in the fall. According to Army Corps study manager Greg Graham, about 100 million cubic meters of sediment—half mud, half sand—has settled behind the four dams. Although the mud should erode quickly and get flushed out to sea, the sand will tumble downstream slowly. "Mother Nature is going to take charge and redistribute sediments as she sees fit," says Graham. Because the project's early stages would kick up so much sediment, Tatro's group has drafted plans to capture salmon heading upstream and truck them around the dams. A more prolonged problem is that after the Snake is channeled around Lower Monumental and Ice Harbor, it could run too swiftly for upstream-bound fish. The Army Corps may stud channels with boulders to create artificial rapids with eddies where fish can rest.

The Army Corps isn't expected to release its full report—including its favored option—until the end of this year. But opponents are already taking aim at any dam breach. One prominent critic is Senator Slade Gorton (R–WA), who argues that the cost of such an operation outweighs its uncertain benefits. Business and agriculture leaders are also up in arms. For instance, Bruce Lovelin, executive director of the Columbia River Alliance, a Portland-based trade association, predicts that if the dams are retired, utility customers would foot the bill for the lost 1200 megawatts generated each year, about 5% of the supply in the Pacific Northwest—enough to power Seattle.

After choosing a strategy, the Army Corps will have to sell it to other agencies, the public, and finally to Congress, which must approve funds to pay for it. Graham says it's too early to bet against the dams. "We see a lot of news articles [saying] the Corps wants to tear out dams," he says. "We haven't concluded anything." Many scientists, however, are pushing for strong measures, and fast. "Unless something is done soon," says Koch, "most of the remaining runs will go extinct." That would deprive the region of a resource even more valuable, perhaps, than megawatts.

–RICHARD A. LOVETT

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MEETING VERTEBRATE PALEONTOLOGY

From Embryos and Fossils, New Clues to Vertebrate Evolution

LONDON—Nearly 200 paleontologists, developmental biologists, molecular phylogenists, and other researchers gathered here on 8 and 9 April for a meeting on "Major Events in Early Vertebrate Evolution." They heard that studies revealing the molecular programs underlying embryonic development are helping paleontologists better interpret their fossils, while new fossil finds show that organisms once had a wider range of shapes and sizes than thought. Together, these efforts are changing our view of how vertebrates came to be.

Something Fishy About Fin Evolution

One of the key unanswered questions about the evolution of fish is how they got their fins, appendages that have helped this group of organisms be so successful. It's an answer that concerns landlubbers as well, as fins eventually became limbs for seagoing creatures venturing onto drier habitats. Now it appears that fins evolved multiple times in primitive fish.

The current view holds that both sets of the paired fins of modern fish arose from the same precursor tissue on the belly of an ancestral fish. But new 400-million-year-old fossils imply separate origins for the two sets of paired fins, which are especially important for the successful adaptations of modern fish and are also the precursors of land animals' limbs. "The materials are truly fantastic and eye-opening," says Xiaobo Yu, a paleontologist at Kean University in Union, New Jersey. "My entire repertoire of existing ideas on fins needs to be reorganized."

Two of the fish fossils that are roiling the waters came from a rich deposit of fish fossils located high up in the Mackenzie mountains of Canada's Northwest Territories, near the Yukon border. Collected by paleontologist Mark Wilson and his colleagues at the University of Alberta in Edmonton, both of the fossils have elaborate sets of spines and fins not seen before.

Modern fish have a set of pectoral fins, one on each flank behind the gills, and a set of pelvic fins, located on the belly just before the anus. A theory dating to the late 1800s says that both pairs of fins evolved from flaps of skin extending all along the bottom of the fish's body. Then the pair nearest the front of the fish somehow migrated upward on the body to form the pectoral fins while the backmost pair remained in their original location as the pelvic fins. According to a more recent theory, proposed by Michael Coates of University College London and Martin Cohn of the University of Reading, both in the United Kingdom, pelvic fins were a later invention brought about when the genetic program for the first set of fins somehow got turned on further back along the body.

Fins galore. The plethora of paired fins in this fossil fish goes against current thinking on the origins of these appendages.

CREDIT: M. WILSON

But Wilson says the new fossil fish don't fit comfortably with that picture. One fossil, called *Kathemacanthus* (meaning necklace of spines), has a large pectoral fin and spine lying high on each side of the animal just behind the head and gill slits. So a series of spines, suggestive of a necklace, runs down each side of the fish below the fin. *Kathemacanthus* also has a second series of paired spines along its belly that get progressively larger and culminate in what appear to be real pelvic fins. The other species, *Brochoadmones*, has the series of intermediate pelvic spines but only a single pectoral fin spine.

Because the pectoral fins are located so high up even in these early fish, Wilson thinks the fins may have first appeared there and not along the belly, as the other views suggest. In addition, he says, "the pectoral [spines] get more finlike as they go up and the pelvic [spines] get more finlike as you go back." Finding such advanced fin structures in two places suggests to Wilson that the early fish didn't start with just the pectoral fins but with pelvic fins as well, likely relying on different sets of genetic instructions for producing the two types.

Some of Wilson's colleagues think this indeed may prove to be how fins arose. "[Wilson] may be right that pelvic and pectoral fins arose independently on two different levels of the flank," says Philippe Janvier, a paleontologist at the Natural History Museum in Paris. But others doubt that it happened that way. Coates, for one, thinks that the spines and "fins" are not true fins, with muscles and supportive internal structures, and so are not telling us much about how true fins evolved.

Wilson, however, points to another recent fossil find, a jawless fish named *Sheilia*, discovered by Tiiu Märss and her colleagues at Tallinn Technical University in Estonia. Previous jawless fish fossils had only pectoral fins, but *Sheilia* also appears to have a set of paired pelvic fins, supporting Wilson's notion that pelvic fins were an early invention. And at the meeting, paleontologist Hans-Peter Schultze from the Museum of Natural History at Humboldt University in Berlin presented a new fish fossil, called *Dialipina*, that he and his colleagues had collected from Arctic Canada. *Dialipina* was from the same time period as Wilson's fish and, like them, had pectoral fins located high on the body and not ventrally, as the older theories predicted.

"We're seeing an upsurge of fish which have character combinations that confound our expectations," says meeting organizer Per Ahlberg of the Natural History Museum in London. Yu adds that the fossils have "mind-boggling [features] that keep paleontologists and developmental biologists busy during the day and sleepless at night."

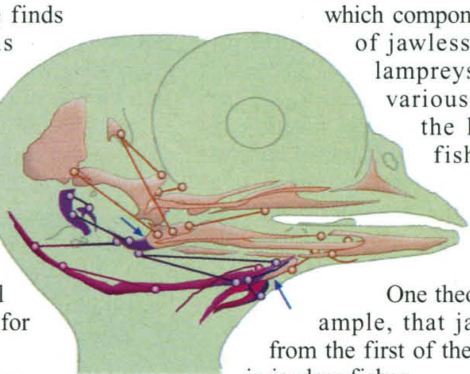
Just Where Did That Jaw Come From?

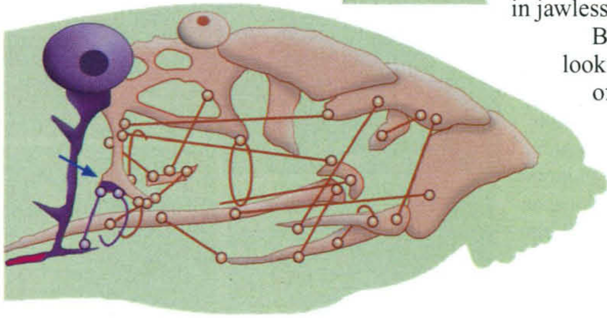
A pelican scooping up a fish, a lion crunching the leg of a gazelle, a parrot fish nibbling on coral—each creature has jaws specialized for its own way of life. For more than a century, biologists have tried to reconstruct how those adaptations evolved by comparing jaw, head, and skull bones in both fossil and living species. But such comparisons can't always establish a link between the jaw components of very different species, so their evolutionary history is often a blank. New findings about how jaws and heads develop could help paleontologists draw the missing connections.

Developmental biologist Georgy Köntges and his colleagues at Harvard University have found that discrete clusters of cells in an embryonic tissue called the neural crest grow into specific parts of the skull and jaw. By identifying the basic developmental modules of all vertebrate skulls, the work "gives us an explanation for the organizational pattern for skulls," says Per Ahlberg, a paleontologist at the Natural History Museum in London. It should also make it easier for researchers to do species-to-species comparisons and thus help them gain a better understanding of how one kind of jaw evolved into another—and perhaps how jaws originated in the first place.

Köntges has been tracing the origins of vertebrate craniofacial components for several years. He began with the chicken, transplanting bits of tissue from the neural crest of quail embryos into the neural crests of early chick embryos. By applying a dye-labeled antibody specific for quail cells, Köntges and his colleagues could then follow the fates of the transplanted neural crest cells. More recently, Köntges and his Harvard colleagues have been tracing the fate of genetically labeled neural crest cells in developing mice.

In both organisms, he finds that neural crest cells emerge from discrete compartments called rhombomeres in the developing hindbrain. Cells from a particular rhombomere then migrate to help form a specific part of the head, such as one of the gill arches, the bony supports for the gills. In chicks and mice, the cells in these arches then continue developing, forming other features of the head. And along with a patch of bone or cartilage, each rhombomere also forms the connective tissue that attaches the bones to each other and to their muscles.





Parallel parts. In the diagrams, colors (beige, pink, or purple) denote brain structures derived from the same parts of the developing hindbrain. This helps maintain the proper bone-muscle connections in the head, as seen in the chick *(top)* and predicted in the lamprey *(bottom)*.

CREDIT: ADAPTED FROM G. KÖNTGES

During development, the data of Köntges's and others show, these modules form a complex mosaic, so that a mature cranial bone can consist of patches of cells from different rhombomeres. But the cells from different rhombomeres never mingle. They "maintain an identity which prevents them from mixing with their neighbors," Köntges explains. The fidelity of this modular organization "ensures proper connectivity," he adds. It guarantees that even if evolution exaggerates one part of the jaw or eliminates another, the remaining structures retain the proper muscle, tendon, and nerve connections.

It could also be a boon to evolutionary biologists. By creating wiring diagrams of the skull and jawbone showing the connections of motor nerves and muscles in a wide range of organisms, researchers should be able to link specific jaw and skull structures to their parent rhombomeres. And that, says Ahlberg, should provide "a framework from which you can interpret the fossils," identifying structures that have common evolutionary roots.

Indeed, Köntges has already begun applying this method to studying jaw evolution. For decades, researchers have debated which components in the heads of jawless fishes such as lampreys correspond to various structures in the heads of jawed fishes—a possible clue to how jaws first evolved about 500 million years ago. One theory holds, for example, that jaws are derived from the first of the bony gill arches in jawless fishes.

But Köntges has taken a fresh look at the jawless lamprey in light of his current findings, and his results cast doubt on that scenario. By tracing the cartilage produced by neural crest cells from the animal's rhombomeres, he finds that the first and second gill arches are fused, so that they look like one continuous structure—something that wasn't supposed to have happened until jawed fish appeared. If the first two arches are already fused in lampreys as they are in jawed fish, then the first gill arch may have never been an independent structure, as current theories of jaw evolution suggest.

Besides helping paleontologists draw connections between different jaw structures, the new work could also unlock the mystery of how the structures evolved in the first place. "We're getting to the point where we can make the link between gene expression patterns and morphology," explains Ahlberg. Learning which genes sculpt rhombomeres into mature skulls and jaws could help paleontologists reconstruct the gene changes that created the diversity of modern lifeforms. The effort to achieve that, Ahlberg notes, "is one of the most important things happening in modern biology."

–ELIZABETH PENNISI