Environmental change drove diversity in Lake Malawi cichlids

October 3 2016

The 800 different cichlid species in Lake Malawi offer a classic example of adaptive radiation. Credit: Margaret Blome

Africa's Lake Malawi is home to hundreds of species of cichlids, the freshwater fish whose broad array of colors make them popular denizens of household aquariums. A new study shows how dramatic environmental changes during the lake's history likely drove that dazzling evolutionary diversity.

The study found that for the last 800,000 years, phases of deep and clear water in Lake Malawi have alternated with phases of shallow and murky water. The timing of the longest-lasting deep phases coincides with explosions of cichlid diversity that have occurred the lake's history.

"The timing of persistent deep water phases is consistent with what evolutionary biologists have suggested as periods of rapid diversification in cichlid species," said Sarah Ivory, a postdoctoral researcher at Brown University and the study's lead author. "We think the deep phases created new shoreline habitats for fish to adapt into, as well as the right conditions for assortative mating, both of which could drive species diversity."

The study, which Ivory co-authored with researchers from the University of Arizona, the University of Rhode Island, the University of Kentucky and the BP Corporation, is published in the *Proceedings of the National Academy of Sciences*.

Lake Malawi stretches for about 350 miles in a narrow basin bordering Malawi, Mozambique and Tanzania in eastern Africa. The diversity of the lake's cichlids, like Darwin's Galapagos finches, is a classic example of "adaptive radiation"—the rapid diversification of species as they adapt to environmental niches.

"Cichlids are a great model system for looking at this evolutionary processes," said Ivory, an environmental scientist in the Institute at Brown for Environment and Society. "There are around 800 species in

the lake, so it's a perfect laboratory for exploring how diversity develops."

Evolutionary biologists have sequenced the genomes of several cichlid species. Using a "molecular clock" technique, biologists can shed light on when species diverged in time. That work has suggested that the lake Malawi cichlids have diversified in fits and starts, with several distinct bursts of diversification beginning about 750,000 years ago.

This new research puts that evolutionary history in ecological context.

Using sediment cores harvested from the lake floor, Ivory and her colleagues assembled an environmental history of the lake spanning the past 1.2 million years. The sediment cores contain fossilized aquatic animals and pollen from plants, as well as important mineralogical information. Changes in the fossil assemblages and mineral indicators in the cores give clues about how environmental conditions—the lake's water level, salinity and other attributes—change through time.

The research showed that between 1.2 million and 800,000 years ago, Lake Malawi was consistently shallow and marshy. But at around 800,000 years ago, things changed dramatically. The lake deepened to near its current 700-meter depth, and its waters became much more sensitive to large climate fluctuations. The researchers believe this shift was likely driven by a tectonic event that closed off the lake's river outlet, allowing the basin to fill up.

Following that tectonic shift, the lake's environment became much less stable. The study found that over the last 800,000 years, the lake has alternated between "blue phases" marked by deep, clear water and "green phases" marked by shallow, algae-filled water. The evidence suggests that there were extended blue phases—each lasting around 100,000 years—that occurred 800,000 and 400,000 years ago, along

with one starting 70,000 years ago that persists today. Between those extended blue phases, the lake rapidly alternated between green and blue phases roughly every 20,000 years.

The timing of the extended blue phases lines up nicely with the molecular clock data, which suggests diversification events around 750,000, 400,000 and 70,000 years ago. Taken together, the results suggest that the blue phases created the right conditions for diversification.

Deepening water would have created new rocky shoreline habitats to which species may become adapted, Ivory says. The clear water also could haveallowed fish to use visual cues when choosing a mate, which could drive the evolution of color patterns in cichlid species. During the green phases, in contrast, lakebed habitats would be flat and sandy, lacking rocky niche environments. The murky water would limit the use of visual cues in mating.

"The turbidity of the water and the lack of diverse environments during the green phases lends itself to hybridization rather than diversification," Ivory said. "We would also expect extinction events during these periods."

But that doesn't mean the green phases are evolutionarily unimportant. The researchers suggest that interbreeding during green phases might have given rise to new hybrid traits, which were then subject to selection during the blue phases. In that way, the green phases be "critical for 'priming the pump' of diversity," the researchers say.

Ivory says that prior research had found a link between the most recent diversification event and the onset of the current blue phase about 70,000 years ago. But this is the first time researchers have shown that the pattern was repeated several times in the lake's history.

"The repetition of this pattern was really interesting to see," she said. "Linking the evolutionary processes to the environmental change through time is really important for understanding the diversity in cichlids that we see today."

More information: Environmental change explains cichlid adaptive radiation at Lake Malawi over the past 1.2 million years, *Proceedings of the National Academy of Sciences*, www.pnas.org/cgi/doi/10.1073/pnas.1611028113

Provided by Brown University