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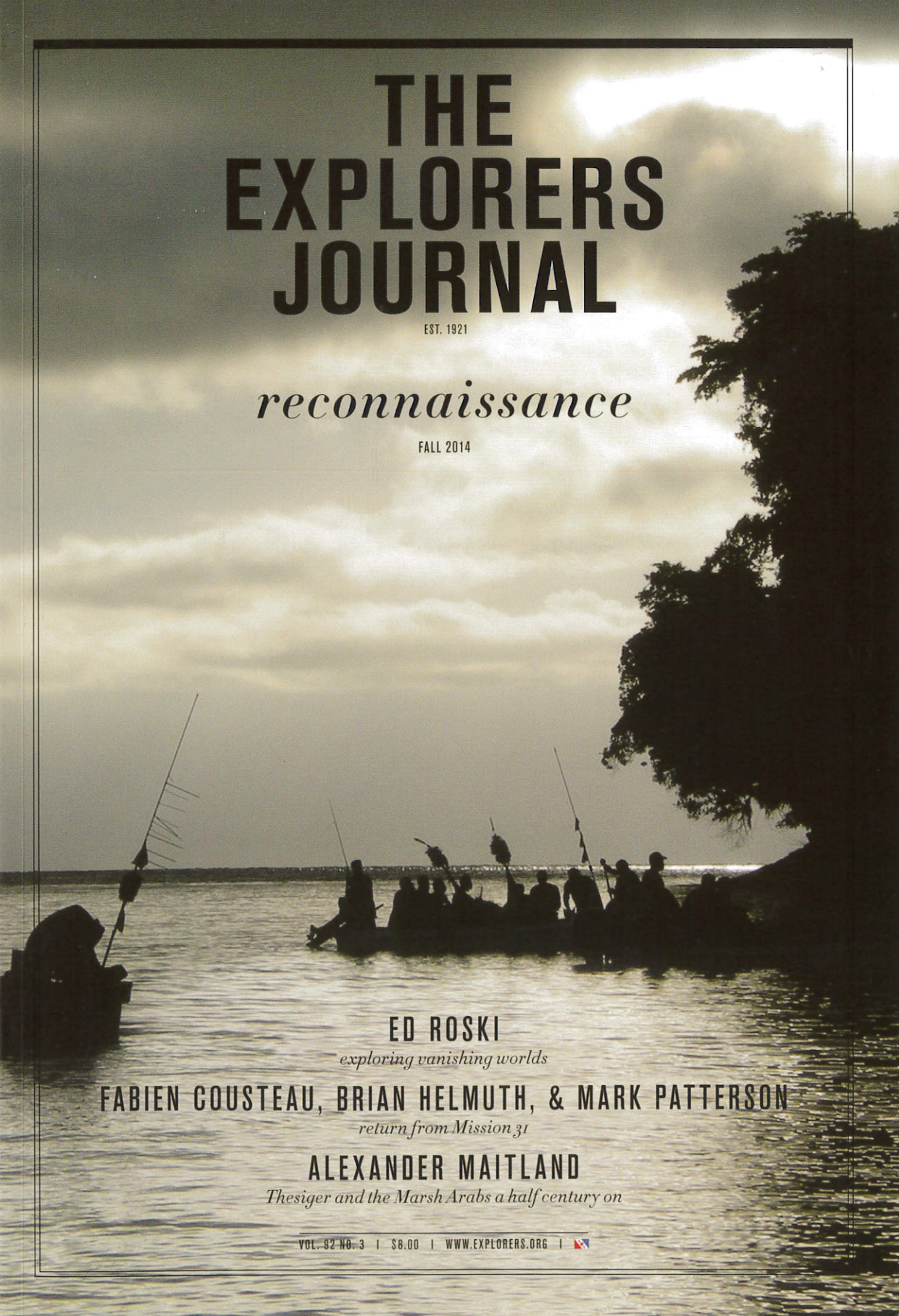

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exploring vanishing worlds

FABIEN COUSTEAU, BRIAN HELMUTH, & MARK PATTERSON

return from Mission 31

ALEXANDER MAITLAND

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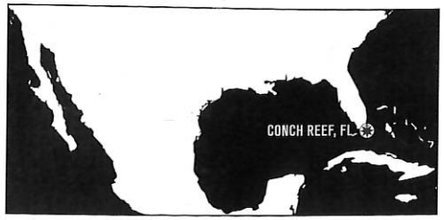
MISSION 31

20,000 mm under the sea

by FABIEN COUSTEAU, BRIAN HELMUTH, AND MARK PATTERSON

AQUANAUT FABIEN COUSTEAU PEERS OUT FROM THE AQUARIUS HABITAT, WHERE HE SPENT A MONTH DURING MISSION 31. PHOTOGRAPH BY KIP EVANS.

Fabien Cousteau, a grandson of Jacques-Yves Cousteau, is an oceanographic explorer, conservationist, and documentary filmmaker who is committed to protecting and preserving endangered marine habitats. A fellow of The Explorers Club since 2007, Brian Helmuth is a professor of marine and environmental sciences and public policy at Northeastern University in Boston, Massachusetts. Mark Patterson is a professor of marine and environmental sciences and civil and environmental engineering at Northeastern, where he serves as director of the field robotic laboratory, designing free-swimming robots for scientific research.



On July 2, 2014, Fabien Cousteau and fellow aquanauts, Mark Hulsbeck and Ryan LaPete, emerged from the waters of Conch Reef, Florida. They had spent 31 days living and working on the bottom of the sea–the longest mission on record in the school bus-sized underwater habitat Aquarius, the world's only saturation diving facility devoted to scientific research. For expedition leader Cousteau, the emergence marked the successful conclusion of Mission 31, a multidisciplinary study of coral reef health and the impact of global climate change, as well as events such as the BP oil spill in 2010, on reef organisms in the heart of the Florida Keys National Marine Sanctuary.

To carry out the expedition, Cousteau assembled a team of more than 30–not only scientists, engineers, and dive specialists, but documentary filmmakers, educators, and communicators tasked with sharing the results of the expedition with the greater public.

The selection of 31 days was by no means arbitrary. A half century earlier, Fabien's grandfather, Jacques-Yves Cousteau, built Conshelf II, a "village under the sea" where his team lived for 30 days at a depth of 10 meters. The underwater experiment resulted in the Academy Award-winning documentary, *World Without Sun*, which captivated audiences, and launched discussions of how humankind would inhabit the seafloor in the future. It also highlighted just how little we know of the ocean floor.

Located at a depth of 20 meters and managed by Florida International University (FIU), Aquarius has served as a training ground for researchers for more than two decades, affording them far greater bottom time than is possible with conventional diving. Through saturation, aquanauts allow the gases (specifically nitrogen) in their bodies to come to equilibrium with those in the pressurized air that they breathe. Whereas a surface diver can spend at most a few hours underwater in a day, with long surface intervals required between each dive, a saturated diver can spend 8 hours or more per day working on the reef, returning to the habitat only for food and rest. At the end of a mission, the aquanauts are returned to surface pressure over a period of 16 hours so that the accumulated nitrogen can be safely released through the diver's exhalations.

For this project, the surface and saturation teams collectively conducted the equivalent of many months, perhaps even years, of research in just 31 days. During this period, nine aquanauts lived on the seafloor, three of whom, Andy Shantz and Adam Zenone of FIU, and filmmaker Kip Evans, traded places at the expedition midpoint with Liz Magee of Northeastern University, Massachusetts Institute of Technology graduate Grace Young, and filmmaker Matt Ferraro. Meanwhile, a team of scientists led by coauthors Brian Helmuth and Mark Patterson, both veterans of multiple previous Aquarius missions, conducted surface-based research as part of the Urban Coastal Sustainability Initiative at Northeastern, where both are on the faculty.

At the start of the mission, the aquanauts deployed a low-tech but novel passive sampling system using treated polyethylene film to see whether toxic compounds–including Corexit 9500, the dispersant released in large quantities in the wake of the BP oil spill in the nearby waters of the Gulf of Mexico–are present in significant amounts at the Aquarius site. As these compounds are resistant to microbial breakdown, they are of concern to both human and ecosystem health as toxins that can bioaccumulate in a variety of organisms. At set times during Mission 31, we harvested subsets of these samplers, and preserved them for sophisticated processing back at Northeastern by Loretta Fernandez, one of our colleagues who developed this technique. Within the next six months, Fernandez and her students will have an answer to this important question.

Most of the experiments were carried out to better understand the lifecycles of coral reef denizens. Graduate student Allison (Alli) Matzelle of Northeastern led a study of how giant barrel sponges (*Xestospongia muta*) respond to changing temperatures on the reef. Some potentially centuries old and known as the "redwoods of the reef," these slow-growing organisms play a vital role, functioning as filters. Every 24 to 48 hours all of the water on a coral reef is processed by the sponges. Their health is indicative of overall reef health. We placed instruments on them that were equipped with sensors to measure the water chemistry entering and leaving these filtering organisms. We also took samples of the water to assess their diet of bacteria and tiny photosynthetic algae, as well as deployed acoustic instruments to measure the pumping activity of the sponges over a two-week period. These measurements are providing us with an unprecedented view into "days in the lives of a sponge." For example, do sponges stop pumping or alter their diet when internal waves deliver cold, nutrient-rich water? Mission 31 data will help answer these questions, allowing us to accurately predict how sponges figure in the flow of carbon on a coral reef, and how climate change may affect the "sponge loop."

Northeastern graduate student Amanda Dwyer undertook the sampling of zooplankton on a daily basis to document how the biomass of this vital food source changes over the lunar cycle. We know there is a lunar periodicity on the reef near Aquarius, which is related to spawning of invertebrates. Polychaetes are known to swarm and spawn at certain lunar phases, and the corals and sponges themselves reproduce with a lunar periodicity. The question was how might this be reflected in the biomass of the plankton.

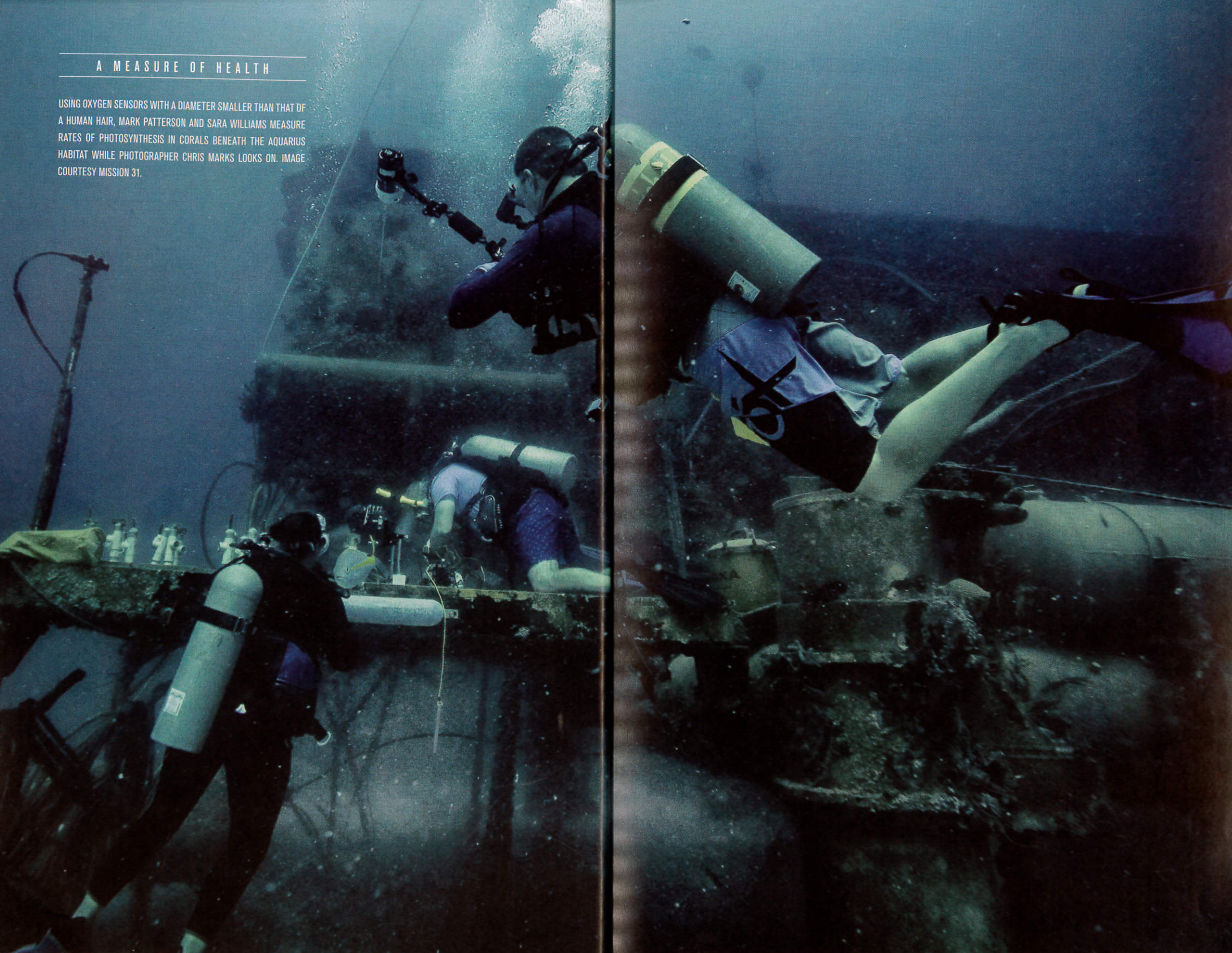
To catch the nighttime plankton that abound on a coral reef, the aquanaut team set up traps late in the afternoon, returning early in the morning to harvest the catch and prepare it for transfer and subsequent analysis by Dwyer and her surface team. It was valuable to collect data over such a long period of time and contrast it with the daytime samples that the aquanauts gathered. It is thought that corals that have access to abundant zooplankton may weather the stress of global change better than those that do not.

With the help of Cousteau's team, Patterson and Northeastern technician Sara Williams from the Coral Biomechanics Lab used a microelectrode amplifier and ultrafine oxygen sensors to ascertain how corals share resources between the polyps of a coral colony, comparing data they obtained against a mathematical model that predicts how different species of coral contend with environmental change. Coral species fall into two body plans: one type has connections colony-wide between the polyps, while the second type does not. As predicted by the model, we found that the species without the colony-wide connection was a network of individuals who only rarely talked to the neighbors.

Grace Young worked with fellow aquanauts to deploy a high-speed camera, an Edgertronic imager in Sexton underwater housing, to obtain rare footage of polychaete tentacle retraction and pistol shrimp feeding strikes, both processes occurring at the scale of milliseconds. Several hours of preparation

A MEASURE OF HEALTH

USING OXYGEN SENSORS WITH A DIAMETER SMALLER THAN THAT OF A HUMAN HAIR, MARK PATTERSON AND SARA WILLIAMS MEASURE RATES OF PHOTOSYNTHESIS IN CORALS BENEATH THE AQUARIUS HABITAT WHILE PHOTOGRAPHER CHRIS MARKS LOOKS ON. IMAGE COURTESY MISSION 31.



were required to capture the footage, something that never could have been accomplished through conventional diving.

Among our most important accomplishments was measuring for the first time how a type of underwater storm, called an internal wave, affects the metabolic rate of sponges and corals, such as the large star coral (*Montastraea cavernosa*). During a storm, the water temperature drops precipitously by many degrees in a matter of minutes, currents pick up, and the water shimmers, as cold nutrient-rich water is carried by these powerful waves from greater depths. These internal waves, first discovered by previous researchers at Aquarius, last several hours and cause a rapid drop in photosynthesis during the day and respiration at night, due to the corals' sensitivity to temperature change. By studying the response of key reef species like the barrel sponge and large star coral to these environmental perturbations, we gain insight into how global change will affect reef function from snapshots of responses to shorter-term changes like internal waves.

From the outset, a key part of Mission 31 was to bring the excitement of expeditionary science to the public. Social media were used to inform the public about the value of saturation diving for science, and some of the unique challenges facing the global ocean.

Four major live outreach events were held in collaboration with the Boston Museum of Science, including a half day devoted to special exhibits and talks by marine scientists from Northeastern. The highlight was a live broadcast on the subject of sustainable use of the oceans that featured a roundtable discussion with Cousteau, Helmuth, and Northeastern University Provost Stephen Director. Other outreach sessions featured a live connection to the habitat with scientists from our surface team visiting. These sessions focused on sponge biology and coral biology, and included a mission wrap-up report on the data gathered. We also conducted a Google Hangout from the Aquarius with the White House Office of Science and Technology Policy, and marine researchers across the planet, on the future of the oceans. Another Google Hangout focused on the status of reefs in the Caribbean and involved experts on Marine Protected Areas from Barbados and Grenada, moderated by reef conservation specialist Stephen Price, an Aquarius veteran from Canada.

We were also fortunate to have Heather Goldstone, a nationally known correspondent from National Public Radio, embedded with the surface team. She was able to visit the wet porch inside the habitat and report on her experiences both with aquanauts and the topside team. Because the second half of the mission would involve so many women in science, we invited teen blogger Morgan Helmuth to cover the mission in its entirety to offer her impressions of what makes (or should make) science exciting to young women.

Mission 31 received substantial publicity and interest on the global stage, with more than 500 million persons aware of the mission before it concluded. The mission will live on in a variety of formats, including a documentary, a traveling exhibit, and the numerous scientific publications planned by Mission 31 team members.

Although Aquarius remains the only habitat currently available for use by diving scientists, we envision a future when more than one such habitat exists. A state-of-the-art future facility would go beyond the technology that began with Conshelf and which is still embodied today in the design of Aquarius, with its metal hull, toggle switches, and hydrocarbon fuel source. A future habitat could be lightweight and mobile for use in different habitats, and extract the energy needed for life support directly from the ocean and sun in a sustainable manner. We hope to return to Aquarius to test some of these concepts in a future expedition and continue our research on coastal sustainability and the impact of climate change on our world's oceans.