A new species of electric eel produces the highest voltage discharge of any known animal

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An article shows that three species of electric eel exist, not just one as previously described, and that one of them produces an electric shock up to 860 volts. Credit: C. David de Santana

There are at least three species of electric eels (*Electrophorus spp.*), not just one as previously believed. Two new species have recently been described with São Paulo Research Foundation—FAPESP's support by a group of researchers affiliated with the Smithsonian Institution and National Geographic Society, among other institutions. One of the new

species can discharge up to 860 volts, the strongest of any known animal.

Electric eels are naked-back knifefishes (*Gymnotidae*) and are more closely related to catfish and carp than to other eel families.

The study, published in *Nature Communications*, not only provides new knowledge about the animal more than 250 years after it was first described but also opens up new avenues of research into the origin and production of strong electric discharges in other fish species.

Gymnotiformes, the knifefish family to which *Gymnotidae* belong, are native to Mexico and South America, are found almost exclusively in freshwater habitats, and are mostly nocturnal. There are currently approximately 250 valid gymnotiform species among 34 genera and five families.

All are capable of producing a weak electric field for communication and navigation (most have very small eyes).

"The electric eel, which can reach 2.5 meters in length, is the only fish that produces such a strong discharge; it uses three electric organs. The shock is used for defense and predation," said Carlos David de Santana, an associate researcher at the US National Museum of Natural History (NMNH), administered by the Smithsonian Institution, and first author of the article.

By correlating DNA, morphology and environmental data, and measuring the discharged voltage, the researchers concluded that the animals in question should be reclassified into three species. The only species of electric eel previously known to science was *Electrophorus electricus*, which Swedish naturalist Carl Linnaeus described in 1766.

South American rivers are home to at least three different species of electric eels, including a newly identified species capable of generating a greater electrical discharge than any other known animal, according to a new analysis published in the Sept. 10, 2019 issue of the journal Nature Communications. *Electrophorus voltai* (shown above), one of the two newly discovered electric eel species, primarily lives further south than *Electrophorus electricus* on the Brazilian Shield, another highland region.Scientists discovered that *E. voltai* can discharge up to 860 Volts of electricity--significantly more than the previously known 650 Volts generated by *E. electricus*. This makes the species the strongest known bioelectric generator, and may be an adaptation to the lower conductivity of highland waters. Credit: L. Sousa

In addition to *E. electricus*, now defined as the species that lives in the northernmost part of the Amazon region, the researchers found sufficient differences to add two new species to the genus: *E. varii* and

E. voltai.

The authors of the article also include Luiz Antonio Wanderley Peixoto, currently at MZ-USP for a postdoctoral internship under the supervision of Aléssio Datovo da Silva, coprincipal investigator for the Thematic Project.

"We used voltage as the key differentiation criterion. This has never been done before to identify a new species," Menezes said. During field measurements using a voltmeter, the researchers recorded a discharge of 860 volts, the highest found in any animal, for a specimen of E. *voltai.* The strongest shock previously recorded was 650 volts.

The name of the species pays homage to Italian physicist Alessandro Volta, who invented the electric battery in 1799, basing its design on the electric eel.

E. varii is named for zoologist Richard P. Vari, a researcher at the Smithsonian who died in 2016. "He was the foreign researcher who most influenced and helped Brazilian students and researchers with the study of fish in South America," Santana said.

Shocking diversity

According to Santana, who has entered many rivers to collect electric eels for research purposes and been shocked more than once, the discharge is high voltage but low amperage (approximately 1 amp), so it is not necessarily dangerous to humans.

As a comparison, a shock from a power outlet can be 10 or 20 amps. If you are unfortunate enough to receive one, you may be unable to pull your finger out, in which case it can be lethal.

South American rivers are home to at least three different species of electric eels, including a newly identified species capable of generating a greater electrical discharge than any other known animal, according to a new analysis published in the Sept. 10 issue of the journal *Nature Communications*. One of the two newly discovered electric eel species, *Electrophorus varii* (shown above), named is after the late Smithsonian ichthyologist Richard Vari and swims through murky, slow-flowing lowland waters. Credit: D. Bastos

The electric eel, however, emits not a direct current but an alternating current (in pulses), and its charge is depleted after a strong shock. Its electric organ takes some time to recharge. Even so, an encounter with a group of these animals in the water can be quite perilous. The shock will not kill a healthy person, but it can be hazardous if you have a weak heart. It can also contribute to a fall or drowning.

"The shock stuns the victim. It's sufficiently strong to help the fish capture prey or scare off a predator," Santana said.

The research conducted by the group has shown that electric eels communicate to convene groups that can electrocute a potential threat. Contrary to what had been previously claimed in the scientific literature, these animals are not solitary and frequently associate in groups of up to

ten during adulthood.

The new classification was based on an analysis of 107 specimens collected in different parts of the Amazon in Brazil, Suriname, French Guiana and Guyana. Initially, the researchers used DNA barcoding to sequence the mitochondrial gene cytochrome c oxidase I (COI), the de facto standard for animal DNA barcoding. They then sequenced nine other mitochondrial and nuclear genes and performed several other analyses to validate the DNA barcoding results.

"Their body shape is highly conserved. It has not changed much during 10 million years of evolution. Only a few details of their external morphology distinguish them, and only an integrated analysis of morphology, genetics and ecology was able to make robust distinctions between the species," Santana explained.

Ecological separation

In addition to showing clear genetic differences, the sequencing data were cross-referenced with ecological data. The species that has kept the name *E. electricus* is confined to an area far north of Amazonia known to geologists as the Guiana Shield, encompassing the northern regions of three Brazilian states (Amapá, Amazonas and Roraima), and Guyana, French Guiana and Suriname.

E. voltai inhabits the Brazilian Shield, which encompasses the south of Pará and Amazonas, as well as Rondônia and the north of Mato Grosso. Shield regions are relatively elevated, exceeding 300 meters in altitude. This particular one has rapids and falls, with clear well-oxygenated water, rocky or sandy bottoms, and low amounts of dissolved salts. These characteristics favor both species, which have flat heads that helps them swim nimbly and hunt in fast-flowing water over stony riverbeds.

The small amount of dissolved salts makes the water less electrically conductive. The researchers therefore believe the animals need to produce stronger discharges to capture prey. This is particularly the case for *E. voltai*, which was found to produce the highest voltage ever recorded in an animal.

In contrast, *E. varii* inhabits the lowest part of the Amazon Basin, living in turbid rivers with relatively little oxygen and sandy or muddy bottoms. In addition, a relatively large amount of dissolved salts increases the conductivity of the water, favoring the propagation of their electrical discharges, which in this species range from 151 volts to 572 volts.

The researchers estimate that the species diverged twice. The first time was in the Miocene, approximately 7.1 million years ago, when they separated from their common ancestor. It was not until the Pliocene, approximately 3.6 million years ago, that *E. voltai* and *E. electricus* reached their present status.

The researchers plan to conduct further genetic studies to verify the hypothesis that ecological separation (shield environment versus floodplain) was one of the factors that led *E. varii* (floodplain) and *E. electricus* and *E. voltai* (shield) to diverge from their common ancestor. In addition, they continue to capture specimens to measure discharges and confirm the 860 volt record. They expect to find new species among other electric knifefish genera.

"The discovery of new electric eel species in Amazonia, one of the planet's biodiversity hotspots, is suggestive of the vast amount of species that remain to be discovered in nature. Furthermore, the region is of great interest to other scientific fields, such as medicine and biotechnology, reinforcing the need to protect and conserve it, and is important for studies involving partnerships among Brazilian researchers, and between us and groups in other countries, to explore the

region's biodiversity," Santana said.

Other groups are currently studying the possibility of using the results of research on electric eels to analyze the enzymes produced by their electric organs to determine their applicability in medication for neurodegenerative disorders such as Alzheimer's disease or as a model to develop batteries for prosthetics and sensors implanted in humans.

More information: "Unexpected species diversity in electric eels with a description of the strongest living bioelectricity generator" *Nature Communications* (2019). DOI: 10.1038/s41467-019-11690-z , www.nature.com/articles/s41467-019-11690-z

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