

## Down on the Farm...Raising Fish

### Aquaculture offers more sustainable seafood sources, but raises its own set of problems

By Hauke L. Kite-Powell, Research Specialist  
Marine Policy Center  
Woods Hole Oceanographic Institution

Imagine for a moment that the beef and poultry in your refrigerator came not from ranches and farms, but from the woods and prairies. Imagine that every pig, chicken, turkey, and steer was “free range,” hunted from wild herds and brought to market. What would that mean to you as a consumer?

In the simplest terms, it would mean that your local supermarket would have higher prices and a less dependable and

less plentiful supply of meat. The idea of abandoning our modern practice of raising livestock and harvesting all of our meat from the wild is patently absurd.

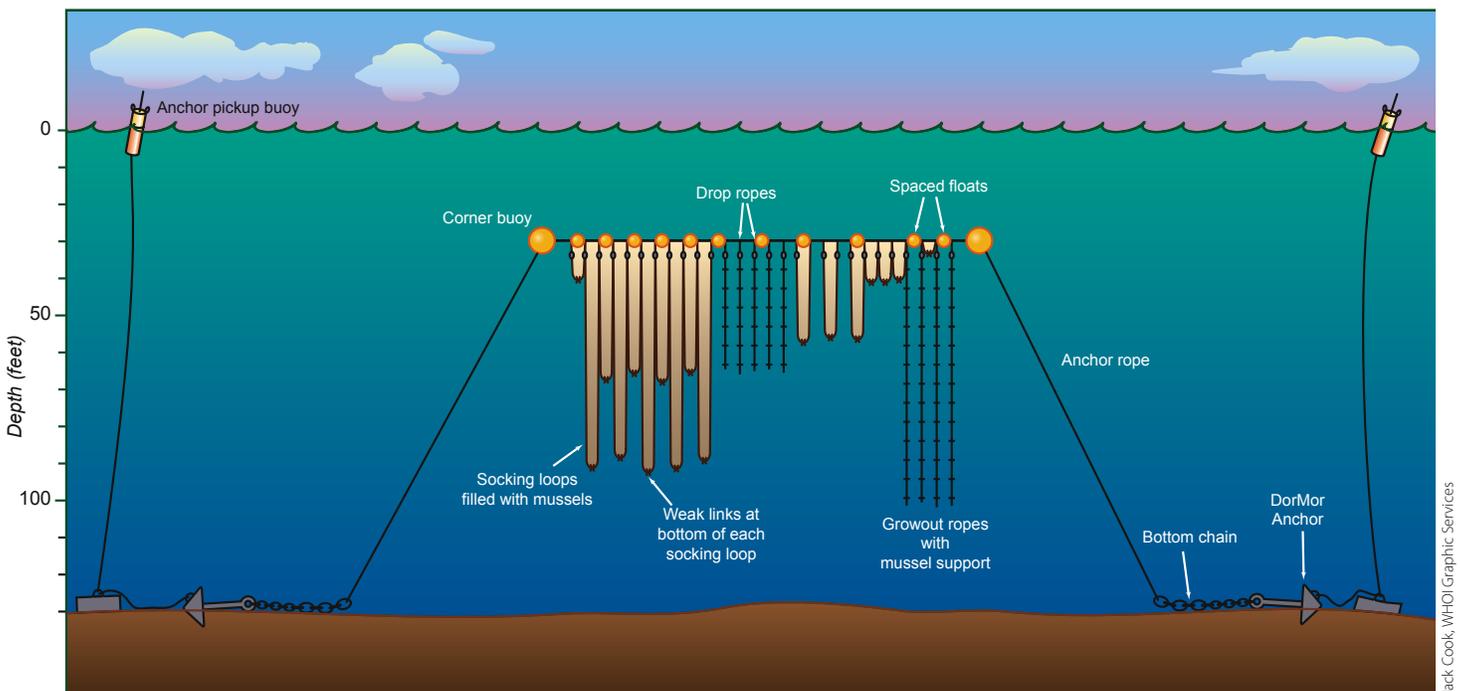
And yet that is exactly how we obtained most of our seafood until quite recently.

Aquaculture, or fish farming, is changing how we think about one of our main sources of protein. With many fish stocks shrinking due to overfishing or environmental degradation, aquaculture holds the promise of more reliable and more sustainable seafood production. The economic and social benefits could be significant for both consumers and producers.

But every benefit has a cost, and the costs of poorly executed aquaculture range from ecological damage to rampant disease in the cultured fish stocks. The financial costs of raising healthy fish also remain problematic in parts of the world. Current research is testing some solutions to these problems.

#### A new wave in the seafood industry

In 1950, about 20 million tons of fish were harvested globally, with nearly all of that catch coming from wild stocks in our oceans, bays, lakes, and rivers. In the five decades since then, the world’s popula-



Jack Cook, WHOI Graphic Services

To study the feasibility of commercial shellfish farming offshore of New England, researchers from the Woods Hole Oceanographic Institution created this demonstration system that grows blue mussels in the open ocean. The “longline mooring” uses submerged ropes and buoys to allow juvenile mussels to develop in nutrient-rich, naturally flushed waters.

tion has tripled. Today, seafood production stands at 130 million tons per year, with one quarter of that total coming from aquaculture. About 20 million tons are farmed in freshwater facilities, 15 million tons in salt water.

Aquaculture first began to contribute significantly to world production in the 1970s, when it became clear that wild capture seafood harvests could no longer keep pace with the demand for fish. Many popular fish stocks had been overexploited even before that era, but the fishing industry compensated by repeatedly switching to previously “underutilized” species. By the 1980s, even diversifying the wild harvest could not increase the yield enough to feed the world’s booming population and growing appetite.

Humans directly consume 75 percent of all seafood produced, with the remainder being processed into fish meal and oil for use in feeds for land animals and farmed fish. Thanks to the development of aquaculture—output has increased more than fourfold since 1985—the per capita supply of fish has remained roughly constant since 1970.

Seafood accounts for about 15 percent of the protein in the average human diet, about 16 kilograms per person per year. Residents of the United States, however, consume 7 or 8 kilograms per person, about half the global average. When they do eat seafood, few U.S. consumers realize that more than half of what they eat comes from fish farms.

### Developing countries outpace the U.S.

By global standards, U.S. aquaculture production is relatively modest, with a value of less than \$1 billion per year of the worldwide total of \$50 billion. Catfish, salmon, and oyster farms dominate the U.S. efforts. Aquaculture development is constrained by economics, especially competition from low-wage foreign producers and a lack of available and affordable coastal real estate. As a result, the U.S. imports more than half of the seafood it consumes.

At the other extreme, China accounts for more than half of world aquaculture production, primarily through its large production of freshwater carp, the world’s most plentiful aquaculture crop. (There are grounds for suspecting that the Chinese production statistics may be inflated.) Other significant crops include shrimp (tiger prawns) grown in coastal ponds, and seaweeds, oysters, mussels, and salmon grown in ocean cages.

Global aquaculture has focused on species that command a relatively high price. The freedom to select target species is greater for the fish farmer than for the wild capture fisher, and farmers have been selling their products for about \$1.50 per kilogram, nearly twice the average price of wild capture seafood. That is good news for the developing world, where aquaculture can feed populations both directly and through income from exports.

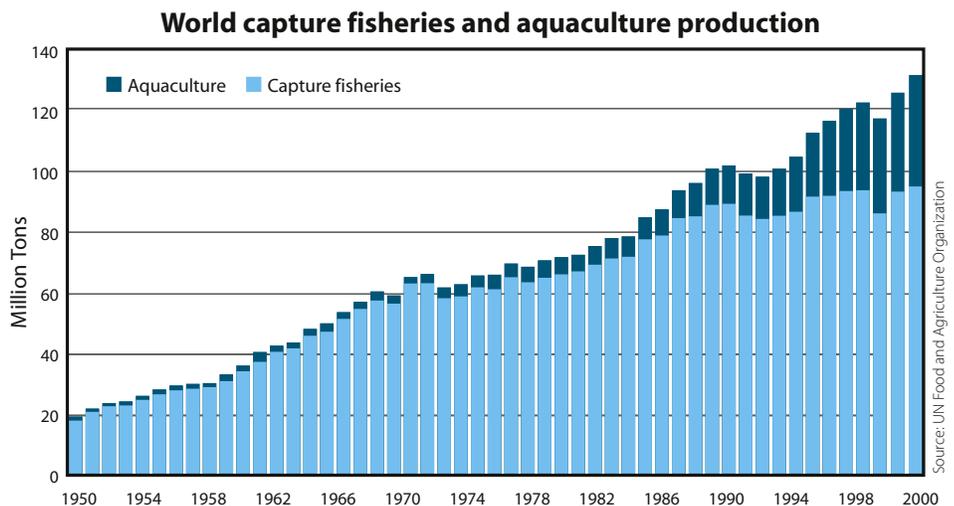
### Fish in a barrel

The most common technique for farming fish is pond culture, where fish are reared in shallow, earthen, open-air ponds that look like flooded agricultural fields. This method is mostly used to grow carp and other freshwater fish in Asia, shrimp in Latin America and Asia, and catfish in

the southern United States. The simplest ponds are “self-contained” ecosystems in which fish feed on naturally occurring water plants. The density of fish stocked in these ponds is generally low—about 1 kilogram per cubic meter of water—but can be increased with investment in feed and in aeration systems that maintain oxygen levels in the water.

A higher stocking density can be achieved in ocean cage cultures (10 to 20 kilograms per cubic meter), where cages or “netpens” are anchored to the seafloor in open waters. This approach is often used for raising carnivorous marine species such as salmon. Natural currents remove waste products and maintain oxygen levels by continually replacing the water in the cages.

The highest densities are achieved in onshore tank farms, where up to 100 kilograms of fish are raised per cubic meter. These industrial style aquaculture methods use pipes, filters, and flushing systems to remove wastes and restore oxygen levels. Onshore systems rely on regular water exchanges—replacing tank water with fresh water from an external supply—or they circulate the tank water through systems of filters and other water quality systems.



*Since 1950, both wild fish catch and farmed fish have increased significantly as the world population has tripled.*



Dale Leavitt, Roger Williams University



Walter Paul, WHOI

*Left: Rigid cages are used to contain surf clams in a shellfish aquaculture demonstration experiment supported by the Woods Hole Sea Grant program. Adolescent clam "seedlings" are held in submerged cages until they grow to commercially viable size and weight. Right: Will Ostrom (blue hard hat), a senior engineering assistant in the WHOI Department of Physical Oceanography, and Joe Alvernes, a crewmember of the fishing vessel Nobska, scrape mussels from a rope that had been submerged for 19 months.*

### Not as easy as it looks

Fish farmers and aquaculture researchers face a number of challenges as they attempt to expand aquaculture production. These include:

- **Reproduction:** To produce ever-larger quantities of fish in a sustainable way (that is, without further depleting wild stocks) and to obtain fish with optimal characteristics for farming, it is necessary to "breed" juvenile fish from specially selected captive stocks. But getting fish to reproduce consistently in captivity remains a challenge for many valuable species, such as tuna.

- **Feed:** There is no one-size-fits-all approach to feeding fish, and the optimal food for healthy growth is often species-specific. Farmers need feeds with ingredients that are economically viable, ecologically sensible, and healthy (free of contaminants) to the animals and consumers. For example, the farming of carnivorous fish such as salmon has been criticized for using excessive quantities of other fish in the production of feed. If the feed fish are plentiful and of little interest for human consumption, and if their fishery is managed properly, there shouldn't

be a problem. But if not properly managed, these practices can contribute to overfishing of wild stocks.

- **Disease management:** As with cattle ranches, farming fish can lead to disease because parasites, viruses, and bacteria have a better chance of propagating in a densely packed population. Controlling disease presents its own problems. The excessive use of antibiotics and other agents can have negative effects on the environment and human consumers (for instance, repeated exposure to antibiotics can lead to immunity to such drugs).

- **Genetics:** Efforts to develop faster-growing fish through genetic manipulation are controversial, in part because escapees may affect wild stocks by competing or interbreeding.

- **Waste disposal:** Natural waste produced by the farmed animals, as well as excess feed, can result in an overabundance of nutrients in the areas around fish ponds or ocean farming areas. If this nutrient loading exceeds certain limits, it can encourage the excessive growth of algae and contribute to algal blooms. This ecological imbalance can culminate in eutrophication, the depletion of oxygen

in the water to a point where it suffocates or drives away marine species.

- **System design and economics:** Engineers must design containment ponds and cages that can address these environmental issues while withstanding the forces of nature, doing all of it at a reasonable cost.

Many of these challenges come into play in two aquaculture ventures in very different settings where researchers from Woods Hole Oceanographic Institution (WHOI) have undertaken demonstration projects: the coast of New England and the island of Zanzibar off the coast of East Africa.

### Yankee thrift and ingenuity

New England has a long association with fishing and seafood, not to mention one of the world's wealthiest populations. Seafood consumption in the region is below the global average, yet 25 percent higher than the U.S. average. Aquaculture production has been limited to mostly oysters and other shellfish, but the collapse of several traditional fish stocks, growing economic and regulatory pressure on fishermen, and an increasing reliance on imports has boosted interest.

There are several obstacles to aquaculture in New England. The first is the ready availability of low-cost seafood imports, which make it tough for local producers in this high-cost-of-living area to compete. The second is a shortage of affordable coastal real estate, both onshore and in nearshore waters, which makes coastal ponds and nearshore cage farming impractical. As a result, the future for this region appears to lie in high-density, onshore tank farming or in offshore, open-ocean operations focusing on high-end niche markets.

Before commercial aquaculture can begin in the open ocean, government agencies are going to have to develop a straightforward system for granting “tenure” to a piece of watery real estate. Depending on the location, several federal or state agencies may be involved in granting a permit for the installation of an offshore growout system. Even far from shore, conflicts can arise if a farm site is in or near established commercial fishing grounds, shipping lanes, or the habitat of protected species. In the long

run, the nation may move toward a marine zoning system, much like that used onshore, to assign priority uses—fishing, shipping, recreation, or aquaculture—to parcels of ocean real estate.

Growing finfish or shellfish in open ocean waters also requires a significant engineering investment. Cages and other “growout” systems need to be able to survive storms and the choppy waves and currents of the North Atlantic Ocean. Within the past decade, cage systems have been developed that can survive hurricane conditions (for instance, by submerging temporarily below the wave energy zone). Still, the economics of supplying and maintaining growout systems far from shore are only now being tested.

WHOI has undertaken one of these demonstration projects in the open waters of Rhode Island Sound, with support from the National Oceanic and Atmospheric Administration, the Sea Grant College Program, and the Massachusetts Department of Fisheries and Agriculture. Researchers and engineers are working to prove the technical and economic fea-

sibility of growing blue mussels on ropes (“longlines”) hanging from submerged buoys in deep water.

Early results from the New England demonstration projects are encouraging. During our first two-year experiment, hundreds of pounds of mussels were harvested from a single longline. Market-size mussels grew on the ropes in half the time they would take to grow in the colder waters north of Cape Cod. The equipment showed very little wear or damage, even though a hurricane passed through the area. Long-term success will depend on developing local markets that are willing to pay a premium for a reliable and consistent supply of fresh seafood, and on engineering to keep costs down.

### Necessity and invention

On the island of Zanzibar, in the Indian Ocean off Tanzania, seafood is not a luxury but a means of survival. It is the dominant source of protein for the island’s one million residents, who consume three to four times as much seafood as the average New Englander. As in the North Atlantic, many wild capture fish stocks are under intense pressure or depleted, and the catch today is half of what it was 20 years ago. But unlike New Englanders, the people of Zanzibar cannot afford to import fish. The per capita income is about \$300 per year.

Aquaculture is critical for the food supply and for economic development of this island. Zanzibar developed a successful seaweed farming industry in the 1980s, and that crop is now second only to tourism in the island’s export trades. Seaweed is a source of carrageenan, a key ingredient in the cosmetics, manufactured foods, and pharmaceuticals industries.

This success has spurred interest in other kinds of aquaculture, such as pond farming of finfish and the addition of shellfish to the seaweed plots in coastal lagoons. Limited infrastructure—unreliable utilities and scarce materials—and the lack of a reliable source of juvenile fish have slowed these efforts. So, too, have



Courtesy of the University of New Hampshire Open Ocean Aquaculture Program

*Researchers and commercial fishermen check on an open-ocean cage for finfish aquaculture in a demonstration project by the University of New Hampshire. The submersible cage is raised for feedings, cleaning, and maintenance, then lowered to allow the farmed fish to develop in open water that is naturally flushed by ocean currents.*



Hauke Kite-Powell, WHOI



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*Aquaculture holds the promise of feeding the impoverished populations of some developing countries, while also providing a key crop for export. Left: Coastal fish ponds on the island of Pemba, Zanzibar. Right: Local fish farmers and researchers from the Zanzibar Institute of Marine Science use nets to haul in fish grown in the coastal ponds.*

concerns about environmental degradation from nutrient loading, which could threaten the island's vital tourism business.

With the technical assistance of researchers from Israel's National Center for Mariculture and from WHOI, and support from the German-Israel Fund for Research and International Development, the Lear Foundation and the McKnight Foundation, scientists in Zanzibar are developing a research and training infrastructure to meet these challenges. They have focused on pond culture using low-technology solutions, such as tidal flow instead of pumps for water exchange. They are working with "biofilters," using shellfish and seaweeds to

remove excess nutrients from pond water before returning it to the sea. Cage culture experiments in protected nearshore waters are also being planned, and work is starting on a simple hatchery to provide juvenile fish for stocking. Researchers are also developing techniques to add shellfish farming to established seaweed plots.

Initial results from pond culture experiments are promising, and scientists on Zanzibar have begun to instruct would-be fish farmers in how to replicate the experimental farms. The hope is that farmed fish will soon increase the supply of seafood protein available to the residents of the island.

### Beating hooks into plowshares

Aquaculture holds great promise, especially in developing countries and historically non-productive coastal areas with few natural wild fish stocks. Negative environmental effects from poor planning, design, and operating procedures have in some cases been problematic, but can be avoided through sensible regulation and monitoring. In the U.S., automation and other technologies will have to be harnessed to compensate for higher labor costs.

But from a global protein perspective, aquaculture is necessary. The question is not whether to farm fish, but how and where.



*Hauke Kite-Powell is a Research Specialist at the Marine Policy Center of the Woods Hole Oceanographic Institution (WHOI) and a Lecturer in the Ocean Engineering Department at Massachusetts Institute of Technology (MIT). He studied naval architecture, marine engineering, policy, management, and economics at MIT, earning his bachelor's degree, two master's degrees, and a doctorate. His research interests include the economics and management of marine industries and resources, including maritime transportation, fisheries and aquaculture, and ocean observing systems. He first came to WHOI as a summer student fellow in 1985 and has conducted research full-time at the Institution since 1988. In addition to his research skills, he was officially admired by science buffs in 1997 when he was chosen as Mr. March for the "Studmuffins of Science" calendar developed by National Public Radio producer Karen Hopkin.*