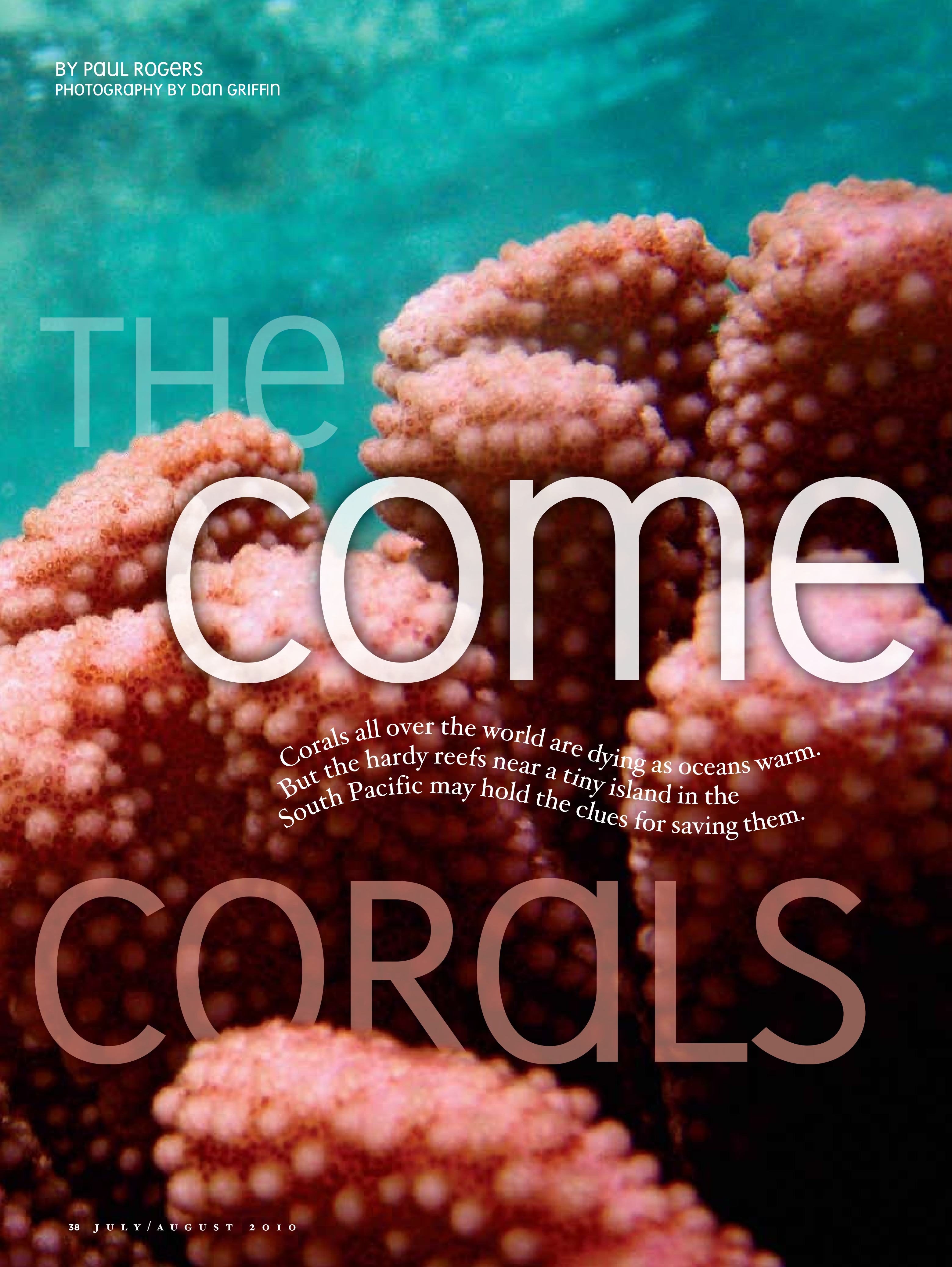


BY PAUL ROGERS
PHOTOGRAPHY BY DAN GRIFFIN

THE come CORALS

Corals all over the world are dying as oceans warm. But the hardy reefs near a tiny island in the South Pacific may hold the clues for saving them.

On a Friday afternoon in late January, Steve Palumbi is 5,000 miles from campus labs and lecture halls, doing the kind of work that gives a professorship its reputation as a great gig: He is guiding a yellow sea kayak through a South Pacific lagoon. The tropical sun beats down on his Lycra diving shirt. "Paddle hard to the right," he says. "Turn the bow into the waves."

In the sky above, a flying fox circles, plucking mangos and bananas off the trees. Coconut crabs with claws like large nutcrackers scurry along the deserted, palm-lined beach. The humid jungle echoes with the squawks of mynah birds. »

Back

Twenty yards ahead, in another kayak, researcher Dan Barshis begins shouting out GPS coordinates. "1831! 6596!" Palumbi stops paddling and looks down. In the clear, warm water below, huge fields of coral teem with a psychedelic panorama of life: striped surgeonfish, green parrot fish, red gobies, yellow tangs.

Palumbi, director of Stanford's Hopkins Marine Station, and Barshis, a postdoctoral researcher in his lab, are plying the waters around Ofu, a volcanic speck of an island that lies between Hawaii and Australia. Ofu is part of American Samoa, the only United States territory south of the equator. In 95-degree heat, the two marine biologists search for the exact coral formations they have sampled on prior trips, going back to 2004. Satellite coordinates help them get within 10 feet. After that, they must locate each individual coral colony from photos.

On this trip, they hope to take about 100 tiny live coral samples—snipped like buds from rosebushes—back to labs on the Stanford campus for extensive genetic tests. They can best determine how the coral is faring when they find the same ones they sampled earlier. "It's a game of hide-and-seek," Barshis says. But the stakes in this game couldn't be higher, given that healthy corals are essential to life on earth—and that the corals on Ofu may prove key to keeping the rest of the earth's corals alive.

A CENTURY AGO, naturalist John Muir famously said: "When we try to pick out anything by itself, we find it hitched to everything else in the universe."

Corals are really hitched. What rain forests are to land, coral reefs are to the ocean—the planet's richest repositories of biodiversity. Crabs, clams, sea turtles, urchins, sponges, starfish and more than 4,000 species of fish swarm, hide, crawl and feed upon reefs. An estimated 500 million people worldwide depend on reefs for food, building materials, coastal protection during storms and hurricanes, and tourism income.

"My favorite fact about coral reefs is that they make up one-tenth of 1 percent of the ocean floor, but they provide habitat for at least 25 percent of marine species," says Kacky Andrews, director of the Coral Reef Conservation Program at NOAA, the National Oceanic and Atmospheric Administration, in Silver Spring, Md. "These are resources that literally hundreds of millions of people depend on."

Although reefs look like colorful underwater plants, corals are actually tiny animals, each usually no bigger than a ladybug. The individual animals, called polyps, are squishy little transparent tubes with tentacles and mouths. For more than 250 million years, they have flourished in ocean waters, eating plankton and secreting out a cup of calcium carbonate—limestone—around themselves. Each coral reef is really a great underwater apartment building—with thousands of polyp tenants—all eating and secreting limestone in dazzling patterns. As each generation dies, the next builds a new layer atop the old ones.

In recent decades, scientists have learned much about the remarkable partnership that keeps corals alive. Billions of single-celled algae floating in the oceans take up residence in corals' cells, giving them their colors. Through photosynthesis, the tiny plants produce sugars for corals to eat. The corals, in turn, give them mineral nutrients and shelter.

But when ocean water heats up, the algae, known as zooxanthellae, stop making sugar, and the corals expel them. Without their algae, the corals revert to bone white and can die, leaving only their rocky skeletons behind.

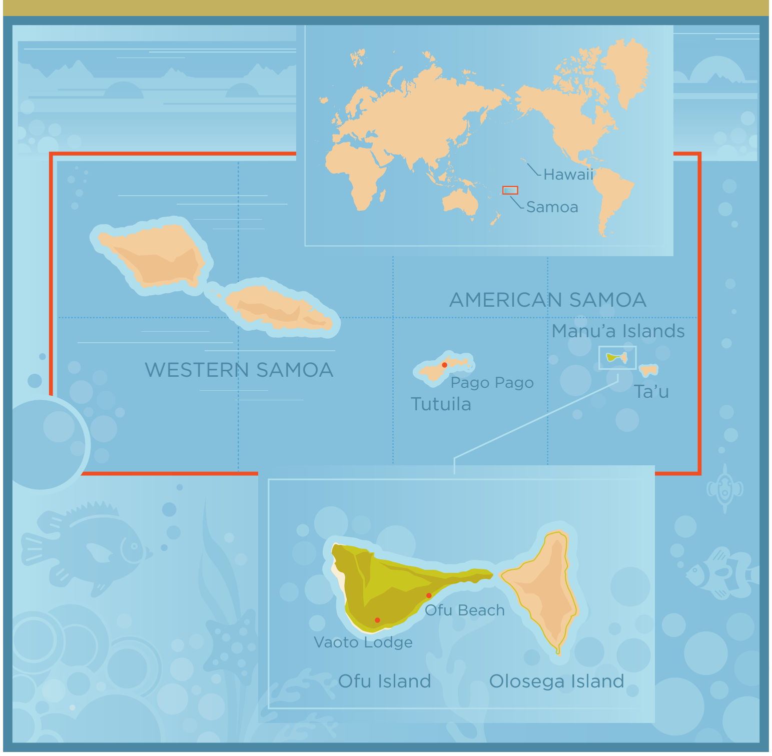
But not in Ofu.

In 2001, Peter Craig, a soft-spoken biologist with the National Park Service in American Samoa, published a paper explaining how, for some reason, corals in shallow lagoons in Ofu survived extremely warm water. As the tides went out in the summer, pools less than 5 feet deep periodically reached temperatures up to 94 degrees. But amazingly, the corals didn't bleach.

"They're supercorals," says Palumbi. "They are doing fine in waters as warm as the ocean is likely to get by the end of this century."

These aren't rare species, but varieties like staghorn and table corals, commonly found around the world. If scientists could learn what makes Ofu's supercorals super, they perhaps could identify other heat-resistant corals in the world, corals more likely to survive global warming. They then could urge political leaders to create new marine parks around these corals to stem overfishing, pollution and other threats. They might even move pieces of coral, growing heat-tolerant reefs in bleached areas where whole marine food chains were crashing.

SUPERCORAL LOCALE



CELIA JOHNSON

SNORKEL TIME: Palumbi off Ofu, where the shallow-water corals are especially strong in the face of temperature changes.

PALUMBI AND HIS Stanford team first came to Ofu in 2004. They were amazed at how well protected its corals were, largely because they lie within a national park.

"Nothing here has changed much," says Deb Malae, 41, who has lived in Ofu off and on since she was 6. "The road got paved. Ofu's population fell from about 500 to 400. The reefs seem the same. I still recognize the same coral heads from when I was a little girl and I swam with my cousins."

But research here comes with hurdles. Ofu has one tiny landing strip, and planes arrive infrequently. There is one dial-up computer connection, and cyclones are not uncommon. The humidity is debilitating, soaking cotton shirts in a matter of minutes.

Gear and logistics pose problems, too. On the most recent trip, Barshis tried to put a high-definition camera on a kite to get aerial photos. But the mounts weren't strong enough, and the images came back as blurry as "the Blair Witch Project." On an earlier expedition, Hawaiian Airlines lost the Stanford team's luggage, and for a week the researchers wore sarongs they made from the curtains of Ofu's lone, small motel, Vaoto Lodge. "You can't have a type-A personality down here," says Palumbi, smiling. "It works against you."

TAG, YOU'RE IT: Carlo Caruso prepares floats that are attached to coral colonies and log their temperatures.

Following up on earlier work from the University of Hawaii, the Stanford scientists have carefully monitored water temperature, tides and light in Ofu's serene lagoons. They have brought back coral samples from 60 colonies and begun painstaking genetic analysis. In one key experiment in 2006 and 2007, Stanford postdoctoral researcher Tom Oliver set up a makeshift lab on the beach. It looked like something from *Gilligan's Island*. He and Palumbi placed more than 30 coral samples in two

a matter of degrees

In the summer of 2002, fishermen, scientists and scuba divers began noticing a troubling pattern around Australia's Great Barrier Reef. Its brilliant colors were turning ghostly white. Corals—the tiny, soft-bodied organisms whose secretions collectively form sturdy reefs—bleach when they are about to die. They die when the temperature of the ocean water increases by as little as two or three degrees.

Great Barrier Reef, a 1,600-mile-long network of coral so vast it can be seen from space, provides shelter and food to more than 1,500 species. It's also central to Australia's economy, supporting a $1 billion fishing industry and attracting 2 million visitors a year who generate $4 billion in economic activity.

Some 54 percent of Great Barrier's reefs bleached that summer. The water was warmed primarily by the episodic climate phenomenon of El Niño, and after the El Niño currents subsided, most of the reef recovered. But that incident, and another bleaching four years earlier, set off alarm bells for marine scientists who fear the gradual increase in ocean temperature from global warming. "We may be witnessing the beginning of a slow-motion degradation of the reef that will only get worse in coming decades," Terry Done, a researcher with the Australian Institute of Marine Science, told the *Sydney Morning Herald.*

Global ocean temperatures have risen 1.3 degrees Fahrenheit since the late 19th century, according to the Intergovernmental Panel on Climate Change.

Rarely seen before the 1970s, coral bleaching now occurs fairly regularly in the Pacific, the Persian Gulf, the Indian Ocean and the Caribbean Sea. "The trends are not good. The long-term outlook is pretty negative right now," says Kacky Andrews of the National Oceanic and Atmospheric Administration. "There's no ifs, ands or buts about it: Climate change is the primary threat."

Already, the world has lost 19 percent of its original coral reefs, according to a survey published in the journal *Science* in 2008. Another 35 percent are under threat of loss in the next 20 to 40 years. As oceans continue to warm, half the corals on earth could be gone by 2050, before today's high school students have retired. A team of British researchers has considered a drastic plan: freezing reef samples in labs—a kind of Noah's Ark to save marine biodiversity—in case they are extinct in the wild by the end of this century. *—Paul Rogers*

50-gallon tubs, then filled them with seawater. In one tub, the water was 82 degrees, the same median temperature as the ocean around Ofu. In the other, they heated the water to 89 degrees for five days.

The results? More than 50 percent of corals from deeper pools, where the water temperature doesn't fluctuate much, died. But corals from shallower pools, where water temperatures fluctuate by up to 10 degrees a day with the tides, had only 10 percent mortality. "We heated them to a temperature that is usually fatal," Palumbi says. "And a good number of them survived."

The researchers performed genetic tests and found that the corals in the shallow pools all had the same kind of algae. The less-hardy corals in the deeper pools had varying types. That suggested the corals may be able to swap out weak algae for more heat-resistant algae—and thereby adapt to warming temperatures. Australian scientists had made similar observations during a vast bleaching incident in the Great Barrier Reef in 2006.

But surprisingly, even the corals from the cooler, deeper pools that were lucky enough to have the heat-resistant algae still died when they were heated in the tubs. "The algae is part of it, but not all of it," Palumbi says. "There has to be something happening in the coral itself. Is it just Ofu corals that can do that? How can they do that? Can any coral do that?"

The fate of the world's corals has concerned Palumbi, 53, for years. The problem has sent him traveling thousands of miles, from the classrooms of Harvard to Stanford, from Fiji to Palau, from the Caribbean to Ofu.

When he was a boy growing up in Baltimore in the 1960s, Palumbi's parents took him on summer getaways to the Maryland shore. Noting his fascination with the ocean, his father, an elementary school principal, bought him an aquarium when he was 8. While other kids took to baseball cards and Hot Wheels, Palumbi began raising tropical fish. He made money in high school selling angelfish, tetras and zebra fish to pet stores. "By the time I was 16," he says, "our whole basement was full of fish tanks."

He studied biology at Johns Hopkins University and met marine ecologists and biochemists. Graduate school followed and the grunt work of a young research aide. "My first summer we got in a truck and drove up the East Coast. We collected minnows in salt marshes from Florida to Maine," Palumbi recalls. "We were trying to see how their environments affected their evolution. We dissected them and put their livers in liquid nitrogen. In order to get a kilogram, it takes 10,000 minnows."

It was summer research in the late 1970s in Jamaica that first illuminated the marvels and perils of coral reefs. Supervised by Johns Hopkins professor Jeremy Jackson, now with the Scripps Institution of Oceanography, Palumbi worked on coral reef studies. He learned to scuba dive. The first time he plunged in and breathed underwater, he was hooked. "It was amazing. Absolutely amazing," he says. "I had no idea that people could do that for a living."

Not long after, disease caused a major die-off of black spiny sea urchins in the Caribbean. It changed the reefs dramatically. Without the sea urchins to eat algae, the algae exploded out of control and smothered the reefs in blankets of goopy green. Normally fish would have eaten the algae, but because of overfishing, there weren't enough left. "Ecological systems have multiple workers doing multiple jobs," Palumbi says. "You can take away some of them but eventually everything collapses."

By the 1990s, Palumbi was teaching undergraduate marine biology at the University of Hawaii—after having earned his PhD from the University of Washington in 1984, married physician Mary Roberts and fathered their two kids. One focus of his research—a kind of conservation forensics—made international headlines. At the behest of a conservation group, he bought whale meat at markets in Japan and showed through genetic analysis that endangered species of whales were being sold in violation of international treaties.

Harvard hired Palumbi as a professor of evolutionary biology in 1996. He worked trying to unlock the evolutionary and genetic questions of urchins, corals, cone snails and other aquatic critters, and wrote *The Evolution Explosion: How Humans Cause Rapid Evolutionary Change.* In 2002, he came to Stanford, where he has helped draw up California's groundbreaking network of "no fishing" zones and written a forthcoming book about the history of Monterey Bay. (He also plays keyboards in Sustainable Soul, a studio band whose members are researchers from a couple of continents.)

His lab is researching several ideas about the Ofu supercorals from those shallow pools. Are they stronger because being exposed to widely fluctuating temperatures makes them tougher? "These corals may just be fit because they have had to survive and tolerate the stress," Barshis says. There's also some evidence that supercorals resist damage from acidification—the condition caused when carbon dioxide from the atmosphere dissolves in the oceans, making them more acidic. Or perhaps they are somehow genetically superior? Basic genetic analysis hasn't yet found differences between the mighty corals and their wimpy cousins, but the researchers plan much more extensive genetic work.

Another key question: Do supercorals exist in other places, or are they just an Ofu oddity?

To help with that mystery, Palumbi and Oliver enlisted the help of Kevin Arrigo, a professor of environmental earth system science at Stanford who uses satellites to track plankton blooms, icebergs and other ocean features. After Arrigo prepared maps showing ocean temperatures, acidity and other conditions around the world, Oliver overlaid them with previously published

PLANT SPECIMAN: Barshis, having found his way to a specific colony, prepares to take a sample of it for testing.

‘There’s a huge need to address global warming. But that’s not going to happen right away. . . . We have to do what we can do to rescue what we can.’

studies showing where heat-resistant algae have been found. It showed that the heat-resistant algae are common in warmer areas. So supercorals might well be found widely.

BASIC QUESTIONS remain: How do the algae resist heat? How do they communicate with corals? Could you “reseed” struggling coral reefs with heat-resistant algae to improve their chances? Dozens of plastic fish tanks on the third floor of Lane Building on the Stanford medical campus may hold the answers.

For 44 years, cell biologist and genetics professor John Pringle has studied yeast. Its cellular structure can help explain the most basic biology of other species, from plants to humans. Six years ago, he heard Palumbi give a talk at the University of North Carolina. A recreational scuba diver, Pringle had been concerned about corals after a major bleaching in 1998 that he followed from afar. But he had never thought to move from studying yeast to a completely different organism.

“Steve said, ‘We need people in our field like you because nobody is doing what you do—cell biology—on corals,’” Pringle recalls.

The following year, by chance, Pringle’s wife, Dr. Beverly Mitchell, a top cancer researcher at the University of North Carolina, was hired by of the Stanford Cancer Center. The couple moved west.

Sitting in his office on the third floor of Lane Building, Pringle taps his computer keys and produces a search of published papers on a well-known protein called p53 that helps suppress cancer tumors in humans and other species. It turns up more than 53,000 studies. But only six are about p53-containing corals, jellyfish or sea anemones.

“Here are these organisms of incredible importance to the ecology and economy of the world. And almost nobody has been doing this kind of research on them,” he says, shaking his head. “If I was a grad student today, and here was this incredible world, wide open, with nobody studying it—what a chance to make a difference!”

Because coral is notoriously finicky and difficult to keep alive in fish tanks, Pringle is working on the next best thing: a type of pale sea anemone called *Aiptasia pallida* that is related to corals and has similar relationships with algae. It has the potential to be for reef science what the fruit fly was for genetics: a model organism that can provide a seamless, consistent, experimental assembly line for study. During the past five years, from one specimen, Pringle’s lab manager Carlo Caruso has cloned more than 10,000 identical anemones.

ANEMONES LIST: Pringle will test varying water conditions with a stock of *Aiptasia pallida,* which will act as a model organism for corals in the lab setting.

In plastic bins that line the walls of the lab, these anemones are ready to be exposed to varying experimental conditions. Researchers can change water temperatures, or pH levels, or types of algae and see what happens, knowing that they have controlled for other variables. “It has the potential to be the Rosetta Stone of these organisms,” Pringle says.

Pringle’s lab also has created techniques to count the number of algae in corals, measuring their health by analyzing them with software and machines normally used in hospitals to do human blood tests. They hope to develop a test kit that would reveal when coral reefs are suffering heat stress. It might look like the test strips that maintenance workers use on swimming pools: Just brush some material off a reef, apply it to a dipstick treated with antibodies, and see if a color change occurs.

Liz Hambleton, a graduate student in Pringle’s lab, provides an analogy. “A doctor

SHORE THINGS: Coral samples come first to the beach, then to tub 'tide pools' assembled by Palumbi, Hambleton and Caruso.

can look at two patients and they both might look fine. But he doesn't know one has cancer unless he does a test." Pringle thinks such a kit could be ready in three years.

In a doomsday scenario, with global warming out of control and reefs bleaching en masse, scientists wonder if they could seed reefs with nutrients to boost the type of heat-resistant algae. They might even try to crossbreed supercorals with weaker corals, something Palumbi compares to the desperate efforts by biologists in the 1980s to save the California condor from extinction by capturing the last birds and breeding them in zoos.

SEA WORTHIES
See a microdocumentary about Ofu's corals at www.stanford.edu/group/microdocs/robotidepools.html.

Such proposals leave some environmentalists intrigued, but troubled. "What they are doing is great. It's hopeful, and encouraging," says Jackie Savitz, pollution campaign director for Oceana, a conservation group based in Washington, D.C. "But we have to remember it doesn't alleviate the need to solve the carbon dioxide problem. It's not a silver bullet. Unless we do more to reduce greenhouse gases, what we are going to lose is of such a magnitude that I don't think we can physically replace it ourselves."

Pringle doesn't disagree. "There's a huge need to address global warming. But that's not going to happen right away. We've already seen mass bleaching events. We have to do what we can do to rescue what we can."

Years more coral research on Ofu and in Stanford's labs is planned. For some residents in American Samoa, the curiosity about supercorals is a point of pride. "We live way out here in the middle of nowhere, and we don't always get the news. When we do we hear about global warming, it's depressing," says Deb Malae. "It's nice that research done here might give the world something hopeful."

Through repetition and discovery, scientists create options for society, Palumbi says. And options generate hope.

Speaking in San Diego in February at the annual meeting of the American Association for the Advancement of Science, Palumbi recounted meeting a graduate student who was considering a career in marine biology. "The student said, 'I'm interested in corals, but I hear they are all going to be gone soon. Do you think that's a good career move?'" Palumbi said, as the audience laughed.

His answer to the student? "When there's a crisis going on, that's a pretty good time to jump into something and learn enough to make a difference. From a scientific view, that's a very timely time to work on that particular thing. Second, if we all felt that way, and we never did anything about something that we thought was just out of our control, then we are writing our own future. And it is one where corals do not thrive, and that future is not one that I'd like to have." ■

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