Salmon (*Salmo salar, Oncorhynchus tshawytscha, Oncorhynchus kisutch*)

Production	
Global production by aquaculture	1.26 million metric tons (mt)
Total global production	2.15 million mt
Aquaculture share of total production	60%
*International Trade**	
Share of exports (w/ wild caught)	94%
Exports	1.3 million mt
Average price	$3,000 per mt
Value	$3.6 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	Medium
Potential to certify	Medium 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 WWF-US initiated the Salmon Aquaculture Dialogue with a meeting in February 2004. There have been 3 subsequent meetings with international participation and one meeting with Chilean stakeholders.

All data for 2003 except where noted. Source: FAO 2005.
*2002 Data

Farm-level Issues in Aquaculture Certification: Salmon

Katherine Bostick, Jason Clay, and Aaron A. McNevin[1]

Executive Summary

Salmon aquaculture production was 1.26 million metric tons in 2003, and is one of the most popular food fish species in the United States, Europe, and Japan. In 1980 farmed salmon made up a negligible percentage of world salmon supply, but by 2003 approximately 60% of global salmon supply was farmed. According to the United Nations Food and Agriculture Organization (FAO) (2005), salmon is farmed in 24 countries. The major producers of salmon are Norway and Chile. The three most common species of cultured salmon are the Atlantic salmon (*Salmo salar*) the chinook salmon (*Oncorhynchus tshawytscha*), and the coho salmon (*Oncorhynchus kisutch*). In aquaculture the Atlantic salmon represents 89% of production and is by far the most economically important cultured salmonid.

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.

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.

Salmon farm siting, depending on the hydrodynamics of the culture environment, may cause most of the negative impacts. Farms situated in poor sites can cause eutrophication, impede the growth and survival of wild salmon stocks, and reduce benthic diversity. Salmon aquaculture also has been criticized for the high content of fish meal and oil incorporated in feeds. The use of antibiotics and other chemicals to combat fish disease and parasitic infestations has been viewed as excessive as well predator and foulant control means should also be incorporated in certification program.

Issues in certification of salmon will include the over-reliance on fish meal in feeds, use of antibiotics and harsh chemicals, water pollution from salmon operations, and habitat and species destruction. Although not the only impacts of salmon farming, research has shown that these are the main threats to the environment.

Introduction

The first evidence connecting humans to salmon was 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

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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.

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.
In 1980 farmed salmon made up a negligible percentage of world salmon supply, but by 2001 more than 1 million metric tons of total production and more than 50% of global salmon supply was farmed (Johnson and Associates 2001). Atlantic salmon is the fastest growing, high-value farmed species with annual production exceeding 1 million metric tons (mt) (Packard Foundation 2001).

Biology

Salmon are of the order Salmoniformes in the family Salmonidae. Numerous species of salmon are found in the wild, and a several are cultured. The Atlantic salmon (*Salmo salar*) (Figure 1), though, is the most important salmon species produced by aquaculture. Morphologically, mature Atlantic salmon are compressed laterally and have a streamlined body. Color and shape of salmon, in general, will change at different life stages. Salmon are carnivores and prey on a variety of aquatic species such as herring, pilchard, squid, and crustaceans.

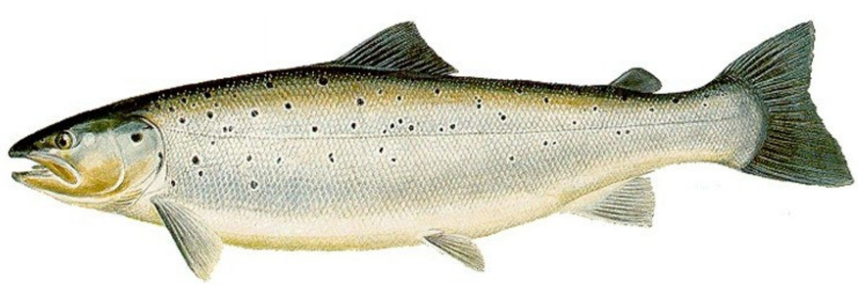

Figure 1. The Atlantic salmon (*Salmo salar*). Source: Atlantic Salmon Federation

Salmon are an anadromous fish, which means that they spend most their adult life in the ocean but returns to freshwater to reproduce. Salmon almost always return with great precision to the river where they were spawned. However, some salmon populations never go to sea, inhabiting lake and river systems. These fish follow a cycle similar to sea-run salmon, except that they migrate between deep-lake feeding areas and spawning grounds along shorelines or in tributaries.

Adult salmon spawn in freshwater streams or lakes, usually in late summer or fall. Their large eggs are buried in the substrate, where embryonic development occurs. The juveniles emerge from the substrate the following spring. Known as fry, they are dependent on external food sources upon emergence. Salmon fry will develop into parr (also known as fingerlings) and will inhabit streams or near-hatching habitat until they become smolts.

The initiation of salmon migration is preceded by the parr-smolt transformation (smoltification), in which the juveniles transform from a stage in their life history adapted for stream habitats to a stage adapted for downstream migration and eventually saltwater habitats. Smoltification is a series of morphological, physiological, and behavioral changes. A combination of endogenous and exogenous factors cues the initiation of migration. Environmental factors interact with endogenous rhythms to modify the fish morphologically, physiologically, and behaviorally to a state of migration readiness. The physical and physiological changes prepare the fish for migration, but exogenous cues such as photo period, water temperature, and salinity may actually trigger the onset of migration. Some species of salmon migrate to the estuary at this stage, yet other species delay migration for months or years.

Salmon are preyed upon by a wide variety of animals. Fish predators include chain pickerel, smallmouth bass, striped bass, and even an occasional large brook trout. Birds such as mergansers, osprey, cormorants, gulls, and kingfishers are known to consume salmon parr and smolts. Additionally, animals such as mink and otter occasionally eat salmon. The survival of salmon in freshwater is less variable than it is at sea. While in the ocean, salmon again are subjected to predation from numerous species of fish (cod, bluefish, and sharks), birds (cormorants, gannets) and mammals (otters, whales) and possibly seals. The mortality rate during life at sea is extremely high.

Depending on the species and stock, the fish spend between one and seven years in the ocean before returning to their native stream or habitat to spawn. Salmon cease to feed before they begin the migration back to freshwater. They begin living off the stored fat in their tissues that has been accumulating during their life in the ocean. When this starts the flesh of the salmon begins to lack flavor, becomes pale in color and is mushy in texture. Most salmon used for food are caught in the ocean before they start upstream where they have the best flavor, color and texture. The migration back to freshwater is far more arduous than that of fresh to salt because of bird and mammal predation and the amount of energy required to swim for consecutive days against the current. Salmon locate their natal streams by sense of smell. Once the fish have reached the spawning area the males, arriving first, will begin to secure gravel beds. Only the most healthy and robust salmon will return to the spawning sites, thus intense competition for territory exists. The females choose their mate by building her spawning bed on a particular territory of a specific male. Females lay eggs and males pass over the eggs depositing sperm. Shortly after spawning Pacific salmons begin to die; however, other species including the Atlantic salmon can spawn multiple times over several years.

Major Production Areas

According to the United Nations Food and Agriculture Organization (FAO) (2005), salmon is farmed in 24 countries. The major producers of salmon are Norway, Chile, the United Kingdom, and Canada, though Chile and Norway account for over 71% of aquaculture production.

Norway has long been the world leader in farmed salmon production. The country has 8,500 kilometers of coastline, much of which is protected from storm surges and wave action. Water temperatures are favorable for growing salmon as a result of the Gulf Stream influence. Almost 99% of the production occurs in sea water environments. The main farming system employs open fish cages and Atlantic salmon is the dominant species produced.

The entire Chilean aquaculture industry has experienced explosive growth over the past decade with farmed salmon representing the largest percentage of the total volume. Chile has several attributes which make it an ideal location for the production of salmon. There are extensive coastal areas, the water is not polluted and is viral disease-free, there are long hours of sunlight during the winter, and they are in close proximity to the largest and cleanest source of fish meal in the world. There are several species produced including some Pacific salmon, but the majority of production is comprised of Atlantic salmon.

Scotland is the primary region for salmon aquaculture in the United Kingdom. Salmon farming was introduced in Scotland in the 1960s but the industry remained small through the 1970s. However, there has been a steady increase of production of farmed salmon over the past decade. Finfish farming is widely distributed along the coasts of Strathclyde and Highland Regions and the Western and Northern Isles. The Atlantic salmon is the only finfish species currently farmed on a major scale in Scottish coastal waters. Sea cage culture in sea lochs, where Atlantic salmon are the primary species raised, is one of the four major forms of commercial fish farming in Scotland. To date, most marine salmon aquaculture production in Scotland has occurred in sheltered areas such as fjord-like sea lochs or voes. Typically, these sites do not have good water exchange, so the licensing and placement of cages must be sensitive to current conditions to prevent an accumulation of solid wastes.

Canada has the world's longest coastline, touching three oceans, and one of the largest continental shelves, which makes the country quite suited for aquaculture. Salmon aquaculture in Canada exists on both the Pacific coast in British Columbia and on the Atlantic coast in Nova Scotia, New Brunswick and Prince Edward Island. Both the Pacific salmons and Atlantic salmon are being cultivated on both coasts.

Production Statistics

In 2003 farmed salmon production was 1.3 million mt accounting for more than 60% of total salmon production (Figure 2).

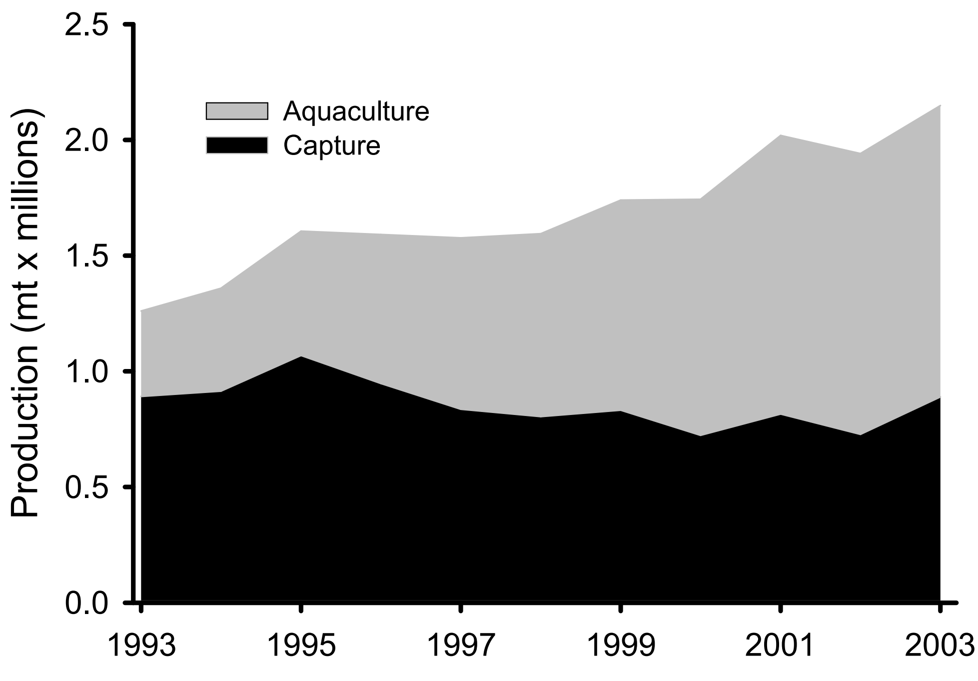

Figure 2. Comparison of salmon production from aquaculture and capture fisheries. Production values are in metric tons (mt). Source: FAO 2005

Aquaculture production of Atlantic salmon has long been dominated by Europe, where it was invented. Total farmed salmon production in Europe reached 730,805 mt in 2003 (FAO 2000). Norway was by far the largest producer at 507,412 mt, followed by Scotland (145,609 mt), the Faroe Islands (56,318 mt), Ireland (16,347 mt), and Iceland (3,708 mt). Other important global producers included Chile with 377,272 mt and Canada with 107,250 mt (FAO 2000). In Chile production has grown at some 9% per year for a decade or more, while prices have dropped a total of 30%.

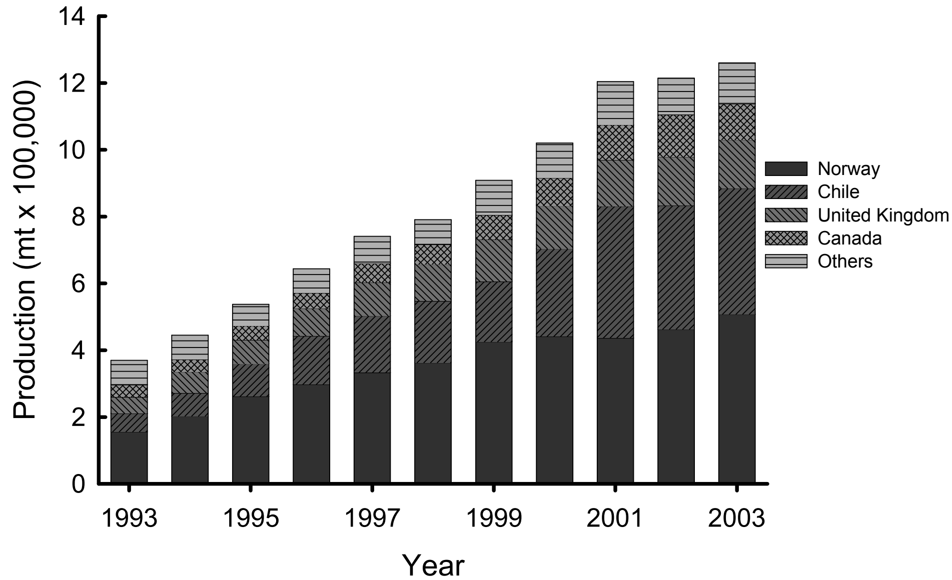

Figure 3. The main countries producing salmon by aquaculture. Production values are in metric tons (mt). Source: FAO 2005.

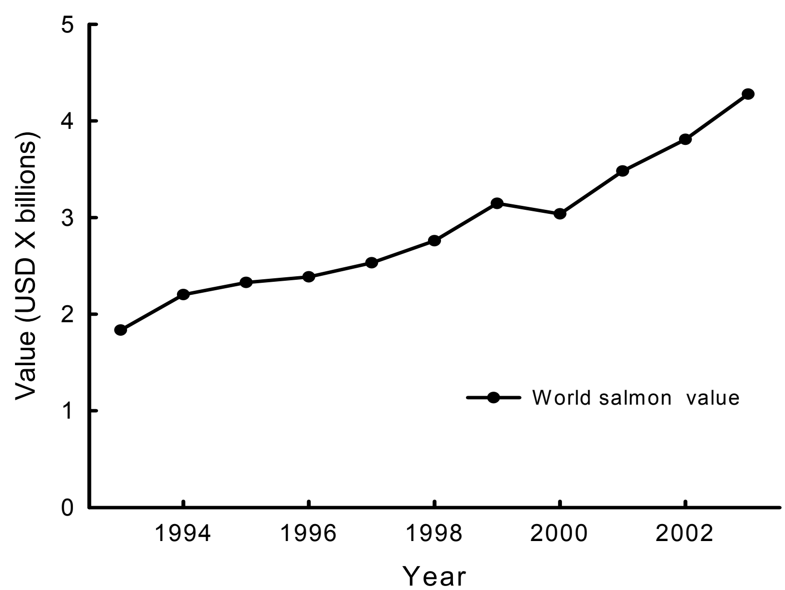

Figure 4. The economic value in billions of US dollars (USD) of world salmon production. Source: FAO 2005.

The European Union, Japan, and the United States are the three biggest markets for salmon. 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% 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).

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% of farms produced more than 1,000 mt of salmon. By 1999 the figure had risen to 59%. During the same period the number of farming operations declined by 29%. Even more consolidation is likely given that by 1996, 106 of the firms operating had a combined production of only 4% of the total. Another trend represented by Scotland is that 47% 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 mt per worker in 1993 to 97.2 mt 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.

The farmed salmon industry has consolidated. Over half of aquaculture salmon is produced by five companies: Nutreco Holding N.V. (165,000 mt in 2001), Fjord Seafood ASA (102,000 mt), Pan Fish ASA (97,000 mt), Stolt Sea Farm SA (55,000 mt), and Statkorn Holding ASA (53,000 mt) (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.

The operating costs for salmon farming, while variable, generally fall into the following proportions. Feed is the largest single expense at about 34% of total costs. The smolts for stocking represent about 23% of the cost with wages, overhead, and depreciation amounting to 13 to 15% 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 4).

Culture Systems

Salmon aquaculture can be divided into two activities – fingerling production and grow-out to market size. 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.

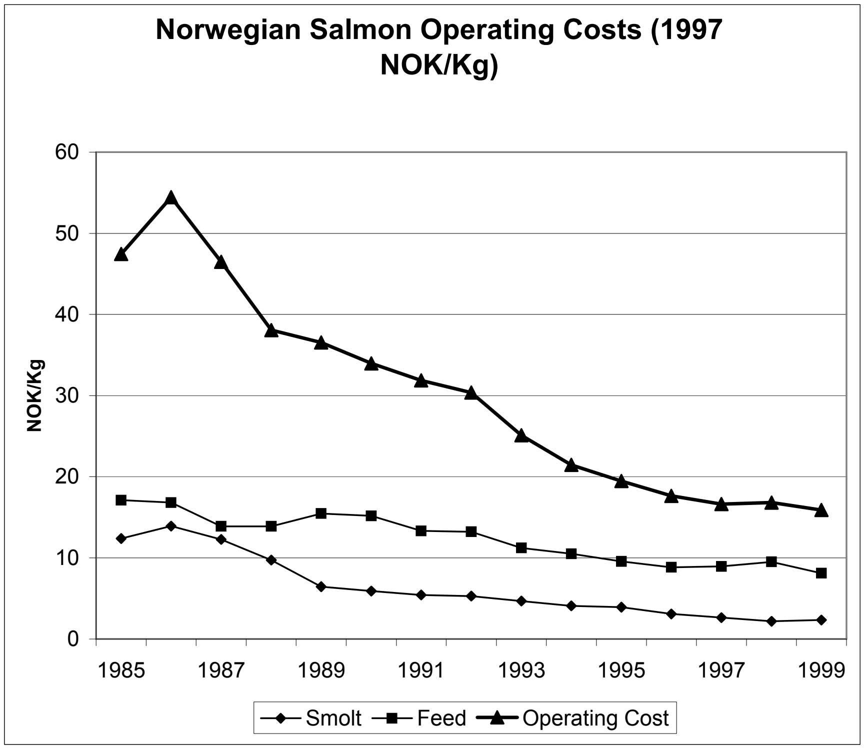

Figure 4. Source: Norwegian Directorate of Fisheries 1999, as cited in Anderson n.d.

Fingerling Production

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 typically is 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 in the wild, 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 salmon fingerlings when it is time to stock their net cages. Large companies tend to be vertically integrated and maintain adult brood stock and sell eggs or recently hatched animals as well as grow them out to market size. 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 the genetic modification of salmon. To allow salmon to grow in the winter in less favorable climates than Europe, DNA from the ocean pout 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

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 stocked at high densities in sea cages. 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 mt of fish at any site. In Canada, however, sites have nearly 800 mt of fish (Ellis and Associates 1996). The size of operations at sites in Chile can be considerably larger.

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.

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% 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%, and taxes decreased by 3.6%. Profits, by contrast, increased by 11.9% 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% 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% 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.

Fish Health

Salmon diseases can decimate entire crops of fish, and there is some fear that these diseases could be affecting wild fish. Viral, parasitic, and bacterial diseases all can impede growth and survival of cultured salmon. The main diseases affecting Atlantic salmon are listed in Table 1.

Table 1. Major salmon health concerns.

Parasitic	Bacterial	Viral
Sea louse	Bacterial kidney disease (BKD)	Salmon papilloma
Sea lamprey	Enteric redmouth disease (ERD)	Salmon swim bladder sarcoma virus (SSSV)
Gill maggot	Coldwater disease (CWD)	Toga virus
Freshwater louse		Infectious salmon anemia (ISA)
Ichthyobodo		Infectious pancreatic necrosis (IPN)

Source: Atlantic Salmon Federation

In hatcheries the major fish disease problems are caused by infectious agents. In juvenile fish, bacterial gill disease, furunculosis, bacterial kidney disease (BKD) and diseases caused by parasites (such as proliferative kidney disease, Ichthyobodo (Costia-infections) are the causes of significant losses. The impact of many of these diseases can be reduced through fish health management, such as the screening of adult fish for egg-associated disease agents, and through appropriate treatments.

Net-cage rearing can reduce the costs of fish production by decreasing construction costs and the need to pump water. However, this form of aquaculture provides an unregulated water supply which can potentially expose captive fish to a variety of toxins, parasites and pathogens (Kent 1992). The exposure to ubiquitous environmental pathogens coupled with the stresses associated with captive rearing can create opportunities for diseases that occur in natural stocks at low levels to become significant causes of mortality in farm-reared fish. This situation is not unique to aquaculture. The management of disease has always been an essential part of all forms of intensive animal agriculture.

Furunculosis is a common bacterial disease that can be a problem in both the freshwater and marine life stages of Atlantic salmon (Munro 1988). It causes boils on the flanks of fish. In 1985, furunculosis was discovered in salmon farms in Norway (transferred salmon smolts from Scotland carried the disease); by 1988, 32 farms were infected; by 1992, it had jumped to 550. (It largely is assumed that massive escapes in 1988 and 1989 helped contribute to the epidemic.) Additionally, more than 74 natural waterways were infected. As a result, the fish at more than 20 farms were slaughtered in an attempt to eradicate the disease. Total damage was put at more than $100 million, although costs to wild salmon populations have not been calculated and the costs are ongoing. The disease is so widespread that no waters with resident salmon populations are considered free of it. Control measures include vaccines and surface disinfection of eggs.

Infectious salmon anemia (ISA) is a highly contagious and lethal viral disease that spreads by horizontal transmission (adult to adult) in both freshwater and seawater (Håstein 1997). The disease was unknown to science before appearing as an epidemic in the Norwegian salmon farming industry in 1984. Within seven years, it had spread to 101 farms and remains a problem today. In Canada, ISA was first observed in New Brunswick in 1996 and spread to 21 farm sites by 1997, and 35 by 1998. Despite widespread culling, 17 sites remain contaminated. In 1999, wild Atlantic salmon in New Brunswick were found for the first time to have the disease, and escaped farmed salmon entering freshwater to spawn were found to carry it. In Scotland, ISA was first reported in 1998. By 1999, about 10% of all Scottish sites were infected, and the disease was found in wild salmon parr. In Chile, ISA was reported in early 2000 in farmed coho salmon. In Maine, USA, ISA appeared in early 2001 and greatly impacted the farming industry. The virus is believed to be carried in mucus, urine and feces and its amplification in farms therefore creates contagious areas for nearby wild salmon, in addition to its transmission by escapees.

BKD was first diagnosed in 1980. BKD is a chronic infection of salmonid fish in fish farm environments (Jansson 2002). Once the bacterium is established, it can be difficult to control and virtually impossible to cure. It is present in the U.S. and Canada, but there has not been a high frequency of occurrence of BKD in the Northeast. It is one of the most devastating diseases for Chinook salmon.

Enteric redmouth disease (ERM) also is caused by a bacterium and occurs in salmonids throughout Canada and much of the U.S. The first instances of the disease were reported in Rainbow trout (*Oncorhynchus mykiss*) in the USA in the 1950s (Ross et al. 1966). This disease usually results in low-level losses, but large-scale problems can occur. Control in fish farms is accomplished through the use of vaccines and surface disinfection of eggs.

Coldwater disease (CWD), caused by a bacterium (Rucker et al. 1953), has recently been found to be a potentially serious problem to Atlantic salmon in New England waters. Studies by the Biological Research Division of the USGS have shown that the pathogen induces pathology and subsequent mortality among juvenile Atlantic salmon, and that the pathogen is vertically transmitted from carrier sea-run adults to offspring via the eggs. Intra-ovum CWD transmission influences egg quality and affects early life stage survival.

Vibriosis occurs in many species and is most likely ubiquitous in saltwater (Tanaka 1975). In infected species, lesions occur in the muscles and hemorrhaging may occur. There have been recent reports of cold-water vibriosis infection in farmed Atlantic salmon in Norway and Scotland. A commercially available vaccine is also used in fish farming operations to reduce losses.

Infectious pancreatic necrosis (IPNV) is one of only a few known viral diseases that affect farmed Atlantic salmon. IPN is endemic in eastern North America. The IPN virus has generally not been found to be a serious source of mortality in Atlantic salmon in North America, but has caused serious mortality in farmed European salmon (Damsgård et al. 1998).

Salmon swimbladder sarcoma virus (SSSV), a lethal retrovirus was detected in wild Atlantic salmon that had been captured as parr (young salmon) in Maine's Pleasant River and reared at a national fish hatchery. Cornell University scientists identified the causative agent as a leision-causing retrovirus known as salmon swimbladder sarcoma virus. This disease and a presumptively causative retrovirus were first reported in young farmed Atlantic salmon in Scotland (McKnight 1978). The disease has not been reported from Scotland since, and the relationship between this and the Maine retrovirus has not been determined.

The sea louse (*Lepeophtheirus salmonis*) is one of the more common ocean parasites of Atlantic salmon. With severely infested fish, often the skin is loose, and flesh may be exposed. In Ireland, Scotland, Canada, and Norway, the development of salmon farming has increased sea louse infestation of wild stocks of salmon. Though salmon farms are stocked with louse-free juveniles, lice exist naturally in the ocean and crowded conditions in open net-pens make salmon farms ideal habitat for lice. The lice can be contracted by wild smolts migrating to the ocean and passing through farming areas. Infestation often results in increased mortality and premature return to freshwater. Studies by various researchers around the world link high levels of sea lice on wild salmon with sea louse infestations in nearby salmon farms or farms that lie along salmon migration paths (Gargan et al. 2000; Tully et al. 1993; Anon 1993; Finstad et al 1994). However, the role salmon farms play in transmitting sea lice to wild salmon is an issue of much debate, in some regions of the world more so than others. There is little question that the impact of sea lice on wild and farmed salmon is negative; the question is how to minimize the impacts on both.

A togavirus isolated in tissue culture has been detected in Atlantic salmon from farms in Maine and New Brunswick (USFWS 1999). The virus appears to be in New Brunswick and has been found in the Cobscook Bay area of eastern Maine, USA. There have been no disease outbreaks found associated with this virus at present.

Feed

Feed amounts and frequency of feeding depends on water temperature and growth stage of the fish. A detailed description of a feeding regime for salmonids is offered by Boyd and McNevin (2004). As temperature increases the amount of feed offered as a percentage of body weight is increased until the temperature reaches its optimum for growth. The percentage of feed offered is decreased when temperature is above optimal and as fish increase in size. Salmon farmers are more likely to overfeed at the fry and fingerling stage because the amount of feed is much less and may not be measured and offered as conservatively as larger amounts of feed required at later stages in growth.

Carotenoid pigments may be fed to salmon to enhance the color of fish flesh. Carotenoids are natural pigments responsible for many of the red, orange, and yellow hues of food products. Astaxanthin is the carotenoid found in wild salmon. Canthaxanthin is a closely related carotenoid used as a feed additive, and can be made synthetically. These carotenoids have some health benefits for humans (Ilfeld undated), and consequently carotenoid supplements are sold for human consumption at pharmacies and health food stores.

Fish meal is derived from small, bony, pelagic fish that generally are not used for human consumption. These are cooked, pressed and the presscake (usually supplemented with condensed fish solubles) is low-temperature dried, finely ground and stabilized with an antioxidant. Salmon feeds typically contain 35% fish meal and 25% fish oil (Tacon 2005). Fish meal and oil use has long been a controversial issue in the production of carnivorous fish. Recently, reports have been issued regarding the polychlorinated biphenyl (PCB) concentrations in farmed salmon. PCBs and other toxins typically are absorbed in fish oil and fat. The extraction of oils from fish meal-fish concentrate these chemicals and feeding high oil content feed to salmon will result in the transfer of PCBs. These toxins will be stored in the fatty tissue of the salmon. Furthermore, these issues show the clear need for the reduction of wild fish for fish meal and oil use in aquaculture.

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 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% 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 mt 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 mt of Atlantic salmon. Nutrient inputs to the marine environment for that year were 6,900 mt of nitrogen and 1,140 mt 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 81% of total production (Pike 2005). Salmon aquaculture is by far the largest user. Analysts have suggested that aquaculture will use more than 90% of fish oil by 2010.

At this time, some 20 to 25% of annual global seafood catch is dedicated for conversion to fish meal and fish oil. Significant amounts of trimmings or rejected food fish are also converted to meal and oil, in 2004 over 5 million metric tons of trimmings were used in this manner. All told, approximately one-third of all wild-caught fish are converted to fishmeal and oil (Tacon 2005). Though a relatively new industry in 1994, the carnivorous aquaculture farms used approximately 15% of the global fish meal output (Ellis and Associates 1996). By 1997 aquaculture used 33% of fish meal supplies (Jacobs et al. 2002) and by 2002 the fraction increased to 46% (Tacon 2005). 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% fish oil though the global average is 25% (Tacon 2005). This has increased from 8% in 1979 (Staniford 2002). Net-cage rearing of 1 kilogram of salmon is estimated to use on average 3.1 to 3.9 kilograms of wild fish (Tacon 2004). 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% 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% 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% 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% of the salmon in the nearby Magaguadavic River were escaped salmon from the farming operation. By 1995, 90% 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% 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 et al. 2002). The European Union's Scientific Committee on Food found that fish can represent up to 63% 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 et al. 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 et al. 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% 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 tributyltin (TBT) have been used in marine paints, and are known to be harmful to shellfish. However, some of these paints also are 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, a TBT containing antifoulant, 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 mt 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 mt of antibiotics were used in salmon farming compared to 11 mt 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 mt of antibiotics, by 1995 usage had increased to 65 mt, and by 1998 it was 100 mt. 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% 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).

Mortality Disposal

The disposal of salmon that die before harvest (morts) has both environmental and health implications. Approximately 20% 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.

Predator Control

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% 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.

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).

Social Issues

Salmon farming is heavily concentrated in Norway and Chile. Social issues have not arisen as a particular concern related to the industry in Norway. However, they have come to the forefront of the concerns surrounding the industry in Chile. Workers in this export-focused industry in Chile accuse industry of violating human rights and actively trying to prevent the formation of and participation in unions. Many workers live in sub-standard conditions, some with no running water or electricity, despite working full-time on salmon farms or in processing plants. Sub-contracting workers has become a common practice, requiring workers to take temporary positions at lower wages (Pinto et al. 2005). It is clear that standard development and/or certification for salmon farming would need to address these issues.

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).

Certification Issues

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.

Open vs. 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.

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% 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% 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.

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% losses of salmon during the grow-out phase of production compared to the industry average of 20%. 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 mt are sold each year. A non-organic producer operating on the same site could produce some 700 mt 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% of the standard system operating on the same area (Ellis and Associates 1996).

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.

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 nearing one to one; currently 1.0 to 1.5 kilograms 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 three or four 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 also has 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).

Feed producers are being pushed to reduce reliance on fishmeal and oil as prices for those commodities are relatively high and likely to rise as demand for them continues to increase.

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.

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.

Possible Areas for Initiating Certification

Norway would be the best place to pilot certification efforts. Considerable research on key environmental impacts including escapes and disease has focused on Norway, the government has stringent laws, and environmental NGOs have been working with the industry for some time. Additionally, Norwegian producers sell primarily into the market in Europe, which is the most receptive to certified product. Due to serious labor concerns in Chile and active conflict between industry and environmental groups in British Columbia, Canada, these are not ideal areas for piloting certification though standard implementation could be piloted with some of the better producers from these regions.

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