DNA markers tell the story of deep sea adaptation

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Clockwise from top left: Santiago Herrera (far left) leads an exploration dive of the ROV Little Hercules in the deep Celebes Sea in 2010; Herrera examines a specimen of a species of colonial salps found in a New Zealnd Kelp forest in 2012; Herrera (left) and Andrea Quattrini (right) store specimens of deep sea corals collected with WHOI's ROV Jason in 2009; and stalked barnacles from the vent fields at the Kawio Barat volcano in the Western Pacific. Credit: NOAA Okeanos Explorer Program, INDEX-SATAL 2010

When you think about the deep sea, you might conjure up an image of the angler fish as portrayed in Finding Nemo or the white whale in Moby Dick—in short, you might envision a dark, mysterious, terrifying world miles beneath the surface where we live.

The deep sea, defined as everything that is 200 meters (or 60 stories) below sea level, makes up more than 95 percent of the world's habitable space, yet it is indeed mysterious—we know very little about these aquatic habitats.

Santiago Herrera, a recent graduate of the MIT-Woods Hole Oceanographic Institution joint program, spent his PhD studying humanity's impact on the deep sea.

Growing up in Columbia, Herrera has been passionate about marine biology since he was a child. He has seen the impact that human activity can leave on the world around us, and, through his passion for the ocean, is driven to better understand how incidents of wide-spread pollution and overfishing may also leave a mark on the deep sea.

The deep sea is more sensitive to damage because organisms grow and reproduce at a much slower rate than organisms in shallower water or on land. The orange roughy fish, for example, cannot reproduce until it reaches the age of thirty. Recovery of these ecosystems would take many times that of land organisms.

Herrera has faced many hurdles in studying the deep sea. "It's a big challenge because we don't have a good inventory of species that live there yet," he says. Scientists rely on what can be collected with a net or captured on video by a submersible for only a few minutes, making it nearly impossible to objectively classify a new species.

However, Herrera has helped transform the way that we think of species in the deep sea by integrating new DNA data with existing paleontological, geological, and oceanographical information. He developed a new toolset of DNA markers—pieces of the genome that are used to establish differences between individuals—to unambiguously determine what makes two species different.

"I think of genes as if they were books in a library," he says. "They have a certain amount of information, and can tell you something about the history of that individual. Two different books are not going to tell the same history; they can tell different histories. So the more genes you sample, the more books you read ... the closer you get to understanding what really happened and to be much more certain and confident on the interpretations and the results that you get"

One of Herrera's favorite deep sea habitats is hydrothermal vents—mineral rich hot springs that were discovered in 1977 by the famed submersible Alvin. Barnacles, a kind of crustacean most commonly found attached to hard surfaces like piers, boats, and rocks, also take up residence in hydrothermal vents far below the surface of the ocean. In fact, barnacles are one of the most common inhabitants of hydrothermal vent ecosystems worldwide.

Herrera examined the genes of barnacles living in many different areas. He discovered that these genes—or "books"—all told the same biographical story. Had they evolved separately, their stories would have been very different from one another. Thus, he hypothesizes that the barnacles are able to disperse larvae over distances up to hundreds of kilometers (comparable to the distance between Boston and New York City). Once there, the young barnacles are able to survive the conditions of this new home, including sizeable differences in ocean depth. Such adaptability is a good indicator of hardiness in the face of changing environmental conditions imposed by human activities.

Herrera also examined the DNA of many coral samples, which revealed apparent mutations, or changes in the DNA, that allowed them to thrive in new environments. These mutations repeatedly appear in different areas with the same environmental conditions, implying that these coral all evolved the same genetic change in response to the condition. Ongoing research seeks to determine the molecular mechanisms triggered by these genetic mutations that allow deep sea coral to adapt to new environments. Knowing the molecular adjustments that coral naturally make in different ocean conditions could help researchers further study coral's survival through global warming.

By further comparing the DNA of additional samples of barnacles and coral, Herrera ascertained information about where and when these species originally evolved and then dispersed. Combining his research with existing paleontological data, he observed a common dispersal at the end of the Cretaceous period (when the dinosaurs went extinct), out of the Western Pacific through the southern hemisphere, that matches the ocean currents of the time. Herrera even found similar evolutionary patterns to groups of organisms outside of the deep sea that originated around the same time, meaning a common set of conditions drove biodiversity both on land and in the sea. Thus, Herrera believes life on the surface of the ocean and in the deep sea are more connected than the vast distance may suggest.

This interconnectedness between land and sea plays out to this day in interactions between coral, the biodiversity they support, and human recreation and consumption. The impacts of damage to shallow water coral are already well known. However, the deep sea contains nearly two thirds of all known coral species, making it the primary home for the majority of coral biodiversity. Human activities are imposing an increasingly imminent environmental threat to these ocean flora and fauna. With corals being some of the oldest living organisms, reaching up to 4,000 years old, they will not be easy to replace. Herrera says, "Out of sight should not be out of mind."

When asked what advice he would give to a student just entering the field, Herrera replied, "Come armed with a skill outside of oceanography … like molecular biology, genetics, computer science, or math. Those will be very important tools to bring in new ideas."

Herrera has helped pioneer the use of genomics to study the deep sea. He is now a postdoc at the University of Toronto in Canada where he studies human epigenetics, looking at the link between environment and disease. Epigenetics is not a well-developed topic in ocean science. Herrera hopes to take this time to gain a new skillset that he can eventually bring back to the field of oceanography that will help him to look at questions in marine science in new and different ways.

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