FEATURES

# SHORE PATROL

Researchers are ringing the Atlantic with hundreds of sensors in a bid to track how ocean warming is affecting coastal ecosystems

*By* **April Reese**, *in Viana do Castelo, Portugal*

One wrong move, and the sea-battered granite boulders lining North Beach here can break an ankle. But this summer, marine biologist Fernando Lima hopped among the algae-covered rocks like a child playing hopscotch. He eventually settled next to a suitcase-size boulder that held what he sought: an electronic sensor, just 3 centimeters wide and shaped like a hockey puck, that he and his research team had embedded in the rock the year before.

Lima, who works with the Biopolis Association and the Research Centre in Biodiversity and Genetic Resources at the University of Porto, aimed to download data from the sensor. First he had to pry off an interloper: a limpet, a coin-size, hat-shaped snail that normally clings tenaciously to tidal zone rocks but had taken up residence on the gray epoxy seal protecting the sensor. Limpet evicted, Lima took out an iPhone and began to download data, including hourly temperature measurements recorded over the past year.

The July fieldwork was just a small part of an ambitious and unprecedented effort to deploy legions of the small sensors—which Lima's team has helped perfect—all along the shores of the Atlantic Ocean. The goal: to fill a big gap in understanding of how climate change and other factors are affecting the notoriously harsh and highly dynamic intertidal zone, where powerful waves and rising and falling tides can create a complex mosaic of microhabitats with dramatically different conditions within the same small patch of shoreline.

Satellites and airborne sensors provide only coarse measurements along these rugged continental edges, and buoys typically float too far from shore to allow accurate readings. In contrast, the on-site sensors can reveal substantial temperature differences in intertidal areas just meters apart.

Over the past 15 years, Lima and marine biologist Rui Seabra, who co-leads the Atlantic Ocean Coupled Coastal Temperature and Biodiversity Observation Network, as the project is called, have embedded nearly 1800 sensors at 162 locations along the Atlantic's eastern and western shorelines. Just this summer and fall, the researchers, with help from collaborators on both sides of the Atlantic, have installed hundreds of additional sensors along 21,500 kilometers of shoreline.

Researchers check on a temperature sensor installed near fire coral on the island of Santiago in the Cape Verde archipelago.

PHOTO: RUI SEABRA

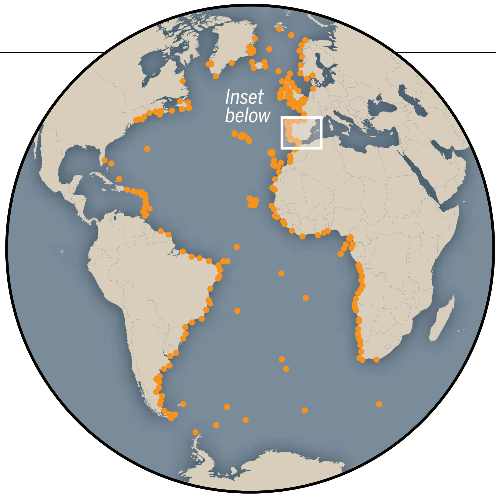
At each site, they and their collaborators also collect images of flora and fauna, to be identified later. Ultimately, they hope to instrument 320 sites and obtain a detailed view of how thermal conditions are affecting intertidal organisms across the entire Atlantic region.

The network could provide "the seminal data set for how climate change is affecting intertidal species," says biologist Gray Williams of the University of Hong Kong. These new data could also aid efforts to protect marine biodiversity as the ocean changes, says biologist Brian Helmuth of Northeastern University, who cohosted Lima when he was a postdoc in the late 2000s. "These very localized measurements," he says, are "critical for any kind of management strategy."

**IT TOOK YEARS** for Lima and his team to perfect the loggers, the scaffolding on which the entire project hangs. The first iteration, fielded in 2008, was inspired by a sensor created by Helmuth in the late 1990s that used a real mussel shell to house some off-

## Coastal sentinals

Nearly 1800 sensors (●) now monitor temperatures at about 160 locations along more than 21,000 kilometers of Atlantic coastline. The Coupled Temperature and Biodiversity Observation Network, which is still expanding, is helping scientists understand how climate change and other factors are influencing the thermal environments of marine organisms in the highly dynamic intertidal zone.

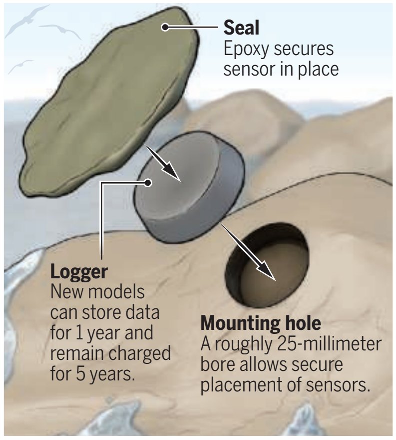



### A closer look

One of the highest densities of sensors is found along the Atlantic coast of Portugal and Spain. Researchers here have been collecting data for nearly 15 years.

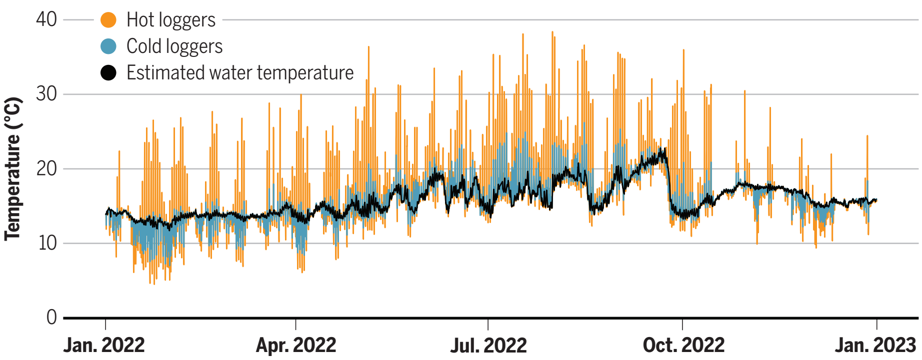

### Made to last

Current sensors record temperature every 30 minutes and are designed to survive the intertidal zone's crashing surf and swirling currents.




### A variable environment

At a site in Portugal, the sensors revealed that intertidal temperatures vary greatly, even in locations just meters apart. Locations exposed to the Sun at low tide can be much warmer (orange bars) than less exposed nearby locations (blue bars).




the-shelf electronics. Lima opted to use a limpet shell instead, creating what he called "robolimpets."

At the time, researchers were still primarily using measurements of sea surface temperature to gauge the thermal stress experienced by organisms in the intertidal zone. But robolimpets Lima installed at 13 sites along the coast of Spain and Portugal confirmed that approach missed potentially crucial variation and underestimated how hot some animals were getting. The devices, which recorded temperatures every 30 minutes, showed that at low tide, invertebrates clinging to south-facing boulders experienced temperatures much higher than their north-facing counterparts just meters away, even at the northernmost sites. The study, published in 2011 in the *Journal of Experimental Marine Biology and Ecology*, also showed much larger daily temperature fluctuations than those inferred from sea surface readings.

Those thermal differences have implications for how different marine animals and plants might respond to warming seas, the researchers noted. Organisms living in microhabitats with higher peak temperatures, for example, might be able to adapt to warmer waters, or migrate just a short distance to survive. But those adapted to cooler temperatures might only survive if they can shift their ranges poleward.

The research also revealed some unexpected drawbacks in the early robolimpet design. At some shorelines popular with visitors, Lima recalls, "we kept losing them." The problem: "They looked like limpets," which people like to eat, he says. "So people were just collecting them all the time." Large numbers were also lost to Portugal's notoriously strong surf.

Over the next decade, Lima worked with Seabra, who first joined the project as a graduate student, to improve the sensors, enhancing data storage, battery life, and other attributes. The latest version, known as the Envlogger, sports a thick plastic housing instead of a limpet shell, can store data for a decade, and has a battery life of 15 years. And unlike robolimpets, the Envlogger can be embedded in a rock, making it less vulnerable to would-be harvesters and waves.

As word of the Envlogger's capabilities spread, Lima and Seabra began to field requests for sensors from researchers around the world. To meet the demand and further improve the devices, in 2018 the two men hired an engineer and founded a nonprofit startup, ElectricBlue, that now sells five different loggers in various colors and shapes. The devices, which cost between €55 and €80 ($58 to $84) each, have been installed on every continent, including Antarctica.

**SO FAR, FEW COASTLINES** have the density of loggers found at the Viana do Castelo site, which is about an hour's drive from Lima's lab in Vairão and not far from where the 44-year-old scientist was raised. About 50 sensors, some just a half-meter apart, are spread in clusters among the rocks.

The temperature and biodiversity data they gather continue to embellish a picture of the ecosystem that Lima and his colleagues have slowly developed over nearly 15 years. During this summer's visit, Cátia Monteiro, a postdoc in Lima's lab who recently documented a drop in the abundance of cold-water algae species in this region, surveyed tangles of brown algae draped across rocks by the outgoing tide. Nearby, research assistant Mar Humet Caballero delicately pressed a tiny square black device against the shell of a limpet to "listen" to its heartbeat. The

CREDITS: (GRAPHIC) D. AN-PHAM AND A. FISHER/*SCIENCE*; (DATA) ATLANTIC OCEAN COUPLED COASTAL TEMPERATURE AND BIODIVERSITY OBSERVATION NETWORK





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Researcher Rui Seabra drills a hole for securely mounting a sensor near Puerto Lobos, Argentina. The devices can record hourly temperatures and store data for up to 15 years, enabling scientists to assemble a detailed picture of the intertidal zone's thermal characteristics.

instrument produces an infrared beam that passes through the shell and reflects off the snail's beating, three-chambered heart. An increased heart rate can mean the limpet is experiencing heat stress, Lima, Seabra, and colleagues noted in a 2016 study.

This and other Atlantic coast sensor sites are revealing "a whole world of thermal complexity that we were not fully aware of," Lima says. For example, the data challenge a widespread assumption, based in part on satellite data, that intertidal temperatures decrease fairly steadily as you move toward the poles. Instead, intertidal zones are a mosaic of highly variable microsites with different daily and seasonal temperature profiles.

Even at cooler, higher latitudes, some microsites "routinely experience high temperatures," Lima says. At the same time, cooler microsites are more common than once thought—even at warmer, more tropical lower latitudes. The sensors have also revealed how, during summers, the upwelling of cold water along Europe's coast—the bane of beach-goers—can help cool the intertidal zone.

"This small-scale variability has a profound impact on the way we think about why species are where they are, and what's going to happen in the future," Lima says. The cooler sites, for example, could serve as refugia for organisms that otherwise could not withstand spiking temperatures.

One of the most valuable insights the sensors could provide is which areas are most vulnerable to warming, says Williams, who has used the loggers to study heat stress in marine snails and is seeking funds to create a similar network in Asia. "I think it [can help] identify hot spots and to see where vulnerabilities will really take place," he says. These emerging hot spots are "not going to happen in the tropics—it's actually going to be further from the tropics, which is not something we would have predicted before. And this will allow us to put our focus more in areas which are really going to need conservation efforts."

**WITH HELP FROM** a constellation of government and philanthropic funders who collectively have contributed nearly €750,000, Lima and Seabra are now working with researchers along the Atlantic coast to fill gaps in the sensor network. The plan is for participants to upload temperature and biodiversity data into a common repository at least once a year.

Data collected by the sensors can be easily downloaded to a mobile phone.

"If we can do this in a way that's coordinated across ecosystems, we can determine what the status of biodiversity is," says Amanda Bates, a biologist at the University of Victoria who used Lima's loggers for a forthcoming study on seabirds on Newfoundland. "Ultimately what we'd really love is a weather network for nature. We need to understand what's changing."

As they expand the network, Lima and Seabra are also hoping to elevate the careers of researchers in Atlantic countries with fewer resources, particularly those in the Global South. The project's open-access data set, expected to come online in 2024, should make it easier for scientists doing localized studies to address larger questions, Seabra says—and perhaps boost their chances of having their findings published.

This year, Lima and Seabra embarked on a trans-Atlantic logger blitz, covering as much coastline as possible. They replaced old sensors, installed new ones, and met with potential collaborators. Lima made his way up the eastern coast of the United States and Canada, as Seabra focused on stretches of South America, Iceland, and Scandinavia. Next stop: islands in the southern Atlantic, in March 2024. "We are focused," Lima says, "on getting this done." ■

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PHOTOS: (TOP TO BOTTOM) FERNANDO P LIMA; RUI SEABRA

# Shore patrol

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