



Solaiman Sheik shows off the harvest from his father's small pond near Khulna, Bangladesh: freshwater prawns, a profitable export. The family also raises fish in the pond and, in the dry season, rice fertilized by fish waste—a polyculture that has tripled output with little environmental downside. PHOTOGRAPH BY JIM RICHARDSON

How to Farm a Better Fish

By Joel K. Bourne, Jr. Photographs by Brian Skerry



In a dark, dank warehouse in the Blue Ridge foothills of Virginia, Bill Martin picks up a bucket of brown pellets and slings them into a long concrete tank. Fat, white tilapia the size of dinner plates boil to the surface. Martin, president of Blue Ridge Aquaculture, one of the world's largest indoor fish farms, smiles at the feeding frenzy.

"This is St. Peter's fish, the fish Jesus fed the multitudes," he says, his raspy voice resonating like a preacher's. Unlike Jesus, however, Martin does not give his fish away. Each day he sells 12,000 pounds of live tilapia to Asian markets from Washington, D.C., to Toronto, and he's planning another farm on the West Coast. "My model is the poultry industry," he says. "The difference is, our fish are perfectly happy."

"How do you know they're happy?" I ask, noting that the mat of tilapia in the tank looks thick enough for St. Peter to walk on.

"Generally they show they're not happy by dying," Martin says. "I haven't lost a tank of fish yet."

An industrial park in Appalachia may seem an odd place to grow a few million natives of the Nile. But industrial-scale fish farms are popping up everywhere these days. Aquaculture has expanded about 14-fold since 1980. In 2012 its global output, from silvery salmon to homely sea cucumbers only a Chinese cook could love, reached more than 70 million tons—exceeding beef production clearly for the first time and amounting to nearly half of all fish and shellfish consumed on Earth. Population growth, income growth, and seafood's heart-healthy reputation are expected to drive up demand by 35 percent or more in just the next 20 years. With the global catch of wild fish stagnant, experts say virtually all of that new seafood will have to be farmed.

"There is no way we are going to get all of the protein we need out of wild fish," says Rosamond Naylor, a

food-policy expert at Stanford University who has researched aquaculture systems. “But people are very wary that we’re going to create another feedlot industry in the ocean. So they want it to be right from the start.”

There are good reasons to be wary.



Nature’s own water filters, giant Japanese scallops thrive on fish waste at an experimental farm off Canada’s Vancouver Island. The farm also uses sea cucumbers and kelp to consume excretions from nearby pens of native sablefish.

The new “blue revolution,” which has delivered cheap, vacuum-packed shrimp, salmon, and tilapia to grocery freezers, has brought with it many of the warts of agriculture on land: habitat destruction, water pollution, and food-safety scares. During the 1980s vast swaths of tropical mangroves were bulldozed to build farms that now produce a sizable portion of the world’s shrimp. Aquacultural pollution—a putrid cocktail of nitrogen, phosphorus, and dead fish—is now a widespread hazard in Asia, where 90 percent of farmed fish are located. To keep fish alive in densely stocked pens, some Asian farmers resort to antibiotics and pesticides that are banned for use in the United States, Europe, and Japan. The U.S. now imports 90 percent of its seafood—around 2 percent of which is inspected by the Food and Drug Administration. In 2006 and 2007 the FDA discovered numerous banned substances, including known or suspected carcinogens, in aquaculture shipments from Asia.

Nor have fish farms in other parts of the globe been free of problems. The modern salmon industry, which over the past three decades has plunked densely packed net pens full of Atlantic salmon into pristine fjords from Norway to Patagonia, has been plagued by parasites, pollution, and disease. Scottish salmon farms lost nearly 10 percent of their fish in 2012 to amoebic gill disease; in Chile infectious anemia has killed an estimated two billion dollars’ worth of salmon since 2007. A disease outbreak in 2011 virtually wiped out the shrimp industry in Mozambique.

The problem isn't the ancient art of aquaculture per se; it's the rapid intensification of it. Chinese farmers started raising carp in their rice fields at least 2,500 years ago. But with that country's aquacultural output now at 42 million tons a year, fish pens line many rivers, lakes, and seashores. Farmers stock their ponds with fast-growing breeds of carp and tilapia and use concentrated fish feed to maximize their growth.

"I was very influenced by the green revolution in grains and rice," says Li Sifa, a fish geneticist at Shanghai Ocean University. Li is known as the "father of tilapia" for developing a fast-growing breed that's become the backbone of China's tilapia industry, which produces 1.5 million tons a year, much of it for export. "Good seeds are very important," Li says. "One good variety can raise a strong industry that can feed more people. That is my duty. To make better fish, more fish, so farmers can get rich and people can have more food."



Workers harvest channel catfish at an America's Catch catfish farm in Itta Bena, Mississippi (left). The farm produces 30 million pounds of fish each year from its 500 ponds. The fish are vegetarians: their feed is made from soy, corn, rice, wheat, and cottonseed meal, with no antibiotics. "We're taking the high road," says owner Solon Scott. "This is a good, sustainable source of protein." A tilapia (right) reveals a mouthful of eggs that will be extracted for hatching at a farm. Mouth brooding—along with rapid growth, a vegetarian diet, and the ability to thrive in dense populations—helps make the tilapia an easy fish to farm.

How to do that without spreading disease and pollution? For tilapia farmer Bill Martin, the solution is simple: raise fish in tanks on land, not in pens in a lake or the sea. "Net pens are a total goat rodeo," says Martin, sitting in an office adorned with hunting trophies. "You've got sea lice, disease, escapement, and death. You compare that with a 100 percent controlled environment, possibly as close to zero impact on the oceans as we can get. If we don't leave the oceans alone, Mother Nature is going to kick our butts big-time."

Martin's fish factory, however, doesn't leave the land and air alone, and running it isn't cheap. To keep his fish alive, he needs a water-treatment system big enough for a small town; the electricity to power it comes from coal. Martin recirculates about 85 percent of the water in his tanks, and the rest—high in ammonia and fish waste—goes to the local sewage plant, while the voluminous solid waste heads to the landfill. To replace the lost water, he pumps half a million gallons a day from an underground aquifer. Martin's goals are to recirculate 99 percent of the water and to produce his own low-carbon electricity by capturing methane from the waste.

But those goals are still a few years away. And though Martin is convinced that recirculating systems are the future, so far only a few other companies are producing fish—including salmon, cobia, and trout—in tanks on land.



A diver nets a ten-pound cobia for sampling before harvest in one of Open Blue's dozen offshore pens. Able to hold hundreds of thousands of fish, but less densely stocked and better flushed than nearshore salmon pens, they produce little pollution. Cobia contain as much healthy fish oil as salmon do.

Eight miles off the coast of Panama, Brian O'Hanlon is going in the exact opposite direction. On a calm day in May the 34-year-old president of Open Blue and I are lying at the bottom of a massive, diamond-shaped fish cage, 60 feet beneath the cobalt blue surface of the Caribbean, watching 40,000 cobia do a slow, hypnotic pirouette above us. The bubbles from our regulators rise up to meet them; one pauses to stare into my mask. Unlike Martin's tilapia or even the salmon in a commercial pen, these eight-pound youngsters have plenty of room.

O'Hanlon, a third-generation fishmonger from Long Island, grew up with New York City's famed Fulton Fish Market as his playground. In the early 1990s the collapse of the North Atlantic cod fishery and the import tariffs imposed on Norwegian salmon bankrupted the family business. His father and uncles kept saying that the industry's future was farmed fish. So as a teenager, O'Hanlon started raising red snapper in a giant tank in his parents' basement.

Now, off Panama, he operates the largest offshore fish farm in the world. He has some 200 employees, a big hatchery onshore, and a fleet of bright orange vessels to service a dozen of the giant cages, which can hold more than a million cobia. A popular sport fish, cobia has been caught commercially only in small quantities—in the wild the fish are too solitary—but its explosive growth rate makes it popular with farmers. Like salmon, it's full of healthy omega-3 fatty acids, and it produces a mild, buttery, white fillet that O'Hanlon claims is the perfect canvas for picky chefs. Last year he shipped 800 tons of cobia to high-end restaurants around the U.S. Next year he hopes to double that amount—and finally turn a profit.

Maintenance and operating costs are high in offshore waters. Although most salmon operations are tucked in protected coves near shore, the waves over O'Hanlon's cages can hit 20 feet or more. But all that rushing water is the point: He's using dilution to avoid pollution and disease. Not only are his cages stocked at a fraction of the density of the typical salmon farm, but also, sitting in deep water, they're constantly being flushed by the current and the waves. So far O'Hanlon hasn't had to treat the cobia with antibiotics, and researchers from the University of Miami have not detected any trace of fish waste outside his pens. They

suspect the diluted waste is being scavenged by undernourished plankton, since the offshore waters are nutrient poor.

O'Hanlon is in Panama because he couldn't get a permit to build in the U.S. Public concerns over pollution and fierce opposition from commercial fishermen have made coastal states leery of any fish farms. But O'Hanlon is convinced he's pioneering the next big thing in aquaculture.

"This is the future," he says, once we've said goodbye to the cobia and are back aboard his orange skiff. "This is what the industry is going to have to do in order to keep growing, especially in the tropics." Recirculating systems like Martin's, he says, will never produce enough biomass. "There is no way they can scale up to meet the market demand. And to make one profitable, it's like a cattle feedlot, where you cram so many fish in you're just trying to keep them alive. You're not providing the best environment possible for them."

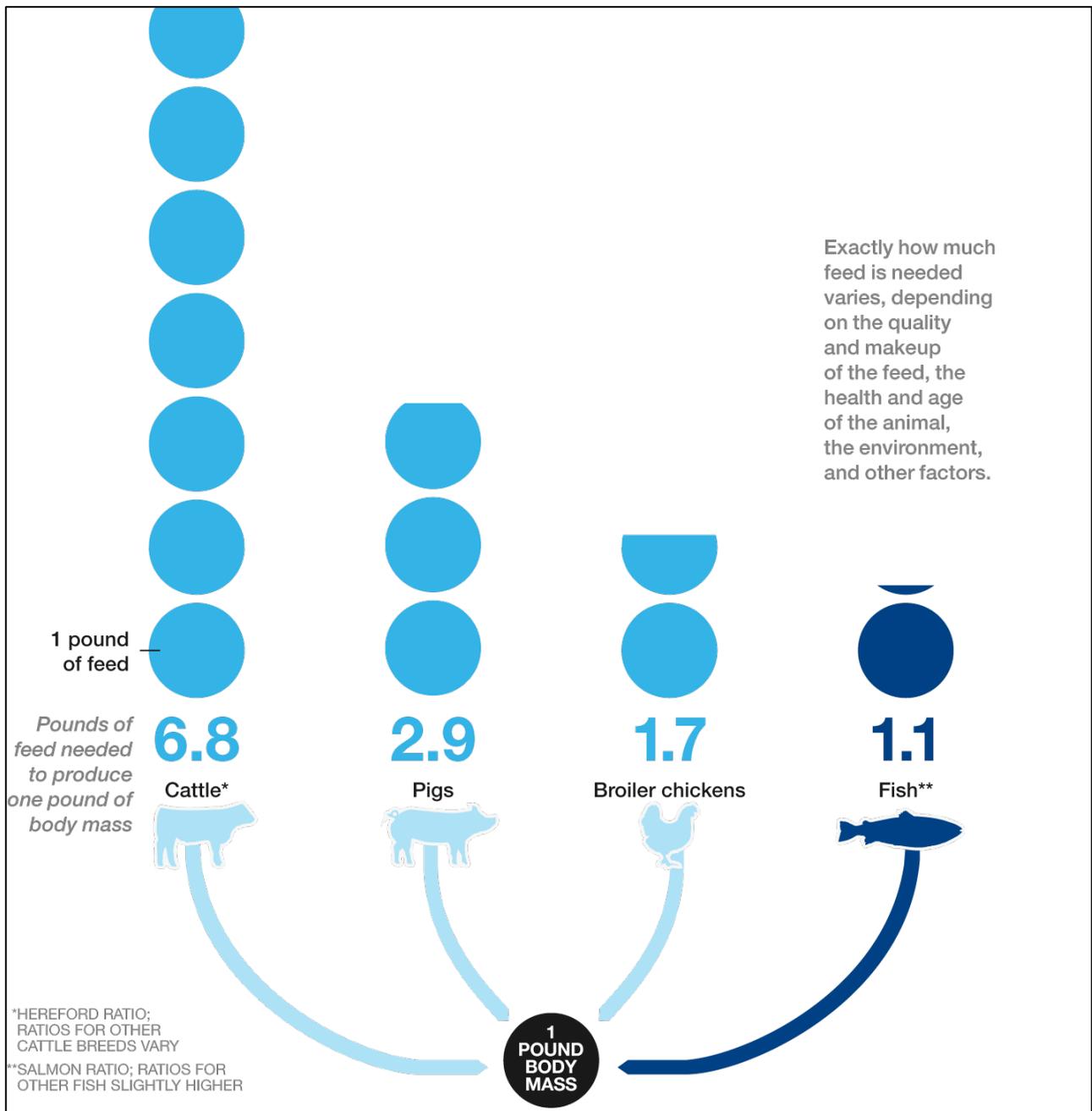


Gustavo Valdez of Pesquera Delly seafoods inspects shrimp grown in the Gulf of California, three miles off Guaymas. His four cages (left) each produce 5 to 13 tons of shrimp every four to six months. They have less impact than a conventional shrimp farm, but they require Mexican government subsidies. "We need to produce 30 tons per cage to be economical," says Valdez

Whether you're raising fish in an offshore cage or in a filtered tank on land, you still have to feed them. They have one big advantage over land animals: You have to feed them a lot less. Fish need fewer calories, because they're cold-blooded and because, living in a buoyant environment, they don't fight gravity as much. It takes roughly a pound of feed to produce a pound of farmed fish; it takes almost two pounds of feed to produce a pound of chicken, about three for a pound of pork, and about seven for a pound of beef. As a source of animal protein that can meet the needs of nine billion people with the least demand on Earth's resources, aquaculture—particularly for omnivores like tilapia, carp, and catfish—looks like a good bet.

Pounds for Pound

Different sources of animal protein in our diet place different demands on natural resources. One measure of this is the “feed conversion ratio”: an estimate of the feed required to gain one pound of body mass. By this measure, farming salmon is about seven times more efficient than raising beef.



But some of the farmed fish that affluent consumers love to eat have a disadvantage as well: They’re voracious carnivores. The rapid growth rate that makes cobia a good farm animal is fueled in the wild by a diet of smaller fish or crustaceans, which provide the perfect blend of nutrients—including the omega-3 fatty acids that cardiologists love. Cobia farmers such as O’Hanlon feed their fish pellets containing up to 25 percent fish meal and 5 percent fish oil, with the remainder mostly grain-based nutrients. The meal and oil come from forage fish like sardines and anchovies, which school in huge shoals off the Pacific coast of South America. These forage fisheries are among the largest in the world but are prone to spectacular collapses.

Aquaculture's share of the forage-fish catch has nearly doubled since 2000. It now gobbles up nearly 70 percent of the global fish meal supply and almost 90 percent of the world's fish oil. So hot is the market that many countries are sending ships to Antarctica to harvest more than 200,000 tons a year of tiny krill—a major food source for penguins, seals, and whales. Though much of the krill ends up in pharmaceuticals and other products, to critics of aquaculture; the idea of vacuuming up the bottom of the food chain in order to churn out slabs of relatively cheap protein sounds like ecological insanity.

In their defense, fish farmers have been getting more efficient, farming omnivorous fish like tilapia and using feeds that contain soybeans and other grains; salmon feed these days is typically no more than 10 percent fish meal. The amount of forage fish used per pound of output has fallen by roughly 80 percent from what it was 15 years ago. It could fall a lot further, says Rick Barrows, who has been developing fish feeds at his U.S. Department of Agriculture lab in Bozeman, Montana, for the past three decades. "Fish don't require fish meal," says Barrows. "They require nutrients. We've been feeding mostly vegetarian diets to rainbow trout for 12 years now. Aquaculture could get out of fish meal today if it wanted to."

Replacing fish oil remains trickier, because it carries those prized omega-3 fatty acids. In the sea they're made by algae, and then passed up the food chain, accumulating in higher concentrations along the way. Some feed companies are already extracting omega-3s directly from algae—the process used to make omega-3 for eggs and orange juice. That has the added benefit of reducing the DDT, PCBs, and dioxins that can also accumulate in farmed fish. An even quicker fix, Stanford's Rosamond Naylor says, would be to genetically modify canola oil to produce high levels of omega-3s.



At dawn on China's Fujian coast, seaweed farmers head out to tend their aquatic fields. Such farms help China grow 12 million tons of food a year with no soil or fresh water and no fertilizer except runoff from the land. Oceans cover 71 percent of Earth yet provide less than 2 percent of our food—for now. Photograph by George Steinmetz

Figuring out what to feed farmed fish may ultimately be more important for the planet than the question of where to farm them. “The whole concept of moving into offshore waters and on land isn’t because we’ve run out of space in the coastal zone,” says Stephen Cross of the University of Victoria in British Columbia, who was an environmental consultant to the aquaculture industry for decades. Though pollution from coastal salmon farms gave the whole industry a black eye, he says, these days even salmon farms are producing 10 to 15 times the fish they did in the 1980s and 1990s with a fraction of the pollution. In a remote corner of Vancouver Island he’s trying something new and even less damaging.

His inspiration comes from ancient China. More than a thousand years ago, during the Tang dynasty, Chinese farmers developed an intricate polyculture of carp, pigs, ducks, and vegetables on their small family farms, using the manure from ducks and pigs to fertilize the pond algae grazed by the carp. Carp were later added to flooded paddies, where the omnivorous fish gobbled up insect pests and weeds and fertilized the rice before becoming food themselves. Such carp-paddy polyculture became a mainstay of China’s traditional fish-and-rice diet, sustaining millions of Chinese for centuries. It’s still used on more than seven million acres of paddies in the country.

In a fjord on the British Columbia coast, Cross has devised a polyculture of his own. He feeds only one species—a sleek, hardy native of the North Pacific known as sablefish or black cod. Slightly down current from their pens he has placed hanging baskets full of native cockles, oysters, and scallops as well as mussels that feed on the fine organic excretions of the fish. Next to the baskets he grows long lines of sugar kelp, used in soups and sushi and also to produce bioethanol; these aquatic plants filter the water even further, converting nearly all the remaining nitrates and phosphorus to plant tissue. On the seafloor, 80 feet below the fish pens, sea cucumbers—considered delicacies in China and Japan—vacuum up heavier organic waste that the other species miss. Minus the sablefish, Cross says, his system could be fitted onto existing fish farms to serve as a giant water filter that would produce extra food and profit.

“Nobody gets into farmed production without wanting to make a buck,” he adds, over a plate of pan-seared sablefish and scallops the size of biscuits. “But you can’t just go volume, volume, volume. We’re going quality, diversity, and sustainability.”

Farming Soars as Wild Catches Stall

With demand rising and many marine fish stocks already overfished, nearly half of all seafood now comes from aquaculture, which has grown at a double-digit clip for decades. Most of the growth is in Asia, home to 90 percent of fish farms. China, the world leader, imports additional fish to make fish oil, fish food, and other products.

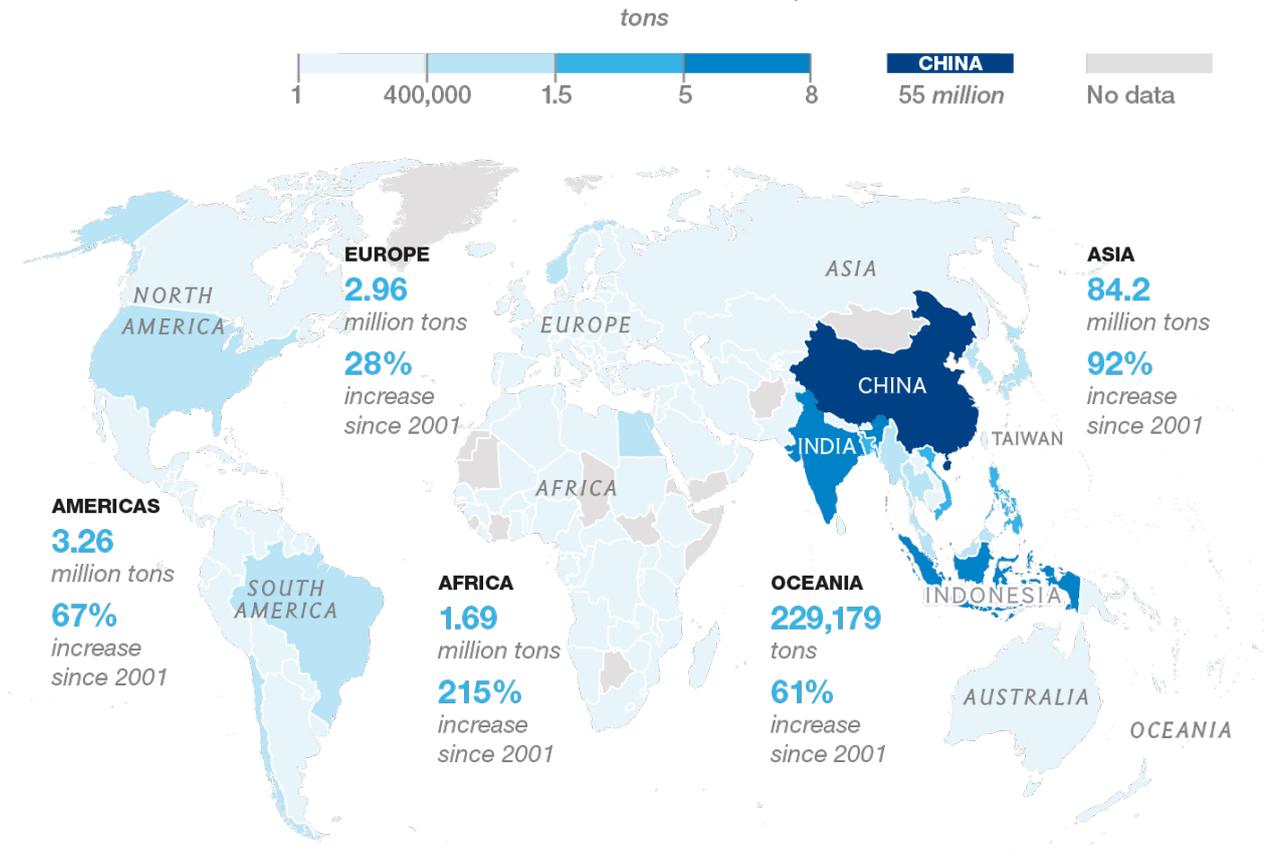
Perry Raso of Matunuck, Rhode Island, farms a monoculture, not a polyculture, but he doesn’t feed his aquatic animals anything at all—and he’s got 12 million of them. Raso is an oyster farmer, one of the new generation of shellfish growers who’ve been blessed by virtually everyone, from the Monterey Bay Aquarium Seafood Watch program to the new Aquaculture Stewardship Council, which recently published its first standards for shellfish. A key to sustainability, these groups say, is learning to eat farther down the food chain. Shellfish are just one step up from the bottom. And besides producing a healthy product low in fat and high in omega-3s, shellfish farms clean the water of excess nutrients.

Raso, with his powerful build, five-o’clock shadow, and fisherman’s hoodie, looks more like the collegiate wrestler he once was than the greenest guy in the aquaculture business. He started his farm his senior year and was soon selling his oysters at farmers markets. “I’d get there, look around, and say, What am I doing around all these crunchy people?” Raso says. “But then I started making more money, started eating local foods, and you know what? That stuff was good.” Raso now serves 800 people a day in the summer at the Matunuck Oyster Bar. Meanwhile the University of Rhode Island has sent him on teaching trips to Africa, where aquaculture is exploding—and where people desperately need affordable, healthy protein.

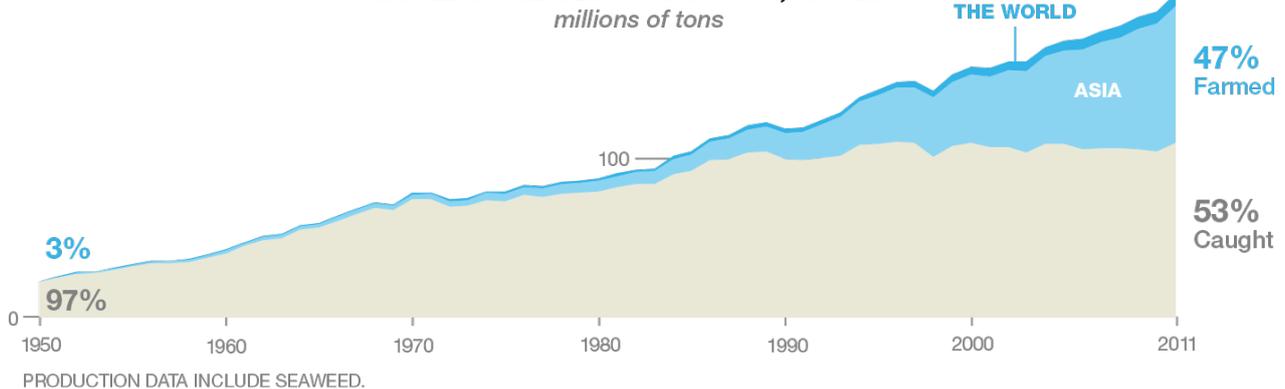
A few hundred miles north, in the clear, frigid waters off Casco Bay, two Maine watermen, Paul Dobbins and Tollef Olson, have stepped down the food chain even farther. After watching one commercial-fishery closure after another devastate Maine’s coastal communities, they launched the first commercial kelp farm in the U.S., in 2009. They started with 3,000 linear feet of kelp line and last year farmed 30,000, harvesting three species that can grow up to five inches a day, even in winter. Their company, Ocean Approved, sells kelp as fresh-frozen, highly nutritious salad greens, slaw, and pasta to restaurants, schools, and hospitals along the Maine coast. Delegations from China, Japan, and South Korea have visited the farm—the seaweed industry is a five-billion-dollar business in East Asia.

Let us all eat kelp? “We call kelp the virtuous vegetable,” says Dobbins, “because we are able to create a nutritious food product with no arable land, no fresh water, no fertilizer, and no pesticides. And we’re helping clean the ocean while doing it. We think the ocean would approve.”

AQUACULTURE PRODUCTION, 2011



WORLD FISHERIES PRODUCTION, 1950-2011



Contributing writer Joel K. Bourne, Jr., is working on a book about food. Brian Skerry photographed the bluefin tuna for our March issue.

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