

Blue Revolution

The Promises and Pitfalls of Fish Farming

A generation ago, agriculture responded to the challenge of rising population by achieving big increases in crop yields—but at considerable cost to environmental and social stability. Now, as agricultural productivity flattens while demand continues to rise, high-tech fish farmers are wading into the breach. But can they replicate the successes of the Green Revolution without repeating and compounding its disasters?

by Anne Platt McGinn

ILLUSTRATIONS BY BRIAN BATTLES

The town of Turners Falls, Massachusetts, on the Connecticut River about 150 miles west of Boston, was one of the many small New England towns that thrived during the Industrial Revolution at the turn of the twentieth century. The textile factories and pulp mills of that era are long gone, but today the town is part of another development that could have global reverberations. This time, it is part of what might someday be called an *integrated* industrial revolution. One of its newer businesses, housed in a corrugated steel building not far from the river, produces fish. Aquafutures, as the name implies, is not a traditional New England fishing enterprise of the kind that launched its boats from the Massachusetts or Rhode Island coast during the country's early history. Through the use of water recirculation technology, the company—one of many in its fast-growing business—is helping to radically change the way fish are produced, and ultimately to determine what role aquaculture will play in supplying food to the world.

Inside this one-acre facility, amidst fish tanks, processing facilities, and support systems, Aquafutures' employees raise hybrid striped bass—a cross between white and striped bass. Shipped in as fingerlings that weigh 2 grams, the bass are kept in this secure environment for about 10 months during which they are given high-protein feeds. Once they reach market-size of about 800 grams, they are shipped to restaurants and supermarkets. While this facility may seem far removed from nature, it is in fact fairly well designed to mesh with the resource constraints of natural systems.

By using state-of-the-art recirculating technology, with computers monitoring temperature, oxygen, and chemical levels, the plant can recirculate each liter of water 250 times before it is discharged. Although the process is energy-intensive, the electrical costs are to some degree offset by the gains in water efficiency. High water demand is a major problem for food production worldwide, whether in irrigating agricultural land or in providing future habitat for fish. Aquafutures has minimized not only its water

use but its pollution, replicating the waste management practices of local dairy farmers who storehouse manure. Workers periodically scoop out waste from the fish tanks and sell it as a nutrient-rich manure to local corn and vegetable farmers.

A world away, on Phuket Island in southern Thailand, aquaculture is having a very different impact. Not far from four-star resort hotels, shrimp-breeding ponds have blanketed the landscape. In the village of Ao Goong (meaning Bay of Prawns), the rural quiet has been displaced by a constant drone of generators circulating air into the ponds and pumping out wastes.

Unlike their contemporaries in Turners Falls, the people of Ao Goong have not welcomed this new business. The wastes from the ponds have been simply dumped on the ground, causing the villagers' coconut trees to turn brown and their well water to go bad. They can no longer use the wells, and have had to haul in drinking water from somewhere else. When the wastes from the cultivated shrimp were redirected into the bay, wild shrimp were killed—destroying the traditional local economy. For generations, the villagers have made their living by fishing shrimp from the sea, but the arrival of commercial prawn farmers is putting them out of business.

As the people of Phuket Island have learned, the environmental and social costs of shrimp farming can be enormous. Shrimp is the most valuable commodity being produced by the booming aquaculture industry, and arguably the most destructive. But it is not alone: a wide range of indiscriminate and poorly planned fish farming operations are leaving their heavy footprints—destabilizing coastal ecology, degrading farmland, and polluting drinking water supplies.

The conundrum is that fish-farming, if properly done, offers great advantages in resource-use efficiency over both traditional fishing and conventional agriculture—advantages the world can ill afford to squander in an era of impending food scarcity. Indeed, integrated fish and rice farming has formed the backbone of traditional agriculture in Asia for centuries. As the world's expanding human popula-



tion drives up global demand for new food supplies, the great potential of aquaculture, combined with some of the horrendous ecological and human impacts it has had so far, have created seemingly intractable tensions between its promoters and its critics. How that tension is resolved will go a long way toward determining how—or with what limitations—we will be able to eat in the future.

The Blue Revolution

As far as is known, the earliest fish farming (or aquaculture) took place in China, where the common carp has been a staple food for millennia. A document called "Fish Culture Classic," written by Fan Li nearly 25 centuries ago (in 460 B.C.), details numerous experiments on the sizes of fish ponds, stocking rates, and harvest yields. In rural inland areas, often on marginal lands, small carp ponds supplemented the output from farm crops for centuries; the ponds were supplied with nutrients from an adjoining pig pen, or from other animals, ducks, food preparation, or nightsoil. Several times a year, the ponds were cleaned out and the resulting rich bottom soil was applied to neighboring fields.

When Emperor Lee came to power during the Tang Dynasty (618–917 A.D.), growers shifted from cultivating carp to other types of fish. The shift was an accident of history: the word for carp sounds like the Emperor's name "Lee" in Chinese, and farmers were apprehensive about the connotations of any talk about "eating carp." Other species were put in the ponds. And, because supplies of newly hatched fish varied from season to season, farmers had to make do with whatever they could get, sometimes raising different species together in the same pond. Gradually, a stable and highly productive system of polyculture—raising many fish together—evolved.

Chinese pond-culture systems continue to be among the most productive freshwater fisheries in the

world today. One of the keys to their continued success is that nearly all the wastes are put to productive use, so the systems are largely self-sufficient and closed: the waste of one species becomes food for another. In more open systems, unused nutrients attract infestations of bacteria, insects, birds, and other organisms, which upset the balance and deplete the food supply needed by the fish.

In the polyculture pond, available nutrients are matched closely to the feeding habits of various fish. Silver carp and tilapia feed on phytoplankton (microscopic plants), while bighead carp graze on zooplankton (microscopic animals). Grass carp, wuchang fish, and common carp eat green fodder, while common carp, black carp, and mud carp forage in sediments at the bottom of the pond. Species are thus combined to maximize yields and minimize inputs, providing a valuable source of food and protein for local consumption. In a pond about two meters deep, for example, an experienced farmer may raise up to 10 tons of fish per hectare each year.

This sort of small-scale aquaculture has also been long practiced by rural villages in Indonesia and India, using local fish varieties. During the early twentieth century, Chinese immigrants brought their experience with polyculture to Thailand. From there, small-scale "integrated" fish farming—that which efficiently combined the feeding of fish with the raising of plants—spread throughout Southeast Asia. But it was not until well past mid-century that commercial aquaculture began its boom in earnest.

During the late 1960s and 1970s, fish farming was touted by international development agencies as a new source of protein that would sidestep the problems of traditional agriculture—which was facing a gamut of problems with soil erosion, increasing fertilizer needs, and scarcity of fertile land and irrigation

water. Fish farming was viewed as a simple yet elegant means of providing food security for growing populations in developing countries. Simply by flooding marginal lands and releasing easy-to-grow fish that most people could afford to buy, social planners predicted, farmers in those countries could create a global revolution in food production.

Indeed, in many ways, aquaculture is a more reliable source of protein than either traditional fishing or farming. Compared to ocean fishing, which can be disrupted when storms or territorial disputes turn boats back, fish farming is less dependent on the weather, less dangerous, and less vulnerable to seasonal ebbs. And while commercial livestock operations depend on a few dozen species of animals, the number of species of fish that can be successfully farmed runs to the thousands.

As a source of animal protein, farmed fish are—in a grain-limited world—a godsend. The estimated "grain feed conversion rates"—the amounts of rice or wheat needed to produce a ton of product—are far more economical for fish than for pork or beef and on par with that of chicken. On average, whereas four kilograms of grain are required for each kilogram of pork, and seven for each kilogram of beef, only two kilograms of grain are needed to produce one kilogram of either fish or chicken.

In terms of how much of the animal is actually consumed by people, fish are also ideal: approximately 65 percent of the raw weight of finfish is eaten, compared with 50 percent of raw weight of chicken and pigs and 40 percent of sheep. (Because fish are supported by water, they don't have to put as much of their growth energy into bones, so more of their weight is edible.) Fish are also low in fat and cholesterol, and a substance found in fish oil, omega-3 fatty acids, helps reduce blood clotting and in turn the risk of heart attacks—all notable advantages over other meats.

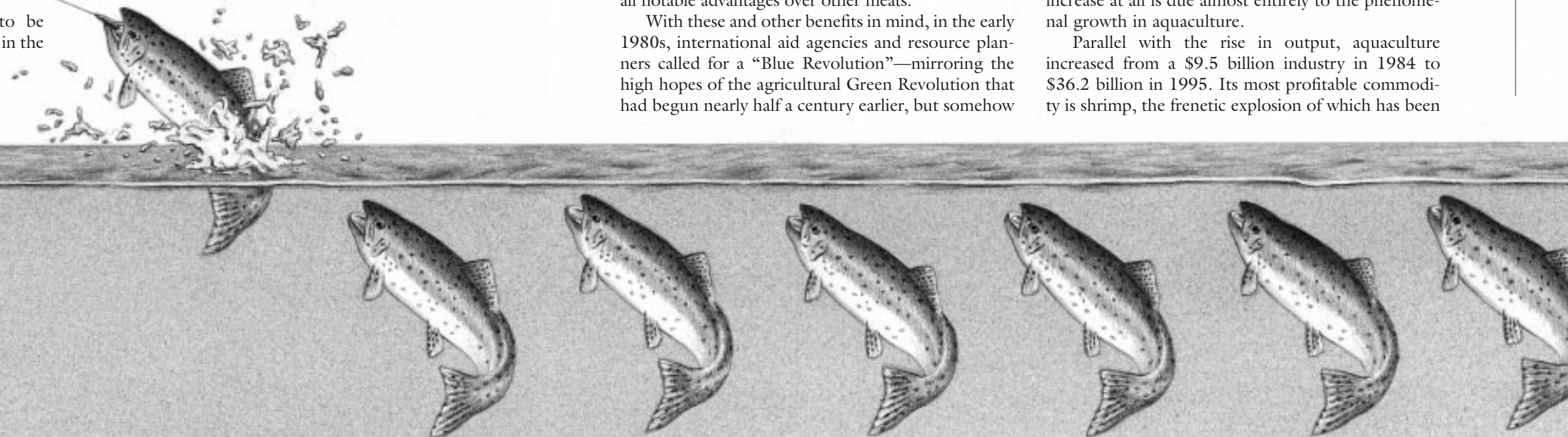
With these and other benefits in mind, in the early 1980s, international aid agencies and resource planners called for a "Blue Revolution"—mirroring the high hopes of the agricultural Green Revolution that had begun nearly half a century earlier, but somehow

not anticipating that the Blue Revolution would also replay many of the most vexing problems the Green Revolution had eventually encountered. Aid agencies funded research aimed at genetically modifying fish to resist disease, grow faster, taste better, and thrive in highly controlled environments. And, as had occurred with such developments in agriculture, yields increased dramatically. In 1993, researchers in the Philippines announced that they had successfully cultivated a strain of tilapia that grows 60 percent faster than its wild cousin. World Bank officials called it the "aquatic chicken." And in a 1995 report, the World Bank referred to fish farming the "next great leap on food production," thanks to genetically improved fish, increased inputs, and technological manipulation of the growth cycle.

Today, aquaculture constitutes one of the fastest growing sectors in world food production. From 12.4 million tons in 1990, farmed fish production nearly doubled to 23 million tons by 1996. For every 5 kilograms of beef produced worldwide, there are now 2 kilograms of farm-raised fish. Clearly, aquaculture will play an increasingly prominent role in the world food supplies, meat markets, and seafood production.

By no small coincidence, the explosion in aquaculture production is occurring at the same time that the world's fishing fleets have suffered catastrophic losses and many ocean fish stocks have dropped to all-time lows. Marine harvests still account for 80 percent of world seafood supplies, but fish farmers are quickly altering the balance. Nearly 40 percent of the salmon consumed today have lived in captivity for most of their lives, compared to just 6 percent a decade ago. Likewise, 40 percent of the mollusks—which include oysters, clams, and mussels—and 65 percent of freshwater fish have lived mostly in farm environments. The fact that world seafood supplies continue to increase at all is due almost entirely to the phenomenal growth in aquaculture.

Parallel with the rise in output, aquaculture increased from a \$9.5 billion industry in 1984 to \$36.2 billion in 1995. Its most profitable commodity is shrimp, the frenetic explosion of which has been



called an “aquatic gold rush.” In the past decade, for example, annual production of giant tiger prawns in Thailand has exploded from 900 tons to 277,000 tons. The world total has jumped more than five-fold, to 500,000 tons. Shrimp farming is now a \$6.3 billion industry that spans 50 countries. Driven by industrial countries’ growing appetites for seafood, shrimp farming has become a major export industry in Bangladesh, Indonesia, India, Thailand, and China. Yet, all of those countries have problems producing enough food for their own populations.

Although high-value carnivorous species dominate the net worth of the industry, production in volume is dominated by freshwater—predominantly vegetarian—fish. In 1995, four of the top five cultured species by weight were species of carp. Worldwide, 10.4 million tons of carp were farmed in 1995—nearly half of all aquaculture production. Other non-carnivorous species, such as catfish, tilapia, milkfish, and shellfish account for an additional 7 million tons, with relatively benign environmental impacts.

Almost 85 percent of aquaculture now occurs in low-income food deficit countries, with China leading the way. Between 1990 and 1995, Chinese output increased from 5.8 to 12.8 million tons—accounting for 62 percent of the world’s total aquaculture production. By 2010, it is planning to double the area under fish cultivation, to 7 million hectares. (By comparison, China’s total grain area covered 85.7 million hectares in 1994.)

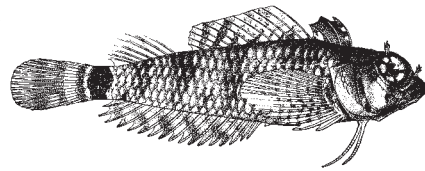
While harvests of wild fish appear to have topped out at close to the maximum level the oceans can sustain, the promise of aquaculture is that it can provide a valuable supplement to traditional fish harvests. Under favorable conditions, estimates the U.N. Food and Agriculture Agency (FAO), aquaculture could supply up to 39 million tons of fish by 2010—about 70 percent more than is produced today.

The Problems

Such plans are ambitious, and rather than sticking with the Chinese model of complex, closed-loop production, development aid agencies and lucrative export markets have encouraged farmers to increase output with fewer species and intensified production. The industry has placed more reliance on artificial inputs such as fishmeal and high-protein feed, chemicals, and antibiotics. In recent years, diverse pond systems have been replaced with a range of high-tech, high-volume systems: floating cages in marine water; tanks with mechanical controls on feed, light, and growth stimulation; and structured raceways that provide artificial flows of water and diversion channels

to simulate the natural environment. In short, recent forms of aquaculture have developed into the equivalent of raising fish in marine feedlots—or factories.

Along with these new systems have come new trade-offs, many of which parallel the problems of the Green Revolution that fish farmers were trying to avoid: high volumes of waste, pollution, poor land-use practices, disease outbreaks, risks of genetic inbreeding, and inequitable use of resources. In terms of environmental impacts, shrimp and salmon farming, which together accounted for 6.3 percent of world output in 1995, are the worst offenders.



Gillias jordani

Indeed, shrimp and salmon farming constitute two of the most resource-intensive food production systems in the world. But the same practices that produce such disastrous results in intensive shrimp ponds and salmon netcages, are being adopted, to varying degrees, in all types of modern fish farming.

To raise fish, large quantities of water are needed as a medium for growth and to replenish oxygen and remove wastes. Exact needs vary according to the type of fish raised, size of farm, rate of ground seepage and evaporation, and production rate. In general, intensive production of common carp and tilapia requires the roughly the same amount of fresh water, per ton of meat, as the not-insignificant amounts needed to raise grain-fed cattle or pigs. (To raise one ton of fish requires 8 tons of water, compared to 5 tons of water for pork and 8.5 tons for grainfed beef.) Intensive shrimp production requires up to 10 times more water. These high demands can place enormous pressures on local water supplies. In the Ranot region of Thailand, for example, development of shrimp ponds has been so rapid that the average groundwater level in the area fell by four meters between 1989 and 1991.

One of the key benefits of aquaculture is its potential for reducing pressure on marine fisheries. Yet, for carnivorous species such as, shrimp, salmon, trout, bass, and yellowtail, aquaculture actually increases demands on marine production in order to provide feed for the farmed fish. The carnivores require amino acids from other fish for growth, which are provided in the form of high-protein feed pellets made from wild fish. An estimated five kilograms of oceanic fish reduced into fishmeal are required to raise one kilogram of farmed ocean fish or shrimp, representing a large net protein loss.

Intensive aquaculture’s high demand for fishmeal is now a leading factor contributing to marine over-harvesting. Worldwide, about a third of the global fish harvest, or 30 million tons, goes to nonfood uses, primarily animal feed, fish meal, and oils. Of this, 17 percent goes to feed fish, while the balance is

used to feed cattle and poultry. It has been estimated that by 2010, carnivorous fish on farms could be taking all of the world’s fishmeal, using up needed protein that could otherwise be used for direct human consumption—a redistribution of marine biological wealth from the poor to the rich.

Further pressure is put on marine ecosystems by aquaculture’s reliance on wild stocks to supply seed. Fish culture in inland lakes and reservoirs of Cambodia, Thailand, and Vietnam rely heavily on small, wild-caught fish for fingerlings, while industrial shrimp farmers divert estuarine waters into large ponds and essentially cherry-pick the best larvae for cultivation, leaving the remains behind for wild harvesting.

Added to these high levels of water and food inputs, is the need for land. Under pressure from Western and Asian business investors and multinational corporations, local governments and authorities from countries such as El Salvador and Thailand have been coerced into granting access to prime agricultural and coastal lands to aquaculture development. Inland fields are flooded for catfish ponds, mangroves are cut down to make way for shrimp farms, and coastal waters are fenced in to raise salmon, mollusks, seaweed, and even cod, often with little regard for previous uses of the land. Whereas traditional forms of aquaculture are designed to be compatible with surrounding resource uses, intensive aquaculture is often imposed on local ecosystems, with significant environmental consequences that extend far beyond the farm.

One of the biggest problems is water pollution. Because fish are raised directly in the aquatic environment, fish waste, uneaten feed, and fecal matter accumulate in the receiving waters and can float directly downstream and into water supplies. Scottish researchers have estimated that between 300 and 1,000 kilograms of solid wastes are produced from each ton of fish raised—up to a ton of waste for each ton of fish. Most of the waste is in the form of organic solids, dissolved nutrients, and inorganic nutrients such as nitrogen and phosphorus. Though they are not toxic, these wastes can cause over-nutrition and the spread of algal “blooms”—massive blankets of green slime on the water’s surface that precipitate bacteria growth, deplete oxygen, and kill much of the life in the water below. Because of high stocking rates, salmon netcage farms in British Columbia, on the Pacific coast of Canada, were found to be producing the waste equivalent of a city of half a million people.

Raising large volumes of fish in controlled environments also puts abnormal stress on the fish themselves, which increases vulnerability to outbreaks of disease both on the farm and in surrounding waters. Fish biologists have identified more than 50 bacterial diseases and host of other health problems—threats that are prompting aquafarmers to inject antibiotics, vaccines

and chemicals to rid their crops of illness. Scottish authorities report, for example, that a newly approved organophosphate chemical called azamethiphos is being used to control the sea lice that infest the flesh of salmon and other fish, but that this chemical also has a tendency to kill young lobsters and herring.

Escapes of domesticated, farmed fish into rivers, lakes, and coastal areas have become a growing risk to already decimated stocks of wild fish. Yet, such escapes are not uncommon. In tropical freshwater systems, two-thirds of escaped fish species have become established. In Europe, 30 percent of all exotic aquatic species came originally from fish-farm escapes. Salmon are especially vulnerable to displacement by farmed stock, as they have specific territorial behavior that is essential for survival in the wild. An accident with a ripped net in 1997 allowed nearly 300,000 farmed Atlantic salmon in Puget Sound to escape into the Pacific. These non-native fish could undermine efforts by federal and state officials to restore endangered wild populations in the Columbia River and elsewhere.

While mismanaged fish farms can “leak” into surrounding areas, they can also exhaust the areas set aside for them. Over time, their high demands for water, feed and sometimes for electric power and other artificial inputs, combined with high levels of pollution and disease, can lead to declining yields and, eventually, pond abandonment. Again, shrimp farming provides the most dramatic illustration: Between 1965 and 1985, shrimp farmers in Taiwan intensified production from 1.4 tons per hectare to 3.6 tons per hectare. But by the late 1980s, the industry in Taiwan had completely collapsed due to a series of disease outbreaks and financial disasters—leading many operators to abandon their ponds.

This practice is not unlike the slash-and-burn farming of tropical forests, which become quickly depleted and are often abandoned after a few years. Between 1985 and 1995, approximately 150,000 hectares of shrimp ponds fell into disuse worldwide, according to estimates by the World Wildlife Fund International. And the rate of abandonment—like that of slash-and-burn deforestation—appears to be increasing. While the average fish pond is good for about 10 years, for high-density shrimp ponds, the typical lifespan is even shorter—about 5 years.

Such unsustainable practices have exacted a heavy cost both to local peoples and to the environment. Once limited to ponds in Taiwan and Thailand, shrimp farming—reinforced by armed members of the international “prawn mafia”—has swelled into a wave of development spreading across South Asia and Latin America, and threatens to overtake shoreline areas in Africa as well. Ironically, the people who suffer the most from such development are often those who have been the most dependent on fishing for their

livelihoods. The traditional fishers are not the ones profiting from the new mass-production operations.

What happened in the Thai village of Ao Goong, for example, is happening now in Bangladesh. Since the 1980s, villagers in the district of Khulna, about 350 kilometers southwest of Dhaka, have been protesting the incursions of commercial shrimp cultivation. In the late 1980s, the area was declared a shrimp-free zone at the villagers' insistence. However, influential shrimp traders persuaded local authorities not only to throw out the zoning but to physically break down protective embankments around agricultural land, flood the fields with saltwater to ruin the crops, and open the way for more shrimp development. In recent years, village women have been physically and sexually abused by shrimp farmers and their guards, and at least 100 villagers have been killed in clashes over land acquisition disagreements.

Sustainable Aquaculture

The most destructive forms of aquaculture still comprise a small share of global output. But they are disproportionately threatening to the future viability of aquaculture as a whole, and to the level of confidence we are likely to have in what could turn out to be a critical food source in confronting future food scarcity. The problem is that while shrimp and salmon are produced in smaller volumes—so far—than carp or mollusks, they are more profitable and more in demand by the expanding international market. The ripple effects of the land grab being felt around the rims of Asia, South America, and the Caribbean can be seen in the rivers and ponds farther inland as well: more pressure is being put on farmers to shift to rapid, mass-production monoculture. Both natural systems and the local human communities they support are being elbowed out.

A critical need, then, is to promote commercially attractive alternatives to slash-and-burn-style aquaculture. One of the advantages of aquaculture is the great variety of available species and methods of cultivation that can be adapted to fit local resources and local needs, whether for supplemental food, income, or jobs. In this respect, though the scale and volume of the small family fish farm may hold little interest in the fast-track commercial world, the model of Chinese polyculture offers a key benefit. By using household and livestock effluent as a nutrient, the traditional system neatly solves two problems that in the modern world tend to be treated separately. In recent decades, however, the increased volumes of waste produced—driven by rising population and rising per-capita consumption—has turned waste disposal into a high-profile problem. The business of waste disposal has been catapulted from a marginal trade into a major growth industry. If new strategies

for urban waste disposal can be developed that allow the nutrient or energy value of waste to be turned from a net cost to a net value, those strategies could offer attractive opportunities for investment.

One such strategy is to recycle waste nutrients into agriculture (see Gary Gardner, "Human Waste: Pollutant or Resource?" January/February). A parallel one is to use the waste to feed fish—and having the fish serve as a means of wastewater treatment. Some studies indicate that fish can reduce water treatment costs by 30 to 90 percent.

In parts of India, this principle has been practiced for decades. Since 1850, the wetlands east of Calcutta have been used for brackish-water aquaculture. Until the 1920s, the water supply came from the River Bidyadhari. When it ran dry in 1928, fish farmers began experimenting with sewage, dividing the wetlands into a series of ponds for aerating sewage, growing fish and vegetables, and diverting semi-treated water to agricultural areas. Today, Calcutta has one of the largest integrated resource recovery systems in the world. More than 12,000 hectares of wetlands are divided into four integrated recovery schemes: garbage-composed vegetable farms, sewage-fed brackish-water aquaculture, wastewater-fed freshwater fishponds, and paddy fields using fishpond effluent. Smaller systems of this kind are also operating in China, Germany, Thailand, and Vietnam.

The human health risks associated with sewage-fed fish have been addressed to some extent through low-tech filtration and maturation ponds, careful monitoring, and public education campaigns about the risks of eating raw fish. Thorough cooking can destroy most pathogenic bacteria, although the people handling the waste and raising the fish remain at risk of illness. A 1990 report by the Asian Institute of Technology, ICLARM, the UN Development Program, and the World Bank Water and Sanitation Program found "no evidence that consumption of fish from sewage-fed ponds increases the risk of excreta-related disease."

An alternative application of this principle is to take it one step further, using the waste generated by aquaculture as an input to another industry—as in the case of the Massachusetts-based Aquafutures company selling its fish waste to local vegetable farmers. Many facilities in the United States and Europe are now cultivating hydroponic vegetables, fruits, and herbs along with fish. Plants float directly on fish pond water with their roots suspended, or in a connected side-channel or pond. Facilities in Missouri, for example, raise tilapia in a tank and then release the fish effluent water into gravel beds, where it feeds vegetables and herbs. The water can then be recirculated back to the fish tank. And, what works for fish waste could eventually work for other waste streams as well: hydroponic systems can be as effective at removing phosphorus from wastewater as the most expensive

high-tech methods available, according to a recent report by the New York-based Environmental Defense Fund.

The technical capability to recirculate water may be a key to the success of such systems in places where fresh water is in short supply. Although complex in design and expensive to build, recirculating systems have been widely adopted by large cities in such diverse countries as China, India, Germany, Israel, and the United States. Used in fish production, they can reduce total water use to one-twenty-fifth of that required by a traditional flow-through system—while giving the farmer better control of other inputs and

ultimately more efficient production. Israel leads the world in the development of water recirculating systems that combine aquaculture and agriculture. In a typical Israeli system, fish farming is the first in a chain of users, in which each link of the chain produces a product of high economic value by allowing several users to benefit from the same water.

On the Israeli-Egyptian border, closed pond systems appear from an airplane as large bubbles on the desert—aquatic greenhouses teeming with tens of thousands of tilapia and carp. These systems have advanced from flow-through methods—in which water is continually flushed through to remove

What is Necessary to Make Fish Farming Sustainable

1. Stop the decimation of sensitive ecosystems

- Restrict locations of fish farms to assure no net loss of mangrove forests or other threatened environments
- Use biofiltration to degrade fish waste
- Maintain buffers between ponds, water sources, and filtration systems

2. Protect local peoples' traditional livelihoods

- Locate farms so there is no displacing of local fishing and spawning grounds
- Guarantee local people access rights to fishing grounds, forests, and agricultural land

3. Reverse net protein loss

- Raise fish that require little or no fish-meal in their diets
- Promote consumption of herbivorous species such as catfish, crayfish, tilapia, carp, and mollusks

4. Stop Escapes

- Ban net-cages from coastal waters
- Monitor farms for escape routes, and keep cages and holding facilities in good condition
- Raise native strains rather than introduced species
- Employ conventional breeding programs rather than transgenic technologies

5. Halt Pond Abandonment

- Reduce stocking rates of fish
- Restrict inputs of chemicals, antibiotics, and pesticides
- Allow ponds to lie fallow
- Remove wastes regularly
- Provide regular maintenance
- Require monocultures to pay for equivalent area of land rehabilitation
- Rotate crop production and maintain a variety of species

6. Recirculate Water

- Charge fish farms for water use and develop market incentives for recirculating technologies
- Invest in R&D to improve recirculating technologies.

7. Integrate with Other Industries

- Use household wastewater to feed fish
- Use locally available ingredients to make feed
- Raise hydroponic vegetables with fish
- Apply fish-farm manure to agricultural land
- Reuse water from fish farms for other industries
- Provide tax incentives for closed-loop production and resource efficiency
- Certify and label aquaculture products produced sustainably

wastes—to biofiltration methods with compartments for removing wastes and recirculating water. (Biofiltration is essentially a natural cleansing process that uses bacteria to degrade the organic waste from fish.) These bubble environments are highly controlled, with paddle wheel-like devices stirring the water to keep it oxygenated, and pH levels, temperature, and nutritional content monitored and adjusted by computer. The bubbles are made of a special plastic that absorbs heat energy during the day and releases it at night. Under these optimized conditions, tilapia grow to full size in about 12 months, thus producing much larger yields than in traditional open ponds where they take 17 months.

A drawback of these systems is that they are expensive to set up and consume prodigious amounts of energy. The investment costs for recirculating systems run between \$4 and \$8 per kilogram of annual output, compared to \$2.20 to \$3.30 for a pond or raceway system. On the other hand, if all aquaculture operations were charged for their discharges, these systems would be more competitive.

In another kind of industrial synergy, U.S. electric utilities are now promoting aquaculture as a way to recycle warm water discharge from power plants. Leasing utility land and selling power plant waste heat to farmers growing fish in warehouses can make good use of this untapped resource, which would otherwise be a pollutant. The partnership also provides the utility with a new high-demand customer. Near Bismarck, North Dakota, the Golden Fisheries company operates a year-round aquaculture facility for warmwater species such as tilapia, using hot wastewater from a coal-fired power plant across the street. In addition to the wastewater, however, the 2-acre dome structure consumes 4.1 million kilowatt-hours of electricity per year, as much as a small town. If energy efficient methods are not adopted, the high energy demand of these intensive systems could make them part of the problem rather than a potential solution.

As with traditional agriculture, technological advances can help address some of the problems associated with aquaculture. Norwegian researchers, by designing fish food that is more easily digested, and by targeting it to the fish more precisely, have reduced the amount of feed needed to produce salmon by 50 percent, resulting in an 80-percent reduction in discharges of solids. They have also found a way to feed salmon successfully without adding fish oil, though it could be a decade or so before the new formula is commercially viable. Soon they expect to eliminate the need for fishmeal altogether, by genetically altering the salmon's nutritional requirements. And new efficiencies are being gained in cleanup, as well as in production. Trout farmers in Idaho, for example, have made some progress in reducing phosphorus discharge by

switching from sinking feed pellets to ones that float, thereby reducing the loss of uneaten food.

Blueprint for a Blue Revolution

If the fish-farming industry succeeds in transforming itself so as to become both highly productive and sustainable, what will it look like? Here's what the research suggests:

First, fish will be more popular than ever. In the past half-century fish consumption has boomed, but as the industry takes better advantage of its inherent resource efficiencies, it will boom even more. The most ubiquitous food of urbanized societies in the future may not be the hamburger, but the fishburger.

Second, there will be a shift in what kinds of fish people like. In recent years, growing numbers of people have shifted from meat-eating to vegetarian diets. For some of the same reasons, in future years many more could shift from eating carnivorous fish to eating varieties that are lower on the food chain. Fewer may choose to eat shrimp, salmon, or shark when they eat out, opting instead to eat plant-fed varieties such as tilapia, catfish, carp, or crayfish. Many menus will indicate that the fish are certified to have been sustainably produced. If the menus don't specify, many customers will ask.

Third, more fish will be produced locally, and the fish served in restaurants will be more likely to be local—and therefore more likely to be fresh. The impetus toward local production will come from growing recognition that sustainable fish farming is best done using readily available resources rather than relying on feeds hauled at high energy cost half-way around the world.

Fourth, there will be a great variety of fish-farming methods used—some based in outdoor ponds, some in fenced-off areas of rivers or bays, some in buildings. But virtually all would, in one way or another, integrate fish production with other industrial or ecological activities: growing hydroponic vegetables, recycling urban waste, purifying fresh water, keeping rivers or wetlands healthy. This will happen because integrated businesses will use resources more efficiently, and therefore be more profitable.

Fifth, consumers of fish will be more likely to believe that how the fish are raised is an important ecological and ethical issue. It is consumer awareness, more than government regulation, that originally gave impetus to the development of such vital movements as the booming market for organic food, the demand for dolphin-free tuna, and the stigmatizing of fur coats or ivory bracelets. Such awareness could eventually put a damper on the huge profits now flowing into unsustainable shrimp- or salmon-producing operations.

Finally, if all goes well, the farmed fish of the

future will be both a thriving local industry in every area of the world and a major opportunity for business investment. Because of its nutritional benefits, as well as its inherent resource-efficiency advantages when properly designed (with recirculating water, etc.), fish farming will move from a boom-town industry still dominated in many places by get-rich-quick entrepreneurs to a more stable and less exploitative sector of the mainstream economy. The shrimp mafias will be pushed aside in favor of people who are willing to be more accountable to their communities.

How will all this happen? Such changes rarely occur without help from committed organizers—but that help is coming, as efforts to protect mangrove forests and local fishers take their place alongside other worthy causes. Organizers of sustainable fish-farming initiatives could engage the services of well known chefs and food editors, for example, to show how carp can be made every bit as delicious as salmon.

A strategy that has already proven successful in other areas is to distinguish sustainable from unsustainable production via certification programs. Successful precedents can be found in at least three industries: timber, paper, and tunafish. Timber producers can apply for special labels that certify their wood has been grown by sustainable forestry methods (no clearcutting and no decimation of endangered tropical hardwoods, for instance), and the growing market for labeled wood is providing an incentive for growers to change their practices. Paper producers, similarly, can reach a growing market for products containing post-consumer recycled fiber, or made without ecologically damaging chlorine bleaching, by qualifying for the appropriate labels. And canned tuna can't carry the now familiar "Dolphin-free" labeling if it has been caught by purse seine nets which encircle schooling dolphins that swim with tuna.

The certification effort for fish so far has focused on wild oceanic fish. The World Wildlife Fund is helping to set up a Marine Stewardship Council to conduct such screening. One of the obstacles it faces, however, is the difficulty of monitoring underwater activities in regions that extend over vast areas of the Earth's surface. Aquaculture, in contrast, should be much easier to observe and certify. Of course, the criteria for certification may not be easy to establish, because the very nature of sustainable aquaculture is its relative ecological complexity and variety (as opposed to the high-volume monocultures favored by the shrimp mafia).

The kinds of criteria worthy of certification have been studied closely by the FAO, which has issued a set of guidelines for sustainable aquaculture development. Some of its key recommendations are included

in the accompanying table, which summarizes the key objectives to be achieved by redesigning the fish-farming industry.

To make fish farming truly sustainable will probably require a carrot-and-stick combination of policies. The carrot will be found in the emergence of robust new markets, much like the booming markets for organic foods, natural fibers, and products made without animal testing or ingredients, that have become multi-billion dollar sectors of the economy in the United States and Europe. The stick will be wielded at least in part by the concern of governments that now recognize the huge damage being done to their coasts, peoples, and economies by loot-and-run commercial aquaculture operations. Several governments have clamped down on such operations as at least a temporary means of stemming the damage until less

damaging alternatives can be established.

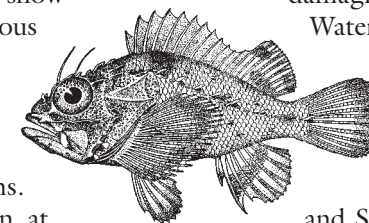
Water-scarce Egypt has banned the diversion of water for fish farming, and China now prohibits converting arable land to aquaculture ponds. Honduras has instituted a moratorium on new shrimp farms; Norway and Scotland have stopped building salmon netcages in coastal waters; and India has banned shrimp farms within 500 meters

of the high-tide zone.

As these restrictions are put in place, however, no government is likely to lose sight of the immense potential that properly managed fish-farming represents for their future food security and economic vitality. The temptations of this industry are not unlike those that accompanied the green revolution half a century ago. The difference is that while the green revolution did indeed produce huge advances in food production (ironically allowing our sense of crisis about expanding population to be deferred another generation), it also brought devastating problems of land erosion, water depletion, pesticide poisoning, and other problems of high-intensity monoculture. But as the Environmental Defense Fund recently concluded, aquaculture does not have to be an inefficient or polluting industry. And indeed, governments may be more savvy about those pitfalls this time around.

The ultimate success of aquaculture may lie in the ability of its developers to leapfrog the mistakes of agriculture—to resist putting chemicals in the water and hormones in the fry, and consuming vast quantities of resources to get their product out. The fish farmers' ticket to the future is to align their business with the growing movement toward integrated, closed-loop production that is already making waves in the agricultural and timber industries.

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Scorpaena albifimbria