The oceanic food web

Overfishing

The evidence is in: humans have a long history of affecting the environment adversely, even those who were thought to have lived in harmony with nature.[315,316] Fisheries provide employment to 200 million people around the world, and supply one-fifth of protein eaten.[317] The oceans were thought so vast that the species could not disappear. We are fishing at higher cost for fish lower on the trophic chain (the decline is about 0.1 trophic level per decade; see Chapter 2).[318,319] While at first this enhances catches, the increase is unsustainable in the long run. Declining or stagnant catches are sure to follow.[318-320] Some have already occurred: BBC reporter Alex Kirby points out what happened to cod (*Gadus morhua*). "In the 1980s, landings of North Sea cod were about 300,000 tonnes annually. This year's catch was set at 80,000 tonnes, but the fish are so scarce that landings amounted to only 50,000 tonnes."[321]

In danger and at risk make up ~ 80% of the fish for which the European Union has quotas.[28]

Part of the problem is a lack of knowledge of how many species are in the seas, where they roam, how their ecosystems function—massive ignorance abounds. In such an atmosphere, it is hard to refute assertions that the oceans are vast, that humans are not really changing things, that it was always this way. The antidote to ignorance is knowledge, and so a $10 billion effort is under way with support from the Alfred P. Sloan Foundation to conduct a census of marine life (the group of more than 500 scientists working together is known as CoML, after the aim). In October 2003, the first census report was released.[322] It reports a mass of marine life totaling 145 Gt, most of the mass in small species such as krill.[322] Over 15,000 species of fish and over 200,000

species of marine animals and plants have been identified, with another million or so expected to be found on the basis of the experiment so far.(323)

Extinctions are expected—and even sooner than people expected, as it has recently been found that the Chinese have been telling "fish stories" ["misreporting" is the way this was characterized] about their catches.(324)

There is still massive ignorance of the behavior of many pelagic (ocean-living) species, as we have come to realize. One part of that realization is that species that were thought to exist over a large range as one species were found to represent two or more species.(325) And, in a contrary experience, it was found that what was considered two stocks of bluefin tuna were indistinguishable.(326) The stocks of bluefin had plummeted to one-fifth of what they were in the 1970s.(326)

When other abalones were fished out along the California coast, abundant deeper-water white abalones (*Haliotis sorenseni*) were allowed to be taken with a provision for minimum size that was meant to protect the stock in perpetuity. The fishery fell apart after just 9 years.(325) The species is now on the verge of extinction because of our behavioral ignorance of marine life. Abalones must be close together to reproduce, but harvesting destroyed abalone communities.(325) Finally, in 1996 the International Union for the Conservation of Nature listed a large number of marine fish as endangered.(325)

The extinction of just one marine mammal (Stellar's sea cow, *Hydrodamalis gigas*, in 1768) and four mollusk species have been documented in the literature.(325) However, hidden away from public view, some ecologists believe that at least 1200 marine species have gone extinct in the last few centuries.(325)

This is a classic case of Tragedy of the Commons, because each user has the advantage if he or she overuses the common resource, and traditionally that is just what has happened. Ever higher technology is brought in to ensnare ever more fish (many of which are thrown away as "trash fish" and not preserved). Managers need to increase harvests at the present, trading short-term gain for longterm destruction.(317) Fisheries are led to a condition of collapse because the common good does not count.

This is especially true for international fisheries.(317) For example, the controversy over an international treaty setting boundaries between U.S. and Canadian waters off the Grand Banks (originally because of concern for possession of the oil thought to be under the Banks) became an excuse for playing politics and led to overfishing by both sides.(327) The outcome was, unfortunately, "massive overexploitation and continual decline of commercially important fish stocks." See also **Extension 26.1, *Sustainability and ecosystem value***.

Pauly et al. argue that fishing is to the sea as hunting is on land.(328) Just imagine what industrialized hunting would do to land wildlife! Whole species can be overfished in just a few years.(23) Pauly et al. claim that while fishermen point to "unspecified 'environmental change' [that] caused, and continues to cause, the collapse of exploited fish populations," if we examine history, it is "abundantly clear that humans have had for thousands of years a major impact on target species and their supporting ecosystems."(328) In particular, they say, "uncontested historical examples of sustainable fisheries seem to occur where a superabundance of fish supported small human populations in challenging climates."(328) They go on to say "whatever semblance of sustainability fisheries in the past might have had was due to their inability to cover the entire range inhabited by the wildlife species that were exploited, which thus had natural reserves."(328)

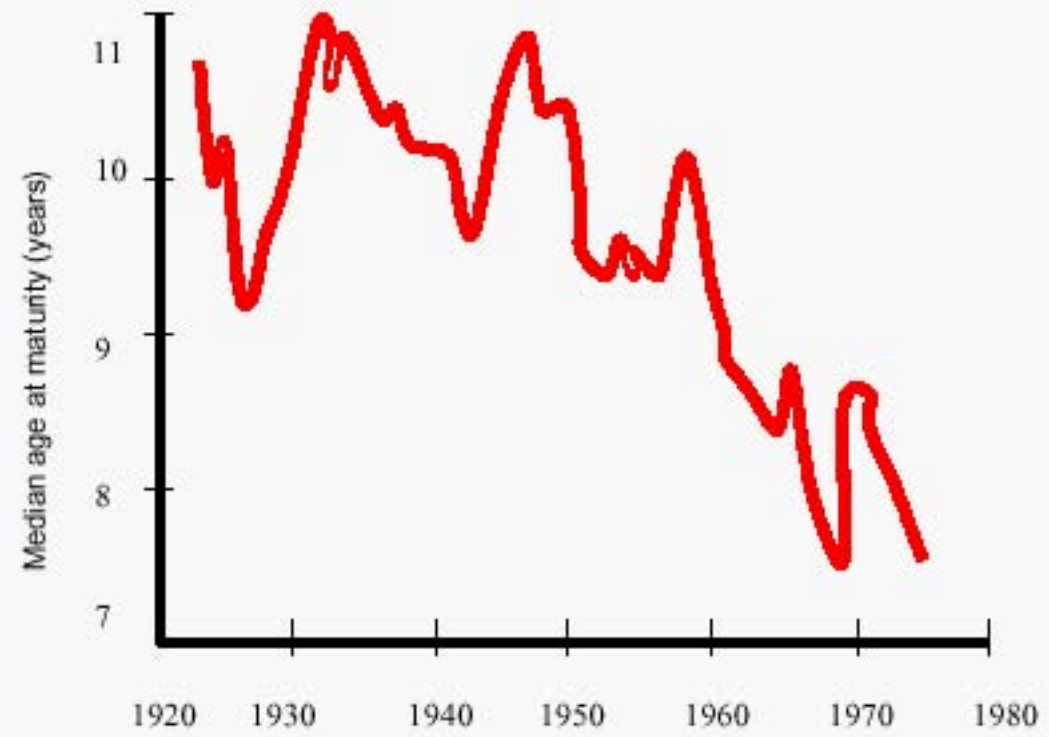

Fig. E26.5.1 Median age of cod catch, 1920 to 1976.
(Prime Minister's Strategy Unit Report, March 2004, Ref. 28)

Overfishing catches all fish regardless of size, and indeed many state laws for anglers mandate a minimum length or weight before the catch is legal. But older females contain many more eggs, and have a much greater impact on species propagation, than younger females. Only in those cases where the older females remain in the ecosystem will there be a chance that the fishery will be sustainable.(328) Data for cod show how the stock of older, larger fish declined as the catch got younger and younger (Fig. E26.5.1). Figure E26.5.2 shows how the spawning stock biomass (SSB) for cod has varied over four decades, continuing the downward trend of Fig. E26.5.1. Figure E26.5.3 shows a drawing of a cod.

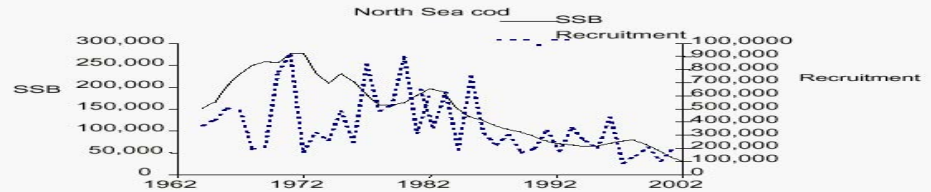

Fig. E26.5.2 Cod SSB and recruitment, 1962 to 2002.
(Prime Minister's Strategy Unit Report, March 2004, Ref. 28)

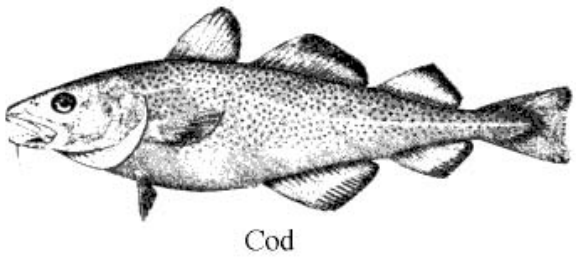

Fig. E26.5.3 Cod.
(Fisheries and Oceans Canada, http://www.dfo-mpo.gc.ca/zone/underwater_sous-marin/atlantic/acod_e.htm)

Predatory fish such as cod have suffered the most from industrial fishing operations. Stocks of cod in the North Sea were even lower in 2003 and 2004, continuing the trend of Fig. E26.5.2.(329) Canada imposed tougher restrictions on cod fishing off Labrador on the Grand Banks.(330) These actions and the state of the cod stock support Myers and Worm in their claim that "large predatory fish biomass today is only about 10% of pre-industrial levels."(331) An additional piece of supporting evidence comes from the collapse of the top ocean predator: the shark. Atlantic coastal and oceanic shark populations exhibited a steep plunge (by 75% over the period 1988 to 2003) as the other predators (shark prey) were overfished, even though the shark were not target fish themselves.(332)

Similarly, there was a collapse of sea mammals in the North Pacific Ocean. It has been suggested that this resulted from whaling activities of the 1800s and especially the 1900s, which practically eliminated the great whales (the gray whale, the right whale, the humpback whale, etc.).(333) Stocks of whales were 6 to 20 times as great before whaling

as they are now.(334) These great whales were preyed upon by killer whales, and supplied all the biomass needed to maintain that population. After the loss of their main prey, the killer whales were forced to find alternate prey—the very species that collapsed.(333)

Prior to the Canadian closure of the cod fishery in the early 1990s, analysis of data show that cod matured at younger ages and at smaller sizes.(335) Hutchings has called this an uncontrolled experiment in evolution and says it provides "compelling evidence of genetic change," that is, that evolution is occurring over the short term due to human pressure.(336) Olsen et al. further point out that when they examined contemporary 1980s data for the Grand Banks for 6-year-old cod, their technique could have predicted the cod fisheries collapse before it actually occurred. Since the pressure on the cod was removed through closure of the Grand Banks cod fishery in 1993, cod have shifted back some toward maturation at older ages and larger sizes, though the fishery has by no means recovered.(335) Assuming the correctness of the ability to predict collapse before it occurs, this provides marine scientists with an important tool in giving scientific advice on "sustainable" fishery practice (assuming the advice is to be followed).

It has also been pointed out that recreational anglers also selectively target these predatory fish, adding additional pressure on the species in most dire straits.(337,338) The effect of recreational angling is estimated to harvest between 4% (337) and 12% (338) of the fish caught overall. For some species and in some regions, the effect can be much greater. For example, about two-thirds of all landings of at-risk fish in the Gulf of Mexico are due to sports fishing.(337)

While it is true that stocks of various fish have waxed and waned over the historical record,(339) the sustained drop seems outside the bounds of such fluctuations—that is, due to humans, who are currently taking about 130 Mt of fish out of the oceans every

year,[24] and are seldom able to adhere to quotas in any meaningful way.[340] The cause is "[o]verestimation of abundance and underestimation of fishing mortality," inefficient catching of target fish when stocks are low, and "[i]ncreased discarding and nonreporting of small fish as the population declined and fishing mortality increased" due to the need to continue fishing no matter what to pay off the huge costs of industrial fishing vessels.[340] The discarding of the juveniles made certain that the stocks could not recover.

The industry disclaims responsibility and advances alternative reasons. One alternative hypothesis, that there was a drop in the number of codfish that survived to age 3 (known as "recruitment"), seems ruled out by analysis of the data.[340] While Myers et al. find "no evidence that poor recruitment contributed to the collapse of cod in Eastern Canada," they make the case that "poor recruitment has certainly been a factor in slowing the recovery" of cod off Labrador.[340] Another alternative hypothesis, that seal predation was responsible, is also ruled out.[340]

We must point the finger of responsibility at ourselves for the collapse of fisheries.

Of course, climate change provides an additional stressor, both directly because of changes in the fishes' local environment, and globally, in the interconnectedness of the oceanic food web. A study of krill from 1926 to 2003 (about 12,000 net hauls altogether) shows krill densities in decline and salp densities increasing in the Southern Ocean (the region around Antarctica).[341] Krill feed the predators caught by commercial fisheries. Salps are inferior food. Atkinson et al. observe that "changes among key species have profound implications for the Southern Ocean food web. Penguins, albatrosses, seals and whales have wide foraging ranges but are prone to krill shortage. Thus the wide extent of our indicated change in krill density—not just its magnitude—is important."[341]

Given the history of overfishing, Pauly et al. believe that fishing cannot increase, and restoration is necessary.(328) They strongly recommend the end of misplaced subsidies that distort the economics of fishing,(328) as do Hilborn et al.(31) Pauly et al. write eloquently that "overcapitalized fisheries are leading, globally, to the gradual elimination of large, long-lived fishes from marine ecosystems, and their replacement by shorter-lived fishes and invertebrates, operating within food webs that are much simplified and lack their former 'buffering' capacity."(328) Consequently, Pauly et al. suggest that dividing the ocean into zones within which all fishing is prohibited could help make the oceans once again sustainable.(328)

These "safe" areas would allow fish to grow larger, allow some females to reach maturity and replenish stocks, and allow fishing elsewhere because young fish respect no boundaries and a proportion of total stock will leave the protected zones. According to a study of marine reserves, "marine reserves, regardless of their size, and with few exceptions, lead to increases in density, biomass, individual size, and diversity in all functional groups. The diversity of communities and the mean size of the organisms within a reserve are between 20% and 30% higher relative to unprotected areas. The density of organisms is roughly double in reserves, while the biomass of organisms is nearly triple."(342)

Even migratory species, which would not be helped directly by the existence of reserves, would gain indirectly from reconstruction of the complex ocean food web.(328) Given the effect on age and average size of fisheries, eventual sustainability will depend on reinstating the natural genetic variation of pelagic species.(343) In addition, the scale of the reserve areas will have to be established in the absence of total knowledge about

crucial characteristics of the species that will live there. The so-called species-area relationship can give some help in making the decisions.(344)

This reserve strategy will not be cheap. It has been estimated that a network of marine reserves targeting 20% to 30% of the oceans would cost between $5 and $19 billion every year to run.(345) While this would involve an increase in spending for conservation by roughly a factor of 100, it is less than current worldwide subsidies to fishing (estimated at between $15 and $30 billion).(52,345) The authors of Ref. 345 note that "a global network with 20–30% coverage (expanded according to model b) could itself directly provide around one million fulltime jobs in MPA protection, almost certainly more than are maintained by all fishing subsidies worldwide."

For centuries people have defiled the coasts, disturbing wetlands and making the nearshore marine ecosystems more vulnerable to further disturbance.(316,317) A major disturbance of the overfishing is the decimation of the shellfish that live in the shallows.(316)

While the fisheries remove only about 8% of the global primary production of the oceans, this represents one-quarter to one-third of continental shelf (and upwelling) production.(317) A focus on the most recent symptoms will miss large parts of a holistic problem, which requires integrated management.

Setting marine parks in which catches are not allowed seems like an obvious things to do, similar to what was done in the National Parks. This is difficult, more difficult than it sounds. When officials tried to ban fishing in a large section of the Florida Keys National Marine Sanctuary, local voters in Monroe County, Florida, passed a nonbinding sense

that they were opposed, and the plan was cut way back, from 10% of the Sanctuary to just 0.5%.[346,347]

Discussion of a similar state plan off overfished California, which would have put most of Santa Monica Bay off limits to fishing, sparked a similar firestorm of opposition.[348] There will be a plan, and there will be fishing limits in order to comply with a state law, the 1998 Marine Life Protection Act.[348] Most present protected area will be enlarged. However, the details will surely be sensitive to political pressure, as was the case off Florida. Already, biologists and fishermen sparred over the area off the Channel Islands—the plan draft says 26%—that would be protected, even before the plan was released to the public (fishermen wanted the restricted area to be 18%, while biologists fought for 50%).[348]

A similar fate befell Ecuadorian Park Rangers trying to enforce conservation policies in the Galapagos Islands. Local fishermen rebelled; their livelihood was at stake. They are "mining the capital" instead of "living off the interest," not realizing the long-term consequences.[349]

If Pauly et al.'s more optimistic scenarios ("policy first" or sustainability first")[23] are to stem what Hilborn et al. call the "race for fish,"[31] a major attitude change will be necessary. There are some indications that that could possibly come to be the case, as in United States-Canadian cooperation in the Grand Banks fisheries and agreements among states in Oceania to provide incentives toward sustainability.[31]

Can hatchery salmon be considered to be the same as wild salmon?

A decision by an Oregon judge that wild salmon and hatchery salmon should be counted together, and thus that salmon were not endangered, concerns zoologists.(350) The scientists say that the hatchlings and the wild salmon are different, even if the hatchlings come from the same genetic stock. That is because hatchery salmon behave differently. They are raised to substantial size before release, whereas many juvenile wild salmon are eaten. The larger hatchery fish compete with their smaller wild cousins, causing increased mortality (and thus reduced recruitment).(350) In addition, hatchery fish can interbreed with wild fish, and the hybrids' poorer viability may take several generations to recognize.(350)

Since the hatchery fish are not imprinted with their home streams as wild salmon are, those who manage to survive in the wild can stray on their return back to land. Hatchery fish beyond the second generation away from the wild "may not assist population recovery; their rate of survival in the wild is much lower than that of wild fish ... hatchery brood stock show domestication effects, genetic adaptations to hatchery environments that are generally maladaptive in the wild."

The authors of Ref. 350 point to the Bay of Fundy, where a century of stocking has not protected the wild salmon. They assert that the Atlantic hatcheries "disguised long-term problems, which probably contributed to the near extirpation of native Atlantic salmon."(350)

Problems of husbandry in aquaculture

Pests develop when we bend ecosystems for our own purposes, and make monoculture out of polyculture. This is true of agriculture, where pests were below threshold of bother until massive numbers of similar plants were grown together, or massive numbers of animals of the same species were raised together. As the discussion of diversity being important for ecosystems emphasizes, concentration of just a few species is an invitation for disease organisms to gather (there's such a rich field of victims!).

The same principle holds true whenever similar conditions arise. Pests get more prominent and disease gets more likely. An example is the relatively new technique for raising salmon in "fish farms" in the ocean. As monoculture grows, there is a point where the population density gets high enough to trigger the response cycle. This cycle can get especially vicious if the animals are crammed together.

Tuna and salmon are the current favorite farmed fish. Tuna are prized in Japan for sushi, and salmon are important in the United States and Europe. Tuna are farmed off Mexico, off California soon (just 5.5 km out, far enough to evade state jurisdiction),[351] in the Mediterranean, and off Australia.[352] Cod are being farmed in Norway, though in small amounts so far.[353] Since tuna and salmon are both predators, they must be supplied with fish meat, usually in the form of fishmeal. About 30 Mt/yr of the total fish catch goes to farmed fish (probably about one-third of the total) or to feed animals.[24,353]

Herding tuna into pens involves mortality estimated at around 10%, and wildlife that comes to prey on the tuna (sea lions, for example) must either be dissuaded from preying on the fish farm or killed.[352] Stories abound of Mexican fish farmers shooting sea lions from boats. The Mexican EPA admits shootings in the past, but denies continued

shootings.(352) Mass dieoffs of farmed fish occurred off Australia. In addition, there have been sardine dieoffs from hemmorrhagic septicemia moving up from Mexico toward Alaska, affecting different species as it goes.(352) The disease is presumed to have been transmitted due to the presence of the farmed tuna.

Salmon are currently farmed in the oceans off northern Europe, North America, and Chile. The Atlantic salmon being farmed in North America and Europe are of the species *Salmo salar*. Pacific salmon are more variegated; they are comprised of seven different species—chinook (*Oncorhynchus tshawytscha*, largest of the Pacific salmon at up to 50 kg), chum (*Oncorhynchus keta*), coho (*Oncorhynchus kisutch*), cutthroat (*Oncorhynchus clarki*, formerly *Salmo*, and so also called cutthroat trout), pink (*Oncorhynchus gorbuscha*), steelhead (*Oncorhynchus mykiss*, whose freshwater form is the rainbow trout), and sockeye (*Oncorhynchus nerka*). These are shown in Fig. E26.5.4.

Analysis of several tonnes of salmon show that farmed salmon have much higher concentrations of organochlorine contaminants.(354) These include PCBs, dioxins, and chlorinated pesticides. Farmed salmon from Europe have higher concentrations of these contaminants.(354) In addition, it appears that farmed salmon have a higher concentration of polybrominated diphenyl ethers (PBDEs), a chemical used as a fire retardant.(355) In this case, Chilean farmed salmon have the lowest concentrations of the farmed salmon.(355) We have already mentioned in Ch. 14 the presence of these chemicals in wild populations far from civilization,(356) and they appear in other pelagic species as well (along with PCBs and other contaminants).(357)

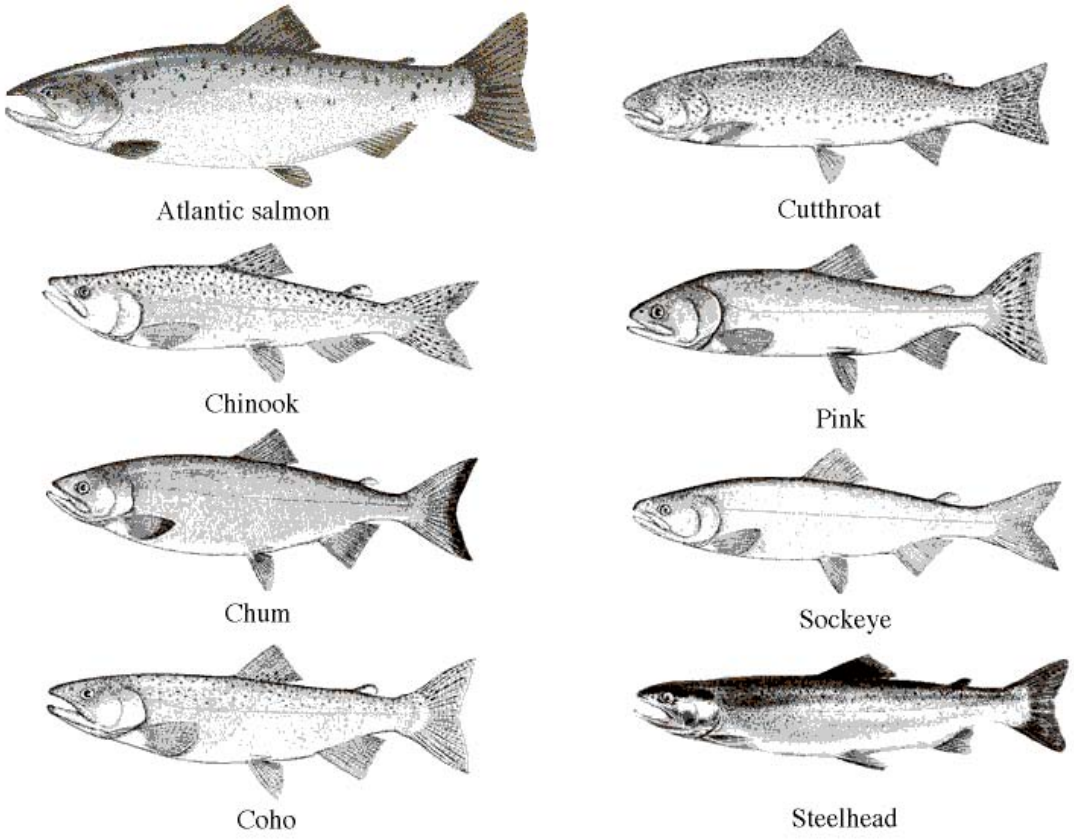

Fig. E26.5.4 Atlantic salmon and the seven different types of Pacific salmon.
(Atlantic salmon, Department of Natural Resources, State of Michigan, http://www.michigan.gov/dnr/0,1607,7-153-10364_18958-45639--,00.html; Pacific salmon, Fisheries and Oceans Canada, *Underwater World: Pacific Salmon* (Nanaimo, BC: Pacific Biological Station, 2002), Fs 41-36/1-2001E)

The stocks of farmed fish grown are based on Norwegian salmon, chosen for fast growth, and these salmon differ from most Atlantic salmon.(358,359) The salmon died much sooner than wild salmon, but do interbreed with native salmon.(358-360) The reproductive success (adult fish to adult fish) of farmed salmon released to a Norwegian river was only about one-sixth that of wild salmon in one experiment,(359) and only about 2% in another experiment in an Irish river compared to 89% for wild salmon.(360) It turns out that the progeny of these mixtures also die sooner than wild salmon (though they live longer than farm salmon).(358) Juvenile farm salmon outcompete wild salmon because of their faster growth, but farm fish and mixes of farm and wild fish exhibited reduced fitness compared to wild fish.(360)

Fish stocks in Maine pens recently met this criterion, and now the fish in Cobscook Bay suffer from a highly contagious and incurable salmon anemia fish disease.(361) Federal officials are fearful of release into wild salmon stocks, and over 700,000 salmon have had to be destroyed. The disease was unknown until 1984, when it was seen in Norway (fish farms were the location). Norway had so many problems with diseased fish that it had to poison many rivers.(362) Over 3 million salmon in Canada have been sacrificed because they caught the disease.(361) On one farm off British Columbia, almost a million young salmon had to be killed.(362) In addition, sea lice have appeared among farmed salmon.(362,363) On one British Columbia farm, nearly 4 of every 5 juvenile salmon were carrying a fatal burden of sea lice. The pesticide emamectin benzoate protects salmon from the sea lice when it is in the feed, but dosing must stop a month before the fish are to be shipped to market so that enough pesticide is flushed out of the fish to make them safe to eat.(362)

Between the escape of 100,000 farmed salmon from Maine oceanic farms and the escape of 500,000 salmon from Pacific farms (there is a fear they would interbreed with wild species and distort the gene pool, since the fish have been bred for farming and are different genetically) and the devastating toll of so much lost fish, it is not clear whether aquaculture will long survive in Maine.(361,363) As of 2003, it was thought that about 1 to 2 million farmed salmon were escaping from north Atlantic fish farms every year.(358,362)

The best thing to reduce the extra pressure on fish stocks would be to make the predatory fish into herbivores instead of carnivores.(353) However, it turns out to be very expensive to feed fish soy or other elements of a vegetarian diet, and it is not clear that the fish

would taste similar to wild fish.(353) Also the supply of fishmeal may fall below demand by 2010 if farmed fish continue to grow by 5%/yr.(353)

One possible alternative solution to enforced vegan diets is development of transgenic fish in the fish farms. The company Aqua Bounty of Waltham, Massachusetts developed an Atlantic salmon with a gene from Pacific Chinook salmon that makes growth occur much more rapidly (six times as fast).(364) The company is waiting as this is written for FDA approval.

This raises interesting questions.(364) Will transgenic fish outcompete natives? Will transgenic fish be easier prey? What happens if transgenic fish interbreed with native fish? Could escape of transgenic species be prevented? The answers to these questions are the subject of current research.