Animals tend to evolve toward larger size over time, study finds

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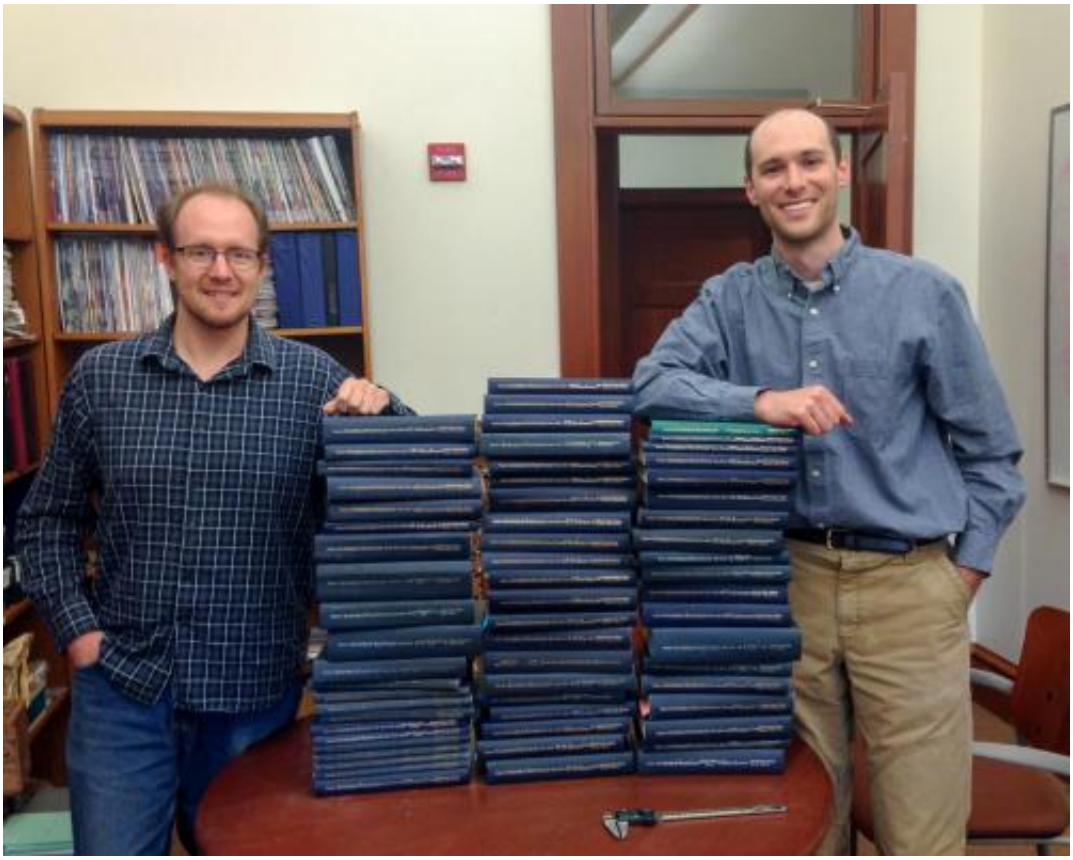

Prof. Jonathan Payne (right) and Noel Heim, a postdoctoral researcher in Payne's lab, stand next to stacks of the Treatise on Invertebrate Paleontology, which they recently used to provide fresh evidence of Cope's rule. Credit: Noel Heim

Does evolution follow certain rules? If, in the words of the famed evolutionary biologist Stephen Jay Gould, one could "rewind the tape of

life", would certain biological trends reemerge? Asked another way: can evolution be predicted?

New research suggests that, for at least one important biological trait-body size-the answer is yes.

In one of the most comprehensive studies of body size evolution ever conducted, Stanford scientists have found fresh support for Cope's rule, a theory in biology that states that animal lineages tend to evolve toward larger sizes over time.

"We've known for some time now that the largest organisms alive today are larger than the largest organisms that were alive when life originated or even when animals first evolved," said Jonathan Payne, a paleobiologist at Stanford's School of Earth, Energy & Environmental Sciences.

What was unclear, however, was whether the average size of animals has been changing over time and, if so, whether that reflects a trend, or directionality, in body size evolution. "It's not something that you can know by just studying living organisms or extrapolating from what you see over short time scales. If you do that, you will absolutely be wrong about the rate, and possibly also the direction," Payne said.

The study, published in the Feb. 20 issue of the journal *Science*, reveals that over the past 542 million years, the mean sized of marine animals has increased 150-fold. "That's the size difference between a sea urchin that is about 2 inches long versus one that is nearly a foot long," Heim said. "This may not seem like a lot, but it represents a big jump."

The research also found that the increase in body size that has occurred since animals first appeared in the fossil record around 550 million years ago is not due to all animal lineages steadily growing bigger, but rather to

the diversification of groups of organisms that were already larger than other groups early in the history of animal evolution.

"That's also something we didn't know before," Payne said. "For reasons that we don't completely understand, the classes with large body size appear to be the ones that over time have become differentially more diverse."

A universal trend?

Named after paleontologist Edward Cope, Cope's rule was formulated in the late 19th century after paleontologists noticed that the body sizes of terrestrial mammals such as horses generally increased over time.

Scientists have attempted to test Cope's rule in other animal groups, but the conclusions have been mixed. Corals and dinosaurs seem to follow Cope's rule, for example, but birds and insects do not. As a result, some scientists have wondered whether the pattern observed in land mammals is a real evolutionary phenomenon or merely a statistical one resulting from random, non-selective evolution, also known as neutral drift. "It's possible that as evolution proceeds, there really is no preference for being larger or smaller," said Noel Heim, a postdoctoral researcher in Payne's lab. "What appears to be an increase in average body size may be due to neutral drift."

To test whether Cope's rule applies to marine animals as a whole, Payne and a team that included undergraduates and high school interns compiled a dataset including more than 17,000 groups, or genera, of marine animals spanning five major phyla-Arthropods, Brachiopods, Chordates, Echinoderms, and Mollusks-and the past 542 million years. "Our study is the most comprehensive test of Cope's rule ever conducted," Heim said. "Nearly 75 percent of all of marine genera in the fossil record and nearly 60 percent of all the animal genera that ever

lived are included in our dataset."

To compile such a vast dataset, the team relied heavily on the Treatise on Invertebrate Paleontology, a 50-volume book set that includes detailed information about every invertebrate animal genus with a fossil record known to science. Using photographs and detailed illustrations of fossils in the Treatise, the team was able to calculate and analyze body size and volume for 17,208 marine genera.

A pattern soon became apparent: not all classes-groups of related species and genera-of animals trended toward larger size, but those that were bigger tended to become more diverse over time. The team suspects this is due to advantages associated with a larger size, such as the ability to move faster, burrow more deeply and efficiently in sediment, or capture larger prey.

"It's really a story of the survival and diversification of big things relative to small things," Heim said.

Virtual evolution

To investigate what might drive these trends toward larger body sizes, the team entered their measurement data into a computer model designed to simulate body size evolution. Beginning with the smaller species from each phylum, the model simulated how their body sizes might change as they evolved into new species. "As time marches forward, each species is assigned some probability of producing a new species, of remaining the same, or of going extinct, at which point it drops out of the race," Heim said.

When a new virtual species was created, the model assigned the new creature a body size that could be bigger or smaller than its ancestor. The scientists ran multiple simulations, each with different assumptions. One

scenario, for instance, assumed a neutral drift model of evolution, in which body size fluctuates randomly without affecting the survival of the species. Another assumed natural selection, or "active evolution," of body size, in which having a larger body size confers certain survival advantages and is thus more likely to propagate through the generations.

The team found that the neutral drift simulation could not explain the body size trends observed in the fossil record. "The degree of increase in both mean and maximum body size just aren't well explained by neutral drift," Heim said. "It appears that you actually need some active evolutionary process that promotes larger sizes."

The team believes that the vast database they compiled will be useful for studying other questions related to body size, such as whether or not organisms near the equator are, on average, bigger or smaller than those living at higher latitudes.

The findings could also prompt other scientists to investigate whether there is a trend in the evolution of other traits. "The discovery that body size often does evolve in a directional way makes it at least worth asking whether we're going to find directionality in other traits if we measure them carefully and systematically," Payne said.

More information: Cope's rule in the evolution of marine animals, *Science*, www.sciencemag.org/lookup/doi/ … 1126/science.1260065

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