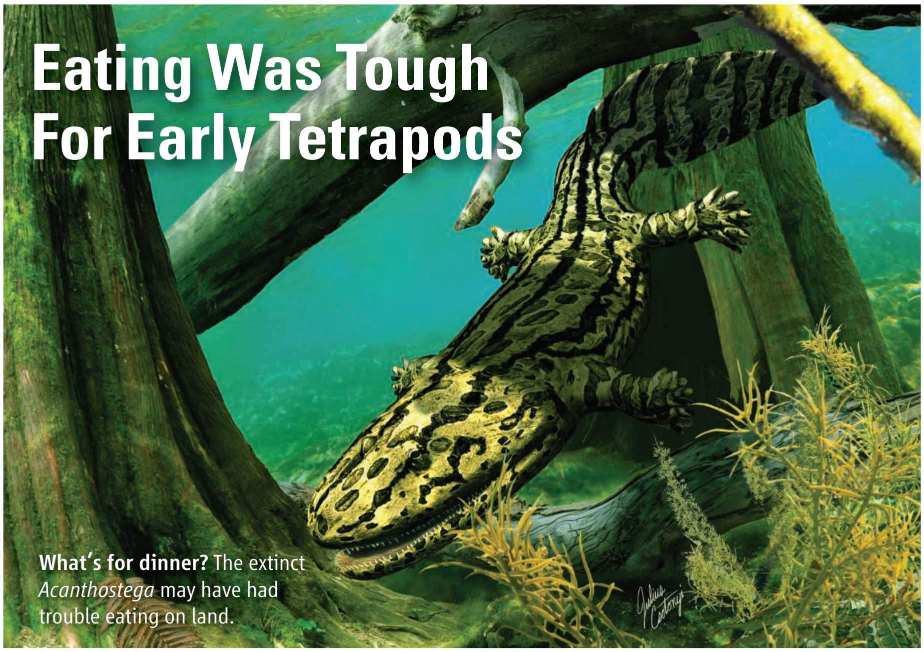
Eating Was Tough For Early Tetrapods



What's for dinner? The extinct *Acanthostega* may have had trouble eating on land.

While a fin-to-limb transition made possible the first steps on land for vertebrates 390 million years ago, it took a long time for ancient tetrapods to leave behind their aquatic ways and become true landlubbers. After that initial landfall, another 80 million years went by before tetrapods developed jaws adapted for terrestrial feeding, according to Philip Anderson, an evolutionary paleobiologist at the University of Massachusetts, Amherst, who presented a survey of fossils from this time period at the meeting.

Those early tetrapods must have had a hard time figuring out how to swallow terrestrial food, if another study presented at the meeting is any guide. That work described the great lengths that some modern fish must go to catch and eat prey out of water. "That's something that paleontologists have not thought about too much," says Alice Gibb, a functional morphologist at Northern Arizona University in Flagstaff. The combination of paleontology and functional morphology evidence shows "that the switch [to eating on land] was awfully hard," concludes Richard Blob, an evolutionary biomechanist at Clemson University in South Carolina.

Vertebrates were among the last animals to crawl onto land. Which locomotor changes enabled this move "is pretty well resolved," says Michael Coates, a vertebrate paleontologist at the University of Chicago in Illinois. But understanding what and how the first four-legged vertebrates ate "is somewhat in its infancy," says Miriam Ashley-Ross, a functional morphologist at Wake Forest University in Winston-Salem, North Carolina.

Some researchers have argued that the first tetrapods were quick to exploit land-based food; others are not sure whether these animals were "surf" or "turf" eaters. Anderson began to wonder about the transition to terrestrial diets 2 years ago, after an initial survey of fossils confirmed that the lower jaws of early tetrapods were very fishlike. He and his colleagues have now extended that work, in all measuring jaws from 97 genera dating from the Devonian 416 million years ago through the early Permian, 295 million years ago. The fossils included classic early tetrapods such as *Acanthostega* and *Tiktaalik*, some closely related fish, ancestral amphibians, and some later evolving reptilelike and mammal-like species. Early tetrapods had elongated jaws, like those in their fish ancestors. But about 80 million years into their evolution, shorter, deeper jaws appeared, Anderson found. These stronger jaws would have been better able to munch on vegetation, he notes.

Early on in tetrapod evolution, "big changes are going on elsewhere in anatomy and the jaws lurch into changing later on," Coates says. During that period, the researchers suggest, these animals may have made brief forays onto land but hunted in the water.

With fishlike mouths, early tetrapods would have faced a difficult task eating on land. Underwater, fish usually rely on suction to draw food into their mouths and swallow. To generate enough inward force in less dense air, a fish—or early tetrapod—would have to expand its mouth 28 times faster, Sam Van Wassenbergh, a biomechanist at the University of Ghent in Belgium, reported at the meeting. And even then, because air is so much less viscous, the air flow might not be enough to draw in prey. Moreover, most fish mouths face forward to grab food items suspended straight ahead in water, not food laying below on the ground.

Many modern terrestrial tetrapods have solved their swallowing problem by having tongues do the job. But Van Wassenbergh started thinking about how early tetrapods might have dined on land after he studied the eel catfish, which lives in the muddy swamps of tropical Africa. It has a tiny head and a long body with no paired fins. When he filmed this fish in 2006, he determined that the secret to its success to capturing insects on land was arching the front end of its body to position the mouth directly over the prey. Once the food is captured, the catfish quickly slips back into the water; only there, where it can take in water to wash down the prey, can it swallow, Van Wassenbergh said.

More recently, he has turned to mudskippers, 15-centimeter-long fish commonly found in the mud in mangrove swamps. In contrast to the eel catfish, the mudskipper has big paired fins and doesn't have to go back into the water with each mouthful of prey.

Mudskippers solve the swallowing problem by carrying water with them, Van Wassenbergh reported. His studies revealed that these fish fill their mouths with water before emerging onto land. They scoot along with their fins, then bend their head down to grab the food. As they do this, they compress the sides of the mouth, moving the water forward and, sometimes, forcing water out as they grab the prey. Instantly, the fish sucks the water back in. That mouthful of water enables them to swallow and keep hunting.

Fossils rarely preserve evidence of the muscles and cartilage connecting bones, and the dearth of such soft tissue data makes it difficult to know how exactly early tetrapods could maneuver their jaws or swallow. But although these animals lacked the complex mouths of mudskippers, Van Wassenbergh "showed that it is possible for something to come up on land and still use the fish suction system," Anderson says. That's certainly food for thought for those trying to reconstruct the life of early tetrapods.

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Nervous System May Have Evolved Twice

Biologists have long assumed that the neuron—with its axon, synapses, long processes called dendrites, and a suite of nerve-specific proteins—is the epitome of a specialized cell and thus likely to have evolved only once in the history of life. But a newly sequenced genome of a comb jelly, an ocean-going predator sometimes confused with traditional jellyfish, threatens to upend this view.

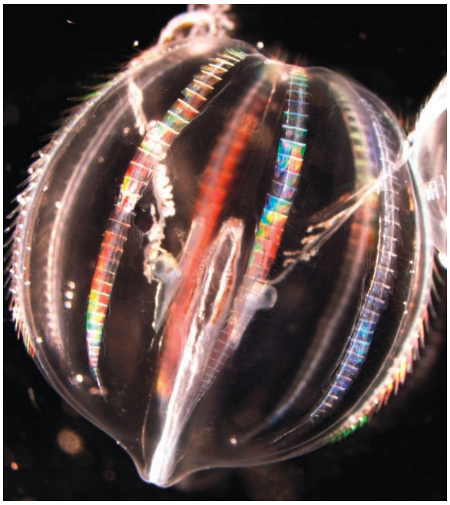
The DNA data put these invertebrates, also known as ctenophores, on a different, older branch of the tree of life from that of other organisms with complex nervous systems. This new placement will be controversial, but it suggests to some researchers that nervous systems arose twice. Indeed, the ctenophore's nervous system does appear to be different from those of other animals because its genome lacks genes for proteins that are considered essential to nervous system development and function. "All the things that are fundamental to [a nervous system] are missing in ctenophores," says Casey Dunn, an evolutionary biologist at Brown University.

Leonid Moroz, a neurobiologist at the University of Florida's Whitney Laboratory for Marine Bioscience in St. Augustine, and his colleagues study ctenophores and other invertebrates belonging to animal groups that arose early in the history of life. Comb jellies have an elementary brain and true nerve cells linked by complex synapses to muscles. In contrast, some of the other groups, like jellyfish and other cnidarians, simply have nets of nerve cells and no real brain—and sponges have no nerve cells to speak of.

Some analyses have indicated that ctenophores branched off on the tree of life late, just before all the bilateral animals; other data have them branching off earlier, alongside jellyfish; and at least one controversial study has them arising even before sponges, considered by some to be the most basal multicellular animals.

Moroz and his colleagues recently sequenced the genome of the comb jelly *Pleurobrachia bachei*. Comparing this genome with those of other organisms, Moroz's team concludes that ctenophores split off early, perhaps even before sponges and another odd group called placozoans, which also have no neurons. In this arrangement of the tree of life, if there were a single origin of the nervous system, sponges and placozoans would have had to discard nerve cells and other neural attributes, Moroz told the meeting. More likely, he argued, ctenophores evolved a nervous system after they split off from other animals and became predators, and then another nervous system arose separately, after the sponges and placozoans split off, in the branch leading to cnidarians and bilateral animals.

Independently, researchers at the National Human Genome Research Institute (NHGRI) in Bethesda, Maryland, have deciphered the genome of another ctenophore, and they made the data available to Moroz and others. At the meeting, NHGRI geneticist Andy Baxevanis said their analysis did not completely confirm Moroz's basal placement of ctenophores. However, other evidence suggests an independent origin of the ctenophorean nervous system. Both sequenced comb jellies lack *Hox* genes, which are considered crucial for patterning the developing nervous system in other animals. Also, the molecules in the *P. bachei* synapses are different from those in the nervous systems of other organisms, including jellyfish, Moroz reported. Ctenophores lack the neurotransmitter serotonin, for example. "There are many ways to skin a cat and there are many ways to make a neuron," he says.


Smart jelly. Ctenophores may have independently evolved a nervous system.

CREDIT: LEONID MOROZ

Chris Lowe, an evolutionary developmental biologist from Stanford University's Hopkins Marine Station in Pacific Grove, California, welcomes the new sequence data and Moroz's conclusion about the independent evolution of the nervous system. "It's great that he's bringing up these issues," Lowe says. Ctenophores are so different from other organisms in their genetic makeup that "they well may have a nervous system that is totally independent."

–ELIZABETH PENNISI

Snapshots From the Meeting >>

Shedding light on how moths track flowers blowing in the wind. Like hummingbirds, hawkmoths hover as they feed on nectar and pollen, so they must track a flower's motion in a breeze to stay with it. Simon Sponberg, a neuromechanist at the University of Washington, Seattle, wondered how moths were able to follow a flower in dim light, because these insects tend to forage at dusk and dawn. By studying the moths' aerial responses to robotic flowers swaying at different speeds in different light levels, he has determined that the moth brain can function even in dim conditions because it takes more time to gather light and produce an image. This adaptation becomes a liability when the flower oscillates more than twice per second, as the moth can't keep up, he reported at the meeting. But Sponberg's high-speed videos of actual flowers blowing in the wind show that blooms typically oscillate more slowly than that. "The moth was free to make this adaptation without having to make a trade-off," Sponberg said. "It tracks at relevant frequencies and doesn't care about what happens" at faster frequencies.

Calcified seaweed bucks the waves with joints. Typically attached to rocks in the surf, coralline algae earned their name because their fronds are calcified, like a coral. Compared with other intertidal algae, such as *Mazzaella flaccida* with its rubbery fronds, these hand-sized seaweeds look quite fragile. Actually, the opposite is true, Mark Denny, a biomechanist of Stanford University's Hopkins Marine Station in Pacific Grove, California, reported at the meeting. His team had previously found that *Mazzaella* can withstand a very powerful single wave, but not repeated battering. In contrast, the coralline alga *Calliarthron cheilosporioides* is "indefatigable," Denny says. He simulated an aquatic battering by gluing the algae to a computer-operated device that repeatedly pulled and released tension on it. The algae often lasted a million cycles before tearing apart and one specimen didn't break after 51 million pulls on it. The algae's secret: The fronds periodically have one-cell-thick joints where the cells are like cables—attached at the top and bottom to the calcified parts but not to each other. Thus, if one cell in a joint fails, the fatigue doesn't spread to the rest, Denny reported. This property may explain why coralline algae dominate the most wave-swept shores, he notes.

–E. P.