Dense bones allowed Spinosaurus to hunt underwater, study shows

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Baryonyx hunting. Credit: Davide Bonadonna

Spinosaurus is the biggest carnivorous dinosaur ever discovered—even bigger than *T. rex*—but the way it hunted has been a subject of debate for decades. It's hard to guess the behavior of an animal that we only

know from fossils; based on its skeleton, some scientists have proposed that *Spinosaurus* could swim, but others believe that it just waded in the water like a heron. Since looking at the anatomy of spinosaurid dinosaurs wasn't enough to solve the mystery, a group of paleontologists are publishing a new study in *Nature* that takes a different approach: examining the density of their bones. By analyzing the density of spinosaurid bones and comparing them to other animals like penguins, hippos, and alligators, the team found that *Spinosaurus* and its close relative *Baryonyx* had dense bones that likely would have allowed them to submerge themselves underwater to hunt. Meanwhile, another related dinosaur called *Suchomimus* had lighter bones that would have made swimming more difficult, so it likely waded instead or spent more time on land like other dinosaurs.

"The fossil record is tricky—among spinosaurids, there are only a handful of partial skeletons, and we don't have any complete skeletons for these dinosaurs," says Matteo Fabbri, a postdoctoral researcher at the Field Museum and the lead author of the study in *Nature*. "Other studies have focused on interpretation of anatomy, but clearly if there are such opposite interpretations regarding the same bones, this is already a clear signal that maybe those are not the best proxies for us to infer the ecology of extinct animals."

All life initially came from the water, and most groups of terrestrial vertebrates contain members that have returned to it—for instance, while most mammals are land-dwellers, we've got whales and seals that live in the ocean, and other mammals like otters, tapirs, and hippos that are semi-aquatic. Birds have penguins and cormorants; reptiles have alligators, crocodiles, marine iguanas, and sea snakes. For a long time, non-avian dinosaurs (the dinos that didn't branch off into birds) were the only group that didn't have any water-dwellers. That changed in 2014, when a new *Spinosaurus* skeleton was described by Nizar Ibrahim at the University of Portsmouth.

Spinosaurus hunting. Credit: Davide Bonadonna

Scientists already knew that spinosaurids spent some time by water—their long, croc-like jaws and cone-shaped teeth are similar to other aquatic predators', and some fossils had been found with bellies full of fish. But the new *Spinosaurus* specimen described in 2014 had retracted nostrils, short hind legs, paddle-like feet, and a fin-like tail: all signs that pointed to an aquatic lifestyle. But researchers have continued to debate whether spinosaurids actually swam for their food or if they just stood in the shallows and dipped their heads in to snap up prey. This continued back-and-forth led Fabbri and his colleagues to try to find another way to solve the problem.

"The idea for our study was, okay, clearly we can interpret the fossil data

in different ways. But what about the general physical laws?" says Fabbri. "There are certain laws that are applicable to any organism on this planet. One of these laws regards density and the capability of submerging into water."

Across the animal kingdom, bone density is a tell in terms of whether that animal is able to sink beneath the surface and swim. "Previous studies have shown that mammals adapted to water have dense, compact bone in their postcranial skeletons," says Fabbri. Dense bone works as buoyancy control and allows the animal to submerge itself.

"We thought, okay, maybe this is the proxy we can use to determine if spinosaurids were actually aquatic," says Fabbri.

Lead author Matteo Fabbri doing fieldwork. Credit: Diego Mattarelli

Closeup of lead author Matteo Fabbri doing fieldwork. Credit: Diego Mattarelli

Fabbri and his colleagues, including co-corresponding authors Guillermo Navalón at Cambridge University and Roger Benson at Oxford University, put together a dataset of femur and rib bone cross-sections from 250 species of extinct and living animals, both land-dwellers and water-dwellers. The researchers compared these cross-sections to cross-sections of bone from *Spinosaurus* and its relatives *Baryonyx* and *Suchomimus*. "We had to divide this study into successive steps," says Fabbri. "The first one was to understand if there is actually a universal correlation between bone density and ecology. And the second one was to infer ecological adaptations in extinct taxa" Essentially, the team had to show a proof of concept among animals that are still alive that we know for sure are aquatic or not, and then applied them to extinct animals that we can't observe.

When selecting animals to include in the study, the researchers cast a wide net. "We were looking for extreme diversity," says Fabbri. "We included seals, whales, elephants, mice, hummingbirds. We have dinosaurs of different sizes, extinct marine reptiles like mosasaurs and plesiosaurs. We have animals that weigh several tons, and animals that are just a few grams. The spread is very big."

Simone Maganuco (middle), Davide Bonadonna (right) and lead author Matteo Fabbri (left) organizing fossils at night. Credit: Nanni Fontana

This menagerie of animals revealed a clear link between bone density and aquatic foraging behavior: animals that submerge themselves underwater to find food have bones that are almost completely solid throughout, whereas cross-sections of land-dwellers' bones look more like donuts, with hollow centers. "There is a very strong correlation, and the best explanatory model that we found was in the correlation between bone density and sub-aqueous foraging. This means that all the animals that have the behavior where they are fully submerged have these dense

bones, and that was the great news," says Fabbri.

When the researchers applied spinosaurid dinosaur bones to this paradigm, they found that *Spinosaurus* and *Baryonyx* both had the sort of dense bone associated with full submersion. Meanwhile, the closely related *Suchomimus* had hollower bones. It still lived by water and ate fish, as evidenced by its crocodile-mimic snout and conical teeth, but based on its bone density, it wasn't actually swimming.

Other dinosaurs, like the giant long-necked sauropods also had dense bones, but the researchers don't think that meant they were swimming. "Very heavy animals like elephants and rhinos, and like the sauropod dinosaurs, have very dense limb bones, because there's so much stress on the limbs," explains Fabbri. "That being said, the other bones are pretty lightweight. That's why it was important for us to look at a variety of bones from each of the animals in the study." And while there are limitations to this kind of analysis, Fabbri is excited by the potential for this study to tell us about how dinosaurs lived.

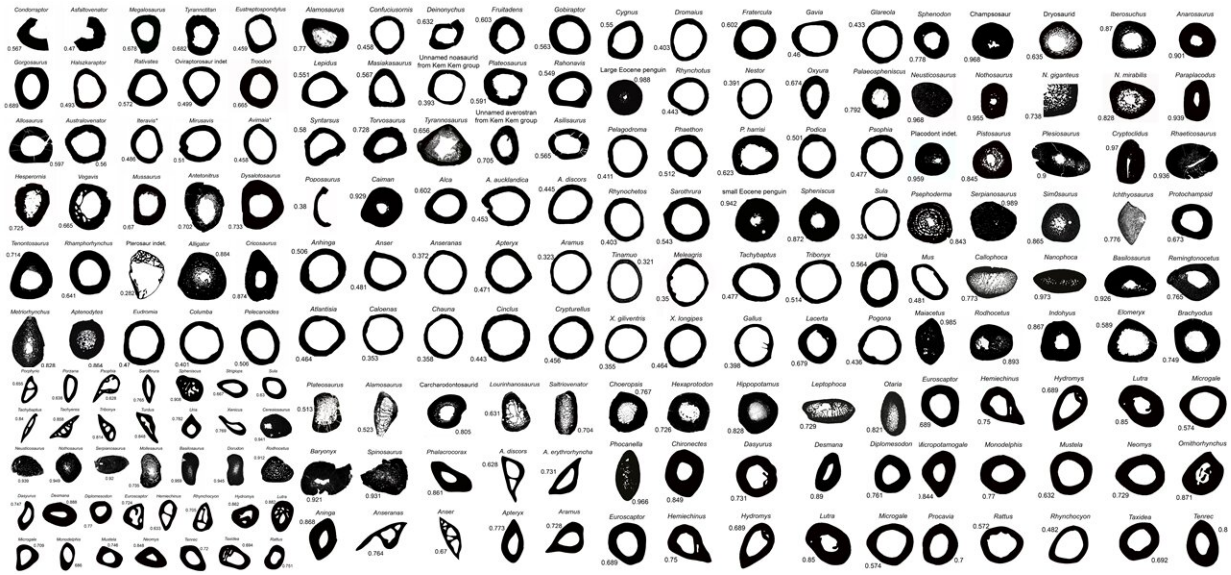

Figure from paper comparing animals' bone densities. Credit: Fabbri et al

"One of the big surprises from this study was how rare underwater foraging was for dinosaurs, and that even among spinosaurids, their behavior was much more diverse that we'd thought," says Fabbri.

Jingmai O'Connor, a curator at the Field Museum and co-author of this study, says that collaborative studies like this one that draw from hundreds of specimens, are "the future of paleontology. They're very time-consuming to do, but they let scientists shed light onto big patterns, rather than making qualitative observations based on one fossil. It's really awesome that Matteo was able to pull this together, and it requires a lot of patience."

Fabbri also notes that the study shows how much information can be gleaned from incomplete specimens. "The good news with this study is that now we can move on from the paradigm where you need to know as much as you can about the anatomy of a dinosaur to know about its ecology, because we show that there are other reliable proxies that you can use. If you have a new species of dinosaur and you just have only a few bones of it, you can create a dataset to calculate bone density, and at least you can infer if it was aquatic or not."

More information: Matteo Fabbri, Subaqueous foraging among carnivorous dinosaurs, *Nature* (2022). DOI: 10.1038/s41586-022-04528-0. www.nature.com/articles/s41586-022-04528-0

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