Snakes do it faster, better: How a group of scaly, legless lizards hit the evolutionary jackpot

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More than 100 million years ago, the ancestors of the first snakes were small lizards that lived alongside other small, nondescript lizards in the shadow of the dinosaurs.

Then, in a burst of innovation in form and function, the ancestors of snakes evolved legless bodies that could slither across the ground, highly sophisticated chemical detection systems to find and track prey, and flexible skulls that enabled them to swallow large animals.

Those changes set the stage for the spectacular diversification of snakes over the past 66 million years, allowing them to quickly exploit new opportunities that emerged after an asteroid impact wiped out roughly three-quarters of the planet's plant and animal species.

But what triggered the evolutionary explosion of snake diversity—a phenomenon known as adaptive radiation—that led to nearly 4,000 living species and made snakes one of evolution's biggest success stories?

A large new genetic and dietary study of snakes, from an international team led by University of Michigan biologists, suggests that speed is the answer. Snakes evolved up to three times faster than lizards, with massive shifts in traits associated with feeding, locomotion and sensory processing, according to the study published in the journal *Science*.

"Fundamentally, this study is about what makes an evolutionary winner. We found that snakes have been evolving faster than lizards in some important ways, and this speed of evolution has let them take advantage of new opportunities that other lizards could not," said University of Michigan evolutionary biologist Daniel Rabosky, senior author of the paper.

"Snakes evolved faster and—dare we say it—better than some other groups. They are versatile and flexible and able to specialize on prey that other groups cannot use," said Rabosky, a curator at the U-M Museum of

Zoology and a professor in the Department of Ecology and Evolutionary Biology.

For the study, researchers generated the largest, most comprehensive evolutionary tree of snakes and lizards by sequencing partial genomes for nearly 1,000 species. In addition, they compiled a huge dataset on lizard and snake diets, examining records of stomach contents from tens of thousands of preserved museum specimens.

They fed this mountain of data into sophisticated mathematical and statistical models, backed by massive amounts of computer power, to analyze the history of snake and lizard evolution through geological time and to study how various traits, such as limblessness, evolved.

This multipronged approach revealed that while other reptiles have evolved many snake-like traits—25 different groups of lizards also lost their limbs, for instance—only snakes experienced this level of explosive diversification.

Take Australia's legless gecko, for example.

Like snakes, this lizard lost its legs and evolved a flexible skull. Yet the creature has barely diversified over millions of years. No evolutionary explosion—just a couple of species scraping out a living in the Australian outback.

So, it seems there is something special about snakes that enabled them to hit the evolutionary jackpot. Maybe something in their genes allowed them to be evolutionarily flexible while other groups of organisms are much more constrained.

"A standout aspect of snakes is how ecologically diverse they are: burrowing underground, living in freshwater, the ocean and almost every conceivable habitat on land," said Alexander Pyron, study co-author and an associate professor of biology at George Washington University. "While some lizards do some of these things—and there are many more lizards than snakes—there are many more snakes in most of these habitats in most places."

The ultimate causes, or triggers, of adaptive radiations are one of the big mysteries in biology. In the case of snakes, it's likely there were multiple contributing factors, and it may never be possible to tease them apart.

The authors of the study refer to this once-in-evolutionary-history event as a macroevolutionary singularity with "unknown and perhaps unknowable" causes.

A macroevolutionary singularity can be viewed as a sudden shift into a higher evolutionary gear, and biologists suspect these outbursts have happened repeatedly throughout the history of life on Earth. The sudden emergence and subsequent dominance of flowering plants is another example.

In the case of snakes, the singularity started with the nearly simultaneous (from an evolutionary perspective) acquisition of elongated legless bodies, advanced chemical detection systems and flexible skulls.

Those crucial changes allowed snakes, as a group, to pursue a much broader array of prey types, while simultaneously enabling individual species to evolve extreme dietary specialization.

Today, there are cobras that strike with lethal venom, giant pythons that constrict their prey, shovel-snouted burrowers that hunt desert scorpions, slender tree snakes called "goo-eaters" that prey on snails and frog eggs high above the ground, paddle-tailed sea snakes that probe reef crevices for fish eggs and eels, and many more.

"One of our key results is that snakes underwent a profound shift in feeding ecology that completely separates them from other reptiles," Rabosky said. "If there is an animal that can be eaten, it's likely that some snake, somewhere, has evolved the ability to eat it."

For the study, the researchers got an inside look at snake dietary preferences by reviewing field observations and stomach-content records for more than 60,000 snake and lizard specimens, mostly from natural history museums. The contributing museums included the University of Michigan Museum of Zoology, home to the world's largest research collection of snake specimens.

"Museum specimens give us this incredible window into how organisms make a living in nature. For secretive animals like snakes, it's almost impossible to get this kind of data any other way because it's hard to observe a lot of their behavior directly," said study co-lead author Pascal Title of Stony Brook University, who completed his doctorate at U-M in 2018.

The study's 20 authors are from universities and museums in the United States, the United Kingdom, Australia, Brazil and Finland.

More information: Pascal O. Title et al, The macroevolutionary singularity of snakes, *Science* (2024). DOI: 10.1126/science.adh2449. www.science.org/doi/10.1126/science.adh2449

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