Fossilized ear bones rewrite the history of freshwater fish

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An artist's reconstruction of the Weberian apparatus in a 67 million-year-old fossil fish. The Weberian structure (gold-colored bones at center) arose from a rib (shown in gray attached to several back bones in the spine) and connect the fish's air bladder (left) with the inner ear (right). The bony structure endows the fish with more sensitive hearing and is still present today in two-thirds of all freshwater fish species. The background depicts the various fish lineages that evolved after the supercontinent Pangea broke up. Credit: Ken Naganawa for UC Berkeley

When saltwater fish long ago evolved to live in fresh water, many of them also evolved a more sophisticated hearing system, including middle ear bones similar to those in humans.

Two-thirds of all freshwater fish today—including more than 10,000 species, from catfish to popular aquarium fish like tetras and zebrafish—have this middle ear system, called the Weberian apparatus, which allows them to hear sounds at much higher frequencies than most ocean fish can, with a range close to that of humans.

University of California, Berkeley paleontologist Juan Liu has now used the structure of this Weberian apparatus in a newly discovered fossil fish to revise the origin story for the evolution of freshwater fish.

Fish with a Weberian ear system, referred to as otophysan fish, were thought to have moved into fresh water approximately 180 million years ago, before the supercontinent of Pangea had broken up into the continents we see today.

Based on Liu's new timeline, they now appear to have arisen much later—about 154 million years ago, during the late Jurassic Period—after the beginning of Pangea's breakup and coinciding with the appearance of today's oceans.

Acronichthys maccagnoi fossil (with scale), which was located well inland from the shoreline of the Western Interior Seaway. Credit: Don Brinkman, Royal Tyrrell Museum

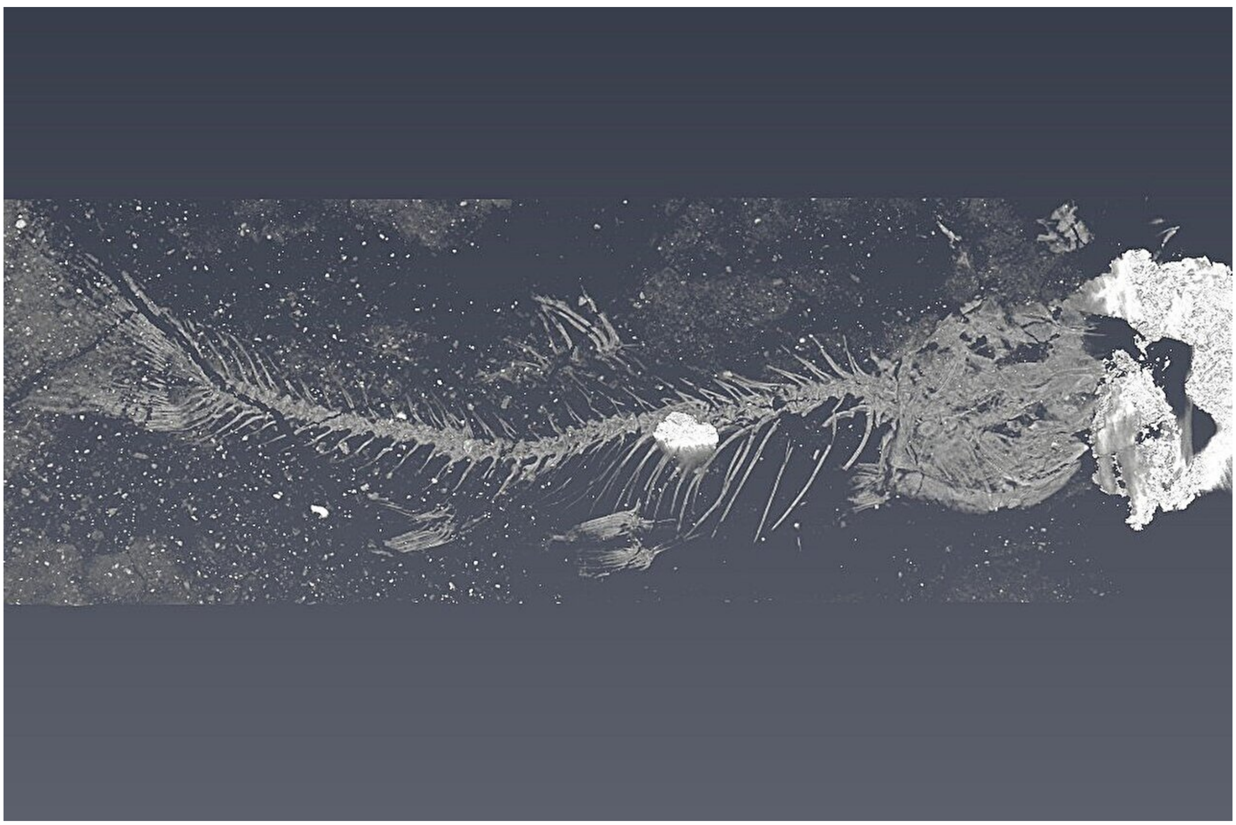
Liu's analysis of fossil and genomic data implies that the fish originally developed precursor bones of their superb hearing while still in the ocean.

Only later did they develop fully functional enhanced hearing, after the two separate lineages moved into fresh water: one evolving into today's catfish, knife fish and African and South American tetras; the other evolving into the largest order of freshwater fish, the carp, suckers, minnows and zebrafish.

"The marine environment is the cradle of a lot of vertebrates," said Liu, an assistant adjunct professor of integrative biology and an assistant curator in the UC Museum of Paleontology.

"A long time consensus was that these bony fish had a single freshwater origin in the large continent Pangea and then dispersed with the separation of different continents.

"My team's analysis of some fantastic fossils that shed new light on the evolutionary history of freshwater fish and found completely different results: the most recent common ancestor of otophysan fish was a marine lineage and there were at least two freshwater incursions after that lineage split up."



X-ray based CT image rendering of Acronichthys maccagnoi fossil. Credit: Lisa Van Loon

This finding reshapes our understanding of the evolutionary history and intricate biogeography of the world's most successful group of freshwater fish, she added.

"These repeated incursions into freshwater at the early divergence stage likely accelerated speciation, and are key factors in explaining the extraordinary hyper-diversity of otophysans in modern freshwater faunas."

Liu and her colleagues describe and name the 67 million-year-old fossil fish, Acronichthys maccagnoi, in a paper published in the journal *Science*. In that paper, the researchers analyze 3D scans of the fossil's Weberian structure and the genomes and morphology of modern fish to revise the genealogy of freshwater fish, and also simulate the frequency response of the fossil fish's middle ear structure.

A Rube Goldberg-like structure in the middle ear

Ears that work underwater require a different anatomy than ears that detect sound traveling through the air. Many land vertebrates evolved an eardrum-like structure that vibrates in response to sound waves. That eardrum moves a Rube Goldberg-like array of bones in the middle ear—in humans, the malleus, incus and stapes—that amplify the sound and poke the fluid-filled inner ear, which jiggles and eventually jostles hairs that send signals to the brain.

But sound waves in water go right through a fish, which has a similar density to the surrounding water. So fish developed a bladder filled with air—essentially a bubble—that vibrates in response to sounds passing through the fish. Those vibrations are transferred to the fish's inner ear in a rudimentary way in most saltwater fish, which limits their hearing to bass notes below about 200 Hertz.

Otophysan fish, however, developed bony "ossicles" between the air bladder—often inaccurately referred to as the swim bladder—and the inner ear to amplify and extend the frequency range the ears can detect. Zebrafish, for example, can hear frequencies up to 15,000 Hz, not far from the 20,000 Hz limit of humans.

Why these fish need to hear high frequencies is a mystery, though it may be because they live in diverse and complicated environments, from rushing streams to static lakes.

Liu studies the Weberian apparatus in living and fossil fish, and last year published a computational simulation of how the apparatus works. That simulation allows her to predict the frequency response of the bony ossicles, and thus the hearing sensitivity of fish.

Numerous specimens of the newly named fossil fish, a mere 2 inches long, were excavated and collected in Alberta, Canada, over six field seasons starting in 2009 by ichthyologist and co-author Michael Newbrey of Columbus State University in Georgia.

The fossils are housed in the Royal Tyrrell Museum in Drumheller, Alberta. A couple of specimens were so well preserved that the bones in the middle ear were clearly Weberian. The fish is the oldest known North American fossil of an otophysan fish, or Otophysi, dating from the late Cretaceous Period, only a short time before the non-avian dinosaurs disappeared.

Older specimens have been found elsewhere in the world, but none had a well-preserved Weberian apparatus, Liu said.

Technicians with the Canadian Light Source at the University of Saskatchewan in Saskatoon and at McGill University in Montreal captured 3D X-ray scans of the fish, and Liu modeled the ossicles of the

Weberian apparatus in her laboratory. The model suggests that, even 67 million years ago, otophysan fish had nearly as sensitive hearing as zebrafish do today.

"We weren't sure if this was a fully functional Weberian apparatus, but it turns out the simulation worked," Liu said. "The Weberian apparatus has just a little bit lower output power, which means lower sensitivity, compared to a zebrafish. But the peak, the most sensitive frequency, is not too much lower than zebrafish—between 500 and 1,000 Hertz—which is not too bad at all and which means the higher frequency hearing should have been achieved in this old otophysan fish."

She noted that the findings highlight a general pattern in evolution: sudden increases in new species can arise from repeated incursions into new habitat rather than a single dispersal event, especially when coupled with new innovations, such as more sensitive hearing.

"For a long time, we presumed that the Otophysi probably had a freshwater origin because this group consisted almost exclusively of freshwater fishes," Newbrey said. "The new species provides crucial information for a new interpretation of the evolutionary pathways of the Otophysi with a marine origin. It just makes so much more sense."

Other co-authors of the paper are Donald Brinkman of the Royal Tyrrell Museum, Alison Murray of the University of Alberta, former UC Berkeley undergraduate Zehua Zhou, now a graduate student at Michigan State University, and Lisa Van Loon and Neil Banerjee of Western University in London, Ontario.

More information: Juan Liu et al, Marine origins and freshwater radiations of the otophysan fishes, *Science* (2025). DOI: 10.1126/science.adr4494.
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