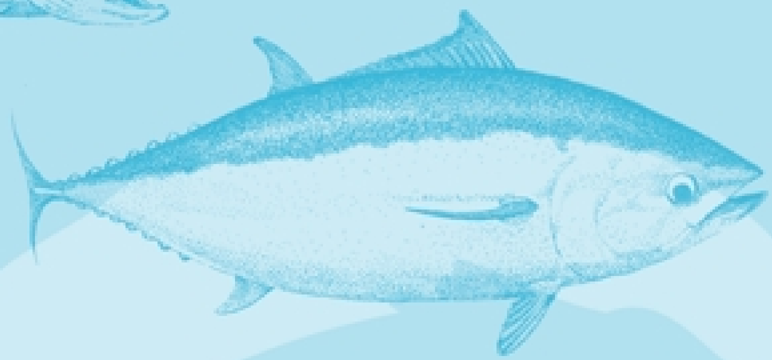
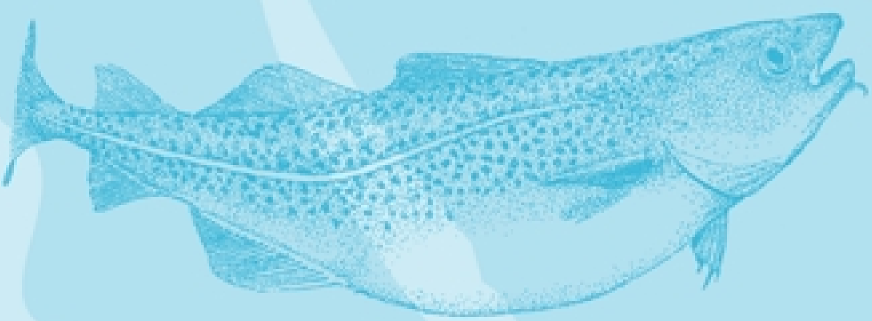
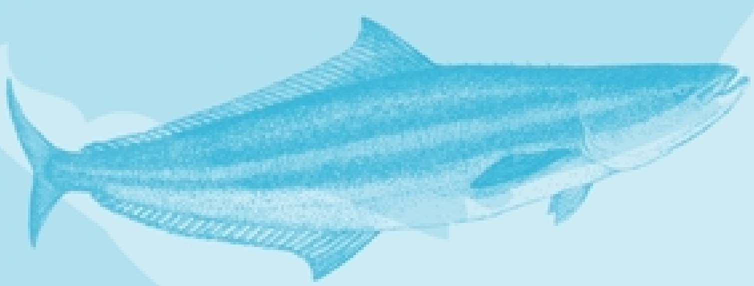


WHAT PRICE FARMED FISH:

A review of the environmental & social costs of farming carnivorous fish

MICHAEL L. WEBER
for the SeaWeb Aquaculture Clearinghouse





SeaWeb
Raising Awareness of the Living Ocean

WHAT PRICE FARMED FISH: A review of the environmental & social costs of farming carnivorous fish

MICHAEL L. WEBER
for the SeaWeb Aquaculture Clearinghouse

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Michael L. Weber is a freelance writer and research consultant who has specialized in marine and coastal conservation for the last two decades. From 1980 to 1990, Mr. Weber directed programs on marine protected areas, sea turtle conservation, and marine fisheries at the Center for Marine Conservation in Washington, DC. From 1990 to 1994, he served as a special assistant to the Director of the National Marine Fisheries Service.

In January 2002, Island Press published his latest book, *From Abundance to Scarcity: A History of U.S. Marine Fisheries Policy.* In June 1999, Island Press published *Fish, Markets, and Fishermen: The Economics of Overfishing,* which Mr. Weber wrote with Suzanne Iudicello and Robert Wieland. In May 1995, W.W. Norton published *The Wealth of Oceans,* a survey and overview of the oceans and ocean policy issues, which Mr. Weber wrote with Judith A. Gradwohl of the Smithsonian Institution.

The present report on farming carnivorous fish builds on an earlier report regarding salmon farming that Mr. Weber wrote in 1997 for the Consultative Group on Biological Diversity.

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Foreword

Humans have farmed fish for thousands of years. During the last quarter of the 20th century industrial-scale aquaculture grew rapidly. Aquaculture seemed full of promise and was proclaimed as an environmentally benign way to relieve pressure on wild fish populations, grow healthy protein and feed the world. As this report suggests, that promise is not being fulfilled, at least for some kinds of aquaculture.

While some types of aquaculture, namely shellfish, vegetable, and freshwater fish farming, including species like catfish, tilapia, and carp, are relatively good ways to grow aquatic food, farming of the higher value carnivorous fish, such as salmon, are resulting in serious environmental and social costs that future generations may end up having to pay for to remedy.

The farming of carnivorous fish other than salmon is expected to grow rapidly over the next decade and is seen as the 'next wave' in the industry. In their rush to pursue commercial production of other carnivores, such as tuna, cod, halibut, and grouper, corporations and governments need to learn from and avoid the impacts associated with the current state of salmon farming. This report by Mike Weber, with substantial research assistance from SeaWeb's Brendan O'Neill, focuses largely on the scientific research regarding the environmental and social issues related to farming salmon. At this time, there is a dearth of information in the scientific literature on the effects of farming other carnivorous species. Clearly, there is an urgent need to conduct rigorous environmental and ecological research on farming these species.

The SeaWeb Aquaculture Clearinghouse, now in its sixth year of existence, takes a science-based approach to aquaculture. We review the latest scientific literature, monitor industry trends, and make recommendations based on what we believe is best for the long-term health and productivity of coastal ecosystems and communities. Our approach has been to try to reverse negative and unsustainable trends in the industry by raising awareness of the issues and identifying and promoting positive developments and best practices. There are many innovative aquaculture operations currently operational or planned. This report touches on some of these sustainable options—where the future of the industry should be headed.

Aquaculture is necessary for the future, as long as it is conducted in an environmentally and socially responsible way. We encourage corporations to take more responsibility for conserving coastal waters, a public resource held in trust by governments for all citizens' use and enjoyment, by developing operational practices that are environmentally friendly. We urge government to look more holistically at aquaculture and its effects on marine ecosystems before it allows the practice to expand.

We hope that this report will contribute to a clearer understanding of the issues. We encourage those who finance, practice and regulate aquaculture to ensure the health and productivity of coastal waters and watersheds, and local communities. Only then can its promise be truly fulfilled.

Bill Mott, Director, SeaWeb Aquaculture Clearinghouse, June 2003

1: Introduction

The 1990s brought explosive growth in farming salmon, as salmon netcages proliferated in coastal waters from Norway and Scotland to Canada and Chile. The headlong expansion of salmon farming ignored growing concerns about impacts on the environment and wild salmon runs and about the wisdom of raising carnivorous fish. Mirroring a pattern of fisheries development that has reduced many wild populations of fish to marginal levels, salmon farming emphasized increases in production and downplayed environmental and biological concerns.

Now that the financial boom of early salmon farming has passed, major players in the industry are shifting their attention to farming other carnivorous species such as cod and halibut, often with active government assistance. This shift toward farming additional species of carnivorous fish poses the same ecological and environmental impacts as salmon farming. It appears that neither government agencies nor the promoters of such aquaculture have learned from the mistakes that have marked the growth of salmon farming.

Sustainable production will be achieved only if governments and the industry confront the problems of the past and adopt policies and practices that avoid those problems in the future.

The carnivorous fish farming industry often claims that it is only meeting consumer demand. However, as continued gluts of farmed salmon and low prices show, even aggressive marketing has not been able to increase demand at nearly the rate of supply. During the 1990s, per capita seafood consumption in the United States stagnated at roughly 15 pounds per person, despite conditions such as a growing economy that are favorable to increased consumption. Furthermore, consumers in the major salmon-consuming countries in western Europe and North America have grown concerned about the taste and healthfulness of farmed salmon.

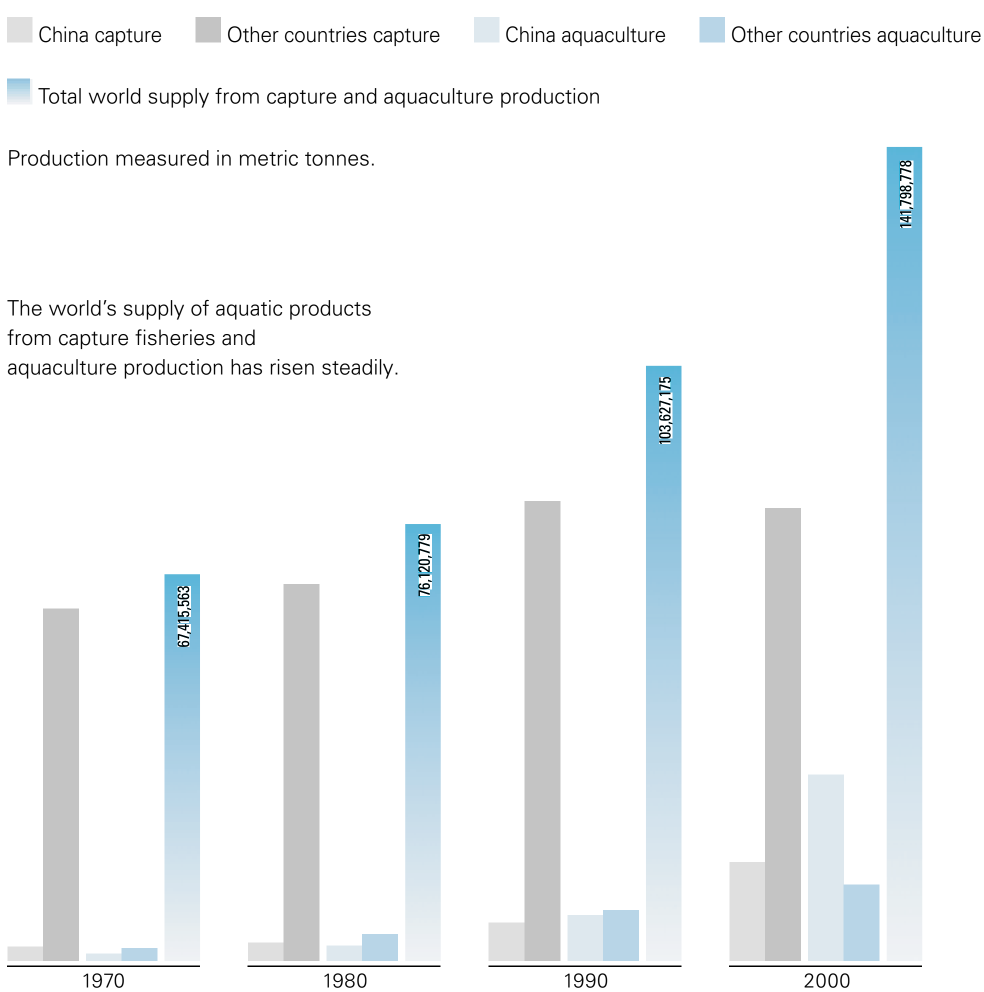
Aquaculture has a pivotal role to play in meeting the need of growing human populations for high-quality protein. We in the industrialized countries enjoy an enormous opportunity to apply our knowledge and ingenuity to closed-cycle methods of traditional aquaculture that not only produce food, but also consume wastes from other human activities. To capture this opportunity will require looking beyond maximizing production and beyond viewing the environment and other wildlife as externalities that are someone else's problems.

This report aims to provide a general overview of aquaculture, with an emphasis on farming salmon and other carnivorous finfish species. The report does not discuss

Aquaculture has a pivotal role to play in meeting the need of growing human populations for high-quality protein aquaculture of shellfish. It should be noted that aquaculture of shrimp, which generates many of the same kinds of environmental and social problems as salmon farming, has accounted for a growing share of the growing market for shrimp in the United States, Japan, and some European countries.

This report summarizes available literature on trends in aquaculture and in farming salmon and other carnivorous species, salient environmental and human health issues, and alternative methods and species for farming fish. The report closes with conclusions and recommendations.

1 : **WORLD CAPTURE AND AQUACULTURE PRODUCTION** WITH CHINA



Source: Food and Agriculture Organization of The United Nations Statistical Database

2: Background

Aquaculture and capture fisheries provide food, fishmeal, fish oil, and other products used in manufacturing, food processing, pharmaceuticals, and other products. In the last 40 years, the world's supply of aquatic products from capture fisheries and aquaculture production has increased steadily *(see figure 1)*.[1]

In 2000, 89 million metric tonnes (mt) of fish were produced by capture fisheries and aquaculture outside of China. (Due to concerns about reliability of fishery statistics for China, the United Nations Food and Agriculture Organization [FAO] now reports China's statistics separately from those from other countries.) Of this, 71% was consumed directly by humans and the balance was processed into other products, principally fishmeal and fish oil used in feeds for cattle, poultry, and fish.[2] China reported overall production of 42 million mt of seafood, of which 81% was consumed directly by humans.

Average per capita consumption of food fish outside of China was 16 kg in 2000, and ranged from 8 kg in Africa to 22.5 kg in Oceania.[3] Fish consumption also varies in other ways. For instance, per capita consumption in industrialized countries averaged 28.3 kg in 2002, compared to 14.8 kg in developing countries that are not suffering a more general food deficit.

Between 1961 and 1999, the share of animal protein supplied by fish increased from 13.7% to 15.8%.[4] In industrialized countries, where there is a greater range of available animal proteins, fish accounted for only 7.7% of the total. In countries where there are serious food deficits, fish contributes nearly 20% of total animal protein. In such countries as Ghana, Indonesia, Bangladesh, and Cambodia, fish supplies as much as half of all animal protein.

Overall, fish is the primary source of animal protein for one billion people.[5] Increases in per capita consumption together with rising human population, principally in Asia, Africa, and South America, have increased worldwide consumption of food fish from 40 million mt in 1970 to 86 million mt in 1998.[6]

Since 1960, the total supply of food fish, excluding China, grew at an annual rate of 2.4%, or slightly greater than the rate of human population growth of 1.8%.[7] In the last decade, landings from capture fisheries have levelled off, and increases in overall supply have come from aquaculture. Now, aquaculture accounts for about one-third of the overall supply of food fish.[8]

...aquaculture accounts for about one-third of the overall supply of food fish

AQUACULTURE

The United Nations Food and Agriculture Organization (FAO) defines aquaculture as follows:

> *The farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.*

In popular use, the term has been applied to other types of activity, such as the fattening of juvenile or adult bluefin tuna.

Farming fish requires developing methods of husbandry that allow a species to complete its life-cycle from hatching to spawning in captivity so that the farming operation is no longer dependent upon wild animals for eggs.[9] Farming fish for commercial purposes also requires that these methods produce fish predictably and repeatedly and at a cost that provides for a profit.[10]

The difficulty of meeting these requirements varies by species and life history. Some species, such as salmon, have proved relatively easy to raise.[11] True marine species are far more difficult to raise in captivity partly because their eggs are quite fragile. In addition, survival of the resulting larvae depends greatly on the availability of microscopic live feed, such as brine shrimp or rotifers, which are expensive to produce.[12]

For the most part, fish and shellfish are farmed in ponds, in tanks, suspended on supporting structures or confined in net cages in lakes or coastal waters. The type and intensity of farming depends on the species and on the final consumer. For instance, the feeding behavior of a species greatly influences the method of farming. Mussels and oysters, which feed on plankton and organic particles in the surrounding water, are grown on the bottom or on suspended ropes or racks.[13] Carp, which feed principally on plants or on plants and invertebrates, are grown in ponds, whose waters are fertilized, sometimes with wastes from other activities such as agriculture, to increase the production of plants in the ponds. Most marine fish, including salmon, are raised in netpens in coastal waters, and are fed on pellets manufactured from forage fish, such as anchovies and herring.

The type of final consumer also determines the species and often the type and intensity of farming method. For instance, most aquaculture in developing countries aims at the production of food for survival and local markets in rural economies.[14,15] In general, such operations are family owned, culture several species at a time, recycle wastes or use wastes in other food-producing activities, and supplement other types of food production and employment.[16,17] Aquaculture in developed countries aims at generating profits from producing moderate- to high-value species for urban or foreign markets, and relies on intensive, high-production forms of aquaculture that require high levels of chemical, energy, and other inputs.[18,19]

In both developed and developing countries, market demand has led to increased intensification of aquaculture production, including a shift to the monoculture of high-value species for affluent markets and the use of fishmeal and fish oil in feeds.[20,21] More intensive types of aquaculture can use space and resources more efficiently if they are carefully planned and managed.[22] However, less than optimal planning and management will increase adverse environmental impact and resulting economic losses.[23]

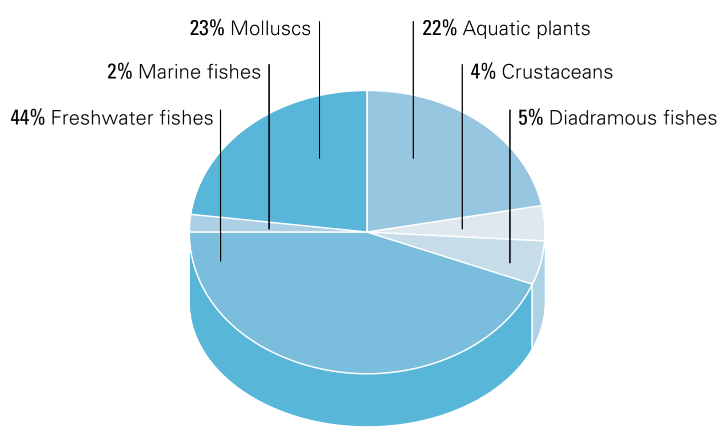
Currently, most aquaculture production is small-scale and supplies local markets. However, in the last two decades, government and private research and development programs have increasingly focused on industrial-scale production of high-end seafood, such as salmon and shrimp, for urban markets principally in the more developed countries, such as Japan, the United States, France, Germany, Italy, and the United Kingdom. Government subsidies and promotion of such aquaculture as a vehicle for economic development have fueled dramatic increases in such aquaculture and have encouraged traditional fish farmers to shift to production of high-end seafood.

TRENDS IN AQUACULTURE PRODUCTION

Volume of global aquaculture production: Between 1985 and 2000, the volume of global aquaculture production grew fourfold from 11.4 million mt to 45.7 million mt, according to the FAO. In 2000, freshwater fishes such as carp, accounted for nearly half of the volume, while aquatic plants such as seaweed, and molluscs such as oysters, each accounted for 22% and 23% respectively *(see figure 2)*. The production of marine and diadromous fishes such as salmon and trout contributed marginally.

In 2000, half of the volume of aquaculture production came from marine waters, 45% from freshwater, and 5% from brackish water. By continent, Asia produced 84% of all farmed products in 2000, followed by Europe at 9% and North America at 3%.

2 : **AQUACULTURE PRODUCTION IN 2000** BY SPECIES GROUP



Source: Food and Agriculture Organization of The United Nations Statistical Database

Reliability of statistics from China

Between 1985 and 2000, overall production by capture fisheries and aquaculture from marine, brackish, and freshwaters increased by half from 91.5 million mt to 141.8 million mt.[24] Reported increases in aquaculture and capture fisheries in China account for most of the overall growth in the supply of aquatic products in the last 15 years as landings from capture fisheries have levelled off *(see figure 2)*.

A recent review found that China's dramatic increases in capture fisheries were likely due to overreporting by government agencies responsible for meeting production targets.[25] The reported increases in aquaculture production by China may well reflect similar exaggeration. Given that China reported 71% of the total volume of aquaculture production in 2000, exaggeration of aquaculture production by China would greatly inflate apparent growth in aquaculture production worldwide *(see figure 1)*.

Finfish production: Overall, aquaculture production of finfish grew fourfold in 1985–2000 from 5.2 million mt to 23.1 million mt, nearly all of it freshwater fish. The most rapid growth occurred in Chile, Egypt, China, and Bangladesh. According to FAO statistics, China produced two-thirds of all finfish, followed by India at 9%.

Production of diadromous fish: The production of diadromous fish such as salmon and trout grew threefold in 1985–2000 from 770,700 mt to 2.3 million mt. Canada, Chile and Norway all dramatically increased their production, primarily of Atlantic salmon. The dominant species in 2000 were Atlantic salmon at 39%, milkfish at 20%, Rainbow trout at 20%, and Japanese eel at 10%. The estimated market value of farmed diadromous fish grew 250%, from $1.9 billion in 1985 to $6.7 billion in 2000.

Production of marine fish: The production of marine fish grew 350% in 1985–2000 to one million mt. In 2000, China led in the volume of production with 42% of the total, followed by Japan with 24%, Egypt with 10%, and Greece with 7%. Production was spread among a large number of species, led by Japanese amberjack, flathead grey mullet, gilthead seabream, and silver seabream. The estimated market value of farmed marine fish also grew 350% from $900 million in 1985 to $4.1 billion in 2000. Japan's production accounted for half the value.

Crustacean production: Overall, production of such crustaceans as shrimp and lobster grew more than sixfold from roughly 267,000 mt in 1985 to 1.6 million mt in 2000.

Mollusc production: Farmed production of molluscs, including mussels and oysters, grew more than fourfold from 2.5 million mt live weight in 1985 to 10.7 million mt in 2000. Nearly all of the production is marine. China produced 80% of farmed molluscs in 2000, followed by Japan at 4%.

Aquatic plant production: Aquaculture production of plants tripled from 3.3 million mt in 1985 to 10.1 million mt in 2000, when China produce more than three-quarters of the total.

3: Overview of Salmon Farming

The rearing of fish in captivity is by no means a recent enterprise. For centuries, people have raised fish and shellfish in ponds and coastal impoundments around the world. However, the recent explosive growth in large-scale industrial farming of carnivorous species of fish such as salmon has fundamentally changed the nature of the enterprise and its impact on other wildlife and on the environment.

Artificial reproduction of salmonids, which includes several species of salmon and trout, was first accomplished about 250 years ago.[26] Toward the end of the 19th century, raising salmonids in captivity grew rapidly, as government agencies and private organizations began raising salmonids for release in an effort to increase populations in the wild. Scientists and governments also transplanted salmonids and other species of fish around the world. Many of these techniques were later adapted for raising trout and, much later, salmon for market.[27]

Generally, farming Atlantic salmon has two phases: a freshwater phase and a saltwater phase. In the first, eggs are hatched and the hatchlings transferred to tanks on land. Eggs may be obtained from local operations or from other regions in a country or from other countries. The hatchlings then are raised for 12-18 months until they undergo smoltification. On most farms, the smolts then are transferred to netpens anchored in nearshore waters. There, they are fed pelleted feed until they reach harvestable size after an additional 12-24 months.[28]

Netpens generally consist of a frame made from PVC or steel over which netting is stretched in order to confine the fish. Another net may be strung over the surface to prevent birds from diving for fish. A stronger net may be strung beneath and around the pen to deter marine mammals from feeding on fish and from inadvertently damaging the enclosure.

Individual pens, which may measure 30 meters by 30 meters square with a depth of about 20 meters, are anchored to the seafloor and generally are arranged in double rows of 8, 12, or 20 pens. The number of fish raised at a site depends upon the size of the pens themselves, the total number of netpens, water depth and currents, and any regulatory restrictions.

Although the scale of salmon farms at first was quite small, individual operations now employ dozens of pens in coastal waters that confine hundreds of thousands of salmon. The proliferation of netpens has transformed the character of some areas from near-wilderness to industrial sites, and fundamentally altered the use of these areas by wildlife and by people. As salmon farming in an area intensifies, so do the problems it generates.

The proliferation of netpens has transformed the character of some areas from near-wilderness to industrial sites

THE SALMON AQUACULTURE INDUSTRY

In less than two decades, production of salmon on farms grew enormously from fewer than 50,000 mt in 1985 to more than one million mt in 2000.[29] Indeed, by 1998, farmed production of salmon in coastal waters surpassed production from wild capture fisheries.[30]

The Norwegian government's promotion and subsidization of salmon farming in the early 1980s as a means for rural development laid the foundation for Norway's continuing dominance of world salmon production *(see figure 3)*.[31] In 2000, Norway accounted for 43% of the million mt of salmon produced on farms.

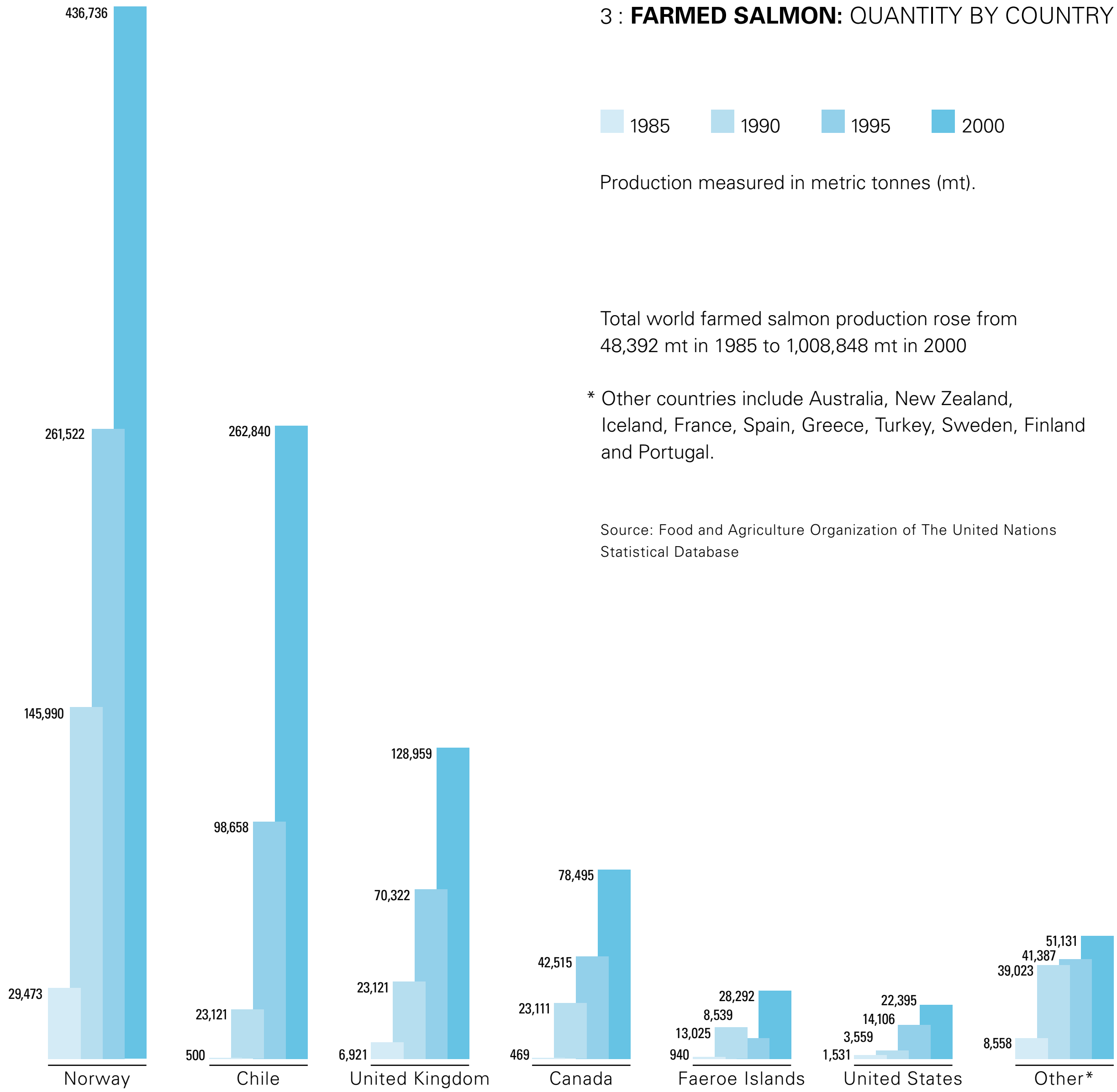
More remarkable than Norway's increase in production has been the increase in production in Chile, which rose from 500 metric tons in 1985 to 263,000 mt in 2000, or 18% of the world total. In all, 14 countries reported farmed salmon production in 2000. Other leaders included the United Kingdom with 129,000 mt, Canada with 78,000 mt, Faeroe Islands with 28,000 mt, and the United States with 22,000 mt.[32] In 2000, 45 commercial farms produced salmon in the United States.[33]

Norway's production of farmed salmon also dominates in market value, fetching $1.2 billion in 2000, or about 38% of the total. Chile's share of total value was greater than its share of total volume largely because part of its production is of coho salmon and trout.

Atlantic salmon has dominated farm production from the beginning. In 2000, 884,000 mt of Atlantic salmon were produced, or 88% of the total.[34] Coho salmon accounted for 109,000 mt, and chinook salmon for 17,000 mt. Over the years, the average wholesale price per pound declined then stabilized for each of the three major species. In 2000, average wholesale prices were $1.41 per pound for Atlantic salmon, $1.71 per pound for coho salmon, and $1.83 per pound for chinook salmon. Declining prices triggered by the flood of farmed salmon has driven prices down for fresh and frozen wild-caught salmon destined for restaurants and fresh-fish markets.[35]

Ownership of the salmon farming industry has become highly concentrated in the last decade. In the early 1980s, in Norway, which has dominated salmon farming until recently, government policy emphasized small fish farms in order to promote rural employment opportunities in remote areas.[36] With this in mind, the government restrained consolidation and growth in the size of individual salmon farms.[37] In 1988, however, the government acceded to industry pressure and allowed individual farms to greatly expand their capacities. The resulting boom in production produced a glut and depressed prices, weakening the financial viability of small farms. Within two years, the government shifted its policy further and relaxed restrictions on corporate ownership of fish farms.[38]

3 : **FARMED SALMON:** QUANTITY BY COUNTRY



Production measured in metric tonnes (mt).

Total world farmed salmon production rose from 48,392 mt in 1985 to 1,008,848 mt in 2000

* Other countries include Australia, New Zealand, Iceland, France, Spain, Greece, Turkey, Sweden, Finland and Portugal.

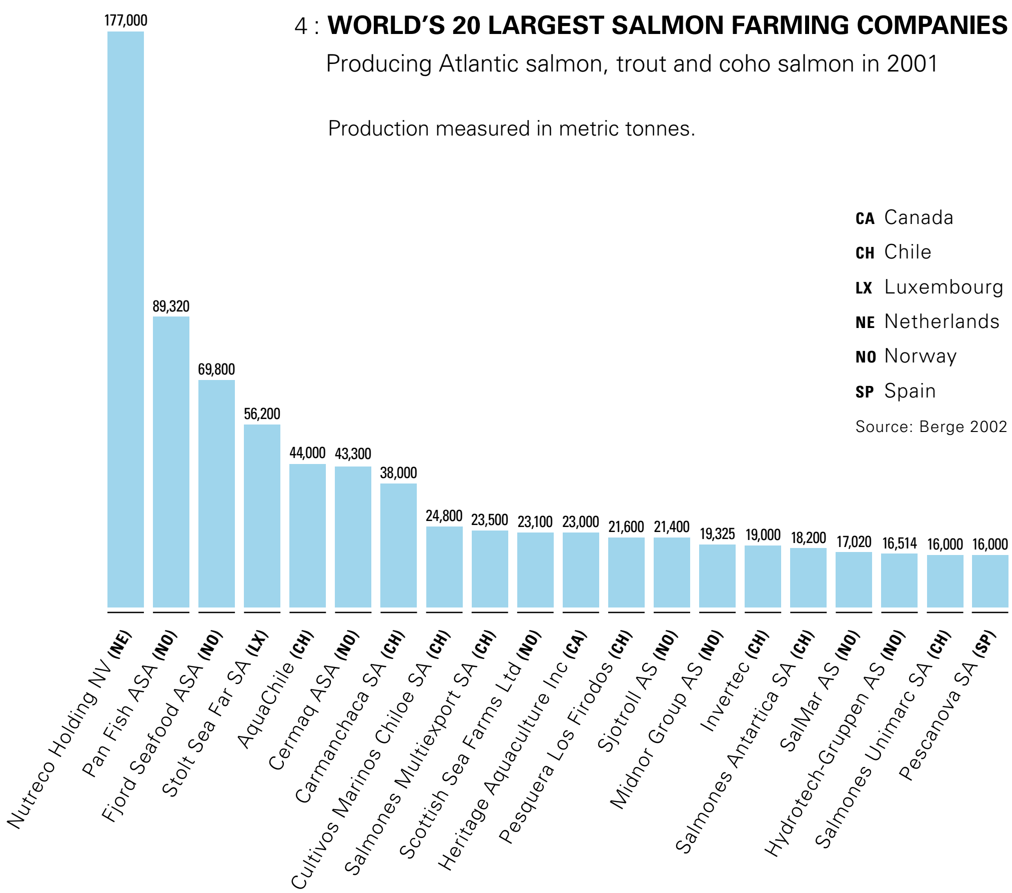
Source: Food and Agriculture Organization of The United Nations Statistical Database

In 2001, 30 companies produced two-thirds of the world's farmed salmon and trout.[39] The top seven companies produced 40% of the world's farmed salmon and trout *(see figure 3)*. Here are brief profiles of several top producers:

- **Nutreco,** a Dutch corporation spun off from British Petroleum, produced 13.4% of global farmed salmon, twice as much as its nearest competitor, Pan Fish ASA.[40] Nutreco's dominance owes something to the fact that it is a fully integrated operation that not only farms salmon, but also manufactures feed, and processes and distributes its salmon and trout. Nutreco owns major salmon farming interests in

Chile, Norway, Ireland, Great Britain, and Australia.[41,42] Together with Cermaq, another salmon producing giant, Nutreco dominates the global fish feed market, and produces chicken and pork as well.

- **Pan Fish ASA,** a Norwegian company, operates marine farms in Norway, the Faeroe Islands, Scotland, the United States, and Canada.[43]
- **Fjord Seafood ASA** is the second largest fish production company in Norway and Chile.[44]
- **Stolt Sea Farm** accounts for one-third of the industrial conglomerate Stolt-Nielsen, which also ships chemicals.[45] Stolt produces farmed salmon in Chile, the United States, Canada, Scotland, and Norway. Besides salmon, Stolt Sea Farm also is engaged in farming turbot, halibut, trout, tilapia, and bluefin tuna, as well as sturgeon for caviar in California.[46,47]
- **Cermaq ASA** has its roots in the Norwegian Government's grain monopoly that was ended in 1995.[48] This primarily



4 : **WORLD'S 20 LARGEST SALMON FARMING COMPANIES**
Producing Atlantic salmon, trout and coho salmon in 2001

agricultural company, which still is 79%-owned by the Norwegian Government, first entered fish farming in 1999.

- **Aquachile S.A.,** which is entirely owned by Chileans, operates hatcheries, smoltification plants, and coastal netpen facilities in Chile.[49] Atlantic salmon makes up 55%, trout 25%, and coho salmon 20% of the company's total production.[50]

The principal markets for farmed salmon are the United States, Japan, and western Europe. Imports of farmed salmon into the United States leapt from $121 million in 1990 to $619 million in 2000, during a period in which wholesale prices declined.[51] In 2001, the volume of imports of farmed Atlantic salmon increased by 13%, while the value increased only 4% to $713 million.[52] Canada and Chile accounted for nearly all U.S. imports of farmed Atlantic salmon.[53]

Although new farming techniques have reduced the costs of production, the growth in the volume of production has reduced prices paid to salmon producers. In many ways, the salmon farming industry has entered a vicious cycle of striving to increase production in order to maintain overall profits in the face of prices weakened by increased production. Once enmeshed in such a cycle, the industry is less likely to invest in addressing problems, such as environmental impacts, that do not help the bottom line of the balance sheet.

SOCIOECONOMIC ISSUES

Proponents often have promoted salmon farming, and other forms of aquaculture, as a means of generating socioeconomic benefits, such as jobs in rural areas. Early growth of the salmon farming industry in Norway was fostered by government programs aimed at promoting job growth in rural areas. More recently, provincial and state governments in Canada and the United States have also characterized salmon farming as a jobs-generator. For the most part, these claims have received much less study than the environmental consequences of salmon farming.

Evaluating the socioeconomic impacts of salmon farming requires a broader scope than measuring impacts in the immediate vicinity of a farm or even a country. This is particularly so because of the rapid growth in the scale and geographical scope of salmon farming. Salmon farming may create jobs in one area or country while reducing jobs in another area or country. Furthermore, as methods of farming salmon have evolved and become more intensive, employment opportunities have declined *(see figure 5).* According to the Norwegian government, the number of people employed in raising salmon from hatcheries to harvest declined 18% between 1994 and 2000, while production of Atlantic salmon and rainbow trout more than doubled.[54]

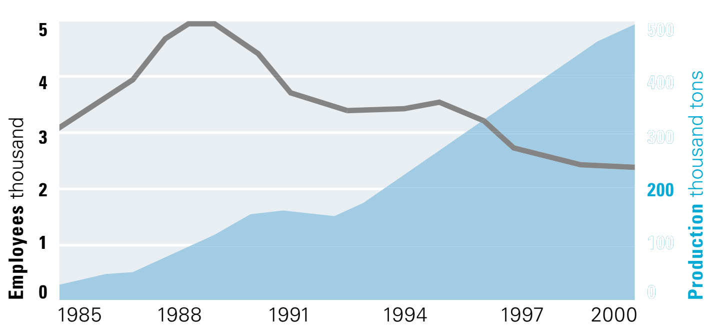
Declining prices caused by the growing glut of salmon farmed in Norway, Chile, and Canada especially has had several negative socioeconomic impacts. In the 1990s, increased imports of low-cost farmed salmon depressed prices paid to commercial fishermen in the United States for competing species such as chinook, coho, and sockeye salmon. Through most of the 1990s, average ex-vessel prices for sockeye salmon remained below $1.50 per pound (in unadjusted dollars), although landings were significantly less than in previous years. The lower prices contributed to such financial instability in fishing fleets along the Pacific coast of the United States that many fishermen simply went out of business, with dramatically negative effects on the economies of rural coastal communities.

Lower prices caused by gluts also are likely to contribute to financial uncertainty for salmon farmers. Small-scale salmon farmers or those who otherwise invest in environmentally preferable production methods are not likely to survive in such a subsidized environment. The race that gluts and low prices fuel also fosters further consolidation of the industry by transnational corporations for whom the status of local environments, wildlife, and economies are likely to be secondary concerns to meeting short-term financial objectives.

It is true that fish farmers are responding to apparent demand from consumers. However, in the industrialized countries, demand often is a creation of sophisticated marketing that seeks to generate demand for product where demand lags supply. Once created, markets may trigger changes in food production thousands of miles away, which themselves have both environmental and socio-economic impacts.

5 : **EMPLOYMENT AND PRODUCTION** IN NORWAY

Farmed salmonids 1985-2000



Source: Norwegian Directorate of Fisheries 2001

4: Environmental Issues

Like other forms of intensive food production, industrial-scale farming of salmon and other carnivorous fish generates environmental and social costs. The extent of these costs depends on such factors as the scale, intensity, and duration of a farming operation, the biological and oceanographic setting, and other past or existing activities in an area.

These costs are rarely evaluated before farming begins or expands. Rather than acting in a precautionary manner, industry and government have largely ignored the risk of damage associated with our lack of knowledge and have expanded farming even in the face of growing evidence of harm. In this way, government and industry plans for expansion of salmon farming have followed the pattern of expansion in capture fisheries over the last several decades—a pattern that has proved ruinous to many fisheries.[55]

In some cases, the consequences of addressing problems caused by salmon farming after the fact have been minor, but in other cases, impacts have been devastating.

The following discussion surveys environmental problems associated with intensive farming of salmon in netcages in coastal waters. Many of these problems were once matters of hypothesis but now are matters of documented fact. Similar problems can be expected in the farming of other carnivorous species in coastal netcages, if industry and government do not adopt a precautionary approach. Unfortunately, it appears as if government and industry have learned little from experience and are investing in increasing production of carnivorous species rather than in understanding and addressing the environmental impacts.

DISPLACEMENT OF WILD POPULATIONS

Large numbers of farmed fish regularly escape from netpens each year. Once escaped, farmed fish can reduce the viability of wild populations, particularly those that have always been small or that have been reduced by overfishing, habitat loss by dams, or other causes.

Each year, hundreds of thousands of salmon escape from cages in coastal waters, when netting is torn open by storms, accidents, or marine mammals. Because most jurisdictions do not require salmon farmers to report the escape of farmed salmon, estimates of escaped salmon must be regarded as conservative.[56,57,58] Although the design and siting of netpens have improved—and possibly reduced—the rate at which farmed salmon are released into the wild, the continued growth in the number of netpens has kept the number of escaped salmon very high—often higher than the number of wild salmon in a particular population.[59]

Like other forms of intensive food production, industrial-scale farming of salmon and other carnivorous fish generates environmental and social costs…that are rarely evaluated before farming begins or expands

Atlantic salmon in the Pacific

Proponents of expanded salmon farming in the Pacific Ocean have maintained that escaped Atlantic salmon will not colonize habitat used by native Pacific salmon.[60] In support of this view, the lack of success in previous efforts to introduce Atlantic salmon into the Pacific Northwest is cited.[61,62]

The lack of knowledge about which factors caused these failures argues against accepting this view as a guide for policy.[63] Indeed, there are a number of cases of successful translocation of salmon, including pink and chinook salmon into the Great Lakes and of chinook salmon into New Zealand.[64]

Previous attempts to introduce Atlantic salmon into the rivers of British Columbia may well have failed because wild salmon populations were still large enough to occupy all suitable habitats, leaving none for introduced species.[65] This happy situation no longer holds for many salmonid populations, such as steelhead on Vancouver Island, whose populations have been greatly reduced in the last century. Unlike conditions several decades ago, suitable habitats are no longer a limiting factor for introduced Atlantic salmon.

Furthermore, past efforts to introduce Atlantic salmon into the Pacific Ocean generally were sporadic and lasted one or just a few years. Recent unintentional releases of Atlantic salmon from farms have occurred regularly for several years, thereby maintaining the competition for habitat with wild salmon.

In any event, the question whether escaped Atlantic salmon could reproduce in the northeast Pacific was settled in 1998 when four juvenile Atlantic salmon were captured in the Tsitika River on the northeast coast of Vancouver Island.[66] Atlantic salmon were found feeding on the same prey as steelhead trout of the same size. Analysis demonstrated that these Atlantic salmon were the offspring of Atlantic salmon that had escaped from salmon farms in the area, survived, ascended the Tsitika River and successfully reproduced.[67]

Successful reproduction by escaped farmed Atlantic salmon was later documented in two additional rivers.[68] Of these three rivers, two support at least two year-classes of juveniles, suggesting the possibility of self-sustaining populations of Atlantic salmon in the near future.

Escaped salmon can have both ecological, health, and genetic effects on wild salmon populations, and thus represent a major threat to wild populations.[69] Indeed, in a review of salmon farming for the Government of Scotland, the Scottish Association for Marine Science and Napier University, concluded that "the current level of escapes is probably unsustainable in terms of the health of wild populations."

In the Bay of Fundy, for instance, runs of wild Atlantic salmon from 33 rivers in the inner Bay fell from as many as 40,000 salmon in the 1980s to a few hundred in 1999.[70] Between December 1999 and December 2000 alone, newspapers reported the escape of nearly a quarter of a million Atlantic salmon from farms in Cobscook Bay, Maine (the principal salmon farming region of the United States), and in the Bay of Fundy in Canada.[71] These were only the most recent escapes of farmed salmon in the region. Adult salmon of farmed origin now make up more than half of the salmon entering Maine's rivers from the sea.[72]

Similar trends and dynamics between farmed and declining wild salmon populations have been documented elsewhere. In Norway, nearly half of the female Atlantic salmon that spawned in the rivers Vosso and Bolstadelva in 1995 were of farmed origin.[73] Salmon escaped from farms account for 20-40% of the salmon catches off the Faeroe Islands.[74]

A growing number of other carnivorous fish species are being raised in netpens as well. Though this development is relatively recent, escapes of farmed fish from these operations already have been documented.[75] For the most part, the potential impacts on wild populations of the same or other species have not been evaluated.

GENETIC IMPACTS

Once they have escaped from netpens, farmed fish may breed with wild fish, thereby introducing their farm-adapted genetic make-up into wild populations whose own genetic make-up reflects adaptations to environmental conditions over millennia.

In contrast to the great reservoir of genetic and behavioral diversity in wild salmon, farmed Atlantic salmon have been drawn from only a few wild strains. Currently, 70% of the eggs used in salmon farms in Norway and half of the eggs used elsewhere in the world derive from descendants of one or two wild populations in Norway.[76,77,78]

Unlike salmon in the wild that have adapted over millennia to enormously diverse environmental conditions, salmon bound for farms have been bred to meet the demands of producing for markets that emphasize uniformity and year-round availability.[79,80] Breeding programs also remove traits that may be critical to the long-term survival of a run in the wild but are undesirable for farming.[81]

Transgenic salmon

In recent years, aquaculturists have introduced genes from other species into the genes of 35 different species of fish to increase cold tolerance, growth and feed efficiency, and disease resistance.[82,83]

In the United States, Aqua Bounty Farms has applied for permission from the Food and Drug Administration (FDA) to market transgenic Atlantic salmon that carry a growth-hormone gene from chinook salmon.[84,85] Salmon injected with the chinook gene and a so-called promoter sequence produce growth hormone year-round rather than only in spring and summer.[86] As a result, these fish grow six times faster, and their offspring grow even faster, reaching market size in 18 months rather than 24 to 30 months.[87,88,89]

Recently, the FDA requested that the National Research Council (NRC) evaluate and prioritize the risks associated with transgenic organisms.[90] The NRC panel expressed the greatest concern about the escape of transgenically modified fish (often called "GMOs") into the wild and the introduction of the engineered genes into wild populations.[91] Like escaped salmon bred through conventional means escaped transgenic salmon could well compete with wild salmon for shelter and food.[92,93]

The NRC panel observed that transgenic fish might reduce the use of fishmeal in feeds and might thereby reduce waste discharged from salmon farms. But the panel also expressed concern that the rapid growth rate of transgenic salmon, increased rate of food consumption, and increased uptake of oxygen indicate that they may be more fit than wild salmon.[94] This additional, increased demand could deplete the food for both transgenic and wild salmon in streams with a limited food supply, jeopardizing the survival of both.[95,96]

Furthermore, among salmonids, size matters in determining dominance in streams.[97,98,99] In experiments, larger salmon were more aggressive and active in courting, and larger females were more aggressive and active in being courted.[100] While transgenic fish may be more successful in reproduction as a result, their offspring may be less fit for survival, for a variety of reasons. The result of such a combination is likely to be a gradual spiraling down of both transgenic and wild populations—a so-called "Trojan gene effect".[101,102,103,104]

If transgenic fish were to breed with wild fish, the transgene could well spread throughout the wild population.[105] If the transgenic fish is more fit for survival than the wild fish, or if the wild population is quite small, the transgenic fish might eventually replace its wild relative or become established in its habitat.[106] Aqua Bounty Farms argues that it will prevent interbreeding by selling only sterile female salmon.[107] However, conventional techniques for making fish sterile leave a small percentage of females capable of producing eggs that can be successfully fertilized by wild male salmon. Also, wild male salmon may attempt to mate with sterile females, diverting their reproductive potential from maintaining the wild population.[108,109,110]

In the end, the NRC panel concluded that there was "a considerable risk of ecologic hazards becoming realized should transgenic fish or shellfish enter natural ecosystems." The panel also expressed great concern about the capacity of Federal agencies and the relevance of Federal statutes to regulate animal biotechnology.[111]

After several generations, salmon bred for farms can differ greatly from the population from which they were originally drawn in size and shape, behavior, growth, and life history.[112] These changes can become part of the genetic makeup that farmed salmon pass on to offspring that result from mating with other farmed or wild salmon.

In some areas, the genetic makeup of salmon in farms has been further confounded by combining different strains. By using milt from European salmon, aquaculturists in Canada and Maine have further hybridized salmon in their farms, so that Atlantic salmon raised in farms there now are 30-50% European.[113,114] The escape of these salmon into the wild presents a clear risk to those remaining wild Atlantic salmon in Maine that recently were listed as endangered species.

In general terms, the flow of genes within a population maximizes genetic diversity of a species, while the flow of genes between different populations will eventually reduce overall diversity of a species.[115] Thus, when breeding occurs between wild salmon and escaped farmed salmon, the genetic makeup of the two populations will converge, leading to a loss in genetic diversity.

If farmed salmon were to escape in small numbers and breed infrequently, such convergence and loss, which takes place over several generations, would be unlikely. However, farmed salmon escape in large numbers each year, thereby exposing wild populations to repeated intrusion. Furthermore, hybrid progeny of farm-wild parents themselves can survive to adulthood and breed with other hybrid salmon, newly escaped farmed salmon, or wild salmon, with the potential of further eroding the wild strain.

In the end, repeated interbreeding of farmed and wild salmon will shift the genetic profile of wild salmon toward domestication and dramatically reduced genetic diversity between and within wild populations.[116,117] Studies in Norway indicate that the difference in some genetic traits between escaped farmed salmon and wild salmon will be halved in little more than three generations.[118] While the precise genetic effects of interbreeding cannot be predicted, they have had a negative effect where they have occurred.[119] For instance, in northern Ireland, interbreeding of farmed and wild salmon resulted in changes in the genetic profile of a small population wild Atlantic salmon.[120]

In farming other species of carnivorous fish, farmers will also breed fish to survive and reproduce in captivity. Quite soon, farmed fish of these other species will have a very different genetic make-up from their wild counterparts. Escape of these fish into the wild may undermine the genetic integrity of wild populations.

PARASITES AND DISEASES

In the crowded conditions of netpens, pathogenic organisms that occur at low levels in the wild, or not at all, may reach epidemic proportions. In addition to killing tens of thousands of farmed salmon each year, disease and parasites can be transferred to wild fish populations.

Parasites: Because it is difficult to monitor diseases in the wild, only circumstantial evidence is available that parasites can spread from farms to wild populations of salmon. Nonetheless, the evidence is quite strong.[121]

Since the 1980s, salmon farms in the North Atlantic have regularly suffered infestations by sea lice *(Lepeophtheirus salmonis)* that can cause serious tissue damage and kill salmon even in small concentrations.[122] Epidemics of sea lice cost the salmon farming industry millions of salmon each year. Generally, marine fish farms pick up sea lice from resident salmon, then reinfect themselves.[123] Salmon farms can also contribute to epidemics of sea lice in wild populations, particularly where pens are sited in migratory routes of wild salmon.[124]

Sea lice infestations remain a major threat to farmed salmon and wild salmonids in the North Atlantic.[125] In Scotland, the concentration of sea lice near salmon farms has been associated with declines in populations of wild sea trout *(Salmo trutta)*.[126]

In 2002, an independent panel reporting to the Canadian government concluded that infestation by sea lice from salmon farms was the probable cause for an extraordinary decline in the number of pink salmon that returned to the Broughton Archipelago, BC.[127]

Diseases: Fish raised in crowded conditions also are susceptible to viral and bacterial diseases, which can be transmitted to wild fish.[128] One example of this transmission was the reintroduction of the bacterial disease furunculosis to Norway through imports of farmed fish from Scotland in 1985.[129] The rapid spread of the disease to salmon in farms and in the wild along the coast of Norway coincided with the escape of large numbers of salmon from farms.[130] The disease decimated salmon in farms and in the wild.

Other diseases that occur in salmon farms, such as infectious pancreatic necrosis (IPN) and infectious salmon anemia (ISA), may also be transmitted to wild salmon. ISA, which can be spread by live fish, fish parts, contaminated equipment, sea lice, and people handling infected fish, may cause high mortality.[131] First documented in Norway in 1994, ISA was later found at salmon farms in New Brunswick and in farmed and wild salmon in Scotland, Nova Scotia, and the Faeroe Islands.[132,133,134] In 2001, ISA was documented in salmon farms in Cobscook Bay in Maine, leading to the destruction of all salmon in netcages and a multi-million dollar government bailout of the industry.[135,136]

A general lack of monitoring likely prevents the detection of other outbreaks in the wild and the evaluation of possible links with salmon farms. Likewise, it is not possible to assess the overall effect of diseases transmitted from farmed salmon on wild salmon populations nor of the vaccines and chemicals used to combat outbreaks of disease.[137]

EFFECTS ON OTHER WILDLIFE

Confining large numbers of fish in coastal netpens attracts marine wildlife that can become entangled in protective nets. Lethal and other measures to deter wildlife from netpens often have direct and indirect negative effects on local wildlife populations.

Fish confined in large numbers in net cages attract predators, including seals, sea lions, sharks, and seabirds. Farmers use several methods to prevent marine mammals from preying upon salmon, damaging nets and releasing salmon. Farmers may enclose smaller netpens in a second "predator" net, for instance.[138] Alternatively, farmers may use acoustic devices that emit high powered sounds underwater that marine mammals find unpleasant. Where these techniques fail to deter seals and sea lions, farmers may shoot animals. (Under the Marine Mammal Protection Act, salmon farmers in the United States are prohibited from shooting seals.)

Besides deterring seals and sea lions from net cages, the high-pitched sounds emitted by acoustic devices can be painful to dolphins, porpoises, and whales, effectively excluding them from areas that may be important to them.[139,140]. Several Canadian studies found that harbor porpoise and killer whales avoided waters within 10 kilometers of an acoustic device.[141,142] The effect of acoustic harassment devices on seabirds, fishes, or invertebrates has not been investigated.[143]

Intensive aquaculture of carnivorous species also can have other, less direct effects on other marine wildlife. The chief of these is the impact on marine ecosystems from the removal of large amounts of forage fish, such as sardines and anchovies, for the production of fish feeds.[144] Such impacts generally are difficult to demonstrate given the lack of monitoring. Combined with declines in the abundance of anchovies caused by El Niño, heavy fishing on anchovies off Chile and Peru has been implicated in large declines in populations of seabirds and their failure to recover.

Confining other species of carnivorous fish in netpens, whether they be bluefin tuna or sablefish, will attract other marine wildlife and will likely create many of the same problems as have been created by salmon netpens.

AQUACULTURE WASTES

Much of the feed used in farming salmon and other carnivorous species enters surrounding waters as uneaten feed or feces. Depending upon oceanographic conditions, these wastes can pollute bottom habitats and organisms.

In general, between 15% and 20% of feed used at salmon farms enters the surrounding environment uneaten, although at the best-run farms, feed losses have been reduced to as little as 5%.[145,146] Feed also enters the environment as feces from salmon. In producing a total of 31,964 mt of salmon in 1995, salmon farms in British Columbia, Canada, released into the environment an estimated 5,178 mt of feces and 6,440 mt of uneaten fish feed.[147]

Increased use of fish oil in feed, improved husbandry practices, and improved feed conversion ratios have reduced wastes generated by individual salmon farms. However, where the number and size of farms have increased, waste effluents from farms overall probably have not declined to the same degree and can remain quite significant regionally.

The scale of environmental impact from wastes will depend upon the size of the farm, the density of fish per pen, the duration of the farm at a particular site, the physical and oceanographic conditions at the site, the biota of the area, and the capacity of the environment to absorb the wastes. Determining the impacts of wastes in a particular area beforehand has not been a priority of government or industry and, as a result, the tools for modelling such impacts have not been developed.

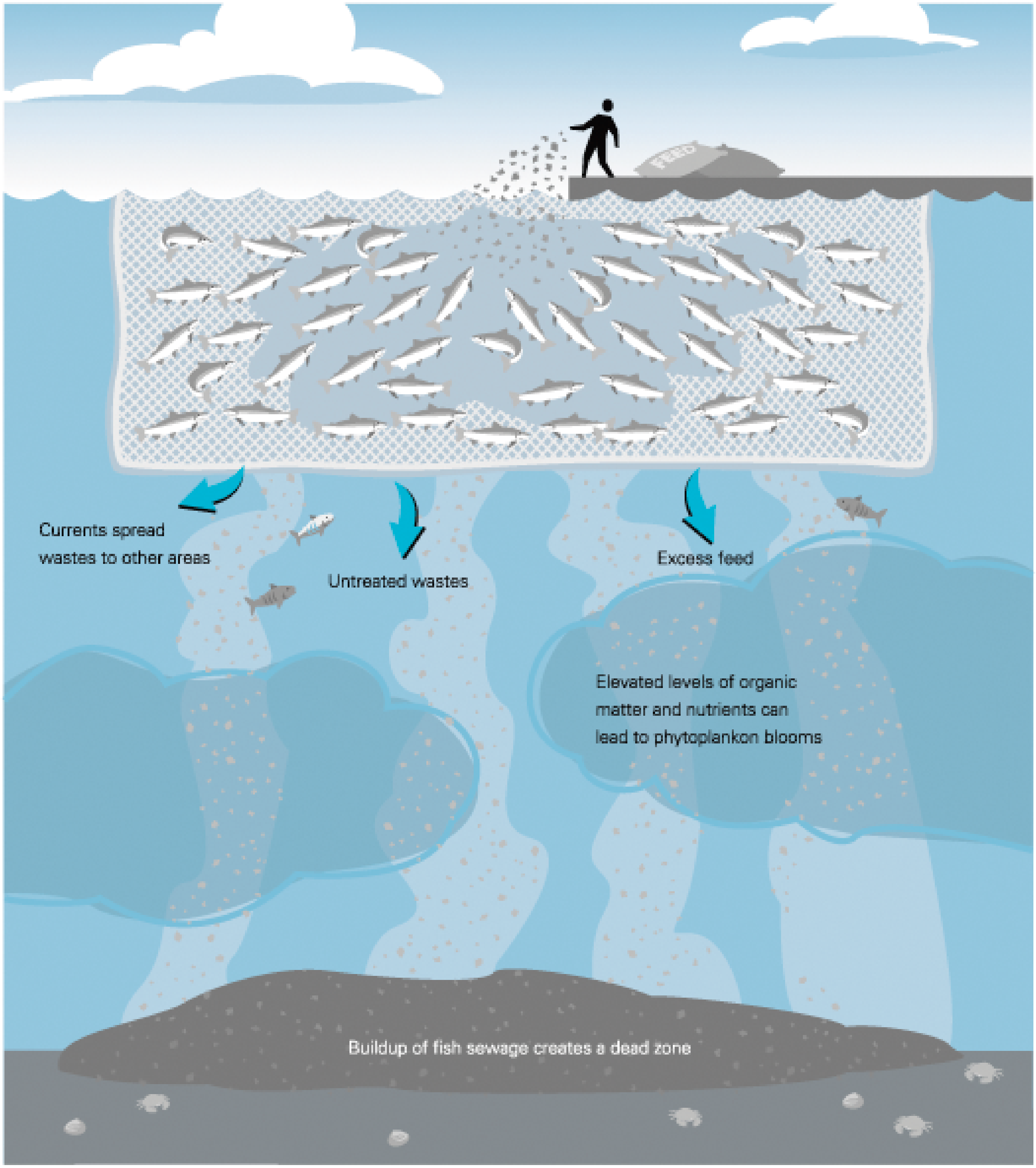
Nutrients in feces and wastes from lost feed can accumulate beneath and near salmon cages. As bacteria degrade nutrients, they consume oxygen in sediments.[148] If waste levels are high enough and overwhelm the capacity of animals that feed on such detritus, sediments can become anaerobic and the water immediately above hypoxic. In extreme situations, the diversity of animals in the sediments declines and includes only animals that can tolerate polluted conditions.

Where there is little flushing of the area by tides and currents, wastes from netpens can create a dead zone beneath the pen. In other situations, the impact on the seabed may be minimal. Beyond the bottom beneath the pen itself, impacts may extend between 100 and 500 feet.

Depending upon the scale and duration of salmon farming and the oceanographic characteristics of an area, it takes between a few months and five years before benthic communities recover their diversity and abundance after cessation of salmon farming.[149,150,151,152]

The impacts of wastes from farming other carnivorous species in netpens have received even less attention than salmon farming, but can be expected to be similar in nature and scale.

6 : WASTE STREAM POLLUTION FROM FARMING FISH IN NETPENS



Much of the fish feed is excreted as waste, and a significant portion of uneaten food sinks to the bottom. Wastes can smother life on the seafloor as well as result in elevated levels of organic matter and nutrients in the water column. It has been estimated that a typical salmon farm produces as much waste (fecal solids) as 62,505 people, all of it discharged into the surrounding water. Source: Hardy, *Aquaculture Magazine*, Nov/Dec 2000

CHEMICALS AND ANTIBIOTICS

Like other aquaculturists, salmon farmers use pesticides and other chemicals, as well as antibiotics, whose environmental and ecological effects are poorly understood. Government controls and reporting requirements regarding the use of chemicals and antibiotics remain spotty.

Aquaculturists use pesticides and other chemicals to combat outbreaks of disease and epidemics of parasites that can cause losses. The environmental and ecological effects of these compounds remain largely unstudied, while the amounts and frequency of their use are largely unreported.[153,154,155,156] Generally, governments impose few controls on the use of chemicals and drugs, and carry out only limited monitoring for compliance.[157] This absence of information creates uncertainty that makes an evaluation of impacts and risks imprecise.[158]

Sea lice treatments: Because sea lice infestations can reduce the market value of farmed salmon production by as much as 20%, salmon farmers employ husbandry practices and chemicals to control sea lice.[159] Some farmers break the cycle of the infestation by fallowing their sites.[160] More frequently, salmon farms use chemical treatments to control sea lice. As recently as 1998, eleven different compounds of five different pesticide types that vary in effectiveness were used in combating sea lice.[161,162] All but one of these compounds, which were originally developed for terrestrial agriculture, are toxic to aquatic invertebrates and/or fish.[163]

Some compounds are applied in a bath, while others are mixed in feed.[164] When these compounds are applied as a bath, a solution containing the compound is released into a netpen which often has been enclosed within a tarpaulin. After the treatment, the tarpaulin is withdrawn and the solution is released into the environment. When applied through feed, these compounds may enter the environment in uneaten feed or in feces. Because sea lice frequently reestablish themselves, treatments must be repeated.

For the most part, farmers are not responsible for reporting outbreaks of sea lice or the use of these chemicals. As a result, little is known about how much of these compounds are used in salmon-farming countries, with the exception of Norway.[165] A recent study for the Government of Scotland expressed concern that continued growth in the number of salmon in farms would outstrip the efficacy of even the most effective chemicals in protecting wild Atlantic salmon populations from sea lice infestation.[166]

Little research has been conducted on the lethal and sublethal effects of these compounds. What studies have been conducted suggest that crustaceans are the organisms most sensitive to these pesticides and that organisms are more vulnerable earlier in life than later.[167] More recent studies have found that one pesticide licensed in several countries for combating sea lice on farmed salmon triggers premature molting by egg-bearing lobsters.[168] Furthermore, compounds used in bathing solutions, like other pesticides, include other "inert" ingredients as solvents or carriers for the pesticides.[169] These inert ingredients can be more toxic than the active ingredients.[170,171]

Antibiotics: Farmed salmon also are vulnerable to bacterial infections such as bacterial kidney disease, furunculosis, and bacterial septicemias. Salmon farmers and other fish farmers treat outbreaks of these and other diseases with various antibiotic compounds, chiefly oxytetracycline, oxolinic acid, trimethoprim, sulphadiazine, and amoxycillin.[172] These compounds may be incorporated into feed and applied intermittently for up to two weeks, or applied as a bath.[173,174]

The use of antibiotics in salmon farming appears to be declining as vaccines have been developed.[175] In Norway, where antibiotic use has been documented, the amount of antibiotics used in salmon aquaculture declined from 48,000 kg per year in 1987 to 680 kg per year in 1998, while salmon production grew dramatically. This decline in volume of antibiotics is due partly to the use of more potent antibiotics.[176] Elsewhere, little information is available on the use of antibiotics in salmon farms.

Antibiotics in feed can enter the water either directly in uneaten food or indirectly in the feces of treated animals.[177,178,179] Because antibiotics bind with particles, they can accumulate beneath salmon cages where fish have been treated.[180] Antibiotics may persist in sediments from a day to 1.5 years.[181] Depending upon environmental factors, the accumulation of antibiotic residues in sediments may reduce microbial degradation of uneaten feed and feces beneath salmon cages, fostering anaerobic conditions.[182]

Several studies found antibiotic residues in wild fish around salmon farms that were above recommended levels.[183] For instance, oxolinic acid was found in the tissue of pollock, wrasse, crabs, and mussels up to two weeks after treatment of salmon in net farms.[184]

Metals: Salmon and other fish farms paint or wash their nets and structures with compounds to slow the buildup of fouling organisms.[185] Many of these compounds are based on copper, which can be toxic to benthic plants and animals.

Fish feed includes metals such as zinc, copper, cadmium, and mercury as supplements or as part of the meal upon which the feed is based.[186] Surveys in Scotland found concentrations of some metals beneath some salmon cages that were likely to cause damage to benthic invertebrates, such as worms and clams.

FEEDS AND FEED CONVERSION RATIOS

Farming carnivorous fish results in a net loss of fish protein. Unlike farmed herbivorous and omnivorous fish, such as carp, catfish, and tilapia, which consume a plant-based diet, farming carnivores requires a diet containing large amounts of fishmeal and fish oil. Even with improvements in feed and breeding, three pounds or more of wild fish are still required to produce one pound of farmed salmon or other carnivorous fish.

Most fish and shellfish farmed around the world feed on plants, either directly or in food pellets. As a result, farming most freshwater finfish species, including carp, milkfish, tilapia, and catfish, produces more fish than is consumed in the form of fishmeal and fish oil in feeds.[187,188] By contrast, most marine and diadromous finfish species, which are carnivorous, consume large amounts of fishmeal and fish oil and are net consumers of fish.[189,190] Depending upon the species, fish food will also include more or less plant material, vitamins, amino acids, minerals, medications, and pigments.[191]

Most fishmeal and fish oil is manufactured from anchovies, sardines, capelin, and sandeels.[192,193] The opportunity for future increases in catches of fish for the production of fishmeal and fish oil are limited.[194]

As aquaculture production has grown, fishmeal and fish oil have been diverted from other uses, such as feed for pigs and poultry or as hardening for budget margarines.[195] In 2000, aquaculture consumed 35% of the world's annual production of fishmeal and 57% of the fish oil.[196] Fish oil is particularly important in intensive aquaculture because it strengthens the immune system and increases tolerance to crowded conditions.[197] The balance of fishmeal is used principally by the livestock industry, while fish oils not used in aquafeeds are mostly directed to human consumption in food products. If the current rate of growth in consumption continues, aquaculture will account for 56% of the world's annual production of fishmeal and 98% of the fish oil by 2010.[198]

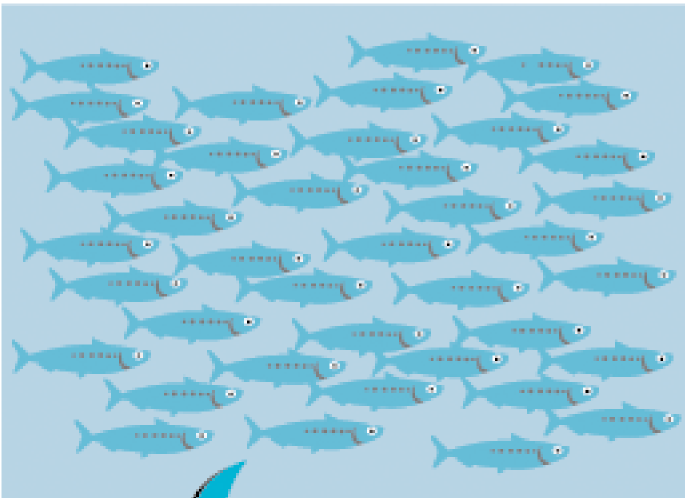
In recent years, a debate has arisen over the net gain or loss in protein produced by farming carnivorous species of fish such as salmon.[199,200,201] This debate is part of a larger debate over the efficient use of all types of resources, from money to energy, in food production.[202] *(See Appendix for additional discussion.)*

One approach to this controversy is to analyze the efficiency of food production, as measured by the feed conversion ratio or FCR of salmon and other animals. The term feed conversion ratio generally is defined as the amount of feed required to produce one unit of animal product. Because fish are cold-blooded and have low metabolic rates, they are more efficient in converting feed to tissue than are other animals.

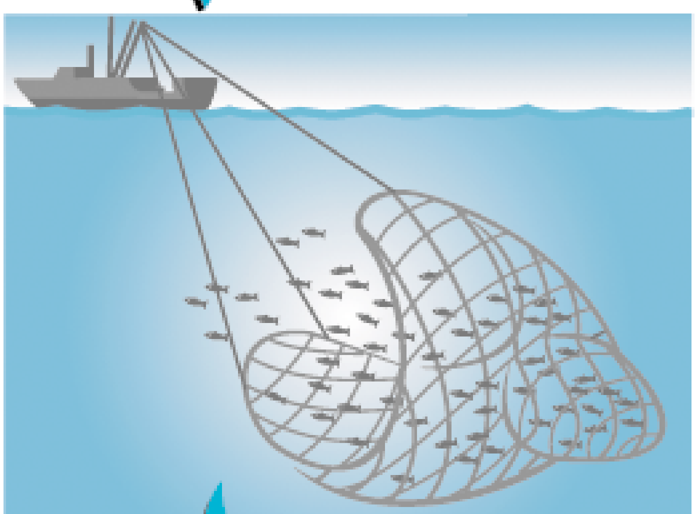
Generally, as greater knowledge is gained about the dietary requirements of individual species, the amount of feed and of ingredients such as fishmeal and fish oil can be reduced.[203] However, such

7 : **NET LOSS** FROM OCEAN TO PLATE

Farming carnivorous fish such as salmon results in a net loss of fish protein since they are fed a diet rich in fishmeal and fish oil obtained from wild fisheries. In 2000, the production of 876,000 mt of farmed salmon required fish oil manufactured from 2.5 million mt of small pelagic fish. Put another way, **approximately three pounds of small wild fish are taken from the oceans to produce only one pound of farmed salmon.**



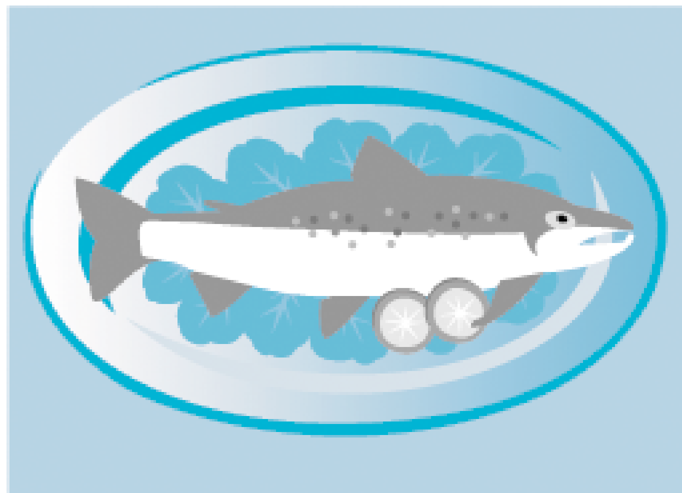
Small pelagic fish such as anchovies and sardines are caught by industrial fishing fleets.



The small fish are processed into fishmeal and fish oil.

Fish raised in densely packed netpens are fed manually or by machine. Food waste and excretion pollute the surrounding water (see figure 6).

After about two years, the salmon are harvested and transported to market primarily from Norway, Chile and Canada.



knowledge comes only very slowly. Even after two decades of intensive farming, knowledge about key elements in the nutrient requirements of Atlantic salmon is lacking.[204]

Although breeding and husbandry have improved the feeding efficiency of farmed salmon over the last two decades, the reduction in nominal FCRs owes much to the substitution of fish oil for fishmeal in feeds.[205] Because it takes nearly twice as much fish to produce a pound of fish oil as it does to produce a pound of fishmeal, the reduction in FCRs have been offset by an increase in the amount of fish needed to produce the feed for salmon.[206] According to an analysis by the David Suzuki Foundation, the amount of wild fish required to produce salmon feed has actually increased by 11% since 1980.[207] Even at the FCRs of 1:1, two to five pounds of wild fish are still required to produce one pound of farmed salmon.[208]

The potential for substituting vegetable oils for fish oil is limited as well. Besides affecting the flavor and physical quality of the meat, vegetable oils may also compromise the immune system of fish.[209] More importantly, however, substituting vegetable oils for fish oils changes the composition of the fat in farmed fish, reducing the amount of healthy omega-3 fat and increasing problematic omega-6 fat.[210] Developing plant substitutes for fish oils has faced a number of other obstacles, including the absence of essential amino acids and essential fatty acids.[211]

If forage fish are not converted to fishmeal and fish oil to feed salmon, other carnivorous fish species, poultry, or cattle, what might they be used for? In the past, there have been repeated efforts to expand markets for the direct consumption of forage species such as herring and anchovies either as canned or smoked products or as protein powder.[212] For the most part, these efforts have met with limited success.[213,214] However, given expected increases in worldwide demand for protein and limited alternatives, such products may well account for a greater share of fish supply for direct human consumption in the future.[215,216]

The relative abundance, low cost, and high nutritional value of many species makes them particularly attractive candidates as sources of protein and healthy fats in both developing and developed countries.[217] Recently, the FAO and Peru's national fish institute began promoting proper handling of anchovies by fishermen as a means of fostering consumption of anchovies by Peruvians of all economic classes.[218]

As importantly, forage species play a critical role in marine ecosystems that support populations of marine mammals and seabirds as well as commercial and recreational fisheries. Furthermore, considering the fuel and other resources required to catch and process forage fish into fishmeal, not to mention other resources consumed in farming salmon and other carnivorous species, it may well make better sense to let marine ecosystems feed commercially desirable fish, instead.

5: Human Health Issues

NUTRITIONAL QUALITY

For several decades, government agencies, nutritionists, and doctors have urged reduced consumption of saturated fats found principally in animal products. However, nutritionists have made an exception with marine fish, because the fatty acid omega-3 in the tissue of many types of marine fish provides unique and significant health benefits. Other similar fatty acids, such as omega-6, can aggravate health problems.[219]

According to a recent analysis, the flesh of farmed salmon had significantly more fat than did wild salmon, reflecting the high levels of fish oil in salmon feed.[220] Fat levels in farmed salmon even exceeded fat levels in jack mackerel and anchovies used in the production of fishmeal and fish oil.[221] Furthermore, farmed Atlantic salmon had the lowest ratio of omega-3 to omega-6 fatty acids of all species analyzed.[222] For this reason, the analysis concluded that farmed Atlantic salmon was, nutritionally, the least desirable of the fish tested.[223]

CONTAMINANTS

In recent years, concerns have arisen over levels of dioxin, polychlorinated biphenyls (PCBs), and other chemicals in fish oils from northern hemisphere fish.[224] Because

In recent years, concerns have arisen over levels of dioxin, polychlorinated biphenyls (PCBs), and other chemicals in farmed salmon

8 : **FAT COMPOSITION** Comparison among various fish

Based on a 100 gram serving of raw fish

	Farmed Atlantic salmon	Wild Atlantic salmon	Farmed coho	Wild coho	Wild chinook	Wild chum	Wild pink salmon	Wild sockeye	Wild mackerel	Wild anchovies
Total fat content (grams)	10.85	6.34	7.67	5.93	10.44	3.77	3.45	8.56	7.89	4.84
Ratio of omega-3 to omega-6 fatty acid	1.1	3.9	2.3	3.2	4.1	4.7	5.2	2.3	5.0	9.3
% of total fat that is omega-3 fatty acids	**18%**	**32%**	**17%**	**25%**	**16%**	**20%**	**33%**	**15%**	**20%**	**33%**

Source: Bell and Paone 2001

these chemicals persist in the environment, they are now ubiquitous.[225] Some of these chemicals, such as PCBs and dioxin, are considered among the most toxic of man-made chemicals and are thought to cause cancer, disrupt the endocrine system, cause developmental and reproductive problems, and other health problems.[226] Government restrictions on the production of these chemicals have led to a general decline in their presence in the environment and in humans, who are exposed primarily through food.[227] For the most part, foods in the United States and elsewhere are not screened for the presence of these chemicals, partly due to the expense of such tests.[228,229]

Fish and their prey in polluted waters accumulate these chemicals in their fat.[230] As fish higher in the food chain consume contaminated fish, whether in the wild or in the form of fishmeal or fish oil, these chemicals bioaccumulate. Because of their significantly higher fat content, salmon are particularly likely to accumulate such chemicals.[231]

It is not surprising then that contamination by dioxins, PCBs, and polycyclic aromatic hydrocarbons has been found in farmed salmon fed fishmeal and fish oil manufactured from forage fish from polluted waters.[232,233,234]

Studies of residues in the tissue of farmed fish are limited in the United States and elsewhere. One small Canadian study of farmed salmon found levels of these chemicals three to six times the levels recommended by the World Health Organization.[235] A more recent study of Scottish salmon found “surprisingly high” levels of PCBs.[236] Sampling in the United Kingdom has found detectable levels of such toxic chemicals as DDT and chlordane in nearly all samples of farmed salmon.[237] In contrast, toxic chemicals were found in only one-quarter of canned wild salmon.

ANTIBIOTICS

Key concerns regarding the use of antibiotics in aquaculture have to do with the development of resistance to antibiotics and the presence of antibiotics in wild fish and shellfish harvested from areas surrounding fish farms. For the most part, these impacts have received little study.[238]

Bacteria may develop resistance to specific antibiotics in several ways, including genetic mutation or environmental factors.[239] The increasing use of antibiotics in medicine and agriculture already has increased the prevalence of bacteria that are resistant to specific antibiotics.[240] This increasing resistance has undercut the effectiveness of antibiotics in treating human and animal disease.[241]

In 1994, a task force of the American Society of Microbiologists reported that the use of antibiotics in aquaculture was a major concern.[242] Among other reasons for this concern, the task force cited the following:

- When applied in aquaculture, antibiotics often enter the surrounding environment where they may interact with environmental contaminants;
- The antibiotics used in aquaculture are also used in treating human disease and infection;
- While the precise factors causing the development of antibiotic resistance are unknown, studies have demonstrated increased resistance of bacteria in the intestines of fish;
- Bacteria found in wild fish have been found resistant to several antibiotics.

Already, some strains of the bacteria that cause furunculosis and other diseases have developed resistance to drugs commonly used on salmon farms.[243,244,245,246] Other naturally occurring bacteria beneath netpens also have developed resistance to commonly used antibiotics.[247,248,249,250,251]

More than two-thirds of the seafood consumed in the United States is imported, and much of this is from farmed production that may receive even less oversight of the use of antibiotics and chemicals than occurs in the United States.[252] Currently, the government conducts only token efforts at screening imported fish for residues of drugs and chemicals that are banned in the United States but used elsewhere.[253]

In Canada, the agency that promotes the production and sale of food also is responsible for screening meat for drug residues.[254] Salmon are screened for some but not all drugs used on farms in some but not all months of production.[255] By the time drug tests are completed, contaminated salmon has already been sent to market.[256] Although limited studies have found drug residues in wild fish near salmon farms, the Canadian government does not screen wild fish for drugs.[257]

If governments can only provide this modest screening of salmon for toxic residues, they will likely provide even less screening for farmed products of other finfish species that depend upon contaminated sources of feed.

6: The Farming of Other Carnivorous Species

As with salmon farming, the shift of government and industry toward farming other carnivorous fish species will likely generate many of the same environmental, human health and social problems

As markets for salmon become glutted and prices continue to decline, many multinational corporations involved in aquaculture are diversifying their operations by adapting methods of farming salmon to other species of carnivorous fish. Because farming in netpens reduces operating costs, partly by using surrounding waters as a no-cost repository for wastes, many of these initiatives presume the use of netpens.

As with salmon farming and its reliance on external sources of feed high in animal protein and oil, and on chemicals and drugs for the prevention or treatment of epidemics of disease or parasites, the shift of government and industry toward farming other carnivorous species will likely generate many of the same environmental, human health and social problems.

Generally, neither government agencies nor the industry have devoted nearly as much effort to identifying and addressing such problems beforehand as they have to developing techniques for farming additional species in coastal waters.

A brief summary of recent efforts to expand the farming of carnivorous species of fish follows.

ATLANTIC COD

For more than a century, Atlantic cod *(Gadus morhua)* have been reared for release as fry in an effort to enhance wild populations.[258] Cod sometimes have been caught as juveniles then raised for sale in markets.[259]

In recent years, however, governments have been moving toward requiring that cod raised in captivity and sold in markets be obtained from hatcheries.[260,261] In the 1990s, techniques for maintaining captive broodstock were developed, making it possible to reduce reliance on wild adults for production of juveniles and to breed for specific characteristics.[262]

Unlike salmon larvae, which can rely on a yolk sac for nutrition early in life, oceanic carnivores such as cod have no yolk sac. For the purposes of aquaculture, then, raising most oceanic carnivores requires providing the right mix of live zooplankton as feed to larvae.

Juvenile and adult fish are fed commercially available feed pellets or fishmeal mixed with fish oil. Specialized cod feeds contain one-third the amount of oil in salmon feed because high-oil feeds cause enlarged livers in cod.[263] Juvenile cod are raised to market size in sea cages, using technology very similar to that used in salmon aquaculture.[264] Besides susceptibility to

Vibriosis, farmed cod also are susceptible to sea lice, which are treated as in salmon.[265]

Since 1987, Atlantic cod have been cultured at one time or another in commercial quantities in Canada, Iceland, and Norway.[266] After a peak production of 645 mt in 1990, production fell to 167 mt in 2000. An estimated 600 mt were produced in 2001.[267] Some sources estimate that Norwegian cod farmers may produce as much as 10,000 mt in 2004 and 400,000 mt by 2015-2020, twice as much as the Norwegian allocation for wild cod in 2002.[268]

Cod farmers are counting somewhat on landings from capture fisheries remaining far below historic levels to keep cod prices high in order to compete against wild cod.

BARRAMUNDI

Barramundi *(Lates calcalifer)* has been farmed for more than a decade. Production grew tenfold between 1985 and 2000 and reached a peak of 23,277 mt in 1999.[269] Thailand and Indonesia accounted for nearly half the total, followed by Malaysia, Taiwan, and Australia. In Australia, barramundi are grown in ponds, recirculating tanks, and netpens, which are sometimes moored in ponds.[270]

Concerns have grown that barramundi escaping from freshwater and coastal netpens will breed in the wild and affect the genetic integrity of wild populations.[271]

COBIA

Cobia *(Rachycentron canadum)* is a popular sport fish in tropical waters around the world including the Gulf of Mexico.[272] In recent years, cobia have been artificially propagated and raised in offshore cages in Taiwan. In 1999, Taiwanese farmers exported about 500 mt of whole fish to Japan where it was consumed as sashimi. In 2000, production reached 2,626 mt.[273]

In the United States, the National Sea Grant College Program has supported research into commercializing the aquaculture of cobia and enhancement of wild populations.[274] In 2002, cobia and mutton snapper *(Lutjanus analis)* were prompted to spawn in captivity and the resulting fingerlings reared in Florida in a hatchery research program.[275] The success overcame one of the principal obstacles to marine fish farming on a large scale: A dependency on the capture of juveniles from the wild for rearing.

Despite open questions about the degradation of water quality, compromising the genetic structure of natural populations and other issues, the Gulf of Mexico Offshore Aquaculture Consortium stocked cobia in an experimental net cage moored 25 miles off Mississippi in August 2002.[276]

GROUPER

Grouper have been taken from the wild as juveniles and grown out to market size on a commercial scale in Japan, Taiwan, Hong Kong, Southeast Asia, and the Middle

East.[277] Overall, aquaculture production of different species of grouper has grown sevenfold from 388 mt in 1985 to 2,996 mt in 2000.[278] More than half of the production was greasy grouper *(Epinephelus tauvina)* produced in Malaysia and Hong Kong, and 42% was slender grouper *(Anyperodon leucogrammicus)* produced in Thailand.[279]

In Thailand and elsewhere, grouper generally are fed fish with vitamin and mineral supplements.[280] A study in China reported that grouper fed fish had a feed conversion ratio of 7-8:1. When fed dry pellets, grouper require high levels of protein and fat.

Although there have been successful small-scale experiments with grouper of the North Atlantic, such as Nassau grouper *(E. Striatus)* and goliath grouper *(E. Itajara)*, there are no commercial scale operations at this time.[281] In the United States, likely species are Nassau grouper, gag grouper *(Mycteroperca microlepis)*, and black grouper *(M. Bonaci)*.

HALIBUT

Atlantic halibut: In 1985, the government of Norway began providing significant funding for research on culturing Atlantic halibut *(Hippoglossus hippoglossus)*. By 2000, several hatcheries were providing juvenile halibut for grow out, and commercial and research production programs were underway in Norway, Canada, Iceland, and Scotland.[282] Recently, the rearing cycle for Atlantic halibut was closed so that farmers of Atlantic halibut need not rely on eggs from wild-caught halibut for their hatcheries.[283]

Because halibut remain on the bottom rather than in the water column, they are not as suitable for raising in netpens as other species, such as salmon.[284,285] For the time being, it appears that halibut will be more suitably raised in land-based tanks, although significant amounts of halibut are raised in netpens in coastal waters.[286] Among other benefits of raising halibut in tanks is more efficient consumption of feed.[287] Feed conversion ratios of less than 1:1 have been achieved.[288] Like salmon, halibut require feed that is high in fishmeal and fish oil.[289]

Predicted increases in production of farmed Atlantic halibut have not materialized.[290,291] By 2001, total production was below 1,000 mt.[292] Norwegian farms now harvest 400 mt of market-size halibut each year.[293] The economics of farming Atlantic halibut benefit from the substantial decline in catches of wild halibut.[294]

Pacific halibut: Modest levels of research on rearing Pacific halibut have been carried on for several years, but commercial production has not begun.[295]

RED DRUM

Efforts to culture red drum *(Sciaenops ocellatus)* began in the 1970s in an effort to restore populations off Texas depleted by heavy gillnetting and environmental degradation.[296] A ban on commercial catch of red drum eliminated a source for fresh fish markets and restaurants, generating a potential market for cultured red drum. Technology for high-density recirculating systems and for types of feed for larvae other than live rotifers continues to develop.[297] Techniques for raising red drum now are being tested with other Sciaenids, including black drum *(Pogonias chromis)*.

Commercial scale production of red drum grew in the 1990s, reaching 2,115 mt at an average price of $3.19 per pound in 2000.[298] Ecuador reported 90% of the production, followed by Israel and Martinique. Red drum also are cultured in small quantities in the southeastern United States.[299]

SEABASS AND SEABREAM

Farming of European seabass *(Dicentrarchus labrax)* in the Mediterranean has grown from 581 mt in 1985 to 52,817 mt in 2000 *(see figure 8)*.[300] Greece produced half the total in 2000, followed by Egypt and Italy. The growth in volume has turned European seabass into a commodity, much like salmon, and as a result, average prices have dropped from $7.80 per pound in 1992 to $2.60 per pound in 2000.[301]

Farmed production of seabream has grown dramatically in the last 15 years, particularly in Asia and the Mediterranean. Global production of seabream has been dominated by silver seabream, led by Japan which accounted for nearly all 28,595 mt of production.[302] Farmed production of gilthead seabream has grown from 554 mt in 1985 to 71,291 mt in 2000.[303] Portugal produced 58% of the total followed by Italy at 11%, and several other Mediterranean countries.[304] The growth in volume has driven average market prices down from peak of $7.68 in 1989 to $2.31 in 2000. Farmed populations of seabream in the Mediterranean Sea now are much larger than those of wild fish.[305]

TURBOT

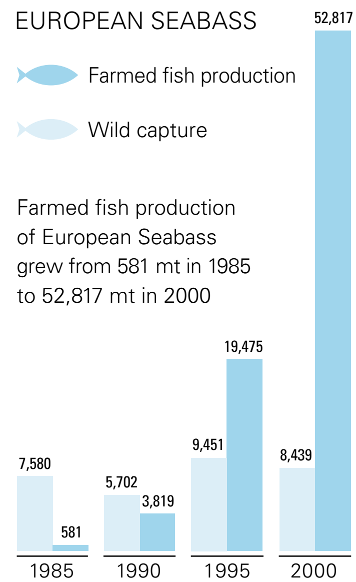
In 2000, five European countries reported production of 4,785 mt of farmed turbot *(Psetta maxima)*, an enormous increase from just 53 mt in 1985.[306] Spain accounted for nearly three-quarters of the production, followed by France and Portugal. In the late 1990s, Chile also produced several hundred mt of turbot in tanks.[307] Feed conversion ratios ranged between 1.2:1 and 1.5:1. Most turbot is grown in landbased tanks.

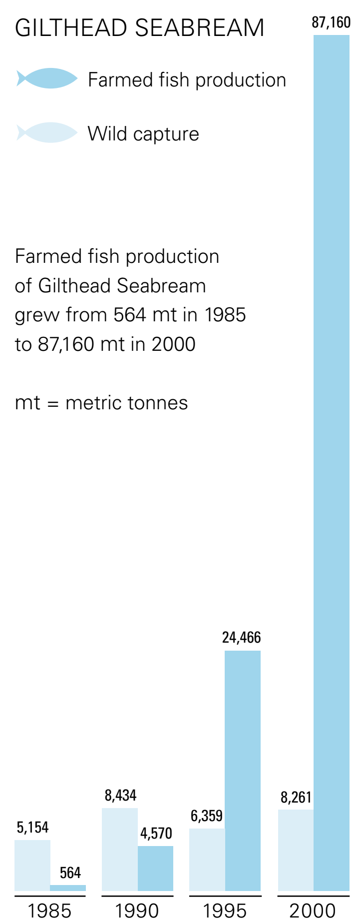
OTHER PROSPECTIVE SPECIES

In recent years, there has been considerable discussion and growing research on farming other carnivorous species.

- Raising mutton snapper *(Lutjanus analis)* is being developed as a means of offsetting growing imports of snapper from abroad into the United States.[308]
- Similarly, culture of southern flounder *(Paralicthys lethostigma)* has been considered as a replacement for wild catches off the southeastern United States that have been reduced by 75%.[309]

9 : FARMING OF OTHER CARNIVOROUS SPECIES





Source: Food and Agriculture Organization of The United Nations Statistical Database

- Declines in the fishery for summer flounder *(P. Dentatus)* off the northeastern United States in the 1980s led the National Marine Fisheries Service to fund research into the culture of summer flounder in 1990.[310,311] Later, some disaster relief funds approved by Congress after the collapse of the New England groundfish fishery were provided to several companies to demonstrate the commercial feasibility of culturing summer flounder. High production costs, lack of capital, and the recovery of depleted wild populations have prevented commercialization.

- In the early 1990s, Norwegian scientists collected spotted wolffish *(Anarhichas minor)* from the Barents Sea and established a broodstock.[312] Juvenile wolffish were raised in raceways and fed salmon-feed; market-size wolffish were produced in three years. Optimistic estimates place captive production of spotted wolffish in northern Norway at 40,000 mt in 2020.[313]

- Scientists in Spain have begun research on culturing blackspot seabream *(Pagellus bogaraveo)*. The aim is to raise juvenile seabream in floating cages.[314] The government of Spain has been supporting several projects to commercialize production of blackspot seabream.

- Tautogs *(Tautoga onitis)* range from Nova Scotia to South Carolina. Their popularity with sport and commercial fishermen has led to declines in the last 15 years.[315] Scientists with the National Marine Fisheries Service have been experimenting with the culture of tautogs as a source for markets and for stock enhancement.

- The Australian government has been encouraging farming of yellowtail kingfish *(Seriola lalandi)* in coastal netpens.[316] Fishermen and environmental groups have called for moving existing operations onto land to avoid impacts of escaped kingfish on other fish populations.[317] Thousands of kingfish already have escaped from small-scale netpen operations.[318]

- Fundación Chile recently launched a project in collaboration with several Chilean salmon farming companies to develop methods of farming southern hake *(Merluccius australis)*.[319] Chilean catches of southern hake in the wild have declined although overall catches have remained relatively steady.[320] The Fundación's proposal includes only a very superficial and wishful assessment of possible environmental impacts.

- In recent years, several Canadian companies have been attempting to farm sablefish or black cod *(Anoplopoma fimbria)*.[321] Sablefish range along the west coast of North America where a commercial fishery has operated for many years, supplying a market in Japan primarily. Farmed sablefish were expected to be sold on the market for the first time in 2002.

No one knows which of these species will match the enormous growth in production that marked the growth in farmed Atlantic salmon over the last two decades. Government agencies and industry members are investing millions of dollars to find that species and to build markets for new products. Much less effort is being devoted to assessing and reducing the kinds of environmental and ecological costs that farming such species in netpens will more than likely cause. Unlike salmon, whose biology, ecology, and genetics are relatively well known, our knowledge about many of these other species is very poor.

Tuna fattening

The Japanese market for sashimi-grade tuna has fueled intense fisheries that have reduced populations of southern bluefin tuna *(Thunnus maccoyii)* in the South Pacific and Indian Oceans and northern bluefin tuna *(Thunnus thynnus)* in the Atlantic and Mediterranean.

In the last decade, the drive to provide the Japanese market with bluefin tuna has led to the capture of small tunas for fattening in sea cages.[322] This activity, often misleadingly referred to as aquaculture, is based primarily in Australia, Spain, and Croatia. Unlike most forms of aquaculture, the fattening of bluefin tuna does not rely on animals propagated and raised in captivity. Instead, wild tuna are captured, confined, and fed a diet rich in oils.

In the Mediterranean, as many as 2,000 bluefin tuna are confined to a single cage, and eight or more cages are combined at a single site, often located in nearshore areas used by fishermen and recreationalists. The tuna are fed sardines, anchovies, mackerel, or other pelagic species for seven months.[323] Reported feed conversion ratios are as high as 20 pounds of fish to one pound of tuna.[324] These poor conversion ratios indicate high levels of waste that enter the surrounding environment.

Unless techniques can be developed for domesticating bluefin tuna so that they reproduce in captivity, current fattening operations will remain dependent on wild populations.[325] The Australian government recently announced an investment of $28 million in a long-term project to domesticate southern bluefin tuna, something that Japanese researchers have been trying to do for three decades.[326]

The diversion of bluefin tuna, some of which are undersized, to fattening operations has generated a number of problems that are only now starting to be addressed.[327] Among these are the following:

- increased problems in data regarding catches of bluefin tuna,
- increased investment in fishing vessels that will further increase pressure on stressed populations of bluefin tuna,
- increased demand for pelagic species,
- the lack of a regulatory framework for an activity that falls outside existing fishery management regimes, and
- competition for space in the nearshore.

7: Aquaculture Alternatives

…it is useful to step back from the industrial model of food production… and to survey the world for other possible models that may better reflect sustainable principles

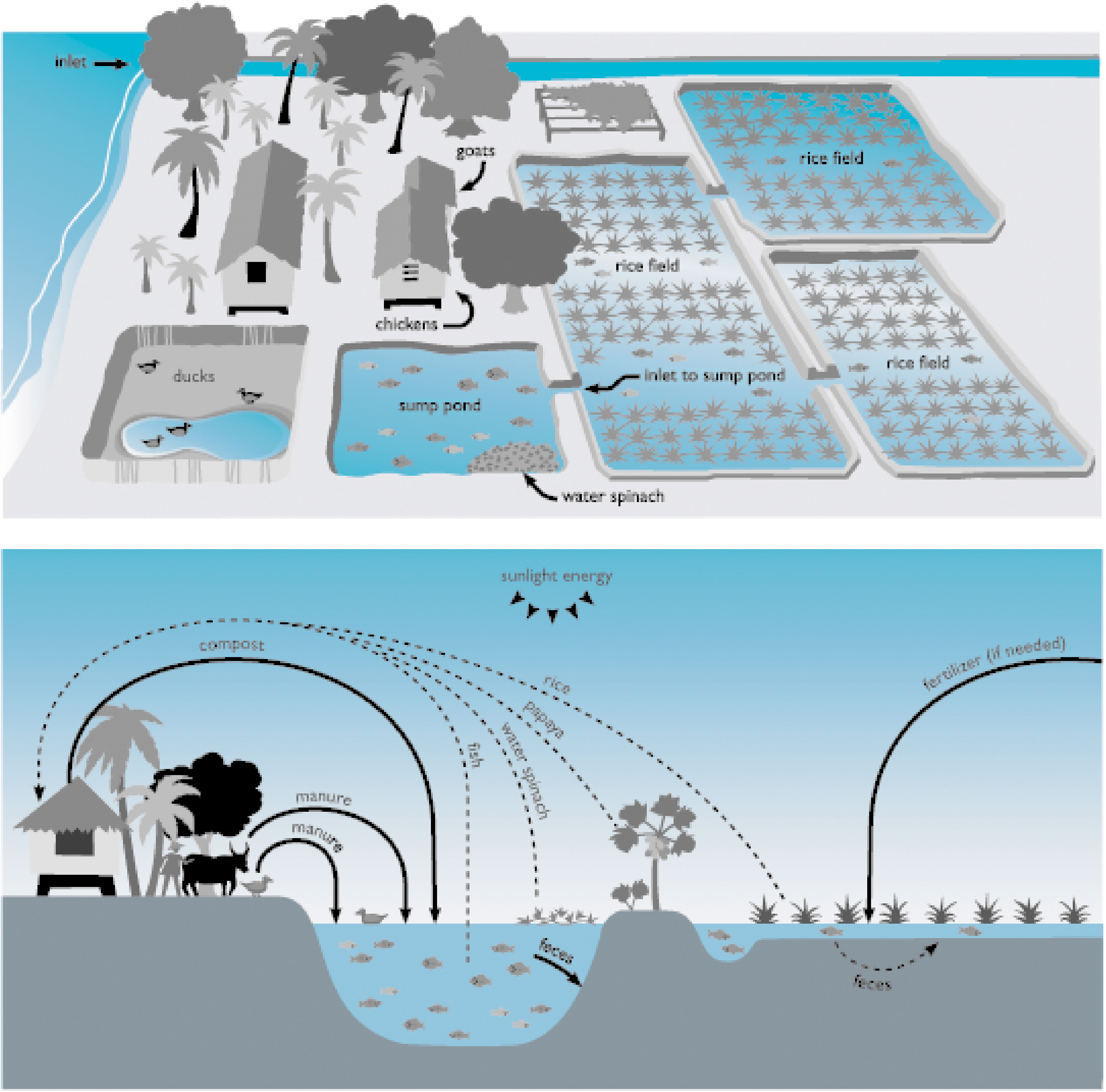
In thinking about alternative farming practices, it is useful to step back from the industrial model of food production to which we have become accustomed, and to survey the world for other possible models that may better reflect sustainable principles. For instance, small-scale agriculture-aquaculture, which is based on centuries of successful experimentation in rural areas in Asia, integrates the production of vegetables, livestock, poultry, and fish *(see figure 10)*.[328] Wastes of one activity become inputs to another, thereby optimizing the use of resources and reducing pollution. Fish play a unique role in such systems by converting low-grade feed and wastes into high-quality protein that can be harvested at will.[329]

The garden-pond-livestock system common in Viet Nam since the 1980s illustrates the basic principles.[330] In upland areas of Viet Nam, fish ponds are constructed close to houses so that domestic and kitchen wastes drain directly into the fish pond, where they act as fertilizers and feed. Livestock pens and a garden are also located near the pond. Livestock manure is used for fertilizing trees and vegetables. Manure also is applied to fish ponds, where it fosters the growth of algae upon which planktivorous fish feed directly. The algae also feed small invertebrates that in turn feed other types of fish. Every three to four years, the pond silt, which is rich in nutrients from fish and plant wastes, is removed and used as compost, enriching soil that otherwise is vulnerable to degradation. Water stored in farm ponds also can be used to irrigate crops during dry seasons.[331]

Besides relying on a variety of wastes to fuel productivity, such systems also rely on diverse producers. For instance, fish ponds in Viet Nam and elsewhere in Asia usually host several species of carp and other fishes. Silver carp *(Hypophthalmichthys molitrix)* feed entirely on phytoplankton. Grass carp *(Ctenopharyngodon idellus)* feed on larger plants. Common carp *(Cyprinus carpio)* feed on plants and animals, while bighead carp *(H. Nobilis)* feed on zooplankton.

For the most part, such systems do not require the introduction of additional fertilizers and other materials. Because of this and because wastes are largely recycled, such systems are closed and more or less self-sufficient. Besides fruits, vegetables, and livestock produced in such a system, the pond produces an average of 1,000 pounds of fish per acre per year, although yields as high as 9,000 pounds per acre have been achieved.[332,333]

10 : **TRADITIONAL INTEGRATED AQUACULTURE** USING PRACTICES FROM THE PAST FOR A SUSTAINABLE FUTURE



Integrated aquaculture, such as this traditional rice-fish system, can provide mutual benefits to all the organisms. Interdependent relationships are established and allow for a balanced use of available aquatic resources. An additional benefit of the system is reducing the net production of waste.

Source: Food and Agriculture Organization of the United Nations, Fisheries Technical Paper 407.

Such systems are most appropriate for rural areas, particularly in developing countries, where production of food for subsistence and for local markets is key to regional welfare.[334] However, when viewed both as food producers and as waste utilizers, such ponds also play a role in reducing environmental damage otherwise caused by concentrated wastes from such intensive food production systems as poultry production.[335] Given increased wastes from intensive production of poultry and livestock in both developed and developing countries, waste-fed aquaculture may provide a means for significantly reducing pollution of lakes, streams, and coastal waters. However, such uses of aquaculture have attracted little research and development in the United States or elsewhere.

The point of these examples is not to suggest that they be substituted for more modern systems, but to suggest that more modern systems can become more efficient if they are integrated into a larger system that relies more heavily on the reuse of local resources.

In many areas, land-based systems are not closed. Not only does their productivity depend upon fertilizers and feed that are manufactured elsewhere, but they also discharge their wastewaters into streams, lakes, and coastal waters. Similarly, land-based systems of tanks often are not closed, but rely on a regular flow of water into and out of the tanks in order to wash out ammonia and other waste by-products.[336] Alternatives to open tank systems include systems that treat and recirculate their waste waters.[337] Such systems use different technologies to remove solids, maintain oxygen levels, break down nutrients, remove carbon dioxide, and disinfect waste waters.

The use of closed, recirculating, land-based water systems in producing finfish is attractive on several grounds.[338] Compared to open systems including coastal netpens, a closed, recirculating system on land provides the farmer with greater control over the environment of the fish and over exposures to disease, parasites, predators. A recirculating system requires less water than pass-through systems. This feature reduces reliance on outside sources of water and the discharge of wastes. It also insulates a farm somewhat from poor quality water. Finally, such closed systems eliminate the risk of impacts on wild populations due to escapes and do not degrade the surrounding environment. Depending upon the plants used in stripping nutrients from waste waters, such integrated systems can offset costs with revenues from seaweeds produced in the treatment of wastewaters.[339]

Although the operating costs for recirculating systems are similar to those for conventional tank systems, the high cost of construction has militated against the use of recirculating systems generally.[340] As a result, recirculating systems are feasible only in high-value niche markets, as for striped bass in white tablecloth restaurants, for tropical or ornamental fish markets, or in markets where year-round availability is critical.

Netpens in coastal waters are at the other end of the spectrum from the integrated agriculture-aquaculture systems described above. Netpen systems rely entirely on outside sources for feed and on surrounding waters for treatment of their wastes. While some progress is being made in reducing the reliance of carnivorous fish on relatively high levels of animal protein and fish oil in their feed, fish farmed in coastal netpens will continue to rely on external sources of food.

Pilot projects have demonstrated some promise for recapturing the nutrients in feces and uneaten feed by cultivating seaweeds or raising mussels or oysters near netpens.[341] In Chile, where heavy harvesting has reduced stands of seaweeds, *Gracilaria chilensis,* an endemic seaweed, has been grown on ropes suspended near salmon cages in southern Chile for two months. The seaweeds nearer salmon cages grew faster than others, and reduced nitrogen in

Carp polyculture in China

In the Pearl River Delta in southern China, deep ponds have been dug from low-lying areas over the past 500 years and the excavated soil built into dikes to protect the ponds from major floods. Plants on the dikes and in the water feed pigs and fish, whose wastes in turn fertilize plants both on the dikes and in the water. Unlike most fish ponds, these deep ponds can host several kinds of fish. Their high rate of production-four to six tons of fish per acre each year-has helped make it possible for this 300-square mile agricultural area to support 1.2 million people.

As wastewater engineer George Lai Chan has shown, this type of aquaculture is a sophisticated, closed-loop system. The key to its success is that all wastes are put to productive uses within the system: plankton, grass carp, and common carp are nourished by plant and animal wastes; silver and bighead carp consume different kinds of plankton; mud carp graze the detritus on the pond bottom. Farmers harvest the fish, but because they add wastes, they do not deprive the system of nutrients. In this way, each pond becomes a closed cycle, and no unused nutrients accumulate to attract other organisms that would disturb the balance.

wastes from the salmon cages by 5% and phosphorus by 27%, while producing a crop of seaweed worth an estimated $34,000 in 1996.[342] Similar experiments in growing mussels adjacent to salmon cages proved less promising.[343]

None of these technologies reduce the risk of escape of farmed fish into the wild. The surest method of eliminating the unintentional release of farmed fish is complete containment.[344] The frequency of escapes of farmed salmon may well be reduced through improvements in netting and design of netpens. However, these improvements may well be overwhelmed by the increasing number of farming sites that will be in areas exposed to storms and other extreme events.[345] With the exception of early life stages of salmon, farmers generally have opted not to incur the additional cost of raising salmon in tanks or completely contained netpens. In June 2002, Agrimarine Industries in British Columbia sold its first harvest of salmon that had been raised in landbased tanks.[346]

In Ireland, Japan, and elsewhere, open ocean aquaculture has developed into an industry that generates about $80 million a year in Ireland alone.[347] The attractions of this technology are a reduction in conflicts common in coastal waters and possibly greater capacity of surrounding waters to assimilate wastes.

In the United States, the use of open ocean fish cages is still in experimental stages. The United States government, industry, and universities have shown great interest in developing cages that can be deployed offshore. In Hawaii, a consortium led by the University of Hawaii Sea Grant College Program conducted a pilot project for raising Pacific threadfin *(Polydactylus sexfilis)* in a semi-submersible cage.[348] A similar project funded partly by the National Sea Grant College Program aimed at testing aquaculture of cobia in a cage 25 miles off the coast of Mississippi.[349]

These projects left many questions unanswered, including economic feasibility. Since the capital and operating costs of farming in the open ocean will be much higher than more conventional approaches, production will have to be more intensive and the species raised will have to fetch relatively high prices in the market.[350]

Catfish farming in the United States

Catfish production dominates aquaculture in the United States, accounting for 73% of the volume and 44% of the total value.[351] After doubling volume to 226,034 mt between 1985 and 1992, production grew more gradually to 271,195 mt in 1999.[352] Unlike farming salmon and other marine species, farming catfish does not rely heavily on fishmeal and fish oil for feed. However, large volume production of catfish can cause other problems common to other forms of intensive aquaculture, including high nutrient levels, algal blooms, escape of exotic species, and epidemics that require treatment with chemicals or drugs. Discharge of pondwaters, as occurs when ponds are drained to harvest the fish, may pollute streams and lakes, but when best management practices are used, catfish farming can be done with little environmental impact. There are other, less intensive methods of growing catfish. At one farm in Alabama, for instance, Dan Butterfield raises catfish in a polyculture system that includes tilapia, several species of carp, bluegill, and bass.[353] Because several of these species graze on algae, this farm does not suffer the algal blooms that conventional farms must manage. Nor does this farm have to discharge wastewaters into surrounding streams and lakes.

Rice and crawfish farming in Louisiana

For the last several decades, rice farmers in Louisiana have taken advantage of plant debris left after harvest to grow that Louisiana specialty, crawfish. Flooding fields after the rice harvest triggers the growth of algae and other organisms on plant remains, and begins a kind of foodweb for crawfish introduced into the fields. In 1999, U.S. crawfish farmers produced 19,495 mt of crawfish that fetched them $28 million.[354]

Recirculating aquaculture in Vermont

Advance Farm Ecosystems (a program of the Intervale Foundation, based in Burlington, Vermont) is developing a system that integrates the activities of aquaculture, vermiculture, mushroom production, and horticulture. The Advance Farm Ecosystem uses ecological processes to convert underutilized raw materials to high quality foods and other agricultural products. The aquaculture program is centered on systems that are self-sustaining and do not rely on fishmeal from ocean sources. The goal is to create efficient recirculating systems that produce high quality fish, shrimp, and hydroponic produce without the need for energy intensive waste treatment. It will serve as a model for food production that is ecologically and economically sustainable, as well as socially responsible.

8: Conclusions and Recommendations

Industrialized aquaculture of salmon and other species that requires intensive use of resources and exports problems to the surrounding environment is overdue for reform

In the last decade, salmon farming has grown rapidly, partly because its ecological and socioeconomic impacts have received little attention. Instead, government agencies and industry have played upon the persistent gap between the general demand for high-quality protein and the stagnation in wild capture fisheries to emphasize expansion of farming of many other types of carnivorous fish. In recent years, as gluts have driven farmed salmon prices down and intensified the race for profits, research has documented a growing list of environmental and social costs.

In a similar way, industry and government agencies based the unsustainable expansion of capture fisheries in the last several decades upon the gap between demand and a presumed limitless abundance of ocean fisheries. While this pattern of development led to initial dramatic growth, it eventually contributed to the decline of many fisheries and to ecological and economic dislocation. The failure of this approach in marine fisheries has led to reforms in fisheries management that no longer emphasize maximum production and that take into account the sustainability of fishing for entire ecosystems.

Industrialized aquaculture of salmon and other species that requires intensive use of resources and exports problems to the surrounding environment is overdue for similar reform. Now, as attention shifts to farming other species of carnivorous fish, government and industry have an opportunity to do things differently and to develop new forms of aquaculture in a way that does not create the same kinds of problems associated with salmon farming. Expansion in farming other species should not outpace our understanding of its effects and our ability to prevent problems and reverse any damage.

Traditional methods of integrated agriculture-aquaculture offer an alternative model of aquaculture that can help in the design of these new approaches to producing food for cash-rich markets. Most importantly, this alternative model links aquaculture production with other food production activities as well as reuse of wastes, instead of viewing aquaculture operations as independent of the resources they use and the wastes they produce. The tremendous ingenuity and investment that led to the spectacular growth of industrial-scale salmon farming surely can build upon these traditional models, improving and adapting them to an industrialized setting.

An overhaul of aquaculture techniques will take time. In the meantime, there are a number of pressing problems in aquaculture that deserve attention by government agencies and industry. In some cases, solutions are clear, although they may require investments that will increase operating costs that now are externalized and borne by the environment and fish and wildlife populations.

RECOMMENDATIONS

- Farming fish in netpen systems pollutes the environment through discharges of feed, feces, and chemicals, and threatens wild fish populations through escapes of farmed fish and the exchange of diseases and parasites. To eliminate these risks, the future expansion of the finfish aquaculture industry should be based on closed systems, total containment of fish, and recovery/reuse of wastes.
- While transitioning to closed containment systems, a number of measures should be taken to protect wild fish populations and coastal ecosystems, including mandatory reporting of escapes, tagging of farmed fish, and use of reproductively sterile stock. Non-native species and genetically modified strains and species of fish should be prohibited from farming systems in which the potential for escape of fish is greater than zero.
- Expected expansion of farming of carnivorous fish will significantly increase demands on world supplies of fishmeal and fish oil, increasing pressure to maintain these supplies possibly at the expense of long-term sustainability of fisheries. Government policy should foster reduced use of fishmeal and fish oil, partly by promoting the farming of low trophic level species that do not require significant amounts of animal protein or oil in their feed.
- In most countries, fish farmers are not required to report the volumes or types of feed, chemicals, and drugs that they use. This information is critical to determine trends or to evaluate impacts. Before expansion of any type of farming proceeds, effective mechanisms for reporting and monitoring the use of feeds, chemicals, and drugs should be in place.
- The impacts of chemicals used in fish farming on other species and on the healthfulness of farmed seafood has received little attention, although many of these chemicals are problematic. Unless farms are required to capture and treat their wastes, they should be required to provide regular monitoring of water quality and of nearby animal and plant communities. Additionally, government agencies should screen both domestically produced and imported farmed fish for chemical residues.

- In setting priorities for policy and funding, government agencies should take into account the collateral and cumulative impacts of expanded farming of high-value carnivorous species so that small-scale operators and those that may use environmentally preferable methods do not have to operate at a considerable disadvantage. Government agencies also should embrace adaptive management in structuring their programs of research, technical assistance, and regulation. Fish farming activities should expand only at a pace that insures sufficient information is available to evaluate possible impacts and that does not risk irremediable environmental damage.

Appendix: Consumption of Fishmeal, Fish Oil and Wild Fish in Aquaculture

Feeds used in aquaculture vary depending upon the species and method of farming. The farming of many species requires the use of so-called compound feeds composed of varying amounts of fishmeal and fish oil. Capture fisheries for small pelagics such as anchovy and sand eel supply the raw material used in manufacturing fishmeal and fish oil.

The following four tables, which are based primarily on statistics and projections prepared by the International Fish Oil and Meal Association, present basic statistics on those species that are farmed entirely or partly with compound feeds. Besides estimates for production and use of feeds in 2000, IFOMA presented projections for 2010.

1. GROWTH IN PRODUCTION

Farmed production of most groups of fish and shrimp that are fed compound feeds is expected to grow at an annual rate of 5% or more between 2000 and 2010, according to the International Fish Oil and Meal Association (IFOMA). If this prediction holds true, total production of these animals will nearly double from 19.2 million mt to 37 million mt. Farmed production of marine flatfish, such as flounder and cod, will grow most rapidly, with an expected 20% annual rate of growth. Farmed salmon will nearly double production. Overall, production of carp will continue to account for nearly three-quarters of the production of these species.

Dependence on Compound Feeds: Some species groups depend more upon compound feeds than other species groups. Salmon, marine flatfish, and trout depend entirely on compound feeds. Eighty percent and more of the production of shrimp, eel, marine fish, including seabass and grouper, relies upon compound feeds. Only one quarter of carp are now fed compound feeds.

Table 1 : Predicted growth in aquaculture production of species fed compound feeds

	Annual rate of growth 2000-2010	Volume of prodution in 000 mt		Percent of prodution on fish feed		Volume of production on fish feed in 000 mt		Feed conversion ratio***		Total feed in 000 mt	
		2000	2010	2000	2010	2000	2010	2000	2010	2000	2010
Salmon	7%	876	1,723	100%	100%	876	1,723	1.4	1.1	1,226	1,896
Marine fish*	5%	856	1,394	60%	80%	514	1,115	2.2	2.0	1,130	2,231
Other marine fish**	20%	105	650	100%	100%	105	650	2.2	2.0	231	1,300
Shrimp	5%	1,034	1,684	80%	90%	827	1,516	1.8	1.6	1,489	2,425
Eel	2%	216	263	80%	90%	173	237	2.0	1.2	346	284
Milkfish	2%	379	462	40%	75%	152	347	2.0	1.6	303	554
Trout	5%	450	733	100%	100%	450	733	1.4	1.1	630	806
Tilapia	7%	974	1,916	40%	60%	390	1,150	2.0	1.5	779	1,724
Catfish	5%	371	604	85%	90%	315	544	1.6	1.4	505	761
Carp	7%	13,983	27,507	25%	50%	3,496	13,754	2.0	1.5	6,992	20,630
Total		**19,244**	**36,936**			**7,297**	**21,767**			**13,631**	**32,611**

* Marine fish include bass, bream, yellowtail, grouper, jacks, and mullets.

** Other marine fish include flat fish including flounder, turbot, halibut, sole, cod, and hake.

*** Dry feed to wet fish

The ratio for wild fish to fishmeal is 4.7:1, and to fish oil 8.3:1 (Tyedmers 2000).

Source: IFOMA undated; Tyedmers 2000

The production of several species groups will increase their reliance on compound feeds between 2000 and 2010. According to the projections of IFOMA, the share of carp production that relies upon compound feeds will double. Milkfish and tilapia production will also significantly increase their reliance upon compound feeds.

While IFOMA expects the feeding efficiency of farmed seafood to increase somewhat for all species groups, increased production and reliance on compound feeds will overwhelm these increased efficiencies. Furthermore, IFOMA's assumed increases in feeding efficiency are best guesses. If these assumed increases do not materialize, demand for the raw materials of compound feeds will likely be higher.

2. FISHMEAL CONSUMPTION

Depending upon the species, compound feeds include more or less fishmeal and fish oil. Compound feeds for salmon and marine fish include 40-55% fishmeal compared to less than ten percent for tilapia, catfish, and carp.

IFOMA expects that the fishmeal share of compound feed will decline slightly for all species between 2000 and 2010. For marine species and salmon, overall consumption of fishmeal will increase, particularly for flat fish. Overall, fishmeal consumption in aquaculture is expected to increase 49% by 2010. Marine fish farming is expected to consume nearly 60% of the fishmeal consumed by all types of fish farming that rely on compound feeds.

3. FISH OIL CONSUMPTION

Compound feeds for salmon and marine fish include 10-25 percent fish oil, far higher than the percentage of fish oil in feed for most other species. Trout, a carnivorous relative of salmon, consumes feed with 15% fish oil. Overall consumption of fish oil by all species except catfish is expected to increase between 2000 and 2010. By 2010, marine fish farming is expected to consume almost three-quarters of all fish oil consumed in aquaculture, although it will produce only 16% of all fish grown on compound feed.

Table 2 : Predicted growth in consumption of fishmeal in aquaculture

	Percent fishmeal in feed		Thousands of tonnes of fishmeal		Percent change 2000-2010	Percent total use of fishmeal	
	2000	2010	2000	2010		2000	2010
Salmon	40%	30%	491	569	16%	21%	16%
Marine fish*	45%	40%	508	892	76%	22%	26%
Other marine fish**	55%	45%	127	585	361%	5%	17%
Shrimp	25%	20%	372	485	30%	16%	14%
Eel	50%	40%	173	114	-34%	7%	3%
Milkfish	12%	5%	36	28	-22%	2%	1%
Trout	30%	25%	189	202	7%	8%	6%
Tilapia	7%	4%	55	60	9%	2%	2%
Catfish	3%	0%	15	—	-100%	1%	0%
Carp	5%	3%	350	516	47%	15%	15%
Total			**2,316**	**3,451**	**49%**	**100%**	**100%**

* Marine fish include bass, bream, yellowtail, grouper, jacks, and mullets.
** Other marine fish include flat fish including flounder, turbot, halibut, sole, cod, and hake.

The ratio for wild fish to fishmeal is 4.7:1, and to fish oil 8.3:1 (Tyedmers 2000).

Source: IFOMA undated; Tyedmers 2000

4. WILD FISH RATIO

Depending upon the species and processing methods, the amount of wild fish required to produce a pound of fishmeal or fish oil varies. The production of 876,000 mt of salmon required fish oil manufactured from 2.5 million mt of forage fish. Put in another way, it required 2.9 pounds of wild fish to produce one pound of farmed salmon in 2000. Production of marine fish such as seabass and grouper required 3.7 pounds of wild fish.

Although IFOMA expects the demand for fish oil and fishmeal to decrease by 2010, farming of marine carnivorous species will continue to rely disproportionately upon wild fish until more vegetable protein and oil are incorporated into feeds. While salmon and marine fish are expected to require at least 1.8 pounds of wild fish for every pound of farmed fish, all other species except trout will require less than one pound of wild fish per pound of farmed fish. Indeed, most other species fed compound feeds will require less than half a pound of wild fish to produce one pound of farmed fish.

Table 3 : Predicted growth in consumption of fish oil in aquaculture

	Percent fish oil in feed		Thousands of tonnes of fish oil		Percent change 2000-2010	Percent total use of fish oil	
	2000	2010	2000	2010		2000	2010
Salmon	25%	20%	307	379	23%	43%	31%
Marine fish*	20%	15%	226	335	48%	32%	28%
Other marine fish**	10%	12%	23	156	578%	3%	13%
Shrimp	2%	3%	30	73	143%	4%	6%
Eel	5%	8%	17	23	35%	2%	2%
Milkfish	2%	2%	6	11	83%	1%	1%
Trout	15%	15%	95	121	27%	13%	10%
Tilapia	1%	0.5%	8	9	13%	1%	1%
Catfish	1%	0%	5	—	-100%	1%	0%
Carp	0%	0.5%	0	103	NA	0%	9%
Total			**717**	**1,210**	**69%**	**100%**	**100%**

Table 4 : Predicted growth in wild fish used in fishmeal and fish oil for aquaculture

	Thousands of tonnes of wild fish used for fishmeal		Ratio of wild fish used for fishmeal to final production of fish fed on fish		Thousands of tonnes of wild fish used for fish oil		Ratio of wild fish used for fish oil to final production of fish fed on fish oil	
	2000	2010	2000	2010	2000	2010	2000	2010
Salmon	2,308	2,674	2.6	1.6	2,548	3,146	2.9	1.8
Marine fish*	2,388	4,192	4.6	3.8	1,876	2,781	3.7	2.5
Other marine fish**	597	2,750	5.7	4.2	191	1,295	1.8	2.0
Shrimp	1,748	2,280	2.1	1.5	249	606	0.3	0.4
Eel	813	536	4.7	2.3	141	191	0.8	0.8
Milkfish	169	132	1.1	0.4	50	91	0.3	0.3
Trout	888	949	2.0	1.3	789	1,004	1.8	1.4
Tilapia	259	282	0.7	0.2	66	75	0.2	0.1
Catfish	71	—	0.2	—	42	—	0.1	0.0
Carp	1,645	2,425	0.5	0.2	—	855	0.0	0.1
Total	**10,885**	**16,220**	**1.5**	**0.7**	**5,951**	**10,043**	**0.8**	**0.5**

* Marine fish include bass, bream, yellowtail, grouper, jacks, and mullets.
** Other marine fish include flat fish including flounder, turbot, halibut, sole, cod, and hake.

The ratio for wild fish to fishmeal is 4.7:1, and to fish oil 8.3:1 (Tyedmers 2000).

Source: IFOMA undated; Tyedmers 2000

FOOTNOTES

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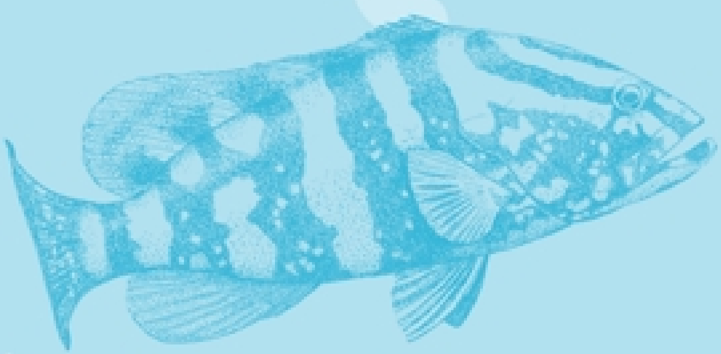
SeaWeb's mission is to promote conservation of the ocean and the web of life it supports. Raising awareness of the living ocean and its fragile state is a key underpinning to saving it. To achieve our mission, we collect and communicate information anchored in science about the importance and condition of the ocean to decision makers and individual citizens.

Since 1998, the SeaWeb Aquaculture Clearinghouse has been raising awareness of the environmental and social issues related to aquaculture and generating involvement from all stakeholders, including the public, in order to encourage its sustainable development. We strive to maintain and promote healthy and productive coastal waters and watersheds through development of responsible aquaculture that is either integrated into the natural ecosystem or developed in closed systems, is diverse on local and regional scales, and is beneficial to local communities.



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Raising Awareness of the Living Ocean

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