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Environmental Report: In Japan, Captive Breeding May Help Save the Endangered Wild Eel ...But Can the Seas Be Saved? 環境報告　飼育下繁殖で絶滅にひんしたウナギは救えるかもしれないが、海の救済はどうなるか

Winifred Bird

As eel populations plummet worldwide, Japanese scientists are racing to solve a major challenge for aquaculture — how to replicate the life cycle of eels in captivity and commercially produce a fish that is a prized delicacy on Asian dinner tables.

Winifred Bird

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This is an expanded and edited version of an article that appeared in Yale Environment 360.

Imaizumi Hitoshi pushes back the silver quilting of a tent at the National Research Institute of Aquaculture in Shibushi, southern Japan, steps into the pitch-black interior, and switches on a flashlight. A tall, tube-shaped aquarium emerges from the darkness. Inside, slivers of reflected light flicker through the water: Japanese eel larvae, hatched just six days earlier. With huge black eyes set in skull-like heads and flat, transparent bodies, they look like tiny visitors from an alien world — which, in a sense, they are.

"This is something you'd normally only see out in the middle of the ocean," says Imaizumi, an aquaculture researcher at the center.

Japan is the world's top consumer of eels, but while most of what's grilled, glazed with sweet-salty sauce, and served up on rice here comes from fish farms, none of those farms hatch their eels from eggs. Instead, they rely on wild young caught in rivers and coastal waters worldwide known as two-inch-long "glass eels." Until very recently scientists knew little about the life of the animal in the open ocean, where sexual maturation and spawning take place.

Leptocephali eel larvae captured on film off Indonesia. One of 800 varieties of eel, only a few of which are eaten.

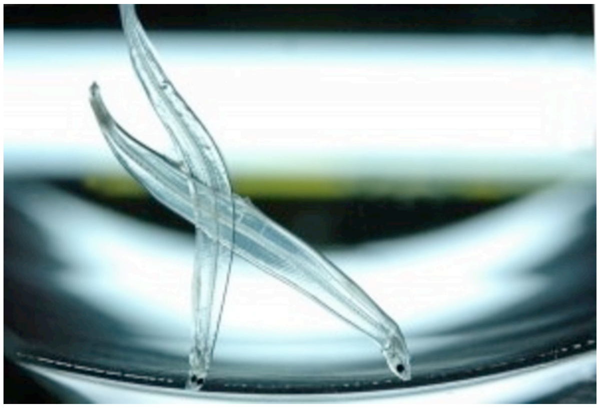
Now, however, many wild eel populations in Asia, Europe, North America, and elsewhere are threatened or on the verge of extinction. To prevent a piece of Japan's culinary heritage (and economy) from disappearing along with them, researchers are racing to close the aquaculture loop by breeding eels in captivity. Imaizumi and his colleagues at the Shibushi laboratory — part of the government-funded Fisheries Research Agency — are among the scientists at the forefront of the ambitious project. In 2010 they pulled together decades of research to successfully raise two generations of eels in captivity for the first time.

Their achievement opened the possibility of an aquaculture industry that neither depends on nor decimates wild stocks, but it also left many questions unanswered. Can researchers design methods that work on a commercial scale? If so, would the resulting closed-loop eel aquaculture industry be environmentally sustainable? Could it help bring back wild populations? The answers matter not only for Japanese eels (*Anguilla japonica*), which inhabit rivers, lakes, and estuaries from the Philippines to Japan, but also for eel species worldwide. According to a recent analysis by Greenpeace, at least 70 percent of global eel catches end up in Japan. Last year about half were raised domestically from the glass eel stage and the remainder imported full-grown from fish farms in China and Taiwan. Many countries export glass eels to Asia, where prices are extremely high. In the U.S., fishermen in Maine were selling glass eels last spring for $2,000 a pound, with some earning more than $100,000 during the two-month spring season. Catches of glass eels there quadrupled from 5,200 pounds in 2009 to 20,700 pounds in 2012. The glass eels are netted in rivers and estuaries and flown to Asia, where they are raised in concrete pens until they are about a foot long – just the right size to fit into a traditional serving dish. Eel populations have been declining globally for decades because of dams, pollution, and other environmental threats. Now, biologists and regulators in Europe, North America, and Japan are growing increasingly concerned about booming glass eel fisheries, as the removal of so many juveniles will further depress populations. The European Union has banned exports beyond its borders and is requiring member countries to draw up management plans that limit glass eel fisheries. U.S. officials are weighing tighter controls on the glass eel fishery as populations of adult American eels (*Anguilla rostrata*) plunge to historic lows.

Fish farmers in Japan still rely most heavily on domestic and imported Japanese eels, but that may soon change. Glass eel catches in Japan have plummeted to less than five percent of their peak in the 1960s, and this February the Environment Ministry listed Japanese eels as endangered. The International Union for Conservation of Nature (IUCN) is currently assessing stocks region-wide. If it decides the species is endangered throughout its range, trade restrictions would become much more likely. Greenpeace Japan oceans campaigner Hanaoka Wakao says that could put eels in other parts of the world at risk.

“Supermarkets are looking for alternatives in places like Tasmania, Indonesia, Australia, and the Philippines,” says Hanaoka, whose organization is pressuring supermarkets to stop selling endangered species like eels and bluefin tuna. “But if these species are taken [in these places] without proper fishery management, the same thing will happen to them.”

Full-cycle aquaculture offers an enticing alternative. Japanese fish farmers have been managing the middle part of the eel life cycle since the late 1800s. The industry is not necessarily sustainable — eels are fed fishmeal and kept in fossil-fuel-heated greenhouses — but it’s efficient. Inoue Satoshi raises a quarter million eels a year in an isolated valley near Imaizumi’s research lab and says that less than one percent die during their seven- to ten-month stint in his concrete pools, even though he uses few chemicals or antibiotics. Replicating the beginning and end of their life cycle remains difficult, however.



Metamorphosing larva of the artificially-hatched Japanese eel. ©Yoshio Yamada

The key problems are common to many kinds of fish, says James Diana, a scholar of sustainable aquaculture at the University of Michigan. "Most marine-spawning species produce very small eggs that drift around in the plankton and suffer 99.999 percent mortality before they even reach the end of the first year," says Diana. "You're fighting that whole life history in aquaculture. Freshwater-spawning species tend to have bigger eggs, more robust young and lower mortality, and they're the ones we've been successful with," he says.

The challenge, he explains, is getting fish through a number of "bottlenecks" in their life cycle. Sexual maturation, for instance, is triggered by a complex set of environmental cues including light levels, temperature, and salinity. Meeting the nutritional needs of larval fish is tricky too, because their diet — made up primarily of plankton — is completely different than adults'.

Despite these difficulties, full-cycle aquaculture does exist for marine-spawning species like sea bass and flounder. Japanese researchers have also closed the life-cycle loop for Pacific bluefin tuna, but not yet in ways efficient enough for commercial production. In the case of eels, the first bottleneck scientists faced was spawning.

"No matter how long you keep a juvenile eel in captivity, it will not mature spontaneously," explains Imaizumi. To make matters worse, most farmed eels turn out to be male, even though the gender balance in the wild is equal. Mimicking the natural conditions that determine gender and trigger spawning has so far proven impossible.

Instead, scientists have developed a set of hormone treatments as rigorous as anything a human couple might undergo at a fertility clinic — with a sex change thrown in. Imaizumi spends months preparing his eels to breed before placing them in breeding tanks at just the right moment. The result is a fairly reliable supply of fertilized eggs. However, stressing the animals with repeated shots and giving them hormones derived from other species lowers the number of healthy larvae obtained. Imaizumi is experimenting with genetically engineered hormones to see if the results are better.
Keeping the larva (called leptocephali) alive until they metamorphose into glass eels is even more difficult. In nature the process takes 110 to 160 days, but in Imaizumi's lab it takes between 250 and 300 days on average, with survival rates below ten percent.

"It's a big challenge because leptocephali are such strange larva," says Michael Miller, a biologist at Tokyo University, where much of the groundbreaking research on Japanese eels has taken place over the past half-century. "Their bodies are filled with transparent gelatinous material that functions to store energy, overlain with only a thin layer of muscle tissue. And their organs are reduced in size, so they are almost completely transparent."

In 2009, Miller's research team leader Tsukamoto Katsumi pinpointed the spawning site for Japanese eels, near the Mariana Trench 1,000 miles southeast of Tokyo — a discovery that has deepened understanding of their spawning ecology and life as larvae.

"[Leptocephali] don't feed on zooplankton like normal fish larvae," Miller says. "Instead they feed on marine snow, which is composed of materials released by phytoplankton that mix with other free material in the ocean and are colonized by microorganisms. It's very difficult to reproduce for aquaculture."

The only workable alternative researchers have discovered so far is a thick, pinkish paste made primarily of shark eggs, soy protein, and vitamins. Light-wary leptocephali are kept in darkened rooms; when the paste is squeezed onto the bottom of aquariums and the lights turned on, they instinctively swim downward and bump into their food. The method worked well enough for Imaizumi's group to achieve its historic 2010 results, but the feed dirties the tanks and is too inefficient for commercial use. Shark eggs aren't a long-term solution either: Spiny dogfish, the shark species leptocephali prefer, is endangered in the northwestern Pacific Ocean.

Researchers throughout Japan are working to overcome these problems so that glass eels can be produced cheaply in huge batches. But even if they succeed, it's hard to predict how an industry-wide shift from fished to farmed glass eels would affect wild stocks. Matthew Gollock, chair of the IUCN team currently assessing Japanese eels, says overfishing is just one of many problems that must be addressed.

"We believe factors such as changing ocean currents, disease, pollutants, fisheries, barriers to migration [such as dams] and freshwater habitat loss are all having an effect on Anguillid eels globally," says Gollock. "Halting one of those in isolation would not totally solve the problem."

The relationship between aquaculture and the health of wild stocks is equally unclear for other species. A 2000 review in Nature turned up little evidence of a conservation effect,[1] but when Diana looked more recently at Atlantic salmon, he found that as farmed fish entered the market in the 1990s wild-caught fish disappeared from the market in almost direct proportion.[2]

"It makes sense that as aquaculture comes in the high market value drops because the fish is no longer rare, and that dissuades commercial fishermen," he says. Most Atlantic salmon eaten today is farmed, and some wild stocks have started to recover. Diana cautions that correlation doesn't equal causation, however; programs to buy out commercial fisherman and other factors have almost certainly played an important role.

In Shibushi, eel farmer Inoue says he would jump at the chance to buy glass eels from a hatchery rather than a fishery. Since he started his business three years ago their price has skyrocketed to about five dollars each, cutting his profit margin to the bone.

"If they're able to raise glass eels, the supply will stabilize and so will the price," he says. But he believes a darker scenario is much more likely: Glass eel imports from East Asia will be banned before aquaculture technology advances, grilled eel will become a rare luxury item, and fish farmers will fight one another to survive. If that happens, he intends to be among the winners.

"China has a huge glass eel fishing industry," he says. "It's not going to disappear overnight if Japanese eels are red-listed. They'll sell on the black market." And would he consider buying from that black market? "Definitely."

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Notes

[1] Naylor R, et al. 2000. Effect of aquaculture on world fish supplies. Nature 405: 1017–1024.

[2] Diana, J. 2009. “Aquaculture Productivity and Biodiversity Conservation,” *Bioscience* 59: 34