shrink. Moreover, changes in exchange rates mean that even if the volume of remittances remains stable, their net value to recipients may decrease. These looming trends hold worrying implications for households, communities, and even national economies in poor countries.

Our experience of previous economic downturns and financial crises—including the Great Depression, the oil crisis of the early 1970s, and the Asian, Russian, and Latin American financial crises between 1997 and 2000—tells us that such crises' impact on international migration is relatively short-lived and that migration trends soon rebound. Few experts are predicting that the current economic crisis will fundamentally alter overall trends toward increased international migration and its growing global reach.

Hot in Here

In the longer term, what will affect migration patterns and processes far more than any financial crisis is climate change. One commonly cited prediction holds that 200 million people will be forced to move as a result of climate change by 2050, although other projections range from 50 million to a startling 1 billion people moving during this century.

In the longer term, what will affect migration patterns and processes far more than any financial crisis is climate change.

The relationship that will develop between climate change and migration appears complex and unpredictable. One type of variable is in climate change events themselves—a distinction is usually made between slow-onset events like rising sea levels and rapid-onset events like hurricanes and tsunamis. In addition, migration is only one of a number of possible responses to most climate change events. Protective measures such as erecting sea walls may reduce the impact. Societies throughout history have adapted to climate change by altering their agricultural and settlement practices.

Global warming, moreover, will make some places better able to support larger populations, as growing seasons are extended, frost risks reduced, and new crops sustained. Where migration does take place, it is difficult to predict whether the movement will mainly be internal or cross-border, or temporary or permanent. And finally, the relationship between climate change and migration may turn out to be indirect. For example, people may flee conflicts that arise over scarce resources in arid areas, rather than flee desertification itself.

Notwithstanding the considerable uncertainty, a consensus has emerged that, within the next 10 years, climate-related international migration will become observably more frequent, and the scale of overall international migration will increase significantly. Such migration will add still further complexity to the migration situation, as the new migrants will largely defy current classifications.

One immediately contentious issue is whether people who cross borders as a result of the effects of climate change should be defined as "climate refugees" or "climate migrants." The former conveys the fact that at least some people will literally need to seek refuge from the impacts of climate change, will find themselves in situations as desperate as those of other refugees, and will deserve international assistance and protection. But the current definition of a refugee in international law does not extend to people fleeing environmental pressures, and few states are willing to amend the law. Equally, the description "climate migrant" underestimates the involuntariness of the movement, and opens up the possibility for such people to be labeled and dealt with as irregular migrants.

Another legal challenge arises with the prospect of the total submergence by rising sea levels of low-lying island states such as the Maldives—namely, how to categorize people who no longer have a state. Will their national flags be lowered outside UN headquarters in New York, and will they be granted citizenship in another country?

The complexities of responding to climate-related movements of people illustrate a more general point, that new responses are required to international migration as it grows in scale and complexity. Most of the legal frameworks and international institutions established to govern migration were established at the end of World War II, in response to a migration reality very different from that existing today, and as a result new categories of migrants are falling into gaps in protection. New actors have also emerged in international migration, including most importantly the corporate sector, and they have very little representation in migration policy decisions at the moment.

Perhaps most fundamentally, a shift in attitude is required, away from the notion that migration can be controlled, focusing instead on trying to manage migration and maximize its benefits.

Critical Thinking

1. According to Khalid Koser, why does international migration matter more now than ever before?
2. What are the reasons for this?
3. What countries are the primary recipients of "irregular" migrants?
4. How do immigrants economically benefit their country of origin?
5. What might the future of international migration look like?

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Article 9

The Blue Food Revolution

New fish farms out at sea, and cleaner operations along the shore, could provide the world with a rich supply of much needed protein.

SARAH SIMPSON

Neil Sims tends his rowdy stock like any devoted farmer. But rather than saddling a horse like the Australian sheep drovers he grew up with, Sims dons a snorkel and mask to wrangle his herd: 480,000 silver fish corralled half a mile off the Kona coast of Hawaii's Big Island.

Tucked discretely below the waves, Sims's farm is one of 20 operations worldwide that are trying to take advantage of the earth's last great agricultural frontier: the ocean. Their offshore locations offer a distinct advantage over the thousands of conventional fish farms—flotillas of pens that hug the coastline. Too often old-style coastal farms, scorned as eyesores and ocean polluters, exude enough fish excrement and food scraps to cloud the calm, shallow waters, triggering harmful algal blooms or snuffing out sea life underneath the pens. At offshore sites such as Kona Blue Water Farms, pollution is not an issue, Sims explains. The seven submerged paddocks, each one as big as a high school gymnasium, are anchored within rapid currents that sweep away the waste, which is quickly diluted to harmless levels in the open waters.

Rather than taking Sims's word for it, I put swim fins on my feet and a snorkel around my neck, high-step to the edge of his small service boat, and take the plunge. From the water, the double-cone-shape cage is aglow like a colossal Chinese lantern, with shimmering streams of sunlight and glinting forms of darting fish. To the touch, the material that stretches taut around the outside of the cage's frame feels more like a fence than a net. The solid, Kevlar-esque material would repel hungry sharks as effectively as it contains teeming masses of Seriola rivoliana, a local species of yellowtail that Kona Blue has domesticated as an alternative to wild tuna.

Why yellowtail? Many wild tuna fisheries are collapsing, and sushi-grade yellowtail fetches a high price. Sims and fellow marine biologist Dale Sarver founded Kona Blue in 2001 to raise popular fish sustainably. But the company's methods could just as well be applied to run-of-the-mill fish—and we may need them. The global population of 6.9 billion people is estimated to rise to 9.3 billion by 2050, and people with higher living standards also tend to eat more meat and seafood. Yet the global catch from wild fisheries has been stagnant or declining for a decade. Raising cows, pigs, chickens and other animals consumes vast amounts of land, freshwater, fossil fuels that pollute the air and fertilizers that run off and choke rivers and oceans.

Where will all the needed protein for people come from? The answer could well be new offshore farms, if they can function efficiently, and coastal farms, if they can be cleaned up.

Cleaner Is Better

To some scientists, feeding the world calls for transferring the production of our animal protein to the seas. If a blue food revolution is to fill such an exalted plate at the dinner table, however, it must operate in environmentally sound ways—and make its benefits better known both to a jaded public and to policy makers with the power to help or retard its spread.

In the past, condemnation might have been apt. When modern coastal fish farming began about 30 years ago, virtually no one was doing things right, either for the environment or for the industry's long-term sustainability. Fish sewage was just one of the issues. Shrimp farmers in Southeast Asia and Mexico clear-cut coastal mangrove forests to make ponds to grow their shrimp. In the salmon farms of Europe and the Americas, animals were often too densely packed, helping disease and parasites sweep through the populations. Fish that escaped farms sometimes spread their diseases to native species. Making matters worse, the aquaculture industry represented (and still does) a net drain on fish mass; wild forage fish—small, cheap species that humans do not prefer but that bigger, wild fish eat—are captured in large quantities and ground into feed for the bigger, tastier, more expensive farmed fish folks favor.

Clearly, such ills were not good for business, and the industry has devised innovative solutions. Kona Blue's strategy of situating the farm within rapid offshore currents is one example. Other farmers are beginning to raise seaweed and filter-feeding animals such as mollusks near the fish pens to gobble up waste. Throughout the industry, including freshwater pens, improvements in animal husbandry and feed formulations are reducing disease and helping fish grow faster, with less forage fish in their diets. It may still be a long time before environmental groups remove farmed fish from "don't buy" lists, however.

Some cutting-edge thinkers are experimenting with an even bolder move. Nations exercise sole rights to manage waters out to 200 nautical miles from their shores—a vast frontier untapped for domesticated food production. Around the U.S., that frontier measures 3.4 million square nautical miles. Submerged fish pens, steered by large propellers, could ride in stable ocean currents, returning months later to their starting points or a distant destination to deliver fresh fish for market.

Ocean engineer Clifford Goudey tested the world's first self-propelled, submersible fish pen off the coast of Puerto Rico in late 2008. A geodesic sphere 62 feet in diameter, the cage proved surprisingly maneuverable when outfitted with a pair of eight-foot propellers, says Goudey, former director of M.I.T. Sea Grant's Offshore Aquaculture Engineering Center. Goudey imagines launching dozens of mobile farms in a steady progression within a predictable current that traverses the Caribbean Sea every nine months.

Feeding Frenzy

The aspect of marine (saltwater) aquaculture that has been hardest to fix is the need to use small, wild fish as food for the large, farmed varieties. (The small fish are not farmed, because a mature industry already exists that catches and grinds them into fish meal and oil.) The feed issue comes into pungent focus for me when Sims and I climb aboard an old U.S. Navy transport ship cleverly transformed into a feeding barge. The sea swell pitches me sideways as I make my way to the bow, calling to mind a bumpy pickup truck ride I took long ago, across a semi-frozen Missouri pasture to deliver hay to my cousin's Herefords. The memory of sweet-smelling dried grass vanishes when I grab a handful of oily brown feed from a 2,000-pound sack propped open on the deck. The pellets look like kibble for a small terrier but reek of an empty anchovy tin.

The odor is no surprise; 30 percent of Kona Blue's feed is ground up Peruvian anchovy. Yellowtail could survive on a vegetarian diet, but they wouldn't taste as good, Sims explains. Nor would their flesh include all the fatty acids and amino acids that make them healthy to eat. Those ingredients come from fish meal and fish oil, and that is the issue. "We are often pilloried because we're killing fish to grow fish," Sims says. Salmon farming, done in coastal pens, draws the same ire.

Detractors worry that rising demand from fish farms will wipe out wild anchovies, sardines and other forage fish. Before modern fish farming began, most fish meal was fed to pigs and chickens, but today aquaculture consumes 68 percent of the fish meal. Consumption has lessened under advanced feed formulas, however. When Kona Blue started raising yellowtail in 2005, its feed pellets were 80 percent anchovy. By early 2008 the company had reduced the share to 30 percent—without sacrificing taste or health benefit, Sims says—by increasing the concentration of soybean meal and adding chicken oil, a byproduct of poultry processing. The compound feed pellets are a big improvement over the egregious practice of dumping whole sardines into the fish cages. Unfortunately, this wasteful habit remains the norm among less responsible farmers.

A goal for the more enlightened proprietors is a break-even ratio, in which the amount of fish in feed equals the weight of fish produced for market. Farmers of freshwater tilapia and catfish have attained this magic ratio, but marine farmers have not. Because 70 percent of Kona Blue's feed is agricultural protein and oil, it now needs only 1.6 to 2.0 pounds of anchovies to produce one pound of yellowtail. The average for the farmed salmon industry is around 3.0. To achieve no net loss of marine protein, the industry would have to reduce that ratio. Still, farmed fish take a far smaller bite than their wild equivalents do: over its lifetime, a wild tuna may consume as much as 100 pounds of food per pound of its own weight, all of it fish.

The pressure to reduce sardine and anchovy catches will increase as the number of fish farms grows. Aquaculture is the fastest-growing food production sector in the world, expanding at 7.5 percent a year since 1994. At that pace, fish meal and fish oil resources could be exhausted by 2040. An overarching goal, therefore, is to eliminate wild fish products from feed altogether, within a decade or so, asserts marine ecologist Carlos M. Duarte, who directs the International Laboratory for Global Change at the Spanish Council for Scientific Research in Majorca.

One breakthrough that could help is coaxing the coveted omega-3 fatty acid DHA out of microscopic algae, which could replace some of the forage fish content in feed. Advanced BioNutrition in Columbia, Md., is testing feed that contains the same algae-derived DHA that enhances infant formula, milk and juice now sold in stores. Recently researchers at Australia's Commonwealth Scientific and Industrial Research Organization coaxed DHA out of land plants for the first time. Duarte suggests that fierce competition for agricultural land and freshwater means that fish farmers should eventually eliminate soy, chicken oil and other terrestrial products as well, instead feeding their flocks on zooplankton and seaweed, which is easy to grow. (Seaweed already accounts for nearly one quarter of all marine aquaculture value.)

Despite improvements in marine fish farming, prominent environmentalists and academics still shoot it down. Marine ecologist Jeremy Jackson of the Scripps Institution of Oceanography says he is "violently opposed" to aquaculture of predatory fish and shrimp—basically, any fish people like to eat sashimi-style. He calls the practice "environmentally catastrophic" in the pressure it puts on wild fish supplies and insists it should be "illegal."

Smarter than Beef

Jackson's point, echoed by other critics, is that the risk of collapsing forage fisheries, which are already overexploited, is too great to justify serving up a luxury food most of the world will never taste. Far better would be to eat the herbivorous sardines and anchovies directly instead of farmed, top-end predators.

Sims agrees that we should fish lower on the food web but says that does not mean we need to eat lower. "Let's get real. I eat anchovies on my pizza, but I can't get anyone else in my family to do it," he says. "If you can get a pound of farmed sushi for every pound of anchovy, why not give people the thing they want to eat?"

Certain people scoff at fish consumption—whether wild-caught or farm-raised—on the premise that the planet and its human inhabitants would be healthier if people ate more plants. But society is not rushing to become vegetarian. More people are eating more meat, particularly as populations in the developing world become wealthier, more urban and more Western. The World Health Organization predicts a 25 percent increase in per capita meat consumption by 2050. Even if consumption held steady, crop and grazing areas would have to increase by 50 to 70 percent, at current yields, to produce the food required in 2050.

That reality begs for a comparison rarely made: fish farming versus terrestrial farming. Done right, fish farming could provide much needed protein for the world while minimizing the expansion of land-based farming and the attendant environmental costs.

Land-based farmers have already transformed 40 percent of the earth's terrestrial surface. And after 10,000 years to work out the kinks, major problems still abound. Cattle eat tremendous amounts of heavily fertilized crops, and pig and chicken farms are notorious polluters. The dead zones underneath coastal fish farms pale in comparison to the huge dead zones that fertilizer run-off triggers in the Gulf of Mexico, Black Sea and elsewhere and to the harmful algal blooms that pig farm effluent has caused in Chesapeake Bay.

A growing number of scientists are beginning to compare the environmental impacts of all the various protein production systems, so that society can "focus its energies on efficiently solving the most demanding problems," writes Kenneth M. Brooks, an independent aquatic environmental consultant in Port Townsend, Wash. Brooks estimates that raising Angus beef requires 4,400 times more high-quality pasture land than sea-floor needed for the equivalent weight of farmed Atlantic salmon filets. What is more, the ecosystem below a salmon farm can recover in less than a decade, instead of the centuries it would take for a cattle pasture to revert to mature forest.

An even more compelling reason to raise protein in the sea may be to reduce humanity's drain on freshwater. As Duarte points out, animal meat products represent only 3.5 percent of food production but consume 45 percent of the water used in agriculture. By shifting most protein production to the ocean, he says, "land agriculture could grow considerably without exceeding current levels of water use."

Of course, collecting and transporting soybean meal and chicken oil and feeding fish flocks all consume energy and create emissions, too. Fuel consumption and emissions are greater for farms that are farther from shore, but both types of farming rate better than most fishing fleets. The only way offshore farmers can be profitable right now is to raise high-priced fish, but costs can come down: a few experimental farms are already raising cost-competitive mussels in the ocean.

Environmental Distinctions

If providing more fish to consumers is an answer to meeting global demands for protein, why not just catch more fish directly? Many wild fisheries are maxed out, right at a time when global population, as well as per capita demand for fish, is booming. North Americans, for example, are heeding health experts' advice to eat fish to help reduce the risk of heart attacks and improve brain function.

What is more, fishing fleets consume vast amounts of fuel and emit volumes of greenhouse gases and pollutants. Widely used, indiscriminate fishing methods, such as trawling and dredging, kill millions of animals; studies indicate that at least half the sea life fishers haul in this way is discarded as too small, overquota or the wrong species. All too often this so-called by-catch is dead by the time it is tossed overboard. Aquaculture eliminates this waste altogether: "Farmers only harvest the fish in their pens," Sims notes.

Goudey points out another often overlooked reality: you can grow fish more efficiently than you can catch them. Farmed fish convert food into flesh much more effectively than their wild brethren, which expend enormous amounts of energy as they hunt for food and evade predators, seek a mate and reproduce. Farmed fish have it easy by comparison, so most of their diet goes into growth.

Kona Blue's yellowtail and most farmed salmon are between one and three years old at harvest, one-third the age of the large, wild tuna targeted for sushi. The younger age also means farmed fish have less opportunity to accumulate mercury and other persistent pollutants that can make mature tuna and swordfish a potential health threat.

Indeed, fish farming already accounts for 47 percent of the seafood people consume worldwide, up from only 9 percent in 1980. Experts predict the share could rise to 62 percent of the total protein supply by 2050. "Clearly, aquaculture is big, and it is here to stay. People who are against it really aren't getting it," says Jose Villalon, aquaculture director at the World Wildlife Fund. Looking only at the ills of aquaculture is misleading if they are not compared with the ills of other forms of food production. Aquaculture affects the earth, and no number of improvements will eliminate all problems. But every food production system taxes the environment, and wild fish, beef, pork and poultry producers impose some of the greatest burdens.

To encourage good practices and help distinguish clean fish farms from the worst offenders, the World Wildlife Fund has co-founded the Aquaculture Stewardship Council to set global standards for responsible practices and to use independent auditors to certify compliant farms. The council's first set of standards is expected early this year. The council believes certification could have the greatest effect by motivating the world's 100 to 200 big seafood retailers to buy fish from certified farms, rather than trying to crack down directly on thousands of producers.

The Ocean Conservancy's aquaculture director George Leonard agrees that this kind of farm-to-plate certification program is an important way to encourage fish farmers to pursue better sustainability practices. As in any global industry, he says, cheap, unscrupulous providers will always exist. Setting a regulatory "floor" could require U.S. farmers to behave responsibly "without making it impossible for them to compete."

That point is key. Only five of the world's 20 offshore installations are in U.S. waters. Goudey thinks more aquaculture

entrepreneurs would dive in if the U.S. put a licensing system into place for federal waters, from three nautical miles offshore to the 200-mile boundary. "No investor is going to back a U.S. operation when there are no statutes granting rights of tenancy to an operation," Goudey asserts. All U.S. farms exist inside the three-mile-wide strip of water that states control, and only a few states, such as Hawaii, allow them. California has yet to grant permits, despite government estimates that a sustainable offshore fish-farming industry in less than 1 percent of the state's waters could bring in up to $1 billion a year.

Protein Policy

To grow, and do so sustainably, the fish-farming industry will need appropriate policies and a fairer playing field. At the moment, robust government fuel subsidies keep trawling and dredging fleets alive, despite their well-known destruction of the sea-floor and the terrible volume of dead by-catch. Farm subsidies help to keep beef, pork and poultry production profitable. And powerful farm lobbies continue to block attempts to curtail the flow of nitrogen-rich fertilizer down the Mississippi River. "Almost none of these more traditional ways of producing food have received the scrutiny that aquaculture has," Brooks says. The public has accepted domestication of the land but maintains that the ocean is a wild frontier to be left alone, even though this imbalance may not be the most sustainable plan for feeding the world.

Policy shifts at the federal and regional levels may soon open up U.S. federal waters. In January 2009 the Gulf of Mexico Fishery Management Council voted in favor of an unprecedented plan for permitting offshore aquaculture within its jurisdiction, pending approval from higher levels within the U.S. National Oceanic and Atmospheric Administration. NOAA will evaluate the plan only after it finalizes its new national aquaculture policy, which addresses all forms of the industry and will probably include guidance for the development of a consistent, nationwide framework for regulating commercial activities. "We don't want the blue revolution to repeat the mistakes of the green revolution," says NOAA director Jane Lubchenco. "It's too important to get it wrong, and there are so many ways to get it wrong."

Given relentlessly rising demand, society has to make hard choices about where greater protein production should occur. "One of my goals has been to get us to a position where, when people say food security, they don't just mean grains and livestock but also fisheries and aquaculture," Lubchenco says. Duarte suggests we take some pressure off the land and turn to the seas, where we have the opportunity to do aquaculture right, rather than looking back 40 years from now wishing we had done so.

As for Neil Sims's part of the blue food revolution, he is courting technology companies for upgrades. Tools such as robotic net cleaners, automated feeders and satellite-controlled video cameras to monitor fish health and cage damage would help Kona Blue's crew manage its offshore farms remotely. "Not just so we can grow more fish in the ocean," Sims says. "So we can grow more fish better."

In Brief

Meat consumption is rising worldwide, but production involves vast amounts of energy, water and emissions. At the same time, wild fisheries are declining. Aquaculture could become the most sustainable source of protein for humans.

Fish farming already accounts for half of global seafood production. Most of it is done along coastlines, which creates substantial water pollution.

Large, offshore pens that are anchored to the seafloor are often cleaner. Those farms, other new forms of aquaculture. and practices that clean up coastal operations could expand aquaculture significantly.

Questions remain about how sustainable and cost-effective the approaches can be.

Critical Thinking

1. What is the Blue Food Revolution?
2. What are some of the environmental challenges facing large-scale fish farming?
3. Can fish farming be more sustainable than raising livestock?
4. How does this article complement or contradict Article 2?

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