FISHERIES SCIENCE

Ear Stones Speak Volumes To Fish Researchers

Fish are slippery creatures, and scientists who want data on migration patterns as fish go from larvae to adults or on the survival of hatchery fish in the wild have been frustrated by their elusive nature. Researchers can't put wire nose tags on larval fish, nor can they follow the fish around to learn where they go and what they do. The answers are there, but they're locked up inside the fish's head.

Now biologists are starting to extract those answers in the form of tiny ear stones called otoliths. The stones have been used to tag larval fish and to tell populations apart—information that can be crucial for fisheries management. And otoliths may even be used to trace pollution-filled waters a fish swam in months before it was caught. "Otoliths are like biological CD-ROMs," says David Secor of the Chesapeake Biological Laboratory in Solomons, Maryland. "They're constantly recording information about the environment and about how the fish lived. The information on them is never lost and you can retrieve potentially any temporal sequence that you like."

As far as fish are concerned, otoliths areTust there for balance. They're small stones that rest in three fluid-filled chambers of a fish's inner ear. When the fish is upright, gravity pulls the otoliths to the bottom of those chambers, allowing the fish to sense up from down in its watery world.

The reason these stones also tell fish stories is because fish have a circadian clock. Every 24 hours, beginning when the fish is an embryo, hormonal cycles ensure that growth rings of calcium carbonate, protein, and various trace elements picked up from the water are deposited in concentric layers on the otolith. Each ring consists of a pair of bands, one light and one dark, and each thinner than a human hair.

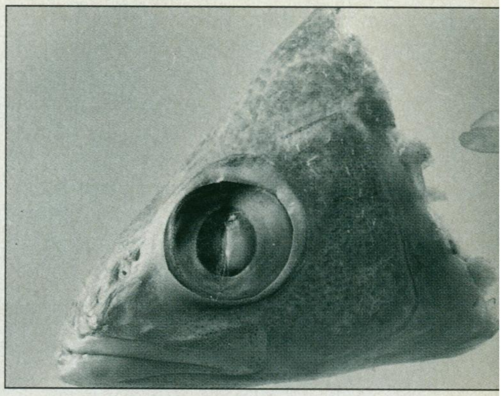
In 1976, Edward Brothers of EFS Consultants in Ithaca, New York, figured out a way to use these rings to brand lake trout while they were still in their eggs. He learned that small increases or decreases in water temperature could make the dark band in the daily rings wider or narrower and, he says, "The light bulb went on!" By moving the temperatures up and down over a few days, Brothers spaced these dark bands so they spelled out the Morse code for LT: Lake trout. "Morse code was not the most efficient way to go," he says, "but it was a good demonstration that basically you could do anything you wanted to do."

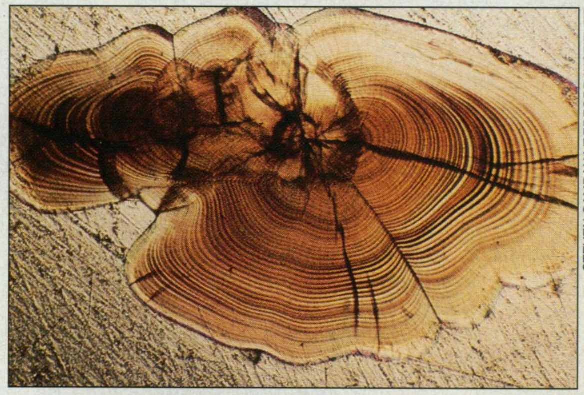
Yet no one really picked up on the implications of Brothers' discovery until the mid-1980s, when worries about managing fish populations created a cottage industry of fish tagging. Hatchery technicians were spending long days putting wire tags on the noses of fish so researchers could track them and determine the effects of environment, age, and size on mortality, define the movements of young fish, and determine the relative abundance of wild and hatchery fish. Then biologists working on otoliths pointed out that a series of minor temperature changes in a tank of fish eggs could mark the fish in a more subtle and less labor-intensive way.

The ability to tag larvae was a significant advantage over nose tags. To bolster local fish populations, hatcheries have been releasing homegrown larvae, but they've had no way of knowing whether the larvae survived, grew, and augmented local fish stocks. "We really had no way to evaluate whether stocking larvae can amount to anything," says Secor. "Being able to mass mark larvae has allowed us to investigate whether [hatchery-reared] larvae will survive or not."

Now researchers can mark and release the young fish and later recapture and examine them. For instance, over the past 5 years biologist Eric Volk and his colleagues at the Washington State Department of Fisheries have tagged some 35 million juvenile salmon. The researchers use a temperature-created bar code design on the otoliths that identifies the juveniles' hatch date and brood. Volk and his team have been able to show that fish released early in the migratory season do not grow as quickly as those released later in the season, indicating that it might be best to release hatchery fish later rather than sooner.

In addition to temperature tagging, scientists can also mark otoliths with chemicals. Exposing larvae or eggs to water treated with tetracycline, for example, creates an easy-to-spot mark on the otolith. Katsumi Tsukamoto of the Ocean Research Institute in Tokyo chemically tagged 10 different strains of masu salmon—90,000 fish in all—that were released at different times of year. When the scientists went looking for the marked fish, however, they didn't find a lot of them. Apparently these hatchery fish had a much higher mortality rate than did wild fish, indicating that the best management plan for enhancing stock in the river was to protect the wild stock.





STEVEN CAMPANA/BEDFORD INSTITUTE

A head for data. Otoliths, like the one being removed from a juvenile striped bass *(top)*, contain a wealth of information. After being cut into thin sections *(bottom)*, the otolith reveals daily rings holding a record of the fish's age and where it's been swimming.

Sometimes, though, tagging indicates that hatchery fish do quite well. Secor and his colleagues recently did a mark-and-recapture study of striped bass in the Chesapeake Bay and found that hatchery fish accounted for 20% to 30% of the fish collected, indicating a fairly high level of success for the hatchery. "It indicates that mortality [in wild fish] may be exceptionally high during egg and yolk sac larval periods," he says, and the hatchery-reared larvae do better because they are protected in the hatchery during those times.

Some of the most exciting work on otoliths involves not the marks placed by researchers, but rather the marks left by the environment. The makeup of the ear stones includes trace elements from the water in which the fish is swimming. Since seawater composition varies in different areas, the combination of elements in successive daily rings can work like a ship's log, revealing where the fish has been.

"The idea behind it," says biologist Steven Campana of the Bedford Institute of Oceanography in Nova Scotia, "is that of elemental fingerprinting, analogous to DNA fingerprinting, except instead of using the genetic makeup of the fish we're using the elemental makeup of its otolith." And that makeup is beginning to let scientists trace wild fish to their spawning grounds, and may reveal migration routes as well.

"Fisheries managers try to define a group of fish that are a single population, grow at the same rate, and come from the same spawning ground so we can manage them properly," says Campana. But determining the size of that population can be hard if other groups keep mixing in. So managers are starting to use otolith elemental composition to tell stocks of fish apart. Campana and his colleagues recently studied cod from spawning grounds throughout the North Atlantic and showed the combinations of trace elements in the otoliths were distinctive enough for researchers to match the otolith—and the cod around it—to a spawning ground with 80% to 90% accuracy.

At the moment, this type of work is limited by the technology used to detect the elements. The most common method is x-ray microanalysis, in which x-rays emitted by different elements after electron bombardment form a characteristic pattern that shows up on a detector. The problem is that a high concentration of the element is needed for the pattern to show up—higher than 100 parts per million, usually—and that means that researchers are limited to searching for a few elements, such as strontium, that are present at a high level.

Because of its relative insensitivity, the x-ray technique is most useful in situations "such as the migration of fish through waters of incredibly different chemistry, so different that we're dealing with estuary or ocean," says biologist John Kalish from the Australian National University in Canberra, Australia. Kalish has looked at the elemental composition of the otoliths of river-spawning and sea-spawning trout of the same species. He was able to discriminate between the two based on the higher strontium/calcium ratio in the sea-spawning variety. The more salt there is in the water, the more strontium there is as well, so there is a higher strontium/calcium ratio in the otoliths of sea-going fish.

More sensitive tools may find subtler differences. Currently Campana, along with Tony Fowler at the Bedford Institute and Cynthia Jones of the Applied Marine Research Laboratory at Old Dominion University, Virginia, are experimenting with a new laser-based technology. They aim the laser at a segment of the otolith, vaporize it, and the resulting gas is analyzed by a mass spectrometer, an instrument that detects elemental particles in that gas at parts per million and even parts per billion.

Campana, Fowler, and Jones plan to use the laser to tease out copper, cadmium, and zinc from otoliths. They've collected fish from two different rivers, one polluted and one relatively pristine, and hope that the heavy metal ratios, associated with pollution, will distinguish the fish. If they do, researchers can use the data when they examine fish of unknown origin to figure out where the fish has been swimming.

By analyzing successive weekly collections of rings, and linking their elemental fingerprints to specific waters, Campana, Fowler, and Jones also hope to be able to track the fish over its lifetime. "If we can start discriminating between locations with fair accuracy then we can start looking at finer and finer differences, temperature differences, salinity exposure, pollutant exposures," says Jones. "If the signal is strong enough, that could allow us to nail down in time and space where the fish have been and for how long." In addition, the otoliths of fish killed by pollution could lead authorities back to the very source of that pollution.

One possible hitch in element analysis is that hormonal changes in the fish—such as those that accompany pregnancy—may affect the chemical composition of the otolith, leading to false element signatures. Biologists are currently debating whether trace elements, which are not important to the physiology of the fish, are actually affected by hormonal changes.

Ultimately, if the technique proves accurate enough, fisheries scientists hope it will allow them to start asking pointed questions with international consequences, such as: "Who's fish are you fishing? Mine or yours?" For instance, a foreign poacher caught with a load of fish on a pier, falsely claiming it came from other waters, could be hooked and reeled in. A current dispute in which Newfoundland inshore fishermen claim that offshore ships are taking their fish—fishermen on the ships claim the fish are from two different stocks—could be resolved. All in all, there's a lot to be learned from the inside of a fish's head.

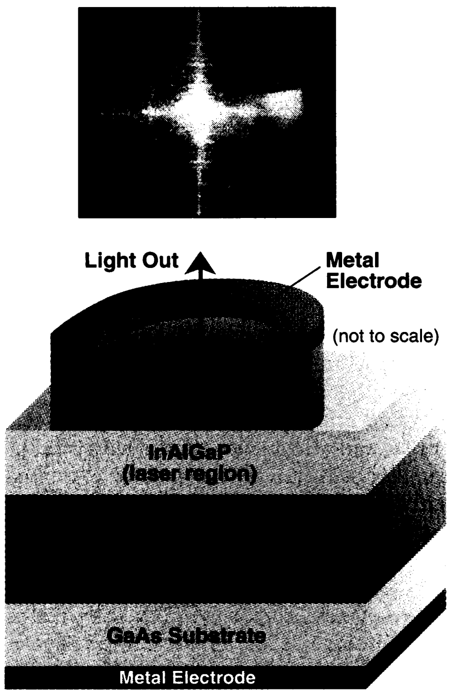
–Suzanne Kingsmill

Suzanne Kingsmill is a science writer based in Quebec, Canada.

TECHNOLOGY

New Laser Serves Red Light, Straight Up

Tiny lasers-on-a-chip have been technological darlings for a long time. Theirs is the light that scans compact discs and beams down glass optical fibers. But commercial semiconductor lasers emit their light from the edge of the chip, which makes it difficult to combine them in arrays that might, say, power a set of optical fibers. As a result, researchers have been trying to develop lasers that direct their light up through the top of a chip instead of out the side. But they've had little success in turning such lasers into efficient, practical emitters of the visible light prized for many applications. Now, researchers at Sandia National Laboratories have fashioned tiny surface-emitters that just may pass technological muster.



Lasing around. A multilayer stack of semiconductor materials shows off its ability to emit bright red laser light by bleaching photographic film *(top)*. The diagram shows the anatomy of the 10-micron-wide structure.

In the 13 May issue of *Electronics Letters*, Sandia materials scientists Richard Schneider and James A. Lott report a new wrinkle on a technology familiar in the opto-electronics world—that of the so-called vertical cavity surface emitting lasers (VCSELs), pronounced "vixels." VCSELs consist of minuscule, multilayered stacks of semiconducting materials and emit light straight up. But until recently, the difficulty of combining different semiconductors in layers of exactly the right geometry to generate visible light had limited most VCSELs to invisible infrared light. Those few that have emitted visible light have done so only when pumped with another laser. The Sandia device overcomes those handicaps, efficiently emitting red light when pumped with an electric current.

To make their VCSEL, the Sandia scientists relied on a fabrication technique known as metalorganic vapor phase epitaxy, which enables them to build up complex multilayered constructions, molecular layer by molecular layer. The light-emitting heart of these constructions is the optical cavity, composed of several 10-nanometer-thick layers of the semiconductor indium-aluminum-gallium-phosphide. The cavity's quantum mechanical properties, which depend partly on