Salmon Aquaculture in the Pacific Northwest A Global Industry with Local Impacts

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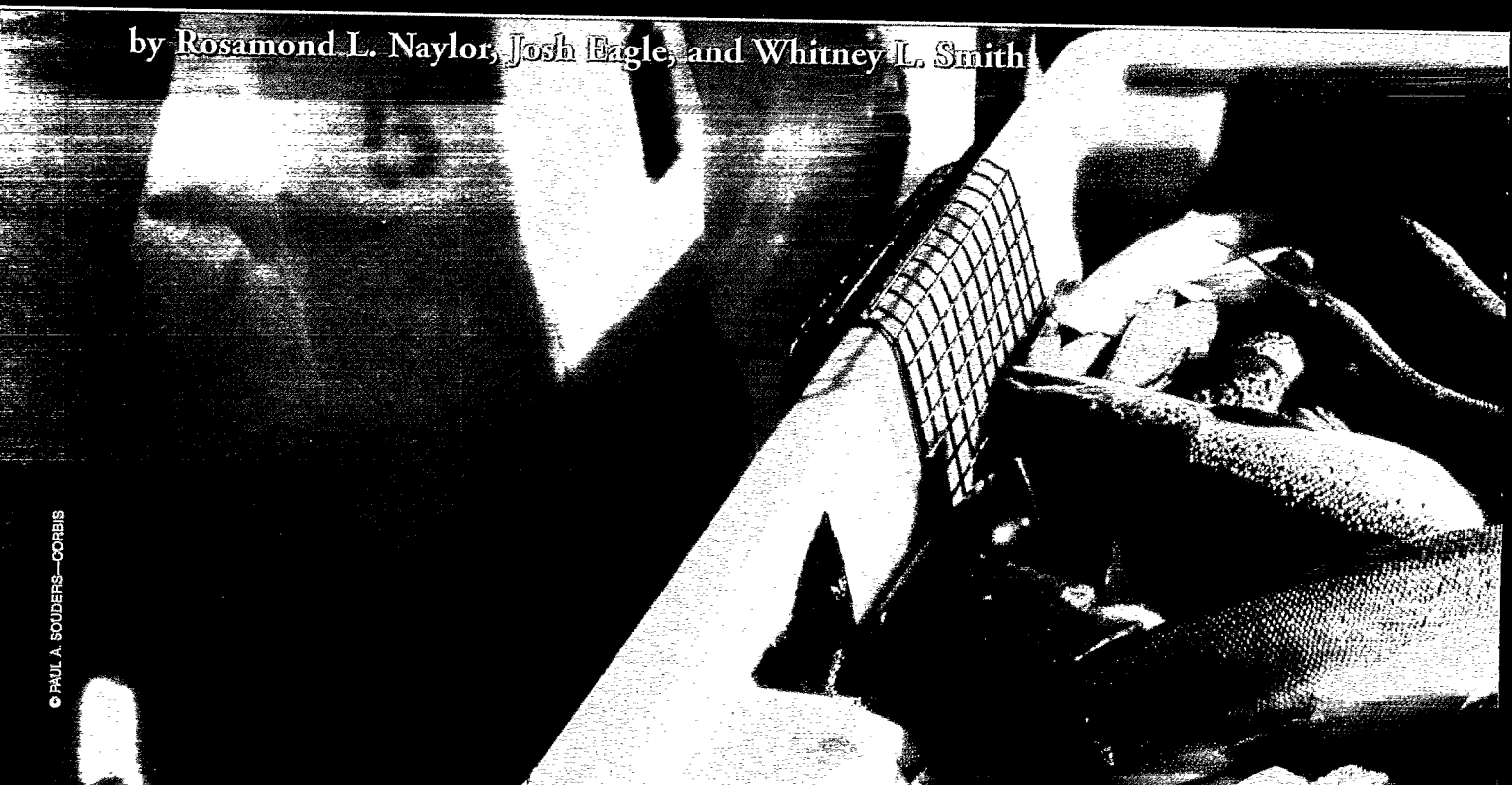
Salmon Aquaculture in the Pacific Northwest

A Global Industry

by Rosamond L. Naylor, Josh Eagle, and Whitney L. Smith

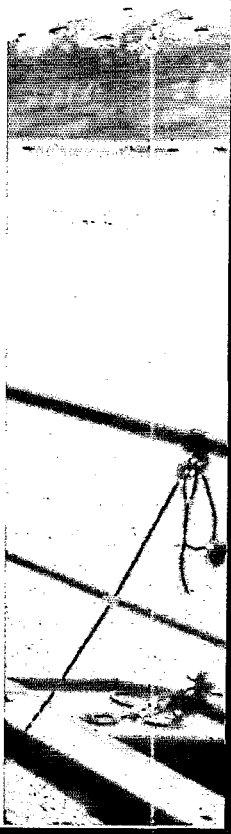


Many locals in British Columbia's Broughton Archipelago welcomed the salmon-farming industry in the early 1980s. It promised jobs, more schools, and higher incomes. It was not until some regular pods of killer whales stopped returning—and later, when some wild salmon populations became diseased—that the locals became concerned. In Alaska, coastal ecosystems were protected from these impacts by a statewide ban on finfish farming in 1989. However, when the price of their commercial salmon catch plummeted in the mid-1990s, Alaskans became worried. Throughout the Pacific Northwest and Alaska, people now see the close connection between salmon farming, the environment, and international markets. As the global aquaculture industry continues to expand, what impacts will it have on local ecosystems and fishing economies?

Salmon aquaculture, which consists of rearing salmon from eggs in hatcheries and then growing them to market size in marine netpens, is indeed a booming industry. Since the late 1980s, there has been a fivefold increase in farm salmon production worldwide.[1] The majority of farm salmon is produced in countries with long, protected coastlines and cold ocean water—most notably Chile, Norway, the United Kingdom, and Canada—and is sold to markets in Japan, North America, and Europe. Global salmon output, including wild catch, has grown from less than 800,000 metric tons (mt) to more than 1.8 million mt during the past 15 years, and virtually all of the growth has come from farms.[2] Consumers now benefit from an abundance of fresh fish in the market throughout the year. Industry representatives have suggested other potential benefits as well, such as reduced pressure on overfished salmon populations and provision of habitat for marine organisms.[3] Given the broad scientific consensus that global fish capture has reached a plateau and that many fish stocks are depleted or close to depletion,[4] aquaculture is often viewed as an important means for replacing, or at least supplementing, capture fisheries and providing a healthy food product to consumers.

The validity of these claims remains a debated topic.[5] Many scientists, environmentalists, and fishers worry that the ecological risks of farm fish—such as the spread of disease and parasites, competition among escaped farm fish and endemic species, and pollution from farm effluent—outweigh the potential benefits. The health advantages of farm fish are also disputed.[6] Taking a close look at a specific region—Washington, British Columbia, and Alaska—where both salmon fishing and salmon farming are important politically, economically, and ecologically, provides insight into this debate. Since the late 1800s, wild salmon capture has played a critical role in the region's economy by providing employment and income to a large number of Native American and nonnative communities along the coast. The region is home to indigenous stocks of sockeye, chum, pink, coho, and chinook salmon, and a large share of the fish captured is sold in international markets. Wild salmon runs have been at record levels in many areas of Alaska since the late 1980s due to favorable climatic conditions and hatchery-enhanced production.[7] Despite these conditions, Alaska's contribution to the global salmon market declined from 40–50 percent in the early 1980s to less than 20 percent by 2000, mainly because of competition with farm salmon.[8] In Washington and British Columbia, several Pacific salmon populations have become threatened or endangered. As shown in Figure 1 on page 20, seven of every ten salmon produced in Washington and British Columbia now come from farms.

In Washington and British Columbia, there is tension within governing agencies—the U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries and the Department of Fisheries and Oceans (DFO) Canada, respectively—that



WITH LOCAL IMPACTS

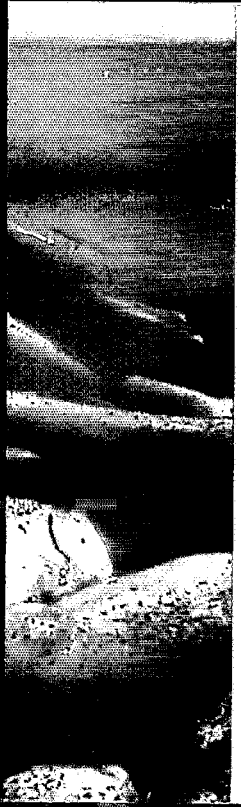
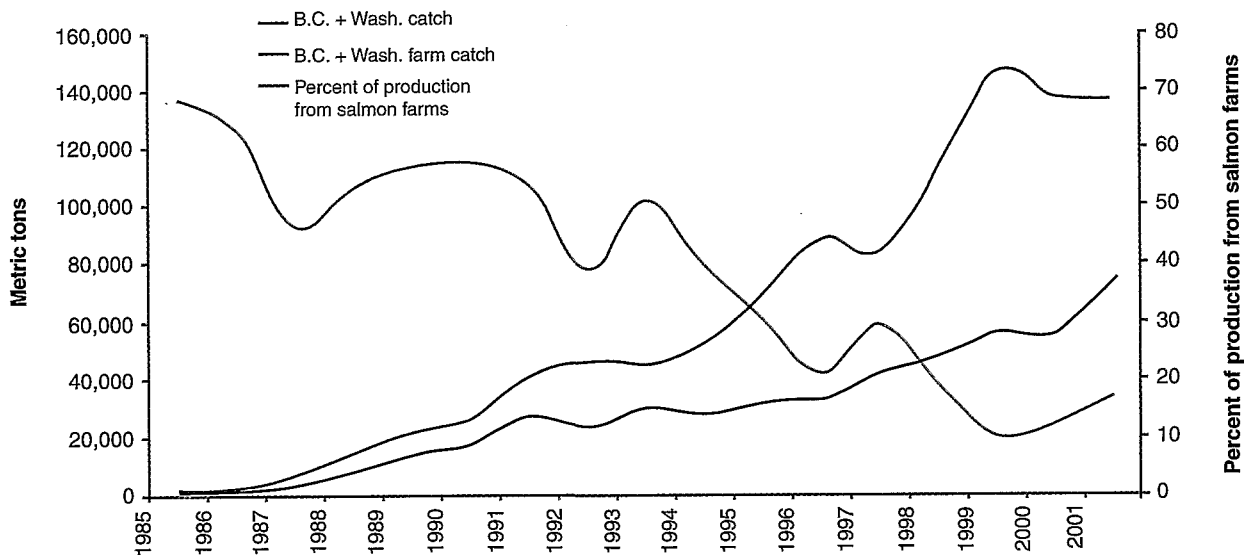


Figure 1. Wild and farmed production in British Columbia and Washington, 1985–2001



SOURCE: U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries, *Commercial Fisheries Landings Database (2002)*, accessible via http://www.st.nmfs.gov/st1/commercial/; and British Columbia Marketing Council, *Salmon Market Database (2001)*, accessible via http://www.bcsalmon.ca/database/farm/fmwtyrs.htm.

have joint mandates to promote aquaculture and to protect ocean resources. There is also mounting regional tension between salmon fishing and salmon-farming activities. British Columbia's government lifted its six-year moratorium on salmon farming in September 2002, while the U.S. government is proposing the development of aquaculture facilities in the offshore federal zone, which lies between 3 and 200 miles off the U.S. coastline.[9] These developments will likely place salmon farms much closer to the Alaskan border, weakening the safety net on coastal ecosystems provided by the state's ban on finfish aquaculture (see Figures 2a and 2b on pages 22 and 23).

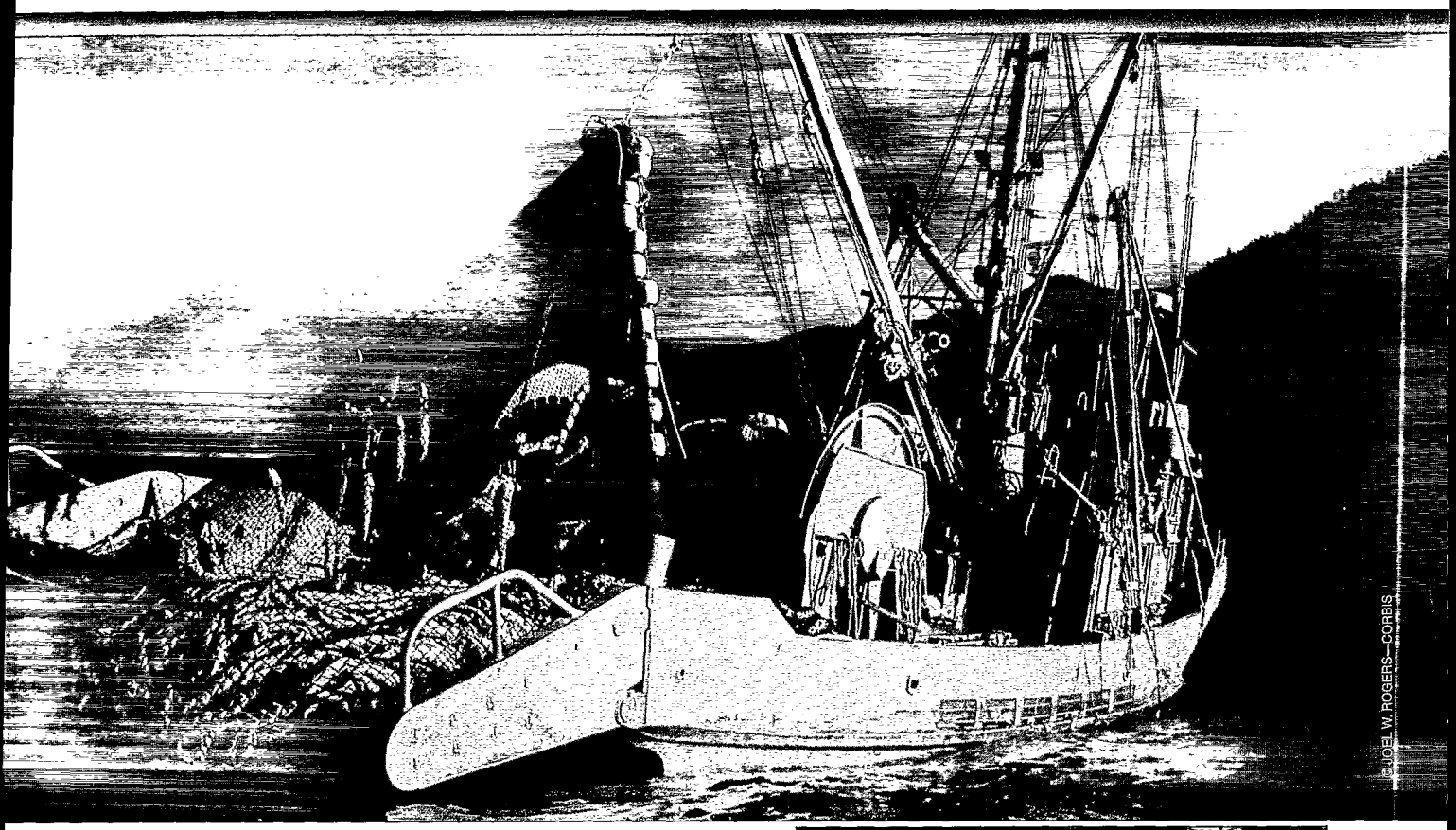
Salmon farming is not the only form of aquaculture with impacts on local fisheries, ecosystems, and fishing communities. Although it is not yet on the same scale as salmon aquaculture, the farming of other carnivorous, highly valued species such as bluefin tuna, cod, and halibut is on the rise in different regions around the world (including, for some of these species, the Pacific Northwest). The debate over salmon farming thus serves as a model for exploring the broader set of issues surrounding marine aquaculture.

The Global Aquaculture Industry

Salmon aquaculture has its roots in hatcheries, in which salmon eggs are fertilized and fish are raised to smolts before being released into the ocean. The development of hatchery technology began in Europe in the late 1700s with the goal of enhancing wild salmon runs that had been depleted by fisheries.[10] It was not until the early 1970s, however, that private salmon-farming companies (which raise smolts from hatcheries to maturity in netpens) began to operate on an international scale. Salmon netpen culture was led by growth in Norway and followed by investments in Scotland, Japan, Chile, Canada, and the United States.[11] Although farm salmon accounted for only 1 percent of global salmon output in 1980, the technology for pen-raised salmon was well developed in Norway, setting the stage for rapid growth. Between 1980 and 1987, salmon aquaculture production showed a thirteenfold increase worldwide.[12] Production expanded into new countries, including Ireland, New Zealand, Australia, and the Faroe Islands. By 1988, aquaculture production dominated the fresh and frozen salmon market in Europe, and U.S. imports of farm salmon accelerated. Even in Japan, pen-raised salmon and trout accounted for roughly 90 percent of fresh imports and 11 percent of frozen imports by the end of the 1980s.[13] By the early 1990s, it accounted for the majority of world trade in salmon.[14]

Industry Consolidation

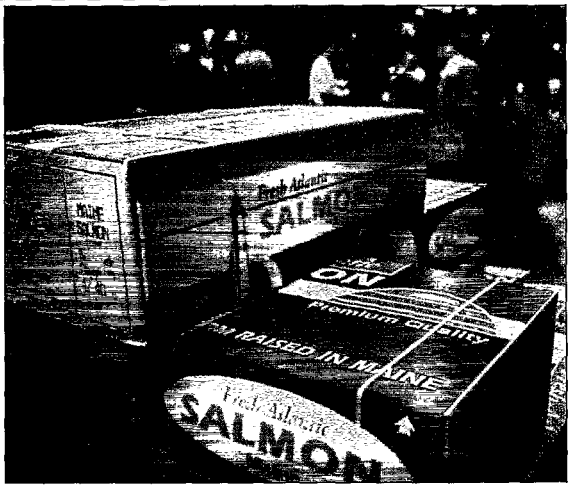
The salmon-farming industry has thrived with the globalization of the world economy. In particular, the industry has benefited from rapid expansion in seafood trade; overnight transportation of fresh products around the world; computerized information flows on fish stocks and markets; strong market demand for a homogenous, made-to-order product; and web-based business-to-business interactions.[15] What has emerged is an industry dominated by a



half-dozen multinational firms that produce a diversity of aquaculture and agriculture products.[16] The firms include Nutreco (based in the Netherlands), Pan Fish, Fjord Seafoods, and Cermaq (based in Norway), Stolt-Nielsen (based in Luxembourg), and George Weston (based in Canada). Several other national and multinational companies operate aquaculture facilities at smaller scales.

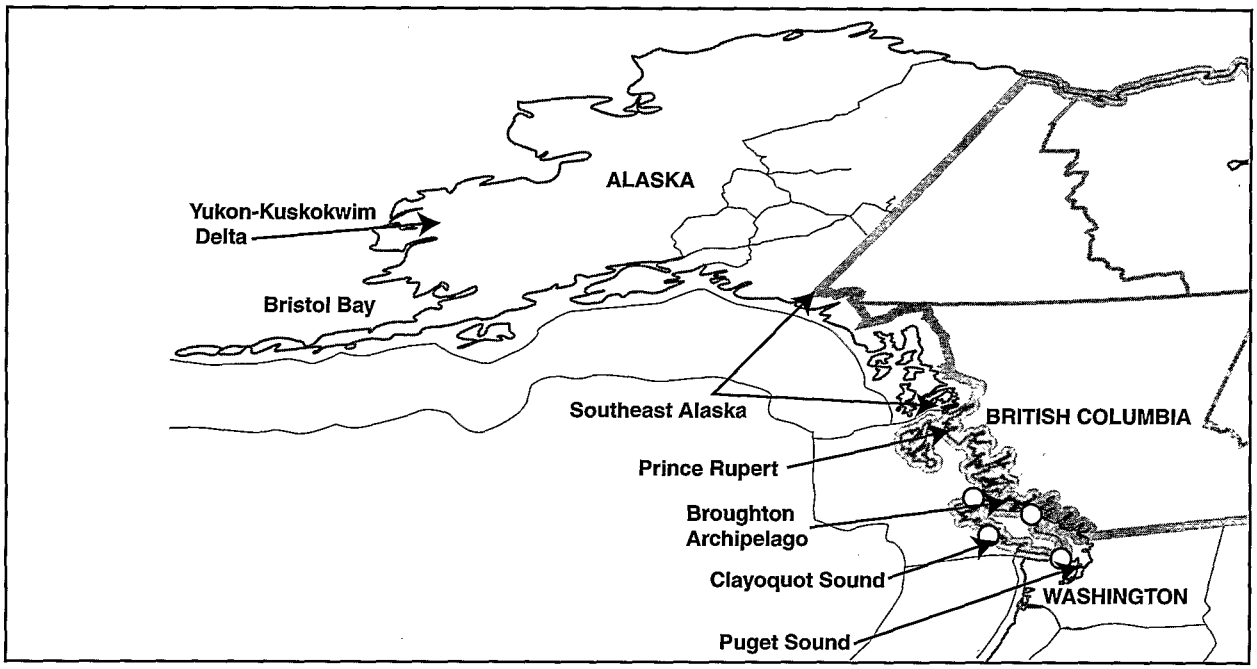
Unlike salmon fishing enterprises—most of which consist of boats and permits owned by individuals who sell their catch to processors or, in some cases, to niche markets—the large salmon aquaculture enterprises consist of vertically integrated feed, hatchery, grow-out (where the smolts are raised to maturity), distribution, and value-added processing companies. Nutreco, for example, controls 40 percent of the world fish feed market, and Cermaq also has large feed shares. Fjord Seafoods and Pan Fish have separate value-added processing and distribution facilities around the world. All of the companies operate in several countries (for example, Pan Fish owns approximately 200 salmon-farming licenses worldwide), and most of them also raise a variety of farm fish, including trout, halibut, cod, turbot, bluefin tuna, sturgeon (for caviar), and sea bream. The diversity of activities and production locations provides some buffering for the enterprises when certain segments of the industry turn down.

In both British Columbia and Washington, the salmon-farming industry has become consolidated. In 1989, there were 50 companies operating 135 farms in British Columbia.[17] Bankruptcies and industry restructuring since that time have forced many companies out of business.[18] There are now only 12 companies operating in the province, and 5 companies own 100 of the 121 farms still in business (see Figure 3 on page 24). Technological improvements and leasing arrangements within the consolidated industry have led to steady increases in production. Even with the moratorium on new licenses in place, farm salmon produc-

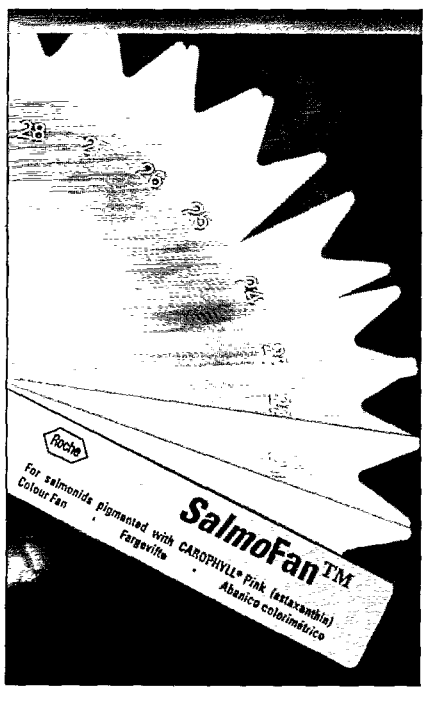


Salmon-fishing operations (above, top) have found it difficult to compete with salmon farms in the marketplace (above), in part because the farming industry can efficiently capture, process, and distribute a virtually made-to-order product on a year-round basis.

Figure 2a. Current locations of salmon farms



NOTE: Red lines represent the 3-mile state jurisdictional limit (U.S.) and the 200-mile Exclusive Economic Zone (EEZ) for both countries. White dots indicate areas (in Puget Sound, Washington, and southern British Columbia) where salmon farms are currently located. Map not to scale.
SOURCE: Data compiled by R. L. Naylor, J. Eagle, and W. L. Smith, 2003. Map based on a National Geographic Society projection, 1999.



LOS ANGELES TIMES PHOTO BY AL SEIB

Salmon farms have considerable control over the size and appearance of their product. Feed additives can enhance the color of the fish, for example.

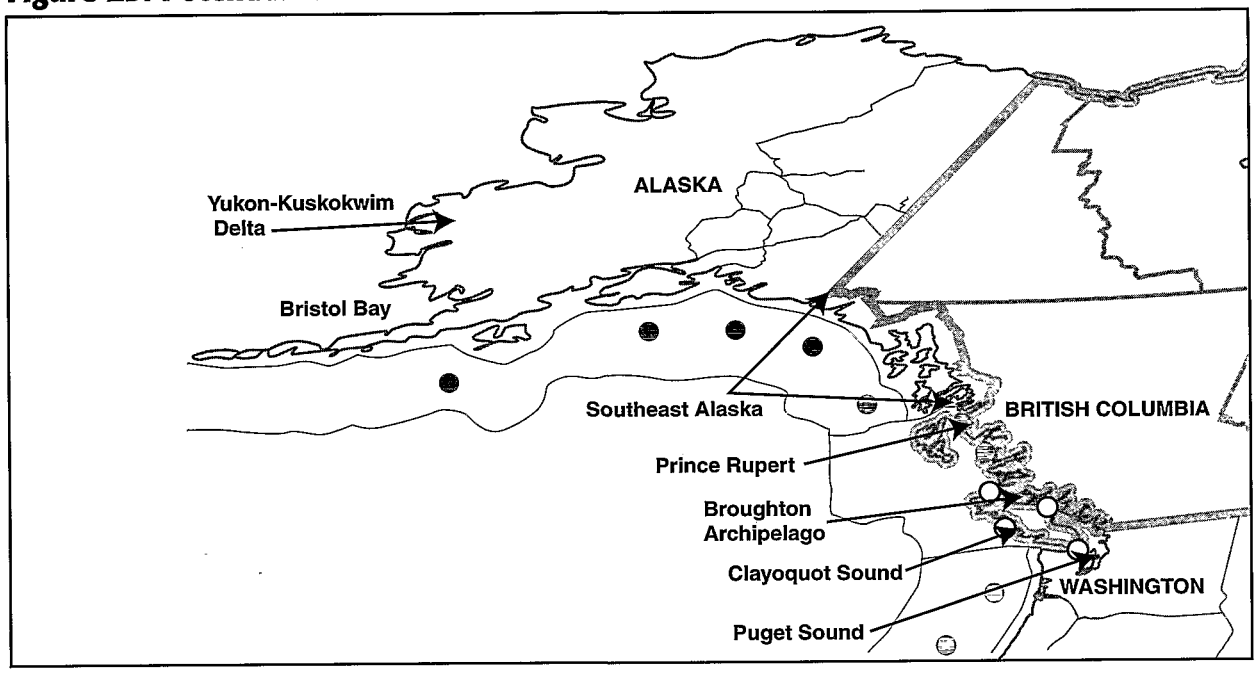
tion more than doubled from an annual harvest of 28,000 mt in 1996 to nearly 68,000 mt in 2001.[19] In Washington, all salmon aquaculture operations are owned by Pan Fish and operated through the Omega Salmon Group. There are currently nine farms operating in Washington with total production of about 6,500 mt.[20]

A Local Perspective

The strong presence of large, multinational companies in the industry is a double-edged sword with respect to the environment. On the one hand, the industry has the capital resources to be able to apply the best technology, infrastructure, and management to minimize environmental impacts of production. For example, many farms in British Columbia and Washington now use stronger netpen infrastructure and apply better maintenance and monitoring to reduce the escape of farm fish into the wild. They also mandate improved feed conversion ratios, which reduces financial costs and effluents. In Norway, Nutreco and another feed company, AKVAsmart, are launching a pilot project to address some of the feed, technology, and environmental problems constraining the aquaculture industry. It will be the first large-scale commercial salmon farm to allow testing of feeds, feeding practices, and technology under real (versus experimental) conditions.[21]

On the other hand, large corporations also have significant resources to put toward influencing government regulation of the industry. There is evidence—in the form of low compliance rates and low fines—that the industry has used these resources to its political advantage. A recent study of compliance conducted by the British Columbia Ministry of Agriculture, Food and Fisheries (MAFF) reported that only one-third of farms were in full compliance with the site management plans they are required by law to follow. Scores were particularly low with respect to keeping records of netpen maintenance (47 percent were in compliance), posting of escape response measures (61 percent),

Figure 2b. Potential future locations of salmon farms



NOTE: Red lines represent the 3-mile state jurisdictional limit (U.S.) and the 200-mile EEZ for both countries. Red dots indicate where governments and aquaculture producers might like to see farms sited in the future (in the U.S. EEZ and the northern coast of British Columbia). White dots indicate where salmon farms are currently located. Map not to scale.
SOURCE: Data compiled by R. L. Naylor, J. Eagle, and W. L. Smith, 2003. Map based on a National Geographic Society projection, 1999.

and the use of predator nets to keep marine mammals and other predators from gaining access to fish and damaging nets (40 percent).[22] A second study, conducted by the British Columbia Ministry of Water, Land and Air Protection, showed that more than one-half of all farms illegally discharged footbath waste into the marine environment. (Footbaths are meant to prevent the spread of fish diseases.) Only a third of all farms were managing net-cleaning waste in compliance with the provisions of the Waste Management Act.[23] Despite these low rates of compliance, between 1999 and 2002, just 27 fines were assessed for farms' violations of the British Columbia Fisheries Act and aquaculture regulations. The average fine assessed was only Can$295 (about U.S.$200). The greatest fine was Can$1,000, even though apparently serious violations, including the escape of thousands of fish, were cited. The total amount of fines assessed during this period—about Can$8,000—was about 0.005 percent of the wholesale value of all salmon produced by the British Columbia farming industry.[24]

In addition, large corporations in British Columbia have some ability to influence regulations indirectly through the selection of aquaculture research grants. The federal government in Canada has established "Centers of Excellence" for scientific research funding related to aquaculture, and grantees must establish a team representing industry, government, and independent science to obtain funds.[25] Because industry and government participation is required for projects to move forward, these groups have significant veto power over the types of projects selected, including projects related to the environmental impacts of salmon farming. Many critics liken this funding source to the earlier tobacco funding in the United States for scientific research on health effects of cigarette smoking.

The potential social effects of a consolidated industry are also mixed. The multinational companies operating in the region provide hundreds of local, year-round jobs in the processing sector and, to a lesser extent, in production and transportation operations. The aggregate number of jobs associated directly and indirectly with the salmon aquaculture industry in British Columbia is estimated to exceed 3,500, and the annual contribution of aquaculture to British Columbia's economy is projected to be more than Can$600 million.[26] These jobs tend to be concentrated in areas where there are hatcheries or processing facilities (such as Port Hardy, Tofino, and Campbell River). As salmon aquaculture expands into more remote areas of British Columbia, providing employment for coastal communities, as advertised, will become challenging.

The communities themselves, particularly First Nations communities, are divided in their acceptance of the aquaculture industry in British Columbia.[27] The establishment of farms in First Nations Territories along the coast in British Columbia has created substantial social tension between residents and the industry. Many First Nations (such as

Figure 3. Structure of the industry in British Columbia

PARENT COMPANY				
George Weston Canada	**Pan Fish** Norway	**Nutreco** Netherlands	**Stolt-Nielsen** Luxembourg	**Cermaq** Norway
AQUACULTURE DIVISION				
Heritage Aquaculture	Pan Seafood	[illegible]	Stolt Sea Farms	Mainstream
FARMING LICENSEE				
Connors Brothers Heritage Aquaculture SKM Enterprises	Sonora Seafarms Seven Hills Aquafarm Omega Salmon Group	[illegible] Kitasoo Aquafarms Hatfield Biotechnology Nutreco Canada	Stolt Sea Farms	EWOS Aquaculture EWOS Site Co.

SOURCE: British Columbia Ministry of Agriculture, Food and Fisheries, *Marine Salmon Farm Sites—June 2003*, accessible via http://www.agf.gov.bc.ca/fisheries/MFF_sites_Current.htm.

the Heiltsuk and Nuxalk Nations) are becoming unified in their stance against salmon farming due to mounting information and observations of ecological risks. Most First Nations have not signed treaties ceding rights to their traditional lands to private corporations, and as a result, they can legally claim compensation when salmon farms occupy their territories.[28] Some aquaculture companies have begun operations without consultation or compensation, however, which has caused public protests.[29] A few First Nations, however, such as the Kitasoo and Ahousaht Nations, are not uniformly opposed to aquaculture and welcome the employment that the farms bring to their communities.

The industry's ability to generate jobs and augment incomes garners strong political favor in British Columbia at a time when the provincial government faces major employment declines. Fishing employment declined under the Mifflin license buyback program,[30] and the logging industry has suffered following increases in U.S. tariffs on imported Canadian timber. Overall ownership and assets in the aquaculture industry are still controlled mainly by foreign companies in both Washington and British Columbia, however, and these companies have the power to divert financial capital from the region or to stop operations if environmental regulations, labor conditions, or trade becomes unfavorable. From a political perspective, meeting the demands of a small group of aquaculture companies may be much easier than trying to placate thousands of independent fishers.

A New Era in the Fishing Economy

Fishers in the Pacific Northwest and Alaska now operate in a changed economic and political environment. Global markets favor consistency and predictability of production,[31] and salmon farmers have far greater control over the timing, consistency, and quantity of production than do fishers. The fishing industry is limited to catching salmon that are migrating back to spawning rivers between June and September, and these fish can only be caught during short "opening" periods. The size of the runs can vary greatly between seasons depending on the life cycle of individual salmon populations, climatic conditions, and ecological factors such as food web dynamics and disease.[32] Millions of fish of varied quality arrive on the docks of processing plants in short periods of time, and they must be processed as quickly as possible (the "sell it or smell it" doctrine) before the next load arrives. As a result, the bulk of Alaskan salmon are still canned despite the shrinking market for canned fish. A smaller number are headed, gutted, frozen, and then shipped to distant plants for further processing into filets and steaks.

The aquaculture industry, on the other hand, can produce a consistent quality of salmon—specified to order by size and cut—at any time during the year. Each salmon farming company stocks a calculated number of smolts in netpens based on an estimate of market conditions two years hence when the fish will be ready for market. Actual production on any given farm may be affected by a

number of factors such as disease, storms, and marine mammal predation.[33] However, operating farms in multiple sites around the world tends to prevent problems at individual sites from disrupting the even and predictable flow of production worldwide.

Both the fishing and farming sectors must now respond to an additional player in the global economy—large retail operations. Like the aquaculture companies, the retail sector is also consolidating, with large enterprises buying up smaller ones. Supermarket chains and superdiscounters, such as Price Club, Walmart, Costco, and Safeway, demand aesthetically pleasing, easy-to-prepare, repeatable products. Salmon farms can deliver such products with precision, as they can control product features such as the weight and color of the fish.[34] Like most retailers, these supermarket chains also prefer to establish the smallest possible number of contracts with fish processing companies to minimize transactions costs. As a result, large processing companies that have traditionally catered to Alaskan salmon fishers are now under economic pressure to supply both wild and farm seafood products to major retail outlets. With diversification into farm products, fishers face greater competition, and their bargaining power with processors is diminishing.[35]

A Drop in Salmon Prices

Salmon prices in international markets have plummeted in recent decades, hurting producers but benefiting consumers. As shown in Table 1 on page 26, prices for Pacific wild-caught species in 2002 were 36–82 percent lower than average prices for the period from 1984 to 1992. Peak salmon prices in 2002 were 54–92 percent lower than they were in 1988. Many salmon fishers in the region who bought their boats and permits during the high-price years of the late 1980s and early 1990s can no longer afford to stay in operation and pay off their debts. Total ex-vessel values in the Alaskan salmon-fishing industry fell from $600 million in 1992 to $150 million in 2002.[36] In the Alaskan sockeye fishery (the main fishery supplying the Japanese market for wild-caught salmon), ex-vessel values fell from $450 million in 1992 to $85 million a decade later. Between 1990 and 2002, selling prices for limited-entry salmon permits in Alaska—key assets for salmon fishers—fell by 75–90 percent for some of the most lucrative fisheries. Fishers who might have bought their permits for $275,000 in the early 1990s can now sell them for only $20,000 to $30,000.[37]

The salmon-farming industry has also been affected by price declines. For the main farm species, Atlantic salmon (*Salmo salar*), the price in 2002 was 61 percent below the peak in 1988. Several salmon-farming companies have experienced lower profits, and in some cases, net losses. Stolt Sea Farms, for example, reported a financial loss from farming operations of $1 million in 2001, corresponding with a 50 percent increase in Chilean production of farm salmon

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Many Alaskans depend on salmon fishing for a living and are strongly affected by changes in the salmon market. Those who live in isolated areas, such as many Native Americans, often have few other sources of income.

Table 1. Change in ex-vessel prices for Alaskan salmon, 1984–2002

Species	1988 ex-vessel price per pound	1984–1992 average ex-vessel price per pound	2002 ex-vessel price per pound	Percent change in price from 1984–1992 average to 2002 (and from 1988 to 2002)
Chinook	2.69	1.93	1.23	-36 (-54)
Chum	.86	.45	.16	-64 (-81)
Coho	1.72	1.02	.37	-64 (-78)
Pink	.79	.34	.06	-82 (-92)
Sockeye	2.37	1.33	.55	-59 (-77)
Farm Atlantic	3.11	–	1.21	-61

NOTE: Ex-vessel prices are the prices fishermen receive at the dock.
SOURCE: Alaska Department of Fish and Game, *Exvessel Price per Pound: Time Series by Species*, 2002, accessible via http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/CATCHVAL/BLUSHEET/84-02exvl.pdf.

between 2000 and 2001.[38] Pan Fish has operated at a loss for the past two years and recently announced that it will be cutting production in many of its facilities as well as selling its pelagic-species subsidiary.[39] Competition within the aquaculture industry is intense, and with depressed prices, corporate attention has turned toward cost-cutting measures.

Adjustments in the Salmon Fisheries

The change in market conditions raises a number of questions related to capture fisheries. Have price declines caused a reduction in wild catch? How is the fishing sector adjusting to the new economic environment? Is the aquaculture industry taking pressure off wild salmon populations and their ecosystems by putting fishers out of business? These questions are frequently debated, often without reference to empirical evidence.

In Washington and British Columbia, wild catch in 2002 was less than a third of the 1986 level, falling from more than 120,000 mt to less than 40,000 mt (see Figure 1). This decline is associated mainly with low salmon runs caused by logging, dams, urbanization, other changes in wild salmon habitat, and climate. In Alaska, a far more pristine environment for salmon, wild catch (including hatchery releases) remained vir-tually unchanged over the same period, with average annual production of 324,000 mt. Hatchery releases accounted for up to 20 percent of Alaska's salmon landings by weight during this time and thus significantly added to overall supplies, particularly in the southeastern part of the state. In addition, subsidies to Alaskan salmon fisheries increased sharply in the late 1990s. It is difficult to quantify the exact impact of subsidies on the fishing industry, but fishing effort and landings would clearly be lower without government aid.[40]

The smaller commercial fisheries in British Columbia and Washington have been hard-hit by declining prices and increased competition from the aquaculture sector, but the overall economic impact has not been nearly as great as it has been in Alaska.

A significant share of the subsidies flowing into the salmon fisheries in recent years has been in the form of disaster relief.[41] Alaska has been disproportionately affected by the recent economic changes because of the state's heavy dependence on commercial fishing. Direct and indirect market activities associated with salmon fishing provides employment for 1 of every 10 working Alaskans and produces annual income to individuals of more than $1 billion.[42] Moreover, revenues from commercial salmon fishing essentially finance the subsistence activities of residents (mainly Native American) in some regions, such as the Yukon-Kuskokwim Delta. Many of the Alaskans who have become dependent on the salmon industry live in isolated areas where other employment opportunities are not readily available. Personal interviews with Alaskan salmon permit holders reveal a general feeling of anxiety, but not hopelessness, in response to changing market conditions (see the box on pages 28 and 29).

In addition to disaster relief, policy discussions have focused on marketing, and to a lesser extent, government purchases of salmon.[43] Many people within the salmon fisheries agree that the wild salmon industry must distinguish its product from the farm salmon product—

in taste, nutritional value, and marketing of a "wild" (and by association, healthy) product. Much less political attention has focused on the more controversial idea of promoting policies that increase efficiency within the fishing sector.[44] There are more than 10,000 salmon boats currently operating in Alaska, each with permits to fish during limited openings. The overall cost of maintaining the fleet, in addition to the cost of government subsidies to support it, are extremely high relative to the value of total fish catch. The industry is in need of legal restructuring aimed at reducing costs and improving quality; allowing new programs such as fishing cooperatives, quotas, permit buybacks, or even fish traps and wheels,[45] would slow the pace of fishing and provide a mechanism to improve quality and competitiveness. One downside to increased efficiency, however, is the loss of fishing jobs and perhaps other jobs dependent on heavy employment in the industry.

The much smaller commercial fisheries in British Columbia and Washington have also been hard-hit by declining prices and increased competition from the aquaculture sector, but the overall economic impact has not been nearly as great as it has been in Alaska. In British Columbia and Washington, low fish stocks and low prices have induced fishers to participate in vessel buyback programs. However, these programs were initiated before the most dramatic price declines associated with farm salmon supplies.[46] For those fishers remaining in the industry, quality and niche marketing have become widespread goals.

Farms Create Ecological Risks

In salmon-farming areas of the Pacific Northwest, fishers voice stronger concerns about the ecological risks of aquaculture than about the price impacts. With the possibility of the industry moving northward to Prince Rupert, British Columbia (see Figure 2b), fishers in Southeast Alaska are also becoming worried about the ecological threats of farming. Should they be worried? Based on emerging evidence in the region—and on the experience of every other salmon-farming region in the world—the answer is clearly "yes."

Spread of Parasites and Diseases

Like many other salmon aquaculture areas around the world, parasites and diseases are a major constraint on production, and their transmission to wild salmon poses risks to wild stocks. One of the largest threats in the Northern Hemisphere is sea lice (also referred to as salmon lice, *Lepeophtheirus salmonis*), which can kill fish by essentially eating their flesh. Sea lice are endemic to the region but have low natural abundance and minimal host damage in the wild; in fact, there is only one pre-aquaculture report of an epizootic spread of sea lice in the wild.[47] Due to the large number of farm hosts relative to wild hosts, sea lice thrive with intense salmon culture. Two barriers limit their natural spread in wild salmon: the change in habitat from fresh to salt water and back again (sea lice generally only live in salt water, and most of them fall off the salmon when the salmon enter fresh water) and the salmon's homing behavior.[48] Both of these barriers can be broken down when sea lice epizootics occur on farms that are located in wild salmon habitat or along salmon migration routes. It is no surprise that sea lice infestations in salmon netpen areas have closely tracked the pattern of aquaculture development worldwide.[49]

LOS ANGELES TIMES PHOTO BY AL SEIB

A marine researcher holds a juvenile pink salmon that fell victim to a sea lice infestation in the Broughton Archipelago, British Columbia. Pink salmon are especially sensitive to such infestations.

Survey of Salmon Fishers

Between November 2002 and May 2003, the authors conducted a survey of 94 salmon fishers who own limited-entry permits in Alaska and Puget Sound salmon fisheries.[1] The goals of the survey were to understand how fishers currently view the change in market conditions, how they are responding to the change, and how they view different policy options surrounding salmon fisheries. Within the survey group, most fishers (84 percent) felt that salmon fisheries were currently in crisis, but only one-third of those believed the crisis was permanent. Virtually all of the respondents (97 percent) plan to continue salmon fishing in the future.

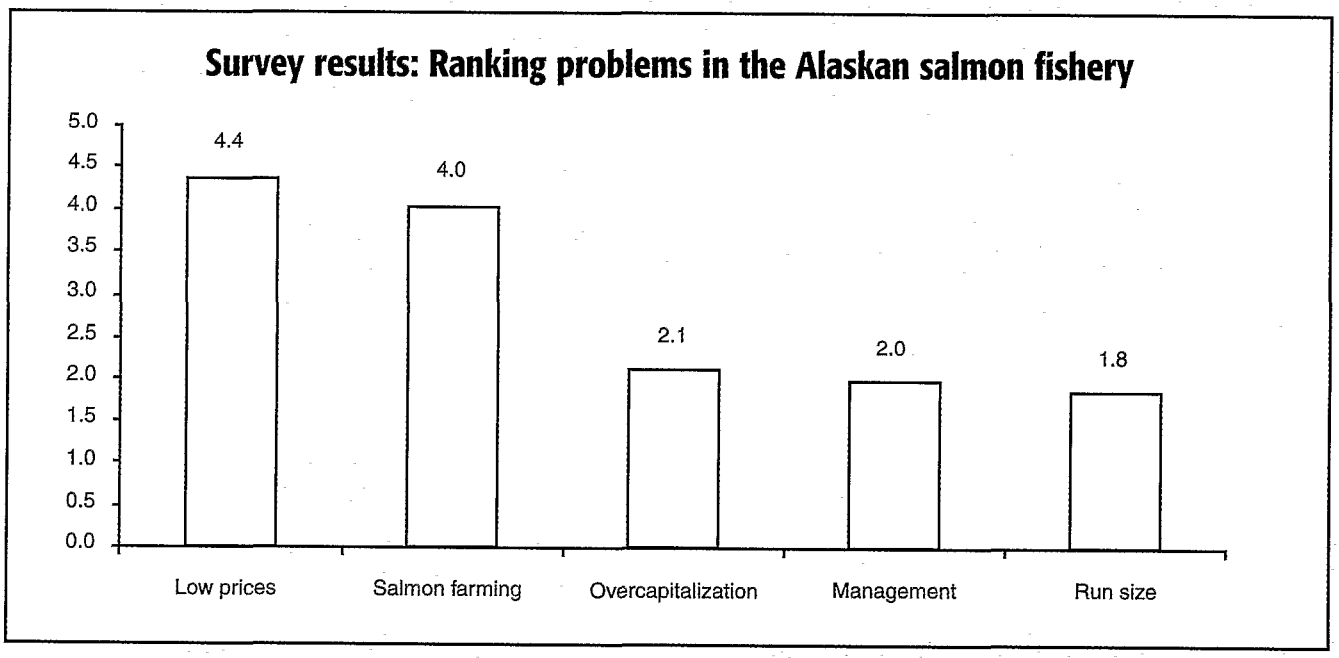
While they might continue to fish, almost two-thirds of the fishers interviewed now have additional employment other than fishing. Those who have sought other jobs reported that their fishing income had dropped by about half. More than half (56 percent) of the respondents also engage in other fisheries, such as crab, halibut, and herring. Thus while some pressure might be taken off the salmon resource, pressure might still be placed on other fisheries, depending on the policies in place.[2]

In ranking the problems afflicting salmon fisheries, respondents gave the highest weights to "low prices" and "salmon farming" (see the figure below). Some fishers also recognized the role of hatchery enhancement in lowering prices for wild-caught salmon. Respondents generally did not feel that state fisheries management was a problem, particularly in southeastern Alaska where the major hatchery runs are located. Fisheries management in virtually all regions places a priority on maintaining the largest runs possible for commercial catch. The size of salmon runs was not considered to be a major problem for most respondents, with the exception of those in the Yukon-Kuskokwim Delta where runs of some species, such as chum, have been extremely low in recent years. Finally, fishers did not see "overcapitalization"—as defined by too many boats or too much equipment on each boat to keep costs down and profits up—as a significant problem, even in Bristol Bay where such conditions are notorious.[3]

When asked about policies that might help improve the situation in the future, 86 percent of respondents favored the development of quality and marketing programs to increase the chances that they might sell their fish for higher prices.[4] Despite the attention to quality and niche markets for wild-caught fish, however, only 29 percent of respondents have tried direct marketing of their catch in the past. Many respondents have contemplated direct marketing of their fish, but few have the desire or business savvy to implement a marketing strategy. Those taking on direct marketing and custom processing are beginning to learn the challenges and risks that processors have traditionally faced, such as insurance, shipping, up-front costs, and market development. As shown in the figure on page 29, views were mixed among salmon permit holders on other policy options, such as cooperative fishing programs, quotas, permit buyback programs, and disaster relief programs.

The survey also revealed—not surprisingly—that fishers generally favor trade restrictions on farm fish and labeling laws that require the source of the fish to be identified. They recognized that Alaska's remoteness contributes to high costs and inconsistent quality. Transportation is expensive and unreliable, making it difficult to market fresh, wild Alaskan salmon or even frozen products. Given the impediment of transportation costs, most respondents felt that it will continue to be challenging to make Alaskan salmon competitive with farm fish in the large retail market.

There was a widely held notion among respondents that aquaculture companies are highly subsidized, thus allowing them to still make a profit with low prices.[5] Most fishers would like to see continued



NOTE: Rankings are from 0 (no problem) to 5 (very significant problem). The graphs indicate the average rank.
SOURCE: R. L. Naylor, J. Eagle, and W. L. Smith, 2003.

subsidies for fishing, much like the continued support that the agriculture sector receives in the United States. Finally, and perhaps most surprisingly, there was also widespread acknowledgment that the aquaculture industry has opened the U.S. consumer market for salmon and, as a result, that sales of wild-caught salmon are likely to rise in the future.

1. Of the 94 fishers owning permits, 32 were from Bristol Bay, 45 were from southeastern Alaska, 9 were from the Yukon-Kuskokwim Delta, 5 were from other regions of Alaska (including Prince William Sound), and 3 were from Puget Sound. Some of the Alaskan permit holders in Alaska lived in Washington during the winter but were identified with the region of their permit. For further information about the survey or to see a sample questionnaire, contact the lead author (R. L. Naylor).

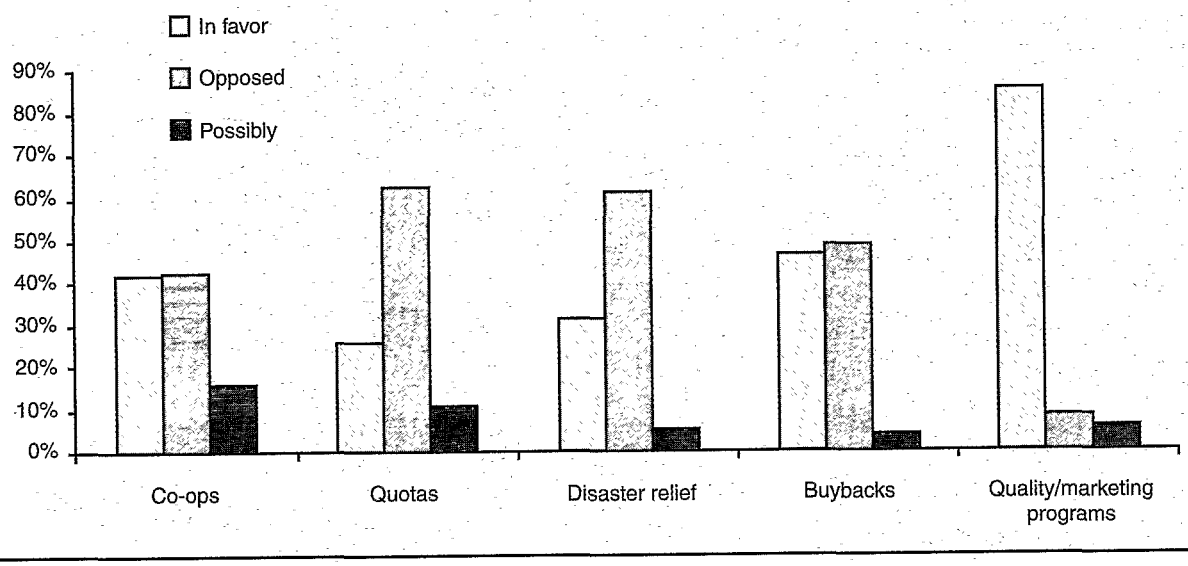
2. For example, the halibut fishery is regulated by individual fishing quotas (IFQs), so the total amount of halibut caught will not change. The crab fishery is regulated by limited entry and discussions are under way to introduce IFQs.

3. Bristol Bay Economic Development Corporation, *An Analysis of Options to Restructure the Bristol Bay Salmon Fishery*, March 2003, accessible via http://www.bbsalmon.com/FinalReport.pdf.

4. The Alaska Seafood Marketing Institute (ASMI) was established in 1981 to address marketing concerns of the fishing industry. Fishers currently pay a 1 percent tax on their output to support ASMI. There is no clear indication that ASMI has been successful to date; therefore, most fishers would like to see additional or improved programs in place.

5. The irony of this view is that the salmon fishing industry is also highly subsidized. See J. Eagle, R. Naylor, and W. Smith, "Why Farm Salmon Outcompete Fishery Salmon," *Marine Policy*, Fall 2003 (forthcoming). Subsidizing two sides of a competitive market within one country may satisfy political demands but is extremely wasteful economically.

Survey results: Policy preferences in the Alaskan salmon fishery

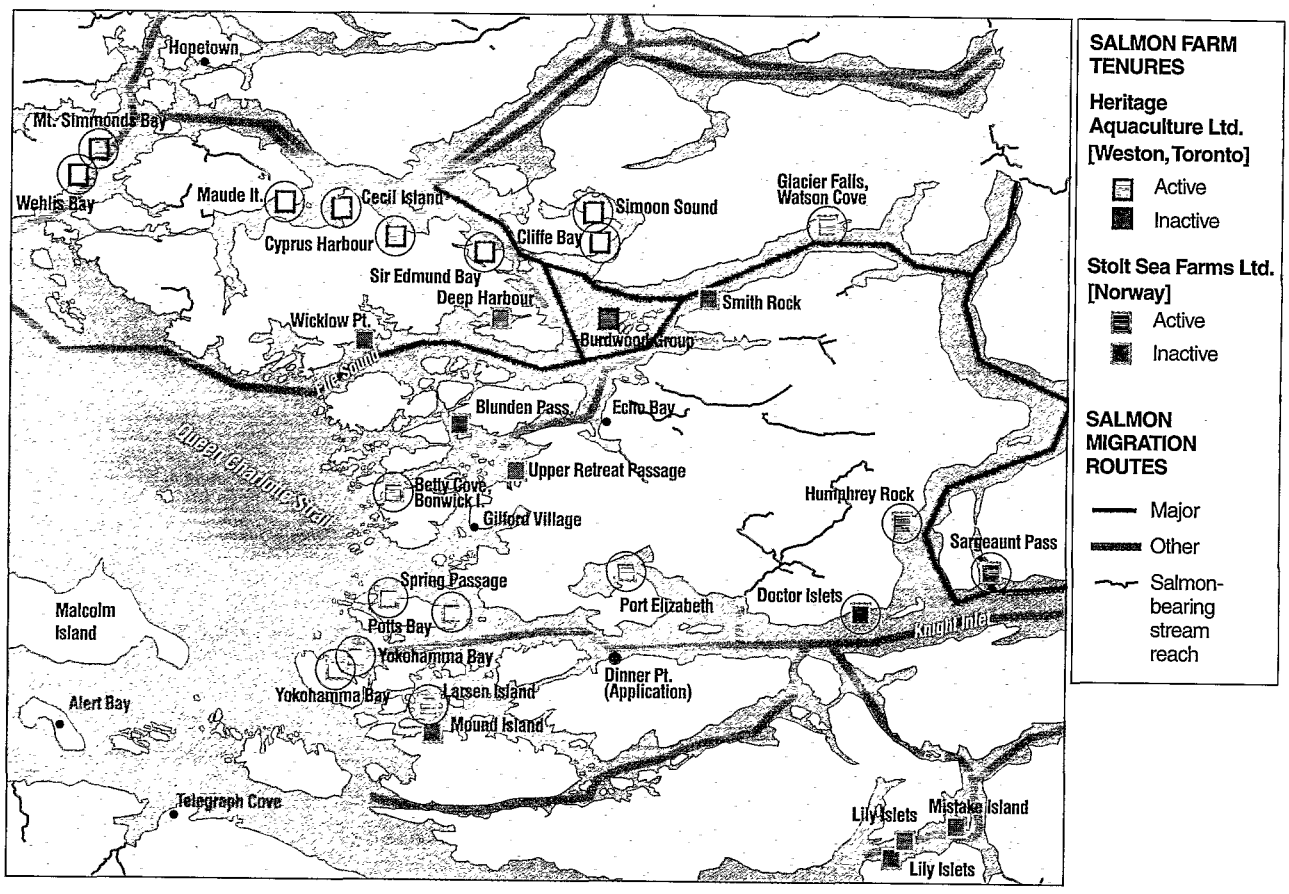


SOURCE: R. L. Naylor, J. Eagle, and W. L. Smith, 2003.

British Columbia is no exception. The Broughton Archipelago (shown in Figure 4 on page 30), off the northeastern tip of Vancouver Island, is home to one of the most densely concentrated farm areas in the world.[50] Many of the farms are sited near salmon-spawning rivers and along Pacific salmon migration routes, and thus act as "pathogen culture facilities."[51] Out-migrating salmonid juveniles come into close proximity to the salmon farms immediately upon entering saltwater, a time when they are most susceptible to sea lice infection due to their small size and surface-swimming behavior.

Pink salmon, the smallest of the wild Pacific species, are particularly vulnerable. Despite earlier assurances from industry officials that the lice would not become a problem in British Columbia, major sea lice infestations have occurred in recent years. Unusually high numbers of sea lice were found on out-migrating pink salmon smolts in areas of high farm concentrations in the spring of 2001.[52] In the following summer of 2002, returns of pink salmon to rivers in one of these areas had dropped by 98–99 percent from 2000 levels.[53] Although the British Columbia Salmon Farmers Association has questioned the connection between low salmon returns and sea lice, the Pacific Fisheries Resource Conservation Council (PFRCC) has recommended fallowing (that is, keeping certain netpens vacant) and rigorous sea lice control measures.[54] Striving for some compromise, the Ministry of Agriculture, Food and Fisheries (MAFF) ordered the fallowing of less than half the farms (11 of 27) in the Broughton Archipelago in time for the out-migration of pink salmon smolts in 2003. In its Broughton Archipelago Action Plan, MAFF chose 11 farms for fallowing be-

Figure 4. Salmon farms and migration routes in the Broughton Archipelago, B.C.



NOTE: Circles around sites indicate a 2 km buffering around active farms.
SOURCE: Map by Jeff Ardon, Living Oceans Society, 2003 (Data for farm locations from Land and Water British Columbia; for salmon streams: Fisheries Information Summary System; for migration routes: local knowledge.)

lieved to be a significant migration route for juvenile pink salmon. Environmentalists claim that this effort is "too little too late." Time will tell.[55]

In addition to problems of sea lice, salmon farmers face various bacterial and viral diseases affecting fish health. Bacterial diseases include bacterial kidney disease, vibriosis, and furunculosis. Fish are commonly vaccinated in hatcheries for these diseases, and when outbreaks occur, antibiotics can be administered in the feed pellets. The most serious viral disease problem in the Pacific Northwest is Infectious Hematopoietic Necrosis (IHN), which most strongly affects Atlantic and sockeye salmon. The IHN virus is able to infect many tissues of the fish, (including the liver, spleen, and pancreas, although the target tissue is the blood-forming kidney, hence the term "hematopoietic"), often causing cell death (or "necrosis") and massive organ dysfunction, resulting in fish death. IHN has caused serious losses to British Columbia salmon farmers in recent years; between August 2001 and May 2002, nineteen Atlantic salmon farms in British Columbia were infected.[56] An additional major outbreak occurred later in 2002 in the Broughton Archipelago, and more than a million Atlantic salmon smolts were harvested and destroyed in this case.[57] While the cause of this epizootic is not known, the disease appears to be transmitted in both directions between wild and farm salmon. Several fish health policy initiatives have been implemented by the provincial and federal governments in Canada,[58] and the industry has its own financial stake in mitigating disease outbreaks. However, the financial costs calculated by the industry do not include off-site impacts on wild salmon stocks from disease (if it is passed from farm to wild) or disease treatments.

Farm Fish Escapes

A more insidious ecological risk to wild salmon comes from the escape of farm fish from netpen facilities.[59] Farm fish are known to escape from pens in all salmon aquaculture areas of the world due to storms, marine mammal predation, and human error. More than one million Atlantic salmon were reported to have escaped from farms in Washington and British Columbia between 1992 and 2002.[60] These num-

bers reflect mainly periodic, catastrophic escapes of thousands or tens of thousands of fish at one time. Both British Columbia and Washington aquaculture regulation mandate reporting of relatively large-scale escape events; however, even more salmon are suspected to escape via chronic low-level leakage from pens, and these escapes go largely unacknowledged and unreported.[61] Escapees are capable of establishing and reproducing in the wild and competing with wild salmon populations for food and spawning habitat.[62] Atlantic salmon have been found in more than 80 rivers in British Columbia, and naturally reproduced feral juvenile populations have been found in three locations.[63] The abundant available habitat that has resulted from logging- and dam-related declines in native competitors in British Columbia provides juvenile feral Atlantic salmon with numerous potential establishment territories.

Escaped Atlantic salmon have been caught by fishers throughout Alaska's southeastern region, and a few have been caught as far north as the Bering Sea. Many fishers and government officials in Alaska are voicing concerns about the potential effects that escapees from British Columbia and Washington farms might have on Alaska's native salmon runs—including competition for prey, space, and mates; disease and parasite transmission; and an eventual decline in native stocks.[64] In Washington and British Columbia, producers are required to report large escapes in a timely fashion (typically 24 hours) and to maintain their netpens to prevent escapes from occurring. To date, enforcement and fines have been minimal for violators, although British Columbia's government has recently established a more comprehensive Escape Prevention Initiative as a key feature of its Salmon Aquaculture Policy.[65]

Effects on Other Marine Life

In addition to the potential effects on wild salmon from farm-related diseases, parasites, and escaped farm fish, salmon aquaculture has broader impacts on other marine life at both the low and high ends of the food web. Farm salmon rely on feed that is rich in fish oil and fishmeal made from small pelagic fish, such as anchovies, sardines, capelin, and sandeels. Estimates in 2000 show that upward of 2.4 kilograms of wild fish processed into fishmeal and fish oil were required on average to produce one kilogram of farm salmon.[66] While not necessarily local in its impact, continued reliance on small, oily fish that are low on the food chain for feed could indirectly affect marine ecosystems thousands of miles from fish farms if stocks of these fish become depleted.[67] At the higher end of the food chain, marine mammals such as seals and sea lions frequently prey on salmon netpens, and several thousand have been shot by aquaculture producers in the Pacific Northwest since 1990.[68] In the past, acoustic deterrent devices (ADDs) were used on farms in British Columbia to prevent predation, but their general ineffectiveness (seals and sea lions became deaf but continued to prey on netpens) and their effects on non-target species (reductions in killer whale and baleen whale populations were recorded in areas where ADDs were used) caused this technology to be phased out in the 1990s.[69]

More than one million Atlantic salmon were reported to have escaped from farms in Washington and British Columbia between 1992 and 2002.

Farm Effluents

Open salmon netpen operations release untreated nutrients, harmful chemicals, and pharmaceuticals into marine ecosystems, using "dilution as a solution" to water quality problems. Because salmon farms in British Columbia tend to be concentrated near the coast in confined waters with large tidal currents (see Figure 4), surrounding areas are exposed to salmon farm effluents. In Washington, salmon farms are located within Puget Sound, an area widely used and enjoyed by residents. Nutrient loading from aquaculture is much less than from agriculture, but it can be significant at the local scale. A salmon farm of 200,000 fish releases an amount of nitrogen, phosphorous, and fecal matter roughly equivalent to the nutrient waste in the untreated sewage from 20,000, 25,000, and 65,000 people, respectively.[70] Many farms in the Pacific Northwest contain four to five times that number of fish. In 1997, 4 out of about 12 salmon farms in Washington discharged almost as many "total suspended solids" into Puget Sound as the sewage treatment plant serving Seattle.[71] Organic matter tends to accumulate underneath salmon cage operations, creating a dead zone that might extend 100 to 500 feet in diameter beyond the farms.[72] A study of British Columbia farms showed that large changes in sediment chemistry and in the benthic community occurred with relatively low salmon stocking and feeding rates in the early stages of production.[73]

Improved feeding efficiency—by distributing the feed more directly to the fish and increasing feed uptake and digestion by the fish—has helped to reduce nutrient loading from individual pens during the past decade. The environmental benefit of these reductions may, however, be offset by future expansion of the industry. In addition, chemicals that are used on salmon farms (for example, antibiotics, parasiticides, and spawning hormones) may pose risks to marine organisms.[74] The use of therapeutic compounds (both pharmaceuticals and pesticides) can harm marine life around the pens, and heavy metals in sediments can damage marine life on the floor beneath the farms. Some aquaculture scientists claim that effluents of

therapeutic compounds, heavy metals, and nutrients pose the highest environmental risks from salmon farming.[75] However, while the effects of these wastes can be measured, the potential ecological risks of farm salmon escapes and diseases appear to be just as large.[76]

Policy Options in a Global Economy

Despite the obvious environmental and economic impacts of salmon aquaculture, the United States, Canada, and other salmon-farming countries have yet to implement and enforce effective measures to protect coastal ecosystems and communities. Five factors can explain inadequate regulation of the industry:

The United States, Canada, and other salmon-farming countries have yet to implement and enforce effective measures to protect coastal ecosystems and communities.

- Governments may value the economic contribution from farming, and multinational aquaculture companies may have significant influence over policy decisions governing coastal resource use and environmental protection.
- The industry grew up too quickly to be regulated effectively.
- Scientific uncertainty persists about the ecological damages from farming activities (for example, the long-run impact of escaped farm salmon on wild salmon populations), or regulatory uncertainty exists about the appropriate tools to solve the problems at hand.
- Salmon-farming countries may be split internally between those who do and do not support aquaculture. These divisions are reflected in intraagency conflicts (for example, within NOAA Fisheries and Fisheries and Oceans Canada). Moreover, there are often territoriality issues involved; for example, Alaska cannot impose regulation on other jurisdictions, and one First Nation cannot regulate aquaculture activities in another First Nation's territory.
- Finally, and perhaps most daunting, government agencies may believe that increased regulatory control will provide multinational aquaculture companies with an incentive to move their facilities to another country with more lenient controls. International movement of funds and operations is common within the salmon-farming industry; however, biophysical constraints on production (the need for protected coastlines with cold water, for example) significantly curtail movement, as do political considerations (a company may decide not to put all its investments in Chile, for example, if it is determined that Norway is a "safer" place to invest).

In this context, what strategies might interested environmental groups, recreational and commercial fishers, coastal residents, and marine scientists pursue in the Pacific Northwest, Alaska, and other salmon-producing areas to minimize the potential harm caused by aquaculture operations? Given the obstacles outlined above, the most obvious approach is to eliminate the institutional and political economy constraints that prevent nations from adopting and enforcing appropriate regulations. For example, a moratorium on salmon farming could be enforced—as was done in British Columbia from 1996 to 2002—to allow environmental policy to catch up with the rapid growth of the industry. Alternatively, efforts could be made to reduce scientific and regulatory uncertainty (for example, with the use of risk assessment models), or to create a single agency for regulating the fishing and aquaculture industries jointly. These strategies could be designed at the national level.

Interested parties are limited at the state level in addressing conflicts between Alaska and Washington (for example, over farm fish escapes), and they are limited at the national level in solving U.S.-Canadian policy conflicts. However, two additional strategies are plausible: the development of ecolabeling schemes to increase the price of sustainably produced salmon and to provide industry incentives for environmental protection; and the creation of an international treaty with specific environmental and product quality mandates.

Regulatory Control

In the United States and Canada, salmon aquaculture is regulated under a number of federal, provincial, and state laws. These regulations cover siting, waste discharge, escape prevention and recovery, endangered species protection, chemical use, marine mammal protection, and health safety standards.[77] Unfortunately, many of these laws and regulations were not specifically designed for aquaculture, and some of the roles specific to aqualculture are fairly weak. In the United States, for example, the Environmental Protection Agency (EPA) proposed effluent guidelines for aquaculture under the Clean Water Act in 2002,[78] but the requirements for netpen systems are essentially limited to feed monitoring and best management practices (that is, the best practices given the economic constraints of the industry). Concerns that tougher effluent controls will severely weaken international competitiveness appear to be unfounded. EPA estimates that salmon netpen systems would incur compliance costs of less than 3 percent of revenues for even the most stringent effluent control options being considered under the revised Clean Water Act and that the proposed regulations would have little, if any, impact on foreign trade.[79]

Nonetheless, aquaculture companies in both the United States and Canada complain of excessive regulatory burdens, which raises the question of voluntary regulations.[80] Should a carrot be granted

to companies who adopt environmentally sound practices (for example, in the form of subsidies for improved technology) as opposed to a stick for those that violate regulations? Voluntary regulations can be more flexible than command and control regulations; for example, firms can define and comply with their own specific performance-based standards, and different policy approaches (such as technical assistance, subsidies, and pollution permits) can be adopted to fit the needs of regulated firms.[81] In addition, technology upgrades (see the box on this page) from voluntary programs can lead to environmental improvements for companies in the short run, providing positive publicity. In the long run, the upgrades could also decrease companies' political resistance to more strict regulations. However, providing aquaculture firms with subsidies to improve technology is bound to create further tension between the fishing and farming industries.

The question remains as to whether voluntary efforts will solve or significantly reduce the environmental problems at hand. The new Aquaculture Waste Control Regulation implemented recently in British Columbia includes performance-based standards, but the potential effectiveness of these standards has been challenged within the scientific community.[82] Based on experience with voluntary approaches for other industries in industrialized and developing countries, success stories and failures both prevail.[83] The most progressive companies are likely to benefit from voluntary regulations and technology subsidies, but the environmental performance of the worst offenders is unlikely to improve under such a scheme. The choice of policy approach is especially important when irreversible environmental damages are at stake, for example, when farm salmon escapes lead to colonization in endangered salmon habitat.

Consumer Governance

Salmon aquaculture companies are more likely to accept environmental regulations—either mandatory or voluntary—if their products can be labeled to reflect environmentally sound practices and sold at a premium to consumers who are environmentally conscious. Salmon fisheries producers also support the labeling of their product as "wild caught" to distinguish it in quality and origin from farm salmon. For eco-labeling to be effective, it must provide financial incentives to companies and individuals to produce a more sustainable product. Only then will resistance to more stringent environmental standards be reduced. However, a number of implementation issues arise with labeling schemes. Who will run the labeling program? Who will pay for it? What standards will be enforced?

In the case of salmon, both aquaculture and wild fishery producers have explored the possibilities of organic, wild-versus-farm, and sustainable labeling schemes.[84] The "sustainable" label is the most advanced of the three options to date; this label has been used in marine fisheries since 1997 with Marine Stewardship Council (MSC) certification.[85] Issues surrounding labeling remain highly contentious, however, even for MSC, which essentially grants certification when fish runs are robust and/or fishery management is sound. Two controversial MSC certifications are now being reviewed: the Alaskan pollock fishery (the largest industrial fishery in the world) and British Columbia's wild-caught salmon fishery (wild fish runs are historically low due to a host of habitat damages, but fishery management is sound). The Alaskan salmon fishery was MSC-certified in 2000, but the certification report did not discuss ecosystem impacts of hatcheries and biomass removal or water pollution from processing plants.[86]

Setting the bar on labeling for farm or wild salmon is a difficult issue. If the bar is set too high, covering the full range of sustainability criteria, then the program could fail from an absence of participation. If the bar is set too low, the program could become meaningless in terms of its initial objective. As aquaculture companies vie for certifi-

Examples of Technical Solutions

A variety of technical approaches are available to reduce environmental damages from salmon aquaculture given the appropriate economic and regulatory incentives.

The most environmentally sound approach is to isolate aquaculture facilities from the natural environment with closed-system containment technologies. Land-based systems, which consist of large cement or fiberglass fish tanks, eliminate the possibility of predation by marine mammals, fish escapes, and disease transmission; in addition, they allow for the treatment of farm effluents. Closed-wall sea pens, which consist of impermeable plastic bags fixed near the shore, also isolate farm stock from the external environment. Performance trials with both land-based cement tanks and ocean "bag" systems are being conducted in British Columbia,[1] but the economic viability of these systems remains in question, particularly with low market prices for salmon.

Other technological options include vaccines that reduce the incidence of cultured fish disease, improved feed technologies that reduce waste and wild fish inputs, and sterilization techniques that minimize the ecological and genetic risks of farm fish escapes.[2]

1. In September 2000, the British Columbia Ministry of Agriculture, Food and Fisheries, in conjunction with the Ministry of Water, Land and Air Protection and B.C. Assets, approved a set of experimental technology farm sites. See http://www.agf.gov.bc.ca/fisheries/technology/new_tech.htm.

2. See R. J. Goldburg, M. S. Elliott, and R. L. Naylor, *Marine Aquaculture in the United States: Environmental Impacts and Policy Options* (Arlington, Va.: Pew Oceans Commission, 2001), accessible via http://www.pewoceans.org/reports/137PEWAquacultureF.pdf; and R. L. Naylor et al., *Fugitive Salmon: A Framework for Assessing Risks of Escaped Fish from Aquaculture*, (Stanford University: Center for Environmental Science and Policy (forthcoming)).

cation under sustainable and organic labeling schemes, the controversy between environmentalists and the industry will almost surely escalate. Labeling may be the quickest and most efficient means, however, of inducing firms to pursue voluntary controls that go beyond existing command-and-control regulations—as long as price premiums for environmentally sound products result. To address the current environmental, economic, and social impacts of salmon aquaculture, labeling schemes for both aquaculture and fisheries will need to be consistent and streamlined so that consumers receive a clear and consistent message.

The success of labeling approaches will depend on the outcome of ongoing international trade negotiations, most notably the U.S.-Chile Free Trade Agreement and the Doha Round of the World Trade Organization (WTO).[87] Current WTO language permits trade protection on the basis of product quality (for example, food products containing residues of a chemical banned in the importing country) but not on the process of production. Labeling schemes remain controversial in trade discussions, especially when exporters perceive labeling by importers as a trade barrier that relates to the process of production. The debate persists within WTO as to whether labels (for instance, labels identifying fish as wild versus farmed) are deemed "unfair and discriminatory." As part of the current Doha Development Agenda, WTO is identifying existing non-tariff barriers that have significant effects on trade, and it is possible that eco-labeling schemes, including MSC, will be challenged if the volume of trade affected is deemed sufficiently large.[88] The WTO Commission on Trade and Environment is soon expected to make recommendations about changes to eco-labeling rules.[89] Within the U.S.-Chile Free Trade Agreement, similar issues persist. Given that farm salmon filets are one of Chile's main exports to the United States,[90] it is likely that Chile will seek to ban or severely limit labeling schemes on salmon as trade negotiations move forward.

International Governance

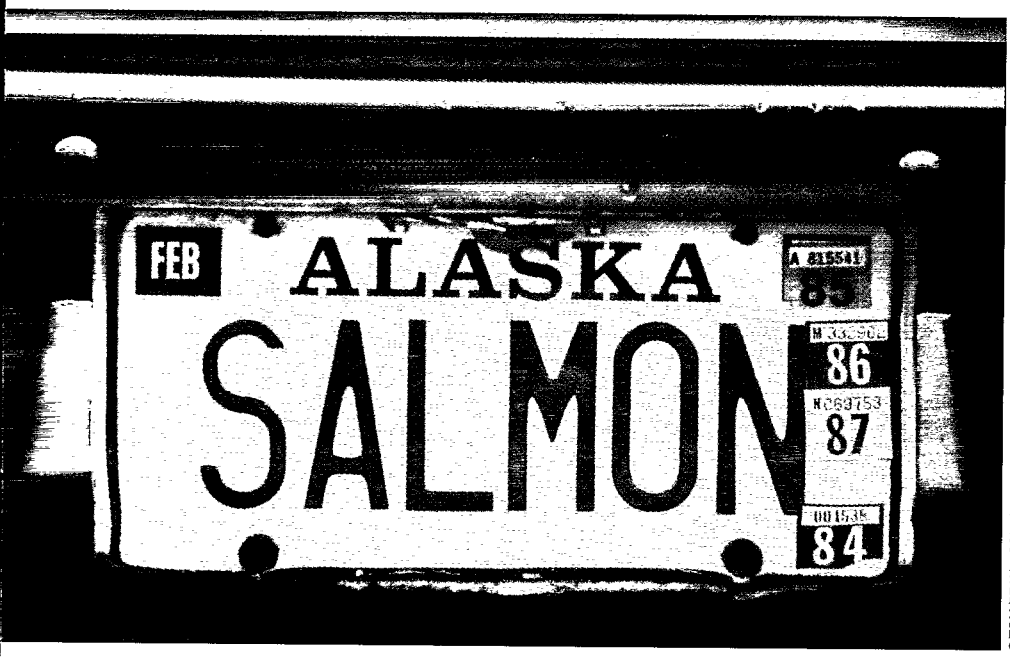
An international agreement among aquaculture-producing countries is another option to "level the playing field" and promote environmentally sound practices. If successful, an international agreement could provide stronger environmental protection than international labeling schemes. Treaties are implemented by national laws, and they generally avoid trade issues within WTO because they are multilateral. With the participation of six key countries—Norway, Chile, the United States, Canada, the United Kingdom, and Japan—more than 90 percent of current farm salmon production would be represented. There are many challenges, however, in creating an international treaty. How will the process get started? Who will lead it? Are there enough interested countries, or will individual countries resist a treaty for the same reasons that they permit lenient or weakly enforced regulations at home? How should the rules be defined? And most important, how long will the process take? Given that the formation of treaties typically entails years of organization before serious multilateral discussions even begin, it is possible that environmental damage from salmon farms will occur long before any agreement is reached.

As a start, voluntary international agreements currently exist on the conduct of salmon farming. In 1994, seven member countries of the North Atlantic Salmon Conservation Organization (NASCO), which produce about two-thirds of the world's farm salmon, signed an agreement in Oslo (known as the "Oslo Resolution").[91] This agreement contained measures on effluent control, siting, escape prevention, and other environmental criteria. However, a monitoring study conducted by the Atlantic Salmon Federation and the World Wildlife Fund found that virtually no progress has yet been made in achieving the goals of the Oslo Resolution.[92] As an intermediate step to a formal treaty, the government signatories of the agreement could agree to a series of coordinated steps to strengthen monitoring, enforcement, and responsibility by the multinational companies operating in their countries. It is possible that the consolidated nature of the aquaculture industry could speed this process. As happened in the development of the Montreal Protocol on stratospheric ozone, it is conceivable that industry could even take the lead.

Salmon aquaculture companies are more likely to accept environmental regulations if their products can be labeled to reflect environmentally sound practices and sold at a premium.

No one can predict the future of governance, but it seems clear that the number of aquaculture sites for salmon and other marine species will continue to expand globally.[93] The optimal approach for preventing environmental and negative social impacts from such activities at the local, national, and global scales would be to have a strong international treaty among aquaculture-producing countries based on stringent regulatory measures on environmental damage and siting within countries. The feasibility of this approach remains questionable, however, especially in the short run. Given that the salmon aquaculture industry is more restricted biophysically in its movement across countries than, for example, the apparel industry or even the shrimp-farming industry, tightening the terms and enforcement of regulations within a smaller group of countries in line with the Oslo Resolution

might be a useful first step. Labeling schemes are also likely to be successful in the near term, and it is important that the credibility of eco-labeling programs is maintained as international trade negotiations pro-gress. Unless some actions are taken internationally, local communities and ecosystems will remain at high risk from the expansion of the global aquaculture industry.



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Without some form of international action, local ecosystems—and the communities that depend on them—may be at risk from a number of problems associated with the expansion of the aquaculture industry.

Rosamond L. Naylor is the Julie Wrigley Senior Fellow in Environmental Science and Policy at Stanford University. Her research focuses on the environmental and equity dimensions of intensive aquaculture and agriculture production and is published in a variety of journals including *Nature*, *Science*, *Food Policy*, and *Environment and Development Economics*. She is an Aldo Leopold Fellow, a Pew Fellow in Marine Conservation, and a contributor to the recent Pew Oceans Commission report on aquaculture. She may be reached by e-mail at roz@stanford.edu. Josh Eagle is director of the Stanford Fisheries Policy Project and lecturer on law at the Stanford Law School. He participates in research projects on fisheries and ocean law and policy. Whitney L. Smith contributed to this article as a research fellow at the Center for Environmental Science and Policy at Stanford University. The research for this article was funded by the David and Lucille Packard Foundation. The authors wish to thank W. Falcon, A. Dean, and E. McCullough for their helpful comments and assistance. The authors are also grateful for numerous interviews and discussions with fishers, farm employees, industry representatives, regulators, scientists, economists, journalists, environmental activists, tribal and First Nations members, seafood processors, and industry analysts.

NOTES

1. Food and Agricultural Organization of the United Nations (FAO), Fishery Statistical Databases, *Aquaculture Production: Quantities 1950–2001*, accessible via http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp.

2. FAO, Fishery Statistical Databases, *Total Production 1950–2001*, accessible via http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp.

3. For example, claims are made that salmon farms act like floating reefs, providing habitat for hundreds of types of invertebrates and plants. See British Columbia Salmon Farmers Association (BCSFA), "Fact Sheets," (Campbell River, B.C.: 2002); and T. Needham, "Farmed Atlantic Salmon in the Pacific Northwest," *Bulletin of the Aquaculture Association of Canada* 95, no. 4 (1995): 38–41.

4. National Research Council, *Sustaining Marine Fisheries* (Washington, D.C.: National Academy Press, 1999); and J. B. C. Jackson et al., "Historical Overfishing and the Recent Collapse of Coastal Ecosystems," *Science*, 27 July 2001, 629–38.

5. R. L. Naylor et al., "Effect of Aquaculture on World Fish Supplies," *Nature*, 29 June 2000, 1017–24; and R. J. Goldburg, M. S. Elliott, and R. L. Naylor, *Marine Aquaculture in the United States: Environmental Impacts and Policy Options* (Arlington, Va.: Pew Oceans Commission, 2001), accessible via http://www.pewoceans.org/reports/137PEWAquacultureF.pdf.

6. There is a large debate on the relative health benefits of wild versus farm salmon. Some studies have shown that farm salmon have a higher fat content and a different, less beneficial fatty acid composition than wild salmon. See R. George and R. Bhopal, "Fat Composition of Free-Living and Farmed Species: Implications for Human Diet and Sea-Farming Techniques," *British Food Journal* 97, no. 8 (1995): 19–22; also T. van Vliet and M. Katan, "Lower Ratio of n-3 to n-6 Fatty Acids in Cultured than in Wild Fish," *American Journal of Clinical Nutrition* 51 (1990): 1–2. Limited tests have also shown that farm salmon contain more dangerous chemical substances than fish that feed in the wild. See M. Easton, D. Luszniak, and E. Von der Geest, "Preliminary Investigation of Contaminant Loadings in Farmed Salmon, Wild Salmon, and Commercial Salmon Feed," *Chemosphere* 46, no. 7 (2002): 1053–74; and M. Jacobs, A. Covaci, and P. Schepens, "Investigation of Selected Persistent Organic Pollutants in Farmed Atlantic Salmon (*Salmo salar*), Salmon Aquaculture Feed, and Fish Oil Components of the Feed," *Environmental Science and Technology* 36, no. 13 (2002): 2797–805. Substantial research on these issues is ongoing.

7. Alaska Department of Fish and Game (ADFG), *Alaska Historical Salmon Catches (All Species), 1878–2002*, accessible via http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/catchval/history/all_1878.htm.

8. G. P. Knapp, *Challenges and Strategies for the Alaska Salmon Industry* (Anchorage: Institute of Social and Economic Research, University of Alaska Anchorage, 2002), accessible via http://www.iser.uaa.alaska.edu/iser/people/knapp/Knapp%20Salmon%20Presentation%2001.pdf.

9. National Oceanographic and Atmospheric Administration (NOAA), *Draft Code of Conduct for Responsible Aquaculture Development in the U.S. Exclusive Economic Zone*, 2002, accessible via http://www.nmfs.noaa.gov/trade/AQ/AQCode.pdf.

10. G. Sylvia, J. L. Anderson, and E. Hanson, "The New World Order in Global Salmon Markets and Aquaculture Development: Implications for Watershed Management in the Pacific Northwest," in E. Knudsen et al., eds., *Sustainable Fisheries Management: Pacific Salmon* (Boca Raton, Fla.: Lewis Publishers, 2000), 393–405.

11. J. L. Anderson, "The Growth of Salmon Aquaculture and the Emerging New World Order of the Salmon Industry," in *Global Trends: Fisheries Management* (Bethesda, Md.: American Fisheries Society, 1997), 175–84.

12. FAO, note 1 above.

13. Anderson, note 11 above.

14. Sylvia, Anderson, and Hanson, note 10 above.

15. Knapp, note 8 above.

16. Information for this section is taken from the following six web sites: www.nutreco.com, www.panfish.com, www.stoltnielsen.com, www.fjord.com, www.cermaq.com, and www.weston.com.

17. British Columbia Ministry of Agriculture, Food and Fisheries (MAFF), *BC Salmon Aquaculture Industry*, (Victoria, B.C.: 2002), accessible via http://www.agf.gov.bc.ca/fisheries/bcsalmon_aqua.htm.

18. Anderson, note 11 above.

19. British Columbia Salmon Marketing Council (BCSMC), *Salmon Market Database*, 2001, accessible via http://www.bcsalmon.ca/database/farm/fmwtyrs.htm; and MAFF, *Fisheries Statistics*, 2002, accessible via http://www.agf.gov.bc.ca/fish_stats/statistics-aqua.htm.

20. NOAA, Northwest Fisheries Science Center, "The Net-Pen Salmon Farming Industry in the Pacific Northwest," NOAA Technical Memo NMFS-NWFSC-49 (Seattle: 2001).

21. S. Fraser, "World's Largest Salmon Farm Opens in Norway for Scaling Up of Feeding Trials," *Growfish News*, 11 May 2003, accessible via http://www.growfish.com.au/Grow/Pages/News/2003/may2003/72203.htm.

22. For information on violations and penalties of provincial aquaculture regulations, see the *Annual Inspection Report on Marine Finfish Aquaculture Operations*, accessible via http://www.agf.gov.bc.ca/fisheries/aqua_report/full_report.pdf. New report

expected to be available in the fall of 2003.

23. Ministry of Water, Land and Air Protection, *Marine Salmon Farming Compliance Report*, February 2002, accessible via http://wlapwww.gov.bc.ca/vir/cos/aquarpt01.pdf.

24. Data provided directly by MAFF, Licensing and Compliance Branch.

25. See http://www.innovationstrategy.gc.ca/cmb/innovation.nsf/SectorReports/CAIA.

26. BCSFA, note 3 above.

27. British Columbia Environmental Assessment Office (EAO), "Volume 2: First Nations Perspectives," *Salmon Aquaculture Review*, (Victoria, B.C., 1997), accessible via http://www.intrafish.com/laws-and-regulations/report_bc/. The term "First Nation" has been adopted by some aboriginal Canadian communities to replace the term "Indian band." (The term "Indian" is viewed as offensive to some people.) Many aboriginal communities in Canada use the term, but some do not; it is a matter of preference for each community. The U.S. term "Native American" is not commonly used in Canada.

28. Farm leases are granted by Land and Water British Columbia, which issues a Crown Land tenure under the Land Act. See http://lwbc.bc.ca/ for more information.

29. S. Hume, "We Are Going to Stop These Fish Farms," *Vancouver Sun*, 1 March 2003. The Heiltsuk First Nation is suing the province and Omega Salmon Group, Ltd., on the grounds that the new Omega hatchery project at Ocean Falls was begun without proper consultation required by law.

30. Fisheries and Oceans Canada, *Salmon Licensing* (Vancouver, B.C., 2002), accessible via http://www.pac.dfo-mpo.gc.ca/ops/fm/Salmon/licensing.htm. The Mifflin Plan was implemented in 1996 when Fred Mifflin was the minister of Fisheries and Oceans. His Pacific Salmon Revitalization Plan called for a 50 percent reduction in the number of salmon-fishing licenses on Canada's west coast.

31. Knapp, note 8 above.

32. K. A. Miller and D. L. Fluharty, "El Niño and Variability in the Northeastern Pacific Salmon Fishery: Implications for Coping with Climate Change," in M. Glantz, ed., *Climate Variability, Climate Change, and Fisheries* (Cambridge, U.K.: Cambridge University Press, 1992), 49–88. Climatic shifts (for example, the Pacific Decadal Oscillation) create long-term unpredictability in the size of fish stocks; salmon catches in Alaska varied fivefold (30 to 150 million fish) in a 25-year period preceding the 1990s. During the 1990s, average catch in Alaska was more than 175 million fish, see ADFG, *Alaska Commercial Salmon Harvests 1970–2001*, accessible via http://www.cf.adfg.state. ak.us/geninfo/finfish/salmon/catchval/history/1970-2001s.htm.

33. Naylor et al., note 5 above; Goldburg, Elliott, and Naylor, note 5 above; and D. J. Noakes, R. J. Beamish, and M. L. Kent, "On the Decline of Pacific Salmon and the Speculative Links to Salmon Farming in British Columbia," *Aquaculture* 183, no. 3–4 (2000): 363–86.

34. Color is controlled using feed additives (canthaxanthin and astaxathin). There has been controversy around the health impacts of these colorant additives. See R. Baker, "Canthaxanthin in Aquafeed Applications: Is there Any Risk?" *Trends in Food Science and Technology* 12 (2002), 240–43. See also European Commission (EC), Scientific Committee on Animal Nutrition, *Opinion of the Scientific Committee on Animal Nutrition on the Use of Canthaxanthin in Feeding Stuffs for Salmon and Trout, Laying Hens, and Other Poultry*, 2002, accessible via http://europa.eu.int/comm/food/fs/sc/scan/out81_en.pdf. The EC recommended a reduction of allowable levels of canthaxanthin in animal feed on 27 January 2003. The recommended level lies above the acceptable daily intake of up to 0.03 milligrams per kilogram of human body weight used by FAO/ World Health Organization (WHO) and the European Commission–Scientific Committee on Food (EC-SCF), which has not changed. The only proven side effect of moderate overdosage of canthaxanthin by humans is reversible deposition of crystals in the eye. Substitution of the natural astaxanthin in feeds causes a substantial increase in costs of feed for aquaculture producers. Meanwhile, retailers are required under the Food, Drug, and Cosmetic Act to notify consumers of the presence of artificial colorants, regardless of proven health effects. Several grocery store chains face a class action suit for "deceiving the public" and have now agreed to put "color-added" labels on their farm salmon. See also D. Cherry, "Kroger to Label Farmed Salmon; 'Color-Added' Labels Coming this Week," *The Wave News Network*, 30 April 2003.

35. Tension between fishers and processors over contracts and prices has always plagued the industry in the Pacific Northwest and Alaska. In May 2003, a major court battle between fishers and processors in Bristol Bay, Alaska, over price fixing ended in a "finding of no liability" verdict for the processors. See D. Cherry, "Bristol Bay Juror: 'There Was Nothing Solid Enough; It Was Too Circumstantial,'" *The Wave News Network*, 27 May 2003. Fishers typically feel underpaid by processors, and processors commonly complain about fishers' excessive demands, especially in years when the market is weak.

36. ADFG, note 7 above.

37. For example, between 1990 and 2002, average selling prices declined from $273,000 to $20,000 for Prince William Sound purse seine permits, from $216,000 to $20,000 for Bristol Bay drift gillnet permits, and from $110,000 to $23,000 for southeastern Alaska purse seine permits. See Commercial Fisheries Entry Commission, *Permit Values*, accessible via http://www.cfec.state.ak.us/pmtvalue/mnusalm.htm.

38. Stolt-Nielsen S.A., *Annual Report 2001*, accessible via the web at http://www.stoltnielsen.com/2001StoltNielsenARpt.pdf.

39. Pan Fish A.S.A., *Reduced Production in Scotland*, 20 May 2003, accessible via http://www.panfish.com/investors/press/pressreleases.html?id=59.

40. J. Eagle, R. Naylor, and W. Smith, "Why Farm Salmon Outcompete Fishery Salmon," *Marine Policy*, Fall 2003 (forthcoming).

41. Alaska has declared a State of Emergency for the state's salmon fisheries and has issued a series of disaster relief programs since 1998. Each program has a different payment structure and is aimed at different groups. Current attention is focused mainly on the Yukon-Kuskokwim Delta area where salmon runs and prices are extremely low.

42. S. Colt, *The Economic Importance of Healthy Alaska Ecosystems*, (Anchorage: Institute of Social and Economic Research, University of Alaska Anchorage, 2001).

43. The U.S. Department of Agriculture (USDA) has been purchasing excess stocks of canned pink salmon for food programs in recent years. USDA purchases of these stocks have almost doubled, from $8 million in 1998 to $15 million in 2003.

44. Eagle, Naylor, and Smith, note 40 above; and Joint Legislative Salmon Industry Task Force, *Final Report and Proposed Legislation*, 4 February 2003, accessible via http://www.ufafish.org/taskforce/Doc/JLSITFfinalreportcorrected.pdf.

45. The fish trap is a floating or fixed device positioned across the migration paths of salmon on their spawning runs and designed to lead salmon into a holding section from which escape is virtually impossible. The trap can be opened to permit escapement as desired and can be used to hold fish for a short period of time before processing. Fish wheels consist of two large baskets that turn on an axle. They are rotated by the river current and scoop up passing fish as they turn. Captured fish slide down a chute into a holding box

that is emptied several times a day. See R. A. Cooley, *Politics and Conservation: The Decline of Alaska Salmon* (New York: Harper and Row, 1963); and S. Colt, *Salmon Fish Traps in Alaska*, (Anchorage: Institute of Social and Economic Research, University of Alaska Anchorage, 1999), accessible via http://www.iser.uaa.alaska.edu/publications/fishrep/fishtrap.pdf.

46. The vessel buyback program in Washington began in 1999 and was intended to compensate fishers affected by Pacific Salmon Treaty negotiations. The Mifflin plan in British Columbia was implemented in 1996; see note 30 above.

47. H. C. White, "'Sea Lice' (*Lepeophtheirus salmonis*) and Death of Salmon," *Journal of the Fisheries Research Board of Canada* 5 (1940): 172–75.

48. A. McVicar, "Disease and Parasite Implications of the Coexistence of Wild and Cultured Atlantic Salmon Populations," *ICES Journal of Marine Science* 54 (1997): 1093–103; and T. A. Bakke and P. D. Harris, "Disease and Parasites in Wild Atlantic Salmon (*Salmo salar*) Populations," *Canadian Journal of Fisheries and Aquatic Sciences* 55 (1998): 247–66.

49. Sea lice epidemics at farm sites commonly precede epidemics in local post-smolt populations. See B. MacKinnon, "Host Factors Important in Sea Lice Infection," *ICES Journal of Marine Science* 55 (1998): 188–92; A. W. Pike and S. L. Wadsworth, "Sea Lice on Salmonids: Their Biology and Control," *Advances in Parasitology* 44 (1999): 234–337. The association between sea lice epizootics and intensive aquaculture production has been documented earlier in Ireland, see O. Tully and K. F. Whelan, "Production of Nauplii of *Lepeophtheirus salmonis* (Krøyer) (Copepoda: Caligidae) from Farmed and Wild Salmon and Its Relation to the Infestation of Wild Sea Trout (*Salmo trutta* L.) off the West Coast of Ireland in 1991," *Fisheries Research* 17 (1993): 187–200; O. Tully, W. R. Poole, and K. F. Whelan, "Infestation Parameters of *Lepeophtheirus salmonis* (Krøyer) (Copepoda: Caligidae) Parasitic on Sea Trout, *Salmo trutta* L., off the West Coast of Ireland During 1990 and 1991," *Aquaculture and Fisheries Management* 24 (1993): 544–45; and O. Tully, P. Gargan, W. R. Pool, and K. F. Whelan, "Spatial and Temporal Variation in the Infestation of Sea Trout (*Salmo trutta* L.) by the Caligid Copepod *Lepeophtheirus salmonis* (Krøyer) in Relation to Sources of Infection in Ireland," *Parasitology* 119 (1999): 41–51; in Norway, see K. Birkeland, "Consequences of Premature Return by Sea Trout (*Salmon trutta*) Infested with the Salmon Louse (*Lepeophtheirus salmonis* Krøyer); Migration, Growth, and Mortality," *Canadian Journal of Fisheries and Aquatic Sciences* 53 (1996): 2808–13; and P. A. Heuch and T. A. Mo, "A Model of Salmon Louse Production in Norway: Effects of Increasing Salmon Production and Public Management Measures," *Diseases of Aquatic Organisms* 45 (2001): 145–52; and in Scotland, see J. R. A. Butler et al., *Patterns of Sea Lice Infestations on Scottish West Coast Sea Trout: Survey Results, 1997–2000*, (Scotland, U.K.: Association of West Coast Fisheries Trusts, 2001). Sea lice infection is the second-greatest cause of economic loss to Atlantic salmon farms in Northwestern Europe after infectious salmon anemia; see Pike and Wadsworth, above here.

50. In 2002 there were 27 salmon farms sited in an area of 406 km^2, and roughly 80 percent of the fish produced on these farms were Atlantic salmon, which are highly susceptible to sea lice. See S. C. Johnson, "A Comparison of Development and Growth Rates of *Lepeophtheirus salmonis* on Naïve Atlantic (*Salmo salar*) and Chinook (*Oncorhynchus tshawytscha*) Salmon," in G. A. Boxshall and D. Defaye, eds., *Pathogens of Wild and Farmed Fish: Sea Lice* (London, U.K.: Ellis Horwood, 1993), 68–82.

51. Bakke and Harris, note 48 above. The evidence presented in this section on parasite and disease infestations in British Columbia, and on regulatory measures to reduce the infestations, was collected from a long series of e-mail correspondences and Internet reports beginning in the spring of 2001. The correspondence is by industry representatives, government officials, and environmental activists (mainly Alexandra Morton, Raincoast Research, Simoom Sound, B.C.) who have been monitoring the situation.

52. The lethal level of sea lice on juvenile pink salmon is thought to be around three per fish, and in 2001, the number of lice averaged seven per fish.

53. The low adult returns of 2002 were the product of eggs laid in the fall of 2000, and they are the same fish as were migrating out to sea in the spring of 2001. The spring of 2003 has thus become a critical period for the remaining pink salmon population, which are the product of eggs laid in 2002.

54. The PFRCC, created in 1997 as a component of the Canada–British Columbia agreement on the management of Pacific salmon fishery issues, is an independent advisory organization for the conservation of Pacific salmon species. See http://www.fish.bc.ca/ for more information.

55. See Figure 4 on page 30. The cluster of inactive farms indicates provincial fallow route. For details of the sea lice action plan, see http://www.agf.gov.bc.ca/fisheries/broughton_sealice_actionplan.htm. In correspondence dated 23 June 2003, Alexandra Morton (see note 51 above) reports that the fallow route was at least a partial success, with lower lice levels this year than in the two previous years. The concern is that potentially infected fish emerging from streams not adjacent to the fallow route are mixing with clean fish as they exit the archipelago ocean-bound.

56. S. Saksida, *Investigation of the 2001–2002 IHNV Epizootic in Farmed Atlantic Salmon in British Columbia* (Campbell River, B.C.: MAFF, 2002), accessible via http://www.agf.gov.bc.ca/fisheries/pdf/IHNV_report.pdf. Areas with IHN-infected sites included the Broughton Archipelago, the east and west coasts of Vancouver Island, and the central mainland coast.

57. Q. Dodd, "Stolt Confirms Second IHN Outbreak in BC," *Fish Information & Services*, 4 September 2002, accessible via http://www.fis.com.

58. MAFF, "Fish Health Policy Initiatives," accessible via http://www.agf.gov.bc.ca/fisheries/health/fish_health_policy_initiatives.htm.

59. R. L. Naylor et al., *Fugitive Salmon: A Framework for Assessing Risks of Escaped Fish from Aquaculture*, (Stanford University: Center for Environmental Science and Policy (forthcoming)).

60. Atlantic Salmon Watch Program (AWSP), *Reported BC Aquaculture Escapes*, accessible via http://www.pac.dfo-mpo.gc.ca/sci/aqua/ASWP/Atl_escapes.PDF.

61. A. Morton and J. Volpe, "A Description of Atlantic Salmon (*Salmo salar*) Captured in the Pacific Salmon Fishery in British Columbia, Canada, in 2000," *Alaska Fishery Research Bulletin* 9, no. 2 (2003): 102–10.

62. In Pacific streams, Atlantic salmon compete mainly with steelhead trout. Atlantic salmon hatch earlier than steelhead and thus have a prior residency advantage in terms of size and competitive ability. See J. Volpe, B. Anholt, and B. Glickman, "Competition among Juvenile Atlantic Salmon (*Salmo salar*) and Steelhead (*Onchorhynchus mykiss*): Relevance to Invasion Potential in British Columbia," *Canadian Journal of Fisheries and Aquatic Sciences* 58 (2001): 197–207; and J. Volpe, E. Taylor, B. Rimmer, and B. Glickman, "Evidence of Natural Reproduction of Aquaculture-Escaped Atlantic Salmon in a Coastal British Columbia River," *Conservation Biology* 14, no. 3 (2000) 899–903.

63. Ibid.; and AWSP, *BC Freshwater Adult Atlantic Salmon Captures and Sightings*, accessible via http://www.pac.dfo-mpo.gc.ca/sci/aqua/ASWP/BC_FW_Adult.PDF.

64. For example, on 19 June 2003 Senator Lisa Murkowski (R-Alaska) urged the Bush Administration to take steps to prevent invasive species from entering U.S. waters, including tougher measures for aquaculture producers to prevent farm salmon escapes.

65. MAFF, *Escape Prevention Initiative* (1999), accessible via http://www.agf.gov.bc.ca/fisheries/escape/escape_prevention_initiative.htm.

66. Goldburg, Elliott, and Naylor, note 5 above; and M. L. Weber, "What Price Farmed Fish: A Review of the Environmental and Social Costs of Farming Carnivorous Fish," prepared for SeaWeb Aquaculture Clearinghouse (Providence, R.I.: 2003), accessible via http://www.seaweb.org/resources/sac/pdf/WhatPriceFarmedFish_high.pdf. Industry representatives challenge these numbers as being too high; however, firm-level information on feed inputs is largely proprietary.

67. Naylor et al., note 5 above; and Weber, note 66 above.

68. British Columbia Environmental Assessment Office (EAO), "Volume 1: Chapter 8: Interactions with Coastal Mammals and Other Species," *Salmon Aquaculture Review* (Victoria, B.C.: 1997), accessible via http://www.intrafish.com/laws-and-regulations/report_bc/v1chp8.htm.

69. British Columbia EAO, note 68 above; and G. Iwama, L. Nichol, and J. Ford, "Volume 3: Part E: Aquatic Mammals and Other Species Discussion Paper", *Salmon Aquaculture Review* (Victoria, B.C., Canada), accessible via http://www.intrafish.com/laws-and-regulations/report_bc/vol3-e.htm.

70. Goldburg, Elliott, and Naylor, note 5 above.

71. Ibid.

72. M. C. M. Beveridge, *Cage Aquaculture*, 2nd ed. (Edinburgh, Scotland: Fishing News Books, 1996), 346.

73. K. Brooks, *An Evaluation of the Relationship between Salmon Farm Biomass, Organic Inputs to Sediments, Physiochemical Changes Associated with Those Inputs and the Infaunal Response—with Emphasis on Total Sediment Sulfides, Total Volatile Solids, and Oxidation-Reduction Potential as Surrogate Endpoints for Biological Monitoring*, a report produced for the (then) British Columbia Ministry of the Environment (Port Townsend, Wash.: Aquatic Environmental Sciences, 2001).

74. Goldburg, Elliott, and Naylor, note 5 above. The use of chemicals in salmon aquaculture is not well documented, and there are few studies that report whether use is increasing, decreasing, or remaining constant. See C. M. Benbrook, *Antibiotic Drug Use in U.S. Aquaculture*, (Sandpoint, Idaho: Northwest Science and Environmental Policy Center, 2002).

75. NOAA, note 20 above.

76. Naylor et al., note 59 above.

77. Goldburg, Elliott, and Naylor, note 5 above; and MAFF, *Salmon Aquaculture Policy Framework*, (1999), accessible via http://www.agf.gov.bc.ca/fisheries/salmon_aqua_policy.htm.

78. See the Federal Register's proposed rules by the EPA [FRL-7263-2], 12 September 2002. EPA's final effluent guidelines are due in June 2004.

79. Ibid.

80. R. Neill and B. Rogers, *Canadian Aquaculture: Drowning in Regulation*, prepared for the Canadian Aquaculture Institute (Halifax, N.S.: 2002), accessible via http://www.aims.ca/Publications/Aquaculture/aquaculture.pdf.

81. D. Kettl and M. H. Armacost, eds., *Environmental Governance: A Report on the Next Generation of Environmental Policy* (Washington D.C.: The Brookings Institution, 2002).

82. C. D. Levings, J. M. Helfield, D. J. Stucchi, and T. F. Sutherland, *A Perspective on the Use of Performance Based Standards to Assist in Fish Habitat Management on the Seafloor near Salmon Net Pen Operations in British Columbia* (West Vancouver, B.C.: Fisheries and

Oceans Canada, 2002).

83. R. C. Anderson, *Incentive-Based Policies for Environmental Management in Developing Countries*, Resources for the Future brief 02-07, 2002, accessible via http://www.rff.org/Johannesburg/Issuebriefs/joburg1.pdf.; and M. Potoski and A. Prakash, "Protecting the Environment: Voluntary Regulations in Environmental Governance," *Policy Currents* 11, no. 4 (2002): 9–14.

84. The aquaculture industry and the Alaskan salmon-fishing industry have both applied for organic labels through USDA certification. They have been rejected due to insufficient control over feed inputs (comprised in part of fishmeal and fish oil derived from wild forage fish) and (in the case of wild capture) insufficient control over the salmon throughout their life cycle. See W. Loy, "USDA Advisory Board Says No to Organic Label for Wild Fish," *Fish Information & Services*, 18 October 2001, accessible via http://www.fis.com. A new provision for organic labeling of Alaska fishery-caught salmon has been reintroduced in the 2003 U.S. fiscal appropriations bill (PL 108, 7). In the United Kingdom, provisions have also been made to label fish sold in supermarkets as wild versus farm origin. See R. Edwards, "Food Agency Caught Out Over Salmon Labelling Delay," *The Sunday Herald*, 15 June 2003, accessible via http://www.sundayherald. com/34586. Finally, the Global Alliance on Aquaculture (an industry-based group) formed the Aquaculture Certification Council in 2002 to address social and environmental criteria for farm operations. Certification is being directed initially toward shrimp farming but could apply to other species over time. See http://www.aquaculturecertification.org/accstan. html.

85. For more information, see the Marine Stewardship Council (MSC) web site at http://www.msc.org.

86. ADFG, *Summary Report on the Certification of Commercial Salmon Fisheries in Alaska*, September 2001, accessible via http://www.state.ak.us/adfg/geninfo/special/sustain/mscreprt.pdf; Environment and Natural Resources Institute (ENRI), *Evaluating Alaska's Ocean-Ranching Salmon Hatcheries: Biologic and Management Issues*, prepared for Trout Unlimited (Anchorage: ENRI, University of Alaska, 2001); D. E. Shindler et al., "Pacific Salmon and the Ecology of Coastal Ecosystems," *Frontiers in Ecology and the Environment* 1, no. 1 (2003): 31–37; and Eagle, Naylor, and Smith, note 40 above.

87. Trade representatives of the World Trade Organization (WTO) met again 10–14 September in Cancun, Mexico, to resume discussions of the Doha Round. The U.S.-Chile Trade Agreement was settled in December 2002 after 10 years of prior negotiation, but discussions over individual trade issues, including salmon trade, are ongoing. See http://www.wto.org and http://www.chileusafta.com.

88. For information on WTO's current activities, see http://www.wto.org/english/tratop_e/dda_e/dda_e.htm. Regarding MSC, also see Z. Grader, P. Parravano, G. Spain and N. Benjamin, "Going Beyond Fish Eco-Labeling: Is It Time for Fair-Trade Certification?" *Fishermen's News*, March 2003, accessible via http://www.pcffa.org/fn-mar03.htm.

89. V. Menotti, P. Parravano, N. Benjamin, and Z. Grader, "Trade Decisions Could Transform Fisheries," *Fishermen's News*, April 2003, accessible via http://www.pcffa.org/fn-apr03.htm.

90. U.S. imports of Chilean farm salmon have increased tenfold in the past decade.

91. The official title of the agreement was the "Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimize Impacts from Salmon Aquaculture on the Wild Salmon Stocks." The seven member countries of the North Atlantic Salmon Conservation Organization (NASCO) in 1994 were Norway, Canada, the United Kingdom, the United States, Ireland, Iceland, and the Faroe Islands (Denmark). Some representation in NASCO has since changed (the Russian Federation, for example, is now a member).

92. G. Porter, *Protecting Wild Atlantic Salmon from Impacts of Salmon Aquaculture: A Country-by-Country Progress Report* (Washington, D.C. and St. Andrews, N.B.: World Wildlife Fund and Atlantic Salmon Federation, 2003), accessible via http://www.asf.ca/Aquaculture/2003osloprogress/01-oslòresprogress.pdf. The regions evaluated for the report include the NASCO member nations in 1994; see note 91 above. In ranking a set of 10 measurable criteria for the reduction of impacts by the industry on wild fish stocks (1 being the lowest and 10 being the highest measures to lessen the impact), the average score was just over 2. Norway had the highest score (3.4), and the United States and Canada had among the lowest scores (0.5 and 2.95 respectively).

93. Weber, note 66 above.