

On the rivers of Suriname, electric eels reveal their secrets

Application Note

It wasn't his quarry's good looks that drew Will Crampton to the wilds of Suriname. It was the animal's technical skills.

With his Fluke ScopeMeter® portable oscilloscope in hand, Professor Crampton and a National Geographic video crew flew into Suriname's 1.3-million-acre Raleigh Vallen nature preserve in July 2011. Their goal: capture the world's most powerful electric fish—*Electrophorus electricus*, the electric eel—and measure its punch.

Lanky and mud-colored, the beady-eyed electric eel can grow up to six feet in length and 45 pounds. It's not a true eel, but one of the neo-tropical knifefishes in the order Gymnotiformes, more closely related to catfish.

Like other knifefishes, the electric eel can generate low-level electrical fields that it uses for navigating through its sometimes turbid environment and for identifying others of its species. But *Electrophorus electricus* can also crank out a dc current powerful enough to stun its prey and to shock potential predators into choosing something else for dinner.

It was this unique capability that attracted producers for the National Geographic's Nat Geo WILD channel as they planned a series on "Animal Superpowers." The eel, which carries on shockingly well in water nearly devoid of oxygen, would fit perfectly in the "Survivors" segment.

Into the wild

So Nat Geo contacted Will Crampton, assistant professor in the biology department at the University of Central Florida in Orlando. Crampton is one of the world's experts on electric fishes. In the 1990s he earned his PhD through a four-year project studying Gymnotiformes in the Brazilian city of Tefé, high up on the Amazon in the state of Amazonas. Crampton knows the tropics and the fish that swim those waters. In 2009, he worked with Nat Geo on an earlier project to investigate electric eels.



Professor Will Crampton (with ScopeMeter Test Tool) and the Suriname expedition crew. Left to right: Sonny, who caught the eel; videographer Roeland Doust of Windfall Films; field station manager; Crampton and Benito, aka "Doctor Five." Crew member at right not identified. Courtesy of Windfall Films, Ltd.

So in July 2011, Crampton and Roeland Doust, producer/director for London's Windfall Films, flew into the Suriname capital of Paramaribo. There they chartered a light plane for the 50-minute flight southwest to Raleigh Vallen and the dirt strip on Foengoe Island, in the midst of the Coppename River not far from Suriname's highest waterfall.

"They wanted a relatively short sequence that just described what the electric eel is, how it generates its electric field, and what it uses it for," Crampton said. Sounds easy, but it wasn't.

"It was challenging—we had great difficulty in actually finding anything," he said. "The water levels were very high. We'd come in the aftermath of a giant series of rainstorms, and the whole river had come up. Everything was flooded. We had to change tactics."

Crampton uses a fish finder he designed to detect the electrical signals that knifefish and electric eels produce. The finder creates an audio signal that warns when the fish are near.

"You can hear the electric eel, which has a very distinctive low-frequency clicking sound," Crampton said, "and you can hear any of the weakly electric knifefishes, which either sound like pulsed clicks or like a hum or whistle or tone. The electric eel is distinctive because of its low pulse rate, and because you can detect it at a great distance."

Using the fish finder, Crampton found a spot where he could hear several eels. By that time the water was receding quite rapidly. He set a trap and also arranged with several local fishermen to fish the channel with hook and line. With just one day to go before leaving, an eel about a half-meter long was captured.

Designed to be electric

In its very shape, the eel is optimized to be electric. It has lost all fins except the pectorals (which look like ears) and the anal fin, which extends nearly the full length of the fish along the bottom. It moves not by wriggling its body, but by undulating this elongated fin, and travels almost as well backward as forward.

"This has evolved because they need to keep their bodies straight to maintain the integrity of the electrostatic field they generate," Crampton said, "and to make it more efficient to generate an image of the world around them."

The eel's body cavity is very compact and close to the head. "That allows them to dedicate most of their bodies to electric organ tissue," he said. "All of the electric fishes in South America are essentially a giant electric battery."

The eel's electric power helps make it possible to survive in waters where oxygen levels can approach zero. The eel is also an air breather, gathering 80 percent of its oxygen by taking in mouthfuls of air. Its mouth is lined with delicate blood vessels to absorb the oxygen. "It has to breathe air," Crampton said. "It'll drown if it can't reach the surface." In the low-oxygen waters where the eel lives, grabbing a breath of fresh air means survival.

"Electric eels swallow fishes, crustaceans, and frogs and things—they swallow them whole," Crampton said. "It's possible that being able to shock things and swallow them without having to manipulate them in their mouth, and without having to worry about spines and things, has enabled them to develop the mouth as a respiratory organ that wouldn't normally be possible in a fish."

From electric fish, two kinds of current

Electric fish, like knifefish, produce electrical signals used for sensing where they and their schoolmates are. Electric eels produce, in addition, more powerful currents for hunting and defense.

The weakly-electric fishes generate signals of just one or two volts, which have an effective range of a few centimeters for navigation, and one or two body lengths for communication.

The electric eel also produces low-voltage electricity for electrolocation, using what's called the Sachs organ. Inside the organ are many muscle-like cells, called electrocytes. Each can only produce 0.15 V, though together the organ transmits a signal of about 10 V at around 25 Hz. Electrosensors in the eel's skin detect distortions in the field caused by nearby objects, giving the eel another sense of its environment.

Using two other organs, the Main organ and the Hunter's organ, the eel can also kick out a stunning charge that it uses in hunting and self-defense. It generates its electrical pulse in a manner similar to a battery, in which stacked plates produce an electrical charge. In the eel, some 5,000 to 6,000 stacked electroplaques are capable of producing a shock at up to 500 volts and 1 ampere of current (500 watts). It's enough to deter just about any other animal, except possibly the alligator-like caiman. "I have heard reports that a caiman will bite an electric eel in half, and then devour it," said eel expert Will Crampton.

Are these electric fish a danger to humans? "Theoretically it could be enough to stop someone's heart and kill them," he said, "but I've never heard of that happening. I don't think there's a single documented case of anyone being killed or even seriously injured by an electric eel. Not one."



While the Electric Eel relaxes in its wading pool, Prof. Will Crampton prepares the Fluke ScopeMeter to test the most powerful electric fish. Courtesy of Windfall Films, Ltd.

How the eel measures up

With the eel safely corralled in an inflatable holding pool, Crampton and the crew deployed their ScopeMeter 190-202 to measure the animal's output. Though it wasn't designed for biometrics in the rain and humidity of the Suriname jungle, the instrument's durability and compact design proved ideal. Its batteries provided ample power for days in the field.

"You can knock it around a bit and not be worried about it malfunctioning," Crampton said. "I didn't test whether it was completely waterproof, but it drizzled with rain at one point and I didn't bother to cover it up. It was fine."

"The Fluke very clearly showed the wave forms," Crampton said. Next came a demonstration using an array of LED lights and capacitors created by Jeff Lambert, electrical engineer in the Crampton laboratory. "We couldn't test it—we don't have any electric eels in the lab," he said. "It's illegal to have electric eels in Florida, except with a permit. They would do very well here." As if on cue, the eel in Suriname lit up the LEDs.

"The finale was to measure voltage," he continued. "You have to isolate the electric eel from any load on its electric circuit. That's done by placing it on a dry plastic sheet. We set up the ScopeMeter so that we had an electrode on the eel's head and a ground on its tail."

This was an eel that was a half a meter long, and I believe the voltage that came up on the screen was 498 volts. The current was about one ampere."

Crampton appreciated the flexibility of the Fluke portable oscilloscope. "With the Fluke 190-202 there's a nice opportunity," he said. "You can capture signals at very high sample rates and pretty good bit resolution just by going straight in—you don't have to amplify either the weak or the strong discharges. I was able to get recordings of the weak discharges when the electric eel was in the water, and to get the strong discharges we had it out on the plastic sheet, and I would just tap it lightly on the head to annoy it, and that would be enough to generate the strong discharge."

Something in the Water . . .

Unlike sound, which can travel tremendous distances in water, electrical signals decay rapidly as distance increases, Crampton said. The nature of water in the Amazon basin also affects the signals. Much of the water is low in mineral salts, and electrical conductivity can range from three to four micro Siemens per

centimeter ($\mu\text{S}/\text{cm}$) to 20 or 30 $\mu\text{S}/\text{cm}$, Crampton said—not far from the 10 $\mu\text{S}/\text{cm}$ of distilled water. That inhibits electrical signals from traveling far. In the so-called “white water” rivers infused with minerals eroded from the slopes of the Andes, conductivity is higher: 100 to 300 $\mu\text{S}/\text{cm}$. Sea water, by contrast, may measure 20,000 $\mu\text{S}/\text{cm}$.



What the Electric Eel lacks in looks it makes up for in talent. The eels can reach six feet in length, weigh 40 pounds and produce a 500-volt DC shock. Here Professor Crampton shows off a midsize specimen. Courtesy of Windfall Films, Ltd.

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