Coral Crusader

RACING AGAINST TIME TO PREDICT THE FATE OF CORALS IN A WARMING OCEAN

by Evan Lubofsky

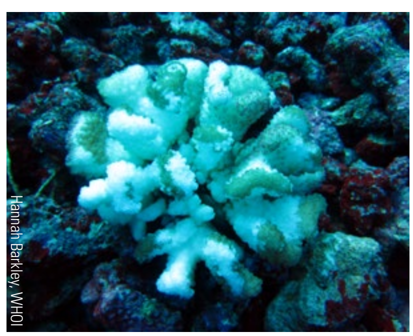
A time bomb is ticking in the ocean, and faster than you might think.

Climate change is making the ocean warmer and more acidic, and corals may not be able to withstand that double whammy. By the end of the century, the combined stresses could push corals past their tipping point, rendering them more susceptible to disease, structural breakdown, and death.

This race against time fuels the work of Hannah Barkley, a graduate student in the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution (MIT-WHOI) Joint Program in Oceanography. Since 2011, she has been doing a full work-up of coral health in the western Pacific. She is investigating how reefs are responding to climate change, examining the combination of factors that will determine their fate, and identifying corals that may be able to survive the impacts of climate change.

"Coral reefs have an overwhelmingly bad prognosis for the future," she said. "The things I find most compelling are the urgency of the situation, and the magnitude of the threat to ecosystems that are so important to so many people."

The ecological and economic impacts of coral are huge. Reefs provide habitats for 25 percent of all marine species and play a key role protecting shorelines from storm damage. The commercial value of U.S. fisheries from coral reefs is more than $100 million annually and about $5.7 billion worldwide, according to the National Oceanic and Atmospheric Administration. Add in revenue from tourism and jobs, and coral reefs generate $9.6 billion annually in net benefits.



One impact of warming ocean temperatures is bleaching, a phenomenon that can kill corals. White or bleached areas of the coral indicate where symbiotic algae have departed from coral tissues. (The corals have retained the algae and their color in the brown patches.) Without the algae to make food, the corals can starve.

Barkley's research has taken her 8,500 miles from Cape Cod to the Rock Islands of Palau to study reef communities. She's made the trek nearly a half-dozen times, hopping from one reef site to the next with colleagues from The Nature Conservancy and the Palau International Coral Reef Center.

"Palau has been an ideal test bed for our research," she said. Because temperature and acidity have already risen in some Palauan bays, they offer a glimpse of coral reefs at the turn of the 22nd century.

Testing the waters

Barkley's interest in coral reefs dates back to her childhood, when she and her family would travel to tropical locales such as Hawaii, the Galápagos Islands, and the Caribbean.

"I was scuba-certified at 12 years old," she said. "We saw a lot of amazing places around the world, which gave me a great deal of exposure to coral. I just loved being in the water and seeing all the beautiful marine life."

In her freshman year at Princeton University, Barkley attended a seminar called "Signals, Yardsticks, and Tipping Points of Global Warming," which took her to the Bermuda Institute of Ocean Sciences (BIOS). "I was thrilled by the idea of snorkeling for lab, and after that first experiment we did on how coral responded to temperature, I was hooked," she said.

So much so that she spent the following summer at BIOS examining the effects of changing ocean conditions on the growth of juvenile corals, which became the subject of her senior thesis project a year later.

One of her advisors at the BIOS summer program was Anne Cohen, a coral scientist at WHOI.

"I was immediately impressed by Hannah's ability to communicate both the details of her project and why it was important," Cohen said. "Her questions to me indicated that she was thinking deeply about her results and had read widely."

"At the end of that summer, I came to WHOI for three weeks to analyze my samples," Barkley said. "During that time, I fell in love with WHOI and decided that I wanted to continue working with Anne and researching coral reefs and climate change in graduate school."

Corals in hot water

To get a firsthand look at water temperatures that Palauan reefs are experiencing, Barkley and her colleagues have deployed an extensive network of underwater temperature sensors around the islands' barrier reef and several reefs inside lagoons.

According to Cohen, ocean warming affects coral reefs in at least two ways.

"First, warm water just 1°C (1.8°F) above normal can break down the relationship between corals and symbiotic algae they host in their tissues," she said. The corals provide bed and board for algae—a protected place to live and chemical compounds they need for photosynthesis. In exchange, the algae produce oxygen and organic materials that corals need to grow. When seawater warms, the colorful algae move out, revealing the corals' underlying white skeletons—a phenomenon known as bleaching. "When this happens, corals can starve and die," Cohen said.

Second, warming also stratifies the ocean into warmer surface layers and denser, cooler, deeper layers, Cohen said. The two layers don't mix easily, which hinders essential nutrients in the ocean depths from rising to the surface where corals and other reef organisms grow.

The WHOI monitoring effort has shown overall temperatures in Palauan waters are hotter than expected—more than 32°C (90°F)—and that lagoon reefs are consistently one degree warmer than barrier reefs.

Addressing acidity

More recently, Barkley and colleagues have shifted their attention to the other major threat: ocean acidification. It's caused by the same scenario responsible for warming the planet and the ocean: the buildup of heat-trapping carbon dioxide (CO_2) in the atmosphere from fossil-fuel burning and deforestation. But in seawater, the CO_2 has another effect. The ocean absorbs excess CO_2, which reacts with seawater to create carbonic acid. The acid binds with carbonate ions in seawater—the building blocks that reef-building corals need to create their calcium carbonate skeletons. That reduces the number of carbonate ions available for corals, making it harder for them to grow their skeletons.

To track the pH levels of Palau's Rock Island bays, Barkley has been collecting water samples from different locales across different times, seasons, and tidal cycles. Analysis of the water chemistry has revealed pH levels of 7.8, considerably lower than today's typical open-ocean levels of 8.1. According to Barkley, this lower pH likely has to do with the Rock Island bays' seclusion and calm waters.

Hannah Barkley, WHOI

Vibrant coral reef ecosystems, like this one off a tiny atoll in the Pacific Ocean called Helen Reef, are threatened by changing ocean conditions, which include warming temperatures and more acidic seawater.

As reef organisms breathe and make calcium carbonate skeletons, they draw down the pH, she said. “The water just sits there in the bays,” with little circulation carrying out old water or bringing in new water.

The picture of health

With such low pH levels, it’s a wonder there are still reefs left in Palau to study. But, as Barkley discovered on a recent trip, these conditions have had no discernable impact on the corals. Nor did the hot-tub-like temperatures appear to have an impact, since there was little evidence of coral bleaching.

Not only were the reefs seemingly unaffected, but certain ones—the lagoon reefs in particular—appeared to be doing well. They were saturated with the vivid, splashy colors that recreational divers dream about, and they sheltered a huge and diverse population of fish.

The finding surprised Yimnang Golbuu, chief executive officer of the Palau International Coral Reef Center, who has been collaborating with Barkley and the Cohen Lab team.

“We knew from our own surveying that the reefs had gotten really hot and did not bleach,” he said. “But when Anne and Hannah came down and told us these areas were also very acidic, we were surprised. That confirmed that these reefs are very special places. This is the message I’ve been giving to state legislators and village chiefs in an effort to get these areas incorporated into our protected areas network.”

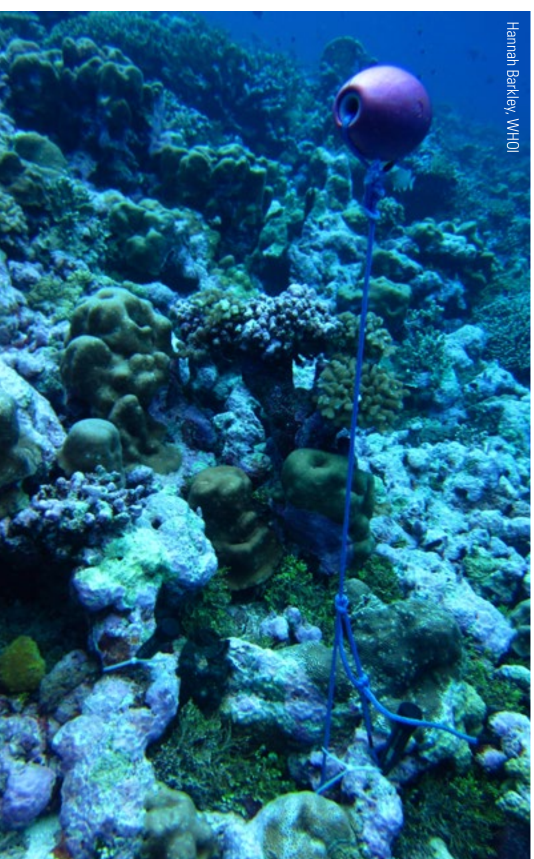
The global signature

While it may be encouraging to see certain reefs holding up in these extremes, appearances can be deceiving.

In peeling back the layers, Barkley and the team discovered one response to acidification that could be detrimental for next-century reefs in Palau and beyond. It’s called bioerosion, and it occurs when organisms such as sponges and mollusks eat away the skeletons faster than corals can produce them and eventually turn them into rubble.

“While we didn’t see the negative coral responses we expected, we did see an 11-fold increase of bioerosion,” said Barkley. The findings were published June 5, 2015, in the journal *Science Advances*. Barkley was lead author of the study.

To the naked eye, a bio-eroded coral core sample looks like an oversize piece of chalk that got caught in a gunfight. Keyhole-size marks are gouged into the top end, and boreholes whittled by organisms run the entire length of the core. The net effect for



A black temperature sensor lies on a coral reef off Palau attached to a purple float to mark its location.

MIT-WHOI graduate student Hannah Barkley collects the tops of cores, the only living part of the coral, which she uses to conduct experiments. (Victor Nestor, Palau International Reef Center).

reefs is less structural integrity and lower tolerance to physical stress from storms, diver fins, and other forms of impact.

“In addition to what we saw in Palau, high levels of bioerosion have been shown in other naturally low-pH sites in Papua New Guinea, Mexico, and other regions,” Barkley said. “It’s the one consistent feature present across all these sites, so it’s likely to be a global signature of ocean acidification in the next century.”

Barkley and colleagues have also found an additional stressor: nutrient loading. When nutrients from fertilizer runoff mix with acidified seawater, bioerosion can be up to ten times more prevalent. This finding was published in a 2014 study led by WHOI grad student Tom DeCarlo.

According to Golbuu, while it’s impossible to control the pH of naturally acidified water, managing land use can help ward off bioerosion.

“We have these areas that are doing well in terms of high coral cover and diversity, but they are being eaten away from the inside by biological organisms,” he said. “This suggests we need to be careful about land use, since high nutrients and pollution can add to the pH problem and make the bioerosion even worse.”

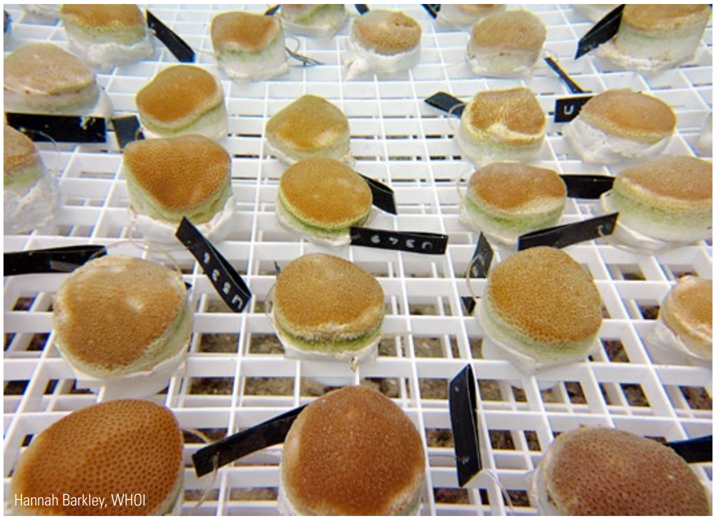
Protecting the survivors

Barkley has discovered that answering complex, climate change-related questions requires a multidisciplinary perspective. She looks at reef biology to understand how well corals are calcifying. She analyzes water chemistry for carbon dioxide, pH, and nutrients, and she investigates physical oceanography for determining water movement and circulation patterns through reefs.

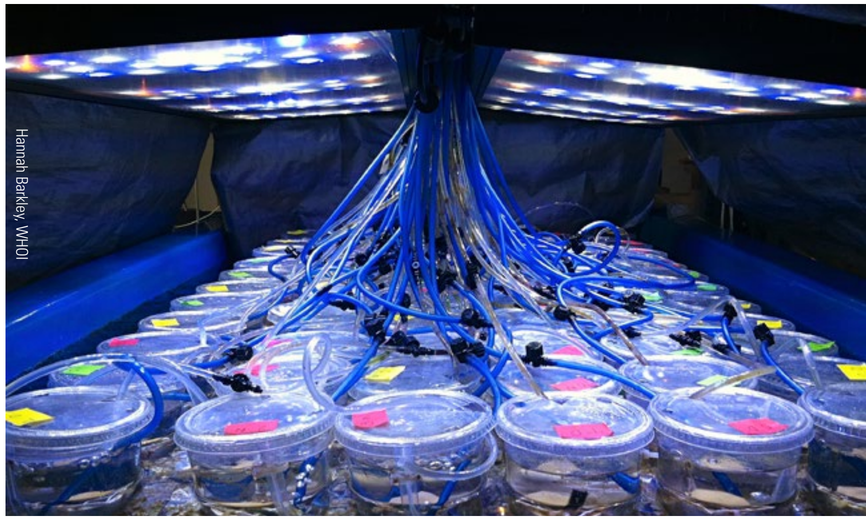
“Increasingly, we’re starting to realize that understanding the impact that climate change has on reefs demands a connection amomg all these disciplines,” she said.

She’s developed a varied skill set, becoming adept at using an underwater pneumatic drill to extract coral core samples, for example, or deploying temperature sensors.

“Depending on the day, I might be out in the field programming instruments, drilling cores, or bottling up water samples,” she said. “Or I could be in the lab titrating water samples for carbon chemistry or analyzing CT scans of the core samples. It’s really cool to be able to have a taste of all these techniques.”



The living tops of corals are brought back to a lab, where they are set in containers with seawater infused with different levels of carbon dioxide to see how each level affects the corals' growth.



The corals are put in containers with different carbon dioxide levels. Green containers have current levels. Yellow ones have levels equal to what is projected in 2100. Red containers have even higher levels.

Barkley is leveraging these tools and techniques to achieve her overriding goal: identifying corals that are most likely to survive the impacts of climate change.

"Many reef conservation efforts in place are geared toward protecting the strongest reefs rather than the most susceptible because these reefs likely have the best chance of surviving the impacts of climate change," she said. "So it's important to find the most resilient reefs—though identifying them can be really difficult. It requires long-term monitoring of all the parameters we've been looking at."

Ultimately, Barkley plans to produce a set of detailed maps that will show pH levels, water temperatures, nutrient concentrations, coral cover, and other aspects of reef health across Palau. These maps will inform the Palauan government as it looks to expand its protection network.

"The greatest thing about Hannah is that she really cares and is helping to make a difference with her research," said Golbuu. "There are a lot of young scientists in the world who are very smart and bright, but I think Hannah is very special. She really wants to contribute to conservation."

This research is funded by the National Science Foundation (NSF), Dalio Foundation Inc., The Nature Conservancy, and The Tiffany & Co. Foundation. Barkley is supported by an NSF Graduate Research Fellowship.

Right: Just below the water off Rock Islands are healthy coral reefs with a high diversity of species, living in high-temperature, low-pH seawater.

Hannah Barkley grew up in Basking Ridge, N.J., and spent most of her childhood turning over decaying logs and wading through muddy streams in pursuit of any creature that would make her parents squirm. As an ecology and evolutionary biology major at Princeton University, she became passionate about marine ecosystems and ocean conservation. She decided to pursue oceanographic research in the MIT-WHOI Joint Program after realizing that studying coral reefs is the coolest job ever. When she's not contemplating carbonate chemistry dynamics, scuba diving to collect samples, or analyzing coral skeletal growth histories, she enjoys traveling to the far corners of the Earth, running long distances, and cooking elaborate meals with unpronounceable ingredients.

Hannah Barkley
Geology & Geophysics