A newly discovered reef offers important lessons in resilience

June 29 2018, by David Pacchioli

Penn State coral reef biologists are studying Varadero reef, off the coast of Colombia, to learn why it is thriving under unusual conditions. Pictured is former postdoctoral fellow Joe Pollock. Credit: Joseph Pollock

The bay of Cartagena might be the last place you'd expect to find a coral reef. The skyscrapers and hotels of resort-heavy Bocagrande hug the nearby beach. Cruise ships and freighters ply the busy harbor. The vibrant, historic city itself is both Colombia's leading tourist destination and one of its major ports.

At one point, indeed, this shallow bay was virtually covered in coral. But that began to change when the Spaniards arrived in 1533. As they discovered the riches of the South American interior, Spanish engineers built the Canal del Dique, diverting the mighty Magdalena River to carry out silver and gold. Emptying into the bay, the canal brought two other things as well, both detrimental to marine invertebrates: fresh water, and tons and tons of sediment. Today, five hundred years later, almost all the coral is gone. But there at the mouth of the bay, hidden beneath ten feet of water so murky and foul you might blanch to stick your elbow in it, lives a square kilometer of reef that is one of the best in all the Caribbean.

Varadero reef has long been known to the inhabitants of the local island communities. Descendants of slaves brought to build the sturdy stone forts that still overlook the harbor, they have always fished the reef for their food. But it was only in 2013 that Varadero was discovered by science. That's when local biologists went diving for an example of a degraded reef, one they thought might be overgrown with invasive sponges. What they found instead was a veritable coral garden, with over 30 species covering up to 80 percent of its surface.

Mónica Medina found out about Varadero a year later. A coral microbiologist at Penn State, she had gone to a conference in Cartagena to give a talk about her work. When the conference was over, a colleague insisted on taking her out to the spot.

"What's crazy is that you swim down and you can't see the person next to you, it's so murky," Medina says. "There's this dirty layer of fresh water on top, and then it gets clear and there's an amazing reef down there."

Under the microscope

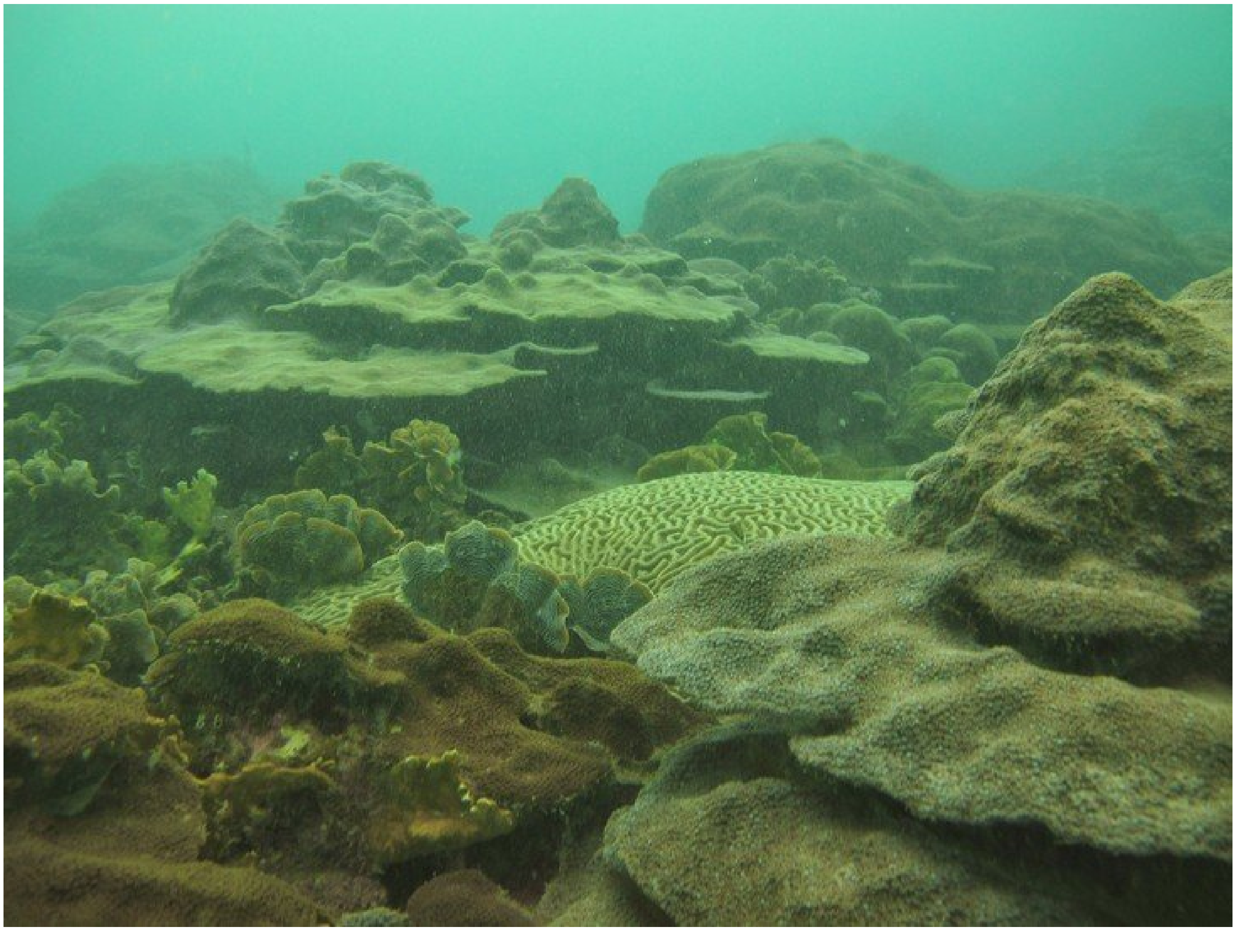
Medina's first thought was automatic: Why is this reef doing so well? Corals, she knew, depend like no other animal on the presence of sunlight. More precisely, the microscopic algae that live within corals depend on sunlight to generate, via photosynthesis, the energy that corals require to live and grow. Corals, therefore, do best in crystal clear waters, shallow enough for sunlight to easily penetrate. How could a reef be thriving here, starved of light and choked with sediment and pollution?

It's a question whose answers may have global implications. With reefs around the world dying off in response to rising ocean temperatures, resilience has become a key concept among coral biologists. As Medina and others have shown, some species of coral have the ability to survive in less-than-optimal conditions, while others perish. What gives these hardier specimens the strength to adapt and bounce back? Pinpointing what makes them different could be vital for corals' survival.

As a microbiologist, Medina was most interested in Varadero's microbiome, the dizzyingly complex community consisting of all the bacteria, archaea, and fungi living within the corals that make up the reef. Like human guts and public toilet handles, each individual coral hosts its own microscopic menagerie, shaped by where it lives and what sorts of organisms it has encountered. Coral that could succeed in this challenging environment, she reasoned, ought to have a very unusual microbiome indeed.

Back in 2007, Medina, then at the University of California at Merced, was one of the first to use next-generation gene sequencing technology to look at microbiomes in corals. That early work she calls comparatively crude: "We just grabbed pieces of coral from a dozen or so species and ground them up and sequenced them, as deeply as we could," she says. Even so, "We uncovered a vast microbial diversity." Subsequent refinements showed that each part of a coral—its skeleton, the soft tissue, and the mucus the animal secretes—harbors its own separate community.

Over the past few years Medina has worked with Rebecca Vega Thurber of Oregon State University to catalogue the biodiversity of coral microbiomes around the world, and she fully expected to find a distinctive signature in those able to survive at Varadero. The question was, why? Was it simply because these corals had acclimated so well to their atypical environment? Or were they in fact genetically different?



Colonies of Orbicella faveolata on Varadero reef in the Bay of Cartagena, Colombia. Credit: Mónica Medina

A race against time

Approaching the answer has meant racing against time. Ironically, Varadero's discovery coincides with a period of great ferment in Colombia, triggered by the signing of a historic peace accord after more than a half-century of bloody conflict. With increased security and a new spirit of optimism, investor confidence is surging, and the long-suppressed forces of economic development have been unleashed. The resulting rapid growth threatens something that the long shadow of violence had managed to protect: Colombia's amazing biodiversity.

The bay of Cartagena, in particular, is undergoing a boom in shipping and luxury tourism. The swell of traffic has engendered plans for dredging to widen its shipping channels, and the current blueprint for that improvement slices right through the heart of Varadero. The reef that survived unnoticed for so long is suddenly in danger of being destroyed.

Throughout 2014 and 2015, Medina and Penn State colleagues Roberto Iglesias Prieto and postdoctoral fellow Joe Pollock worked with a team of Colombian and U.S. biologists to map and survey the reef, detailing its structure and composition and cataloguing the varieties of life they found there. But a much more thorough study would be required if the fuller lessons of Varadero were to be learned.

Local opposition to the government's development plan had not yet gained much traction, so Medina quickly applied to the National Science Foundation for a so-called RAPID grant, reserved for urgent action in the face of impending disaster. When that request was denied, she took her case to journalist Lizzie Wade, who wrote about Varadero for the journal *Science*.

"That story kind of helped us get NSF's attention," Medina says. "It also made the local news take notice, which has helped our Colombian colleagues hold the fort and be more vocal." Soon after the story appeared, Medina and Iglesias Prieto reworked their proposal, and this time the emergency grant was awarded.

Clouds and sun

Orbicella faveolata corals, Varadero reef. Credit: Monica Medina

When they returned to Colombia and began to dig deeper, Medina and Iglesias Prieto discovered that Varadero's story is more complicated than they had first thought. To explain, Iglesias Prieto produces a pair of aerial photographs of the reef, one taken in December 2014 and the other in January 2015. In the earlier photo, the water surface is impenetrable, a murky cloud. In the second, it is nearly transparent—plenty clear enough to show the outline of a reef.

"The first time I went there, the conditions were like this," he says, pointing to the opaque version. "But what we are learning is that the optical properties of the water here change very rapidly." Varadero, in other words, is not always shrouded in turbidity—sometimes the water above it is clear. It all depends on the volume of the sediment plume pouring from the canal, and the prevailing circulation in the bay.

"We don't yet know how much of the time it is one, and how much the other," Iglesias Prieto says. "What we know is that the ty6ransition in either direction can take place in a few minutes."

He and his students have placed sensors in the bay to record these shifts, and are working with ocean circulation experts on computer models to predict them. In the meantime, there is rich evidence to be gleaned from the coral itself.

Corals grow by depositing calcium carbonate to build new skeleton. This calcification depends heavily on the energy produced by the coral's symbiotic algae. Under cloudy skies, photosynthesis tails off, and so does calcification. Conversely, where sunlight penetrates, growth speeds up. It's been known since the nuclear testing at Bikini atoll during World War II that an X-ray of a coral skeleton will reveal bands of annual growth, like tree rings, corresponding to the duration and intensity of seasonal sunlight the animal has absorbed. But that same skeleton, Iglesias Prieto says, may also record changes in light occurring on much shorter timescales —perhaps even those related to the clouds of sediment.

While he continues to examine the skeletal physiology, he and Medina have also been testing her hypothesis about Varadero's microbiome, comparing bacterial samples taken there to samples from three nearby reefs, each a little farther out to sea and therefore less exposed to sediment and pollution. What they have found confirms her suspicion: The Varadero samples are much different from those taken only a few kilometers away.

Orbicella faveolata. Credit: Monica Medina

Analysis is ongoing, but Medina thinks it unlikely that the corals themselves are genetically distinct. "The two reefs are so close together, there's no barrier to prevent gene flow between them," she explains. "I suspect that these corals must have interbred in the past, but once they were settled in these different environments, the demands on them were different. One environment is nutrient-rich, the other nutrient-poor; one has very large oscillations in light availability, the other has always the same light. I think all of this plays out in the microbiome."

To determine how stable their differences might be, Medina and Iglesias Prieto next transplanted small samples of coral from each of the four reef sites to all of the others. Although it's early to say whether the microbiomes contained in these samples are morphing to match their new environments, the researchers have already noticed that transplants from Rosario and Baru survive better on Varadero than the Varadero samples do on these "cleaner" reefs.

"That surprised us," Medina says. "But what we've seen is that when the circulation is right, there is actually very clean water—and good light—over the reef. When it's not, the dirty water contains all kinds of little critters for them to feed on. It looks like they're having the best of both worlds."

Coming home

Recent reports of a Brazilian reef thriving under heavy sediment at the mouth of the Amazon suggest that Varadero might not be as unusual as Medina and others originally believed. There could be coral reefs lurking elsewhere in unlikely spots where no one has thought to look for them. But to Medina, that only makes this one more important. "Given the fact that more and more locations may be facing this sort of pollution, understanding reef response is critical, especially that of a reef that has withstood so many years of abuse," she says.

She is also interested in the human populations that have depended on Varadero—that handful of poor fishing communities, cut off from the mainland, that have existed here for centuries. Can they, like the reef itself, survive the coming wave of development?

Sponges on Varadero. In foreground are orange Agelas sp. At rear, Ircinia sp. Credit: Monica Medina

"Until very recently, these people have been completely ignored," Medina says. "Now the resort chains are moving in. Approvals have been given for 16 marinas." She fears that with tenuous rights of ownership and no political voice, these communities will be lost in the fray. "If the reef is destroyed, they will have nothing," she worries.

Medina has enlisted Penn State anthropologist Carter Hunt, an expert on the social and environmental consequences of tourism, to document life in these settlements at this moment of looming change, and to help explore the interrelationships: how human-caused disturbance can impact a natural system and how the human communities that rely on that system are affected in turn.

With Hunt's help, and that of two other Penn State social scientists, Leland Glenna and Larry Gorenflo, Medina and Iglesias Prieto hope to examine these coupled impacts in real time, combining the historical and genetic evidence recorded in the coral itself with dusty archival documents that detail the environmental history of the bay, and overlaying that with the present-day ethnography.

For Medina, however, Varadero is more than a case study. She was born and raised in Colombia, leaving for graduate school in the U.S. in 1992. "I always wanted to go back when I finished my Ph.D.," she says, "but it was a particularly bad time." Abductions and assassinations were a frequent occurrence—even her own grandfather was kidnapped, though later released.In the years since, a chance to do research in Colombia "was something I always longed for," Medina says. That Varadero should come along, at this turning point, "seems like a dream. It's the ideal project, a chance to do what I do, and to bring it a new meaning. Because I can help these communities. Already, I think we've helped them find their voice." Though the outlook for Varadero is still very much in doubt, "I am more hopeful than I was when we started," she says.

To Medina, to be clear, this project is critical from a scientific point alone. "But it's also a way for me to contribute," she says. "To the peace process, and in general. It brings me home."

Provided by Pennsylvania State University

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