionary change, perhaps a "blue revolution" similar to the "green revolution" that boosted agricultural production in the 1960s and 1970s. Applying traditional breeding techniques as well as recently developed techniques of bioengineering, aquaculture scientists are aiming to increase growth and food conversion rates, disease resistance, and other characteristics.

Scientists in Canada sought to boost the production of salmon farms in Atlantic Canada by implanting a gene that produces a kind of antifreeze in northern fishes such as winter flounder. Although this research did not produce fish that could withstand freezing temperatures, it did lead to technology that increased the growth rate of Atlantic salmon by 400 percent to 600 percent. This technology, which now is being marketed, produces Atlantic salmon that weigh more than six pounds after 16 months of feeding, compared to less than a pound for non-engineered salmon. Canadian government funding has supported other similar research.

In Washington State, scientists are seeking to turn "wild coho salmon into a tamed food source." Beginning with 120 families of coho salmon, researchers developed two lines that have tripled the size of farmed salmon in the United States. Yearlings that would have weighed a little more than half a pound in 1978 now weigh 1.5 to two pounds. Mature farmed coho now weigh 6.7 pounds rather than 1.9 pounds, as they did in 1978.

The use and development of such technology has provoked debate and regulatory review in some countries. The Food and Drug Administration in the United States has yet to approve the use of the technology. In Norway, officials have adopted a wait-and-see approach, citing environmental concerns and possible rejection of engineered salmon by consumers. In the United Kingdom, approval for some uses of the technology is pending.

How much salmon may be produced in the view of industry observers? One Norwegian expert has predicted that farmed salmon production will reach 1.2 million tonnes by the year 2005, nearly tripling current production. This growth in farmed salmon will be fueled partly by large investment by Japanese interests in hatcheries in the Russian Far East.

Aquaculture in some form offers an attractive means of meeting real needs for protein. However, this agenda has little to do with meeting the demand for luxury seafood products, such as salmon, in industrialized countries that have alternative sources of protein. Even if we developed the means of distributing as much salmon as could be grown and feeding the masses with salmon protein, the trade-offs are questionable. If the ingenuity that has engineered salmon to grow several times faster than wild salmon were directed at finding a way of making fish now fed to salmon fit for human consumption, we might be ahead of the game. As it is, feeding fish that we don't care for to fish that we like does little for world hunger.

## LEADING SALMON FARMING COUNTRIES

### NORWAY

Besides being the first country to promote the growth of salmon farming, Norway enjoys some features that have contributed to the meteoric rise of its industry. Thousands of miles of coastline, much of it protected from storms, offered attractive sites for siting fish pens at sea. Coastal waters warmed by the Gulf Stream have been ideal for growing salmon, while snow-fed rivers have provided the large quantities of freshwater needed to operate hatcheries. Salmon farmers have been able to rely on local populations of capelin, sand eel, and pout for feed material. The lack of other economic opportunities reduced conflicts and ensured a large labor force. A strong scientific and technical community assisted in developing and applying new technology. Ready ports, processing facilities, and transportation networks enable Norwegian salmon farmers to get their salmon to market. Norwegian banks took risks and invested heavily. Finally, the Norwegian government supported the growth of salmon farming as a method of rural development. Although pioneers began farming salmon and trout in Norway in the 1960s, the salmon farming industry itself got underway only in the 1970s after technical problems had been overcome. With the Fish Farming Act of 1973, the government began licensing salmon farms, which grew from 13 in 1974 to 84 in 1977. As the Norwegian government continued issuing new licenses, the number of farms rose to 301 in 1983 that produced an average of 30-40 tonnes each-17,298 tonnes in all. By 1984, when 354 farms produced 29,500 tonnes of salmon worth about \$108 million, salmon farming had become Norway's second most valuable fishery after cod.

By 1985, technology had evolved so that farmers could raise 150-200 tonnes of salmon in pens that produced just one-third that amount the year before. This technological development together with the considerable profits that farmers were realizing triggered a gold rush: In 1985, 2,500 applicants competed for 150 salmon farming licenses. In 1986, 636 salmon farms produced 45,675 tonnes of salmon. By 1987, Norway was exporting 47,400 tonnes of farmed salmon that fetched more than \$314 million. In 1988, production nearly doubled to 78,700 tonnes. In 1990, production grew to 146,000 tonnes. The rush to grow salmon had produced a glut on the market. From a price of \$10.50-11.00/kg in the first part of 1988, the price for fresh Norwegian farmed salmon fell to below \$8.80/kg by December 1988. In 1989, when Norwegian farmers exported nearly all the 114,900 tonnes of salmon they produced, earning more than \$500 million, salmon prices fell another 17 percent. Salmon farmers in Scotland and Ireland accused the Norwegians of dumping salmon on the market at below cost, triggering an investigation by the European Union.

During the 1980s, as successful salmon farmers began bridling at government restrictions, they began exporting technology, equipment, and financing to Canada, the United States, and Chile. Today, Norwegian interests, including salmon producing, processing, and trading companies as well as Norwegian banks, play a dominant role in the salmon farming industries in these other countries.

## **CHILE**

Like Norway, Chile possesses nearly ideal conditions for salmon farming as it is currently practiced. The long coastline, inlets, and islands offer sites protected from most storms. The lack of economic development from Puerto Montt south to Punta Arenas offers a labor force, little pollution, and few conflicts between salmon farming and other economic activities. Ice-free waters, stable water temperatures, and more sunlight than in northern hemisphere farming sites fosters faster growth of salmon than elsewhere. Indeed, salmon reach market size six to 12 months earlier than in Norway, thereby reducing costs to Chilean salmon farmers greatly. Chilean salmon farmers also enjoy ready access to large stocks of sardines and anchovies, which keep feed prices lower than in other salmon farming countries. Compared to other salmon farming countries, wages in Chile are extraordinarily low, amounting to \$150 per month in 1989, for instance. Until 15 years ago, one important ingredient was missing: salmon. Until 1987, only coho salmon were grown, largely because they were easy to raise in their freshwater phase and were quick to mature. With continued investment by Japanese interests, the farming of coho grew to supply markets for fresh Pacific salmon in December through March when northern salmon fisheries were closed. In 1985, however, the Norwegian company NorAqua created a subsidiary company called Chisal to operate a hatchery for Atlantic salmon. The advantage of Atlantic salmon is that it can be harvested throughout the year, whereas coho salmon is harvested for only three months.

The number of farms doubled during the 1980s. By 1991, 126 companies operated 471 Atlantic salmon farms, while 41 companies operated 523 Pacific salmon farms. These farms, most of which were in southern Chile, employed more than 1,000 people. Many of these farms were foreign owned. From just one tonne of salmon in 1981, Chile's farmed salmon production grew to more than 34,000 tonnes of salmon in 1991. Of this, 17,954 tonnes were coho salmon, and 14,957 tonnes were Atlantic salmon.

Nearly all salmon farmed in Chile is exported. Japan and the United States account for more than 90 percent of the exports. Taking advantage of the vacuum in the U.S. market created by the tariffs imposed on Norwegian fresh salmon in 1990, Chile aggressively entered the U.S. market. By 1991, exports to the United States had risen to 11,500 tonnes.

## **SCOTLAND**

In 1838, Scottish biologists first attempted to incubate and hatch salmon eggs in an effort to increase salmon populations. In the early 1960s, Scottish biologists tried raising smolts from eggs, and soon developed the ability to raise salmon in sea pens. In 1969, the first commercial salmon farm began near Aberdeen and Loch Ailort.

Now, salmon farms operate in the Scottish Highlands, Western Isles, Orkney Islands, and the Shetland Islands. Many of these areas have high unemployment, and government agencies in the United Kingdom and the European Community have provided loans, training, and technical support to encourage the growth of salmon farming.

Between 1980 and 1991, Atlantic salmon production at Scottish farms increased from 98 tonnes to 40,600 tonnes. In 1991, salmon farming put roughly \$300 million into the Scottish economy and employed 6,300 people. Marine Harvest, Booker-McConnell, and the Norwegian-owned Norsk-Hydro dominate the industry.

The principal market for Scottish farmed salmon has been the United Kingdom, where farmed salmon has become the third most popular seafood after cod and haddock. In 1990, nearly all of the 16,200 tonnes of fresh salmon sold by fishmongers and supermarkets in Britain was salmon farmed in Scotland. When Norwegian salmon production exploded in 1989, prices dropped and Scottish salmon farmers persuaded the British Government to request an investigation by the European Union (EU). The EU later set minimum prices for salmon imports into the EC that remained in effect into 1992 and were revised in 1997.

### **FAEROE ISLANDS**

Lying about 300 miles northwest of the Shetland Islands, the Faeroe Islands are a self-governing region of the Kingdom of Denmark. With the decline of capture fisheries and little land for agriculture, the Faroese invested in salmon farming early in the 1980s and soon became one of the top ten producers worldwide. Although the government provided technical support and some start-up capital, it has not provided additional funding. After an initial importation of broodfish from Norway, the Faroese government banned the importation of smolts in order to protect native salmon stocks. Faroese smolt hatcheries soon were producing more smolts than could be absorbed locally. The glut of salmon on the world market in 1989 effectively prevented export of smolts and a number of hatcheries closed.

Most salmon are raised in very large floating fish farms located in the narrow straits between islands. Operations on these farms, which are vulnerable to storms and are expensive to purchase, are highly mechanized. By 1990, 63 salmon grow-out farms produced roughly 16,000 tonnes of Atlantic salmon annually. By 1992, nine farms had declared bankruptcy.

Nearly all farmed salmon is exported. In 1991, Faroese salmon farmers exported 15,600 tonnes of Atlantic salmon, which fetched \$86 million or about one fifth of all Faroese exports and one tenth of the Faroese Gross Domestic Product. The principal importer of Faroese farmed salmon has been Denmark, which accounted for 40 percent of all exports in 1991. The Danish smoke and re-export most of this to Germany and France.

### **CANADA**

As elsewhere around the world, salmon farming did not get serious in Atlantic Canada until Norwegian money and expertise, in the form of Stolt-Nielsen A/S, collaborated with Canadian Packers in constructing a salmon hatchery in New Brunswick in 1984. Soon, other large interests followed. Connors Brothers LTD, a large fish processing company that provides much of the feed for the local salmon farms, constructed a large smolt hatchery in a nearby lake in 1986. Meanwhile, research overseen by a committee of

federal, provincial, and industrial representatives helped the industry perfect its technology.

Production of Atlantic salmon grew from 647 tonnes in 1986 to 7,925 tonnes in 1990, fetching more than \$36 million. New Brunswick has dominated Atlantic Canada's production of salmon. Initially pursued only on a small scale, a "gold rush" in salmon farming arose by the mid-1980s. This growth was fed partly by government grants and interest-free loans and loan guarantees, amounting to more than CDN\$34 million between 1985-1996. There is some farming of Atlantic salmon in Nova Scotia, where eight farms cultured salmon and steelhead in 1990. Salmon harvests there grew from 37 tonnes in 1987 to 284 tonnes in 1990.

Salmon can be grown year-round in British Columbia (B.C.). Furthermore, B.C.'s 16,000 miles of coastline and inlets, together with a high level of tidal flushing, make for many more possible sites for salmon farms than in the Atlantic. Salmon farming in B.C. began with coho and chinook salmon, largely because these native species were thought to be more suitable. Also, early farms could obtain broodstock and eggs from government-operated hatcheries aimed at enhancing wild populations of salmon. Initially, the Department of Fisheries and Oceans opposed the importation of Atlantic salmon eggs due to concerns about the impact on Pacific salmon. Nonetheless, by 1985, Atlantic salmon were introduced into B.C., and became popular with farmers since they grow quickly in sea pens, reach a profitable size in their second year, and fetch a higher price on the world market.

Like salmon farming elsewhere, the industry in B.C. underwent a boom period where large numbers of entrepreneurs were attracted by the opportunities of supplying a growing market in the United States and by government research and financial support. Between 1984 and 1988, the number of farming sites grew from 10 to 150, and production grew from 107 tonnes to 6,590 tonnes. In 1995, B.C. salmon farms produced 22,000 tonnes of salmon that fetched \$165 million - twice the level of the local capture fishery for salmon. Nearly two-thirds of the production was Atlantic salmon, while chinook salmon accounted for one third and coho a very small fraction.

When its markets were limited to Seattle and Vancouver, the B.C. salmon farming industry could not compete with the flood of Norwegian salmon. Between 1988 and 1990, one third of the companies farming salmon in B.C. went out of the business. Nine companies, or just 18 percent of the total, accounted for 70 percent of the salmon grown in B.C. A recent analysis found that the top six operators in the B.C. salmon farming industry were subsidiaries of multinational corporations, and that two of these were based in Norway, one in Finland, and one in the Netherlands. In 1994, the Provincial Government of British Columbia imposed a moratorium on new net pens while it assesses the impacts of salmon farming in coastal waters

## **UNITED STATES**

Although the United States is only a minor producer of farmed salmon, it exerts a tremendous influence on world salmon prices through its capture fisheries for salmon. In 1991, for instance, U.S. fishermen landed 355,925 tonnes of wild Pacific salmon. By 1995, Pacific salmon landings had climbed to 515,926 tonnes. Most of this was pink salmon destined for canning. However, fishermen also caught 158,618 tonnes of red or sockeye salmon, 22,307 tonnes of coho or silver salmon, and 11,219 tonnes of chinook or king salmon, all of which compete wild farmed salmon. The salmon industry also influenced world salmon farming by compelling the U.S. government to impose tariffs on salmon imported from Norway.

Efforts at salmon farming in the United States began in the late 1960s in the Pacific Northwest. These early attempts built upon decades of experience in raising smolts from eggs for release to the wild as partial mitigation for the damage done by dams. Commercial salmon farming did not begin until 1970. By 1980, 329 tonnes of salmon were produced in pens in the Pacific Northwest. By 1991, salmon farms in Washington, principally, produced 7,100 tonnes of salmon. Like the industry elsewhere, salmon farming in Washington State has consolidated so that it is now dominated by two companies: Global Aqua USA and Scan Am Fish Farms.

The other locus for salmon farming in the United States is Maine, where salmon farming had become the second most valuable fishery after lobster by 1990. (Some salmon farming also has occurred in California, Idaho, and Oregon. The State of Alaska has opposed salmon farming in its waters due to concerns over contamination of its wild salmon fisheries.) Farming of Atlantic salmon began in the early 1980s in Eastport, where the decline of the herring fishery encouraged the development of the new industry. By 1984, Ocean Products Inc. was operating 12 pens that produced 23 tonnes in 1984. Initially, local interests expanded the industry, but by the late 1980s, large firms began moving in, including Maine Coast Nordic Enterprises and Sea Farm Lubec. Between 1987 and 1991, the number of farm sites grew from 3 to 19, which employed 117 people. In 1995, production of Atlantic salmon rose to 10,118 tonnes.

When increased imports of fresh farmed salmon from Norway especially drove prices down, a coalition of Atlantic salmon farmers filed a petition with the International Trade Commission and the Department of Commerce, charging that the Government of Norway was subsidizing its salmon farming industry and that Norway was selling farmed salmon at less than fair value. In June 1990, the International Trade Commission and the International Trade Administration determined that Norwegian salmon producers and exports had benefited from subsidy programs worth 2.43 percent for all salmon exports. In September, the Department of Commerce imposed a 2.96 percent antidumping duty on imported fresh and chilled farmed Atlantic salmon from Norway. The Department of Commerce later imposed company-specific dumping margins ranging from 15.65 to 31.81 percent. U.S. imports of Norwegian farmed salmon fell from 9,450 tonnes in 1990 to 1,320 tonnes in 1991, while imports of fresh salmon from all countries rose to 48,350 tonnes.

The gap in supply soon was filled by Canada and Chile. By 1996, Chile was the largest supplier of fresh Atlantic salmon to the United States, accounting for 42 percent of the market, while the share supplied by U.S. salmon farms had slipped below 20 percent. In June 1997, the same group of U.S. salmon farms that petitioned the ITC and the Department of Commerce to impose duties on fresh Norwegian salmon imports petitioned to have duties imposed on Chilean imports. The Coalition for Fair Atlantic Salmon Trade claimed that Chilean salmon was being sold an average of 40 percent below market, and that the Chilean government had targeted 24 different subsidies to the industry. The DOC's investigation is expected to last until March 1998.

## GLOSSARY

**ALEVIN:** Newly hatched salmon which is still attached to its egg mass.

**ANADROMOUS:** Fish born in fresh water, descending into the sea to grow to maturity, and then returning to spawn in freshwater rivers and streams.

**BROODSTOCK:** Sexually mature male and female salmon used to produce fertilized eggs.

**CAROTENOID:** Yellow or red pigments found in animal fat and some plants.

**CARNIVORE:** An animal that eats animals.

**CONTAMINANT:** An unnatural substance found in the environment, or a naturally occurring substance found in unnaturally high concentrations; a pollutant; a health hazard.

**DETRITUS:** Fine particles of plant and animal matter that are suspended in the water or settle on the bottom.

**DIATOM:** Minute, planktonic single-celled algae with skeletons made of silica.

**DIPPING:** Method used to treat fish infected with sea lice. The fish is netted and placed into a container filled with a chemical treatment (such as Nuvan) which kills the lice. After dipping, the salmon is returned to its pen.

**ECOSYSTEM:** The sum of all plants, animals, and non-living parts of an area.

**EFFLUENT:** The material flowing from a pipe or facility into a lake, river, or bay.

**EL NINO:** An irregular change in the oceanic climate of the Pacific Ocean; warm, low-nutrient water flows east from the South Pacific and along the Equator, then north along the west coast of North American and south along the coast of South America. An especially strong El Nino occurred in 1982-1983, and another severe El Nino is expected in 1997-1998.

**EUTROPHIC:** Describing a situation in which excess nutrients have fostered excessive plant growth; when the plants die and decompose, dissolved oxygen is used up, making the water uninhabitable for animals.

**EYED EGGS:** The stage in the development of a fertilized egg in which the eyes are clearly visible.

**FINGERLING:** Pacific salmon at the parr stage of development.

**FISH LADDER:** A series of interconnected pools created up the side of a river obstruction, such as a dam, to allow salmon and other fish to pass upstream.

**FISHERY:** The combination of fish and fishers in a region, fishing for similar or the same species with similar or the some types of fishing gear.

**FRY:** The third freshwater stage of salmon development, when the egg mass is no longer present and the fish develops characteristic markings.

**FURUNCULOSIS:** A salmon disease caused by the bacteria *Aeromonas salmonicida*.

**GILLNET:** A curtainlike net, suspended vertically in the water in order to entrap fish.

**GRISLE:** Atlantic salmon that become sexually mature after only one year at sea rather than two years.

**GROW-OUT:** The stage when smolts are placed into enclosed pens for their final period of growth.

**HABITAT:** The sum total of all the living and non-living factors that surrounds and potentially influence a plant or animal. Most habitats are described in terms of physical features such as water depth or sediment type.

**HERBIVORE:** An animal that eats only plants.

**HITRA DISEASE:** A salmon disease caused by a cold-water vibriosis.

**JACKS:** Male Pacific salmon that mature after only one winter in the sea.

**JENNYS:** Female Pacific salmon that mature after only one winter in the sea.

**KELTS:** Atlantic salmon or steelhead trout that remain in freshwater after spawning in the fall.

**LANDINGS:** The amount of fish brought back to the docks and marketed.

**MARICULTURE:** Cultivation of marine plants and animals such as oysters and abalone.

**NONPOINT SOURCE:** A widespread, diffuse, or unidentifiable source of contaminants that comes from more than one point.

**NUTRIENTS:** Elements necessary for plant growth, including nitrogen and phosphorus.

**NUVAN:** A chemical, whose active ingredient is dichlorvos, used to rid salmon of infecting sea lice.

**OCEAN RANCHING.** The release of farm-raised smolts into the wild. After feeding in the ocean, the salmon return to their native rivers, where they may be caught.

**OMNIVORE:** An animal that eats both plants and animals.

**ORGANIC:** Having one or more carbon atoms; generally, produced by plants or animals.

**PARR:** The fourth freshwater stage of salmon development, when a characteristic "thumbprint" mark appears on the fish's sides and lateral stripes develop. Pacific salmon at this stage commonly are called fingerlings.

**PHOTOSYNTHESIS:** Process by which plants use energy from sunlight to make organic matter from carbon dioxide and water.

**PHYTOPLANKTON:** Generally, one-celled drifting plants, including diatoms and bluegreen algae.

**PLANKTON:** Generally, relatively small plants or animals that drift passively with currents and are unable to swim against them.

**POPULATION:** A group of individuals of the same species inhabiting a specific geographic area where interbreeding can occur.

**PRIMARY PRODUCTIVITY:** The amount of organic matter produced by plants through photosynthesis in an ecosystem.

**PRIMARY CONSUMERS:** Animals that eat plants.

**RANGE:** The geographical area or areas inhabited by a species.

**REDD:** A nest in the gravel of a stream where a female lays her eggs.

**RUN:** The movement of fish inshore or upstream for spawning.

**SEA LICE:** Small crustaceans (*Lepeophtheirus*) that attach themselves to salmon and feed on their flesh, producing unsightly blemishes. Efforts by a fish to rub the lice off can lead to infections.

**SECONDARY CONSUMER:** Animals that eat other animals, particularly primary consumers.

**SMOLT:** A young salmon ready for life in a saltwater environment.

**SMOLTIFICATION:** The process, including changes in shape, color, and density, that prepares a young salmon for life in a saltwater environment. The skin of the young salmon loses its markings and becomes silvery. Also, rather than preferring to swim against the current, the salmon comes to prefer swimming with the current and in shoals.

**SPAWNING GROUND:** A specific site where fish lay their eggs.

**TRIPLOID:** A genetically developed sterile salmon.

**UPWELLING:** A process by which surface waters that have been driven offshore by winds are replaced near shore by deeper, colder, nutrient-rich water, often resulting in high primary productivity.

**ZOOPLANKTON:** Small drifting animals.

## **SOME USEFUL WEB PAGES**

[The Aquaculture Information Network](http://www.nal.usda.gov/afsic/afsaqua.htm)

<http://www.nal.usda.gov/afsic/afsaqua.htm>

The U.S. Agriculture Department maintains this site, which includes information on various types of aquaculture.

[Aquaculture Information Center](http://aquanic.org)

<http://aquanic.org>

Sponsored by several governmental and non-governmental organizations, this web page offers links to national and international information on aquaculture.

[Aquatic Network](#)

The Aquatic Network includes a large collection of databases, news items, literature, and links regarding a wide range of ocean-related issue areas, including aquaculture.

[BC Salmon Farmers Association](#)

This Association's webpage gives information and views on economic activity due to salmon farming, environmental and other issues, and hot issues.

[FAO Fisheries Department](#)

The United Nations Food and Agriculture Organization includes a large fisheries department that posts information on global fish production, trends, statistics, and other matters

[Gadus Associates, Nova Scotia, Canada](#)

This site, prepared by a fisheries consulting company, offers hundreds of links to other sites on fisheries and aquaculture.

[The Georgia Strait Alliance](#)

GSA's web page includes its detailed comments on the technical reports prepared for the salmon aquaculture review in British Columbia.

[Northern Aquaculture](#)

Aquaculture in temperate waters, including salmon, is the focus of this site which is maintained by Northern Aquaculture magazine.

[The Salmon Page](#)

This web page, which students at Riverdale High School in Oregon developed for themselves, includes loads of links to salmon-related web pages.

[The David Suzuki Foundation](#)

The Suzuki Foundation has been in the forefront of critiquing salmon farming, particularly in British Columbia. Information on the report "Net Loss" can be found here, together with other useful information.

[Tasmanian Salmonid Growers Association](#)

Besides links to the University of Tasmania's Aquaculture Department, for instance, this

web page gives information on salmon farming in Tasmania, burning issues, and other information.

[World Aquaculture Society](#)

The leading professional organization for aquaculturists maintains this page, which includes links to many sources of information.

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