

REBUILDING reefs



With corals at risk, scientists attempt underwater rehab

By Amy McDermott

Coral reefs are bustling cities beneath tropical, sunlit waves. Thousands of colorful creatures click, dash and dart, as loud and fast-paced as citizens of any metropolis.

Built up in tissue-thin layers over millennia, corals are the high-rise apartments of underwater Gotham. Calcium carbonate skeletons represent generations of tiny invertebrate animals, covered in a living layer of colorful coral polyps. Their structures offer shelter, and for about 114 species of fish and 51 species of invertebrates, those coral skyscrapers are lunch.

Important as they are, corals are in jeopardy. Warming oceans are causing more and more corals to bleach white and

become vulnerable to destruction. A prolonged spike in temperatures, just 1 to 2 degrees Celsius, is enough to kill the marine animals. Greenhouse gas emissions also acidify the water, dissolving the calcium skeletons. In some countries, fishermen use dynamite to catch fish, leaving behind coral rubble. Today, more than 60 percent of the world's reefs are at risk of disappearing.

Threats to reefs have “dramatically escalated in the last few decades,” says marine scientist Peter Harrison of Southern Cross University in Lismore, Australia. He has studied corals for three decades. “In my time as a reef researcher,” Harrison says, “I’ve seen it get worse, firsthand.”

Thirty years ago, massive coral bleachings were unheard of. Today, reefs are suffering through a third global bleaching event since 1998. With high ocean temperatures dragging on since

A coral fluoresces purple (left), perhaps as a sunscreen defense for colorless polyps, in a photo taken September 12 of a bleached reef near Okinawa, Japan.



2014, this summer marked the longest and most widespread episode of worldwide coral bleaching on record (*SN*: 7/23/16, p. 5). Australia has been hit especially hard. More than 80 percent of the northern part of the Great Barrier Reef is bleached and close to half of those corals have died, according to a report in April from Australia's National Coral Bleaching Taskforce.

As reefs take a nose dive, scientists from Hawaii to the Philippines and the Caribbean are scrambling to save corals. Approaches that were once considered radical are “now seen as necessary in some places,” says coral biologist Ruth Gates of the Hawaii Institute of Marine Biology on Oahu.

In Florida, researchers are restoring reefs with tiny coral fragments. In Hawaii, Gates is scouring the water for stress-tolerant corals and experimenting in the lab to breed the hardiest individuals. At the 13th International Coral Reef Symposium in

Honolulu in June, Harrison's team reported early promising results of its effort to flood damaged reefs in the Philippines with tiny coral larvae.

What works on one reef won't necessarily save another. So researchers are testing an arsenal of options to rescue a diversity of underwater communities.

A different story

In the early 1980s, Harrison was a graduate student at James Cook University in Townsville, Australia, working on the Great Barrier Reef. At the time, textbooks taught that most corals reproduce by brooding: Fertilization occurred inside the body and larvae were released into the water to replenish reefs year-round. But Harrison witnessed something very different. For a few nights around a full moon in springtime, corals spawned, spewing eggs and sperm into the water to be externally fertilized. The sea was covered in a pink, oily slick.

“We found the corals hadn't read the textbooks,” Harrison says. Eggs and sperm were meeting outside of the coral bodies, and larvae were developing while drifting in the currents.

That discovery spurred a cascade of studies on coral reproduction that led to the modern understanding that many corals reproduce only once or twice a year, in coordinated mass releases of eggs and sperm. Most of the resulting larvae die or drift out to sea, Harrison says. Only a small fraction survive to adulthood. Even so, mass spawns are “how reefs replenish themselves over time,” he says.

Just after Harrison's discovery, the Great Barrier Reef, and then reefs around the globe, experienced bleaching on a massive scale. Normally, tiny algae live inside coral polyps. The algae make sugar and other nutrients for the coral, and can give polyps their characteristic bright colors. But when temperatures spike, algae become toxic. Corals spit out their partners, bleach white and can die if temperatures don't cool enough for the algae to return (*SN Online*: 10/8/15).

Corals worldwide were bleaching more often and more severely than had been recorded in the past. Scientists began to worry that reefs were in trouble. Some researchers, like Dave Vaughan, who manages the Coral Reef Restoration program at the Mote Tropical Research Laboratory in Summerland Key, Fla., took action.

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In those days, Vaughan was a fish farmer, raising saltwater fish species in captivity. He began growing corals for tropical aquarium tanks. At the time, all the corals in the aquarium trade were taken from the wild, Vaughan says. He started growing coral species in captivity as an environmentally friendly alternative.

One day, Philippe Cousteau, grandson of legendary aquanaut Jacques, toured the operation. When the young Cousteau saw that Vaughan was raising corals for aquariums, “he shook his head,” Vaughan remembers, “and said ‘Dave, if you could do this for the aquarium trade, you can do this for the reef.’”

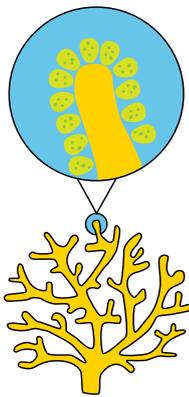
Stressed out

Changing conditions, such as rising ocean temperatures and local pollution, can kill reefs by bleaching corals. Here's how tough times turn reefs white.

SOURCE: NOAA CORAL REEF CONSERVATION PROGRAM

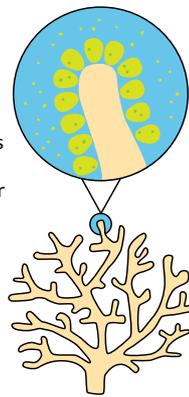
Healthy coral

Photosynthetic algae (dark green dots) live in coral polyps and make nutrients that corals eat.



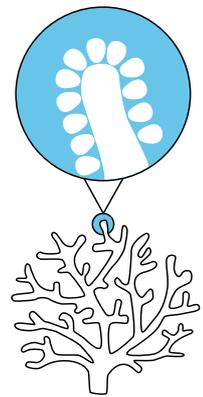
Stressed coral

Algae give corals their characteristic color. Under stress, corals reject the algae and begin to fade to white.



Bleached coral

If conditions don't improve enough for algae to return, corals can starve or succumb to disease.



In those earliest days, most scientists were tackling small-scale reef damage caused by dropped anchors or boat groundings, Vaughan says. To repair that kind of minor damage, scientists began breaking 3- to 5-centimeter fragments from healthy corals on a neighboring reef and transplanting the chunks in damaged spots.

Cousteau's visit convinced Vaughan that he should try restoring reefs. While doing so, 11 years ago, Vaughan made a game-changing discovery: Tinier fragments of coral, only 1 centimeter long, repair themselves 25 to 40 times as fast as scientists had ever recorded corals growing.

Today Vaughan's team is spreading many of these microfragments over the surface of dead coral skeletons in the Florida Keys. As those bits fuse back together, they create a fast-growing "skin" over an otherwise dead reef. Condemned buildings are refurbished rather than razed.

The hope is that thousands of microfragments will carpet a small reef in two to three years, says Chris Page, a biologist at Mote Marine Laboratory working with Vaughan. That's super fast. "There's no way that's happening in nature," Page says.

Vaughan's team is cultivating 17 species for microfragmentation in large troughs on land, with seawater running through them. He is focused on the top six slow-growing massive species that create the foundation of the reef. Some can live for centuries, mounded into boulders the size of a truck.

The Florida researchers plunged their first 200 microfragments into the ocean three years ago, at two sites in a nearshore coral reef off Big Pine Key, Fla. The colonies are now six to eight times as large as they were at planting and have begun to fuse together into areas about the size of a 5-gallon bucket lid. Since then, Vaughan and Page have planted close to 10,000 microfragments in the wild. "People were looking for some glimmer of light," Vaughan says. "And restoration is turning out to be that in a big way."

Seeds of reefs

Fragmentation and the newer microfragmentation are both time- and

labor-intensive, and therefore very expensive. And, Harrison says, they rely on cloning.

When one coral is broken into fragments, to be fattened up and then planted around a reef, each chunk is genetically identical. All those pieces have the same DNA blueprint to fight infection and to deal with stress. Unlike natural reefs, where individuals are genetically distinct and have different vulnerabilities, cloned corals share the same weaknesses.

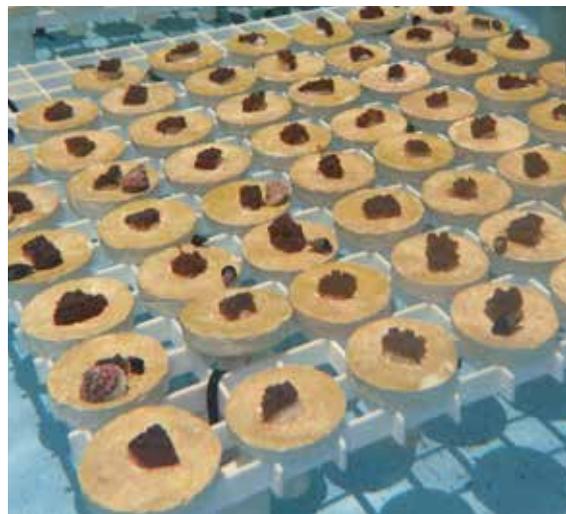
"People have spent years growing coral gardens only to have them wiped out by the next bleaching event," Harrison says. With more diversity, he adds, some of those corals might have survived. In a warmer world where bleaching and disease will probably become more common, "genetic diversity equals resilience."

To address the diversity issue, Vaughan and Page are raising 20 to 30 genetic variants of each coral species, to be planted around the reef. They are also collecting eggs and sperm from wild colonies of four coral species to grow on Summerland Key.

Harrison has been thinking about genetic diversity ever since the early 1980s, when he saw corals spewing sperm and eggs into the ocean. Few of the resulting larvae would survive. Many would drift away and most would die. All while Harrison saw reefs in decline.

What if, he wondered, scientists could take millions of those

Coral microfragments grow on round pucks in nursery troughs (left) on Florida's Summerland Key in 2016. Reef scientist Dave Vaughan (right) plants microfragments from the nursery to restore reef-building corals at the southern tip of Key West.



TOP: E. OTWELL; BOTTOM, FROM LEFT: C. PAGE; CONOR GOULDING/MOTE MARINE LABORATORY

diverse coral larvae and help them settle onto reefs to replenish ailing ecosystems?

Other researchers asked themselves the same question. In the late 1990s and from 2007 to 2009, two teams, in Australia and Palau, released coral larvae onto healthy reef areas in mesh tents pitched over the seabed. In both studies, thousands of larvae settled under the tents, many more than scientists would have seen naturally.

But those early results may have been misleading. Most of the early settlers in Palau died within 30 weeks. Flooding the reef with larvae didn't make a lasting difference in coral numbers. Maybe, the researchers speculated, settlers were too crowded, which meant swamping reefs with larvae made no sense.

Harrison wasn't ready to give up. Even though most of the new settlers had died, those studies were done on healthy reefs, he says. In battered areas, where some baby corals might naturally drift in, but not enough for the reef to self-heal, a flush of larvae could be a shot in the arm.

The idea was to find a badly damaged reef, where the worst problems, such as blast fishing, had stopped. Harrison would bring a few of the reef's mature, sexually active corals to the lab, persuade them to release sperm and eggs in aquarium tanks, and then take more than a million of their larvae back out to the reef. The plan was to saturate the environment with settling babies, as adult corals would have done in healthier days.

In 2013, Harrison's team, led by graduate student Dexter dela Cruz, began a small pilot experiment in the Philippines at a reef called Magsaysay, where nearly two decades of fishing with explosives had taken a toll. Blast fishing is "like hitting the reef with a sledgehammer," Harrison says. Magsaysay's large foundational corals were blown to bits. A once-vibrant city was now a wasteland.

By 2013, the blast fishing had stopped, but Magsaysay wasn't recovering on its own. So Harrison's team brought in larvae from a species of fast-growing, purple-tipped coral, called *Acropora tenuis*, collected from a nearby healthier reef. The scientists released more than a million larvae into floorless mesh tents pitched underwater over the reef. After five days, Harrison's team removed the mesh enclosures.

Over the next six months, most of the tiny coral settlers died. But, by the nine-month mark, the remaining populations had stabilized. Scientists expected more of the juvenile corals to die, but "incredibly and extraordinarily," Harrison says, none have. At 3 years old, the juvenile corals have reached sexual maturity and are now the size of dinner plates. In June, dela Cruz presented the findings in Honolulu.

For slower-growing corals, Harrison's approach will take extra patience. But for fast-growers like *A. tenuis*, reseeding larvae could be a quick and affordable way to help severely damaged reefs bounce back.



Peter Harrison (top, right) and Dexter dela Cruz (left) place millions of *Acropora tenuis* larvae into a mesh tent in April 2016 to rehabilitate Magsaysay, a degraded reef in the Philippines. When those larvae become adults, they spawn, like this *A. tenuis* on the Great Barrier Reef (bottom).

Winning corals

Getting more larvae onto damaged reefs is the first step, Harrison says. But some individuals are stronger and more stress-tolerant than others. As they grow up, these "winners" distinguish themselves by surviving.

Across the Pacific from Magsaysay, biologist Gates is studying winners. Rows of indoor and outdoor aquariums gurgle in her lab on Coconut Island, off Oahu's windward shore. Those tanks are full of *Montipora capitata*, a local and fast-growing coral collected from the patchy reefs surrounding the island.

In 2014 and 2015, unusually warm water hit Hawaii. Under stress, many corals rejected their symbiotic algae, then blanched from a healthy brown to white; some died.

Gates' team patrolled the reefs around the island during and after the bleaching, in search of hardy *M. capitata* individuals that stayed brown, even in hot water. The scientists are also interested in *M. capitata* that bleached, but then recovered. Gates equates the work to professional sports scouting, "out at high schools, looking for the best athletes."

When she finds top performers, Gates brings them to her lab to run them through their paces, exposing each

54
percent

Fraction of the reefs damaged in the Philippines

pro-performer to different temperatures and pH levels in seawater tanks. Some conditions re-create today's oceans, while others mimic future warm and more acidic seas.

Today, Gates is breeding the strongest corals (her first batch of babies was born in June). She hopes that top performers will have "extremely talented kids" that inherit their parents' strengths. It's too soon to tell how the new corals will do once they're planted out on the reef.

"We're trying to give corals a leg up," she says. Reefs healthy enough to survive without human intervention are the ultimate aim. In the next five years, the researchers plan to branch out from *M. capitata* to look for super corals of all five species found in the bay surrounding Coconut Island.

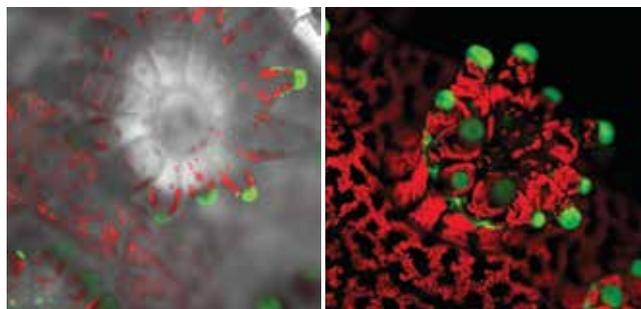
It would be ideal to find those super corals before the next big bleaching event. But for that, the researchers need another sign of resilience. That sign, Gates says, could be hidden in the way corals glow.

Some coral animals, and their symbiotic algae, are loaded with fluorescent proteins that absorb incoming light, then spit it back out by glowing. It's unclear what fluorescent proteins do for corals; they may be a kind of sun block, protecting corals from the intense light in shallow seas, or a form of camouflage or part of the immune system.

Stress affects corals' glowing proteins and changes their fluorescence patterns. In the Pacific and Indian Ocean species *Acropora yongei*, for instance, researchers reported in 2013 in *Scientific Reports* that the concentration of green fluorescent protein fell with temperature stress before bleaching and the coral glowed less intensely. In an earlier study, prolonged high temperatures changed the ratio of green to orange fluorescence in the endangered Caribbean coral *Orbicella faveolata*.

Gates expects that under stress, super corals will keep their healthy fluorescence patterns much longer than corals that are bleaching. One next step, Gates says, is to stress out tiny pieces of coral and watch what happens under a very powerful laser scanning confocal microscope. She'll expose nubbins of coral to acidifying water or increasing temperatures in a petri dish. The microscope will pick up the fluorescence of the nubbins and may indicate which corals will stay healthy the longest.

Once scientists can identify the hardiest corals, they can combine selective breeding with other rehab techniques.



Bleached corals (left) and healthy ones (right) fluoresce differently under a laser scanning confocal microscope. Glow patterns may help scientists identify super corals in the future.



Ruth Gates snorkels by bleached (left) and healthy *M. capitata* (right) on Oahu, Hawaii. She selectively breeds resilient corals.

Approaches like microfragmentation could help super colonies mature super fast. Then, Gates says, "we would have a strategy to get the reef producing its own offspring quite quickly."

No two approaches to saving reefs are the same, which is probably a good thing. Coral fragmentation, reseeding and selective breeding each have their pros and cons.

"The assumption that one size will fit all is completely flawed," Gates says. What might work on the Florida coast wouldn't necessarily work in the Pacific. Like far-flung cities, each reef has different needs and priorities. Their communities of coral vary as do the threats they face. Some problems, like warming oceans, are global in scope. Others, like pollution from roads and agricultural runoff, overfishing and dynamite fishing, are often more localized. Rehabilitation approaches will vary, depending on the type and severity of damage, and how the mosaic of coral species might respond.

Across the globe, "will the things that we do be different?" Gates asks. "Absolutely."

Rather than competing, Gates, Vaughan and Harrison are working toward a common goal: to find the right mix of approaches to support the reefs so they no longer need human help. ■

Explore more

- Peter Harrison, Ronald Villanueva and Dexter dela Cruz. "Coral reef restoration using mass coral larval reseeding." Australian Centre for International Agricultural Research. June 20, 2016. bit.ly/coralreseeding
- Zac H. Forsman *et al.* "Growing coral larger and faster: micro-colony-fusion as a strategy for accelerating coral cover." *PeerJ*. October 20, 2015.
- Global Coral Bleaching: www.globalcoralbleaching.org