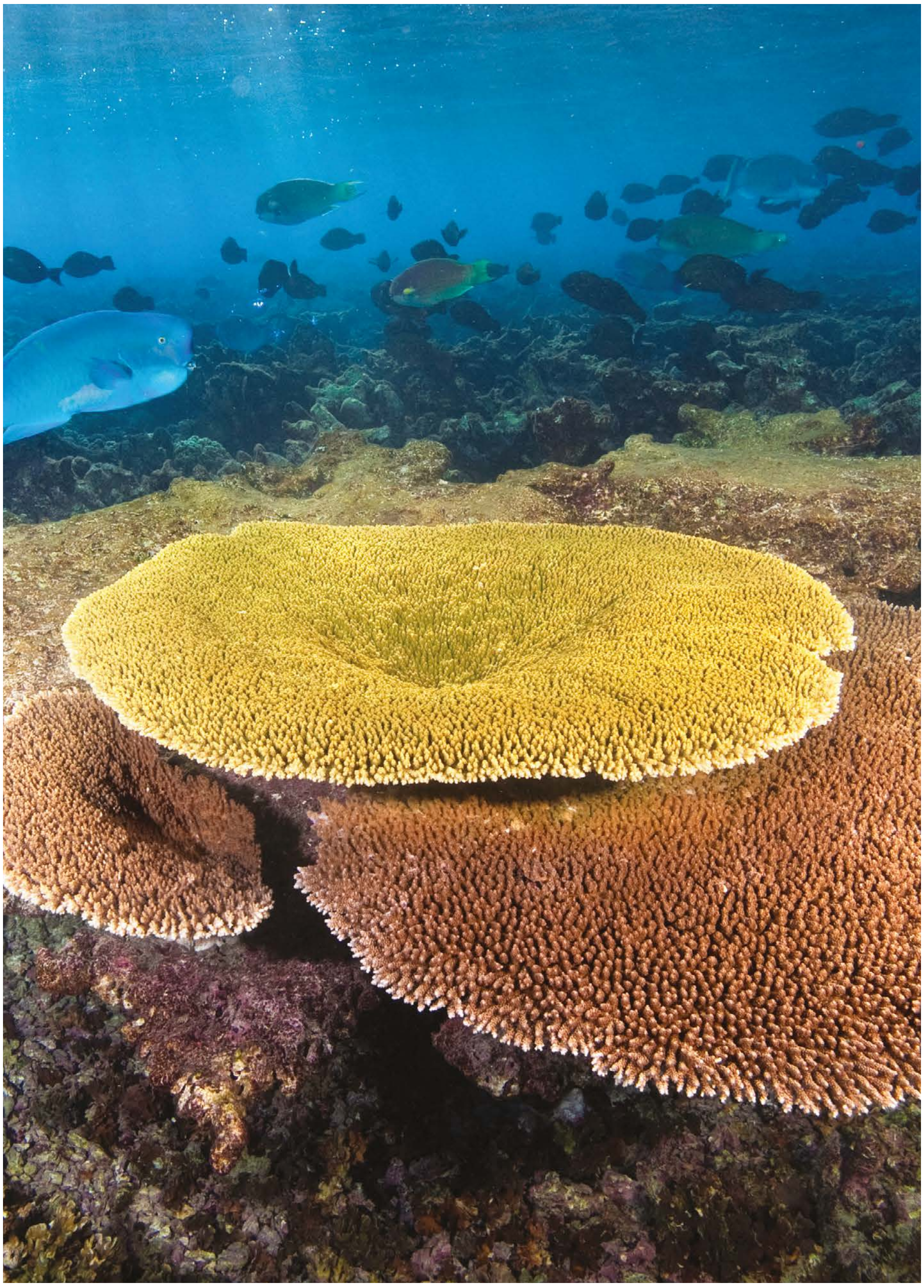

Some coral reefs off the Phoenix Islands in Kiribati seem to be resilient to warming seas.

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HOPE FOR CORAL REEFS

The ocean is warming and reefs are fading. But optimistic marine scientists are working to keep some corals alive until the climate stabilizes. **By Amber Dance**

Anne Cohen dropped into the ocean off the coast of the Phoenix Islands expecting to find desolation. It was 2018, and a powerful El Niño weather system two years earlier had warmed the waters around this mid-Pacific atoll by nearly 3 °C. Coral reefs simmered in the heat.

Such feverish temperatures cause the tiny animals that make up a reef to expel the colourful, symbiotic algae that nourish them. They bleach, starve and die. On her expedition to the islands, part of the nation of Kiribati, Cohen found greyish reefs in which almost 70% of corals had expired.

But she also found reason for hope.

"We'd come across these areas, I'm talking about several square kilometres, with super-high coral cover and super-high coral diversity," recalls Cohen, a marine scientist at the Woods Hole Oceanographic Institution in Massachusetts. Healthy taupe coral branches sprouted from a field of blonde and rose plates, while schools of gold-and-magenta anthias fish flitted to and fro.

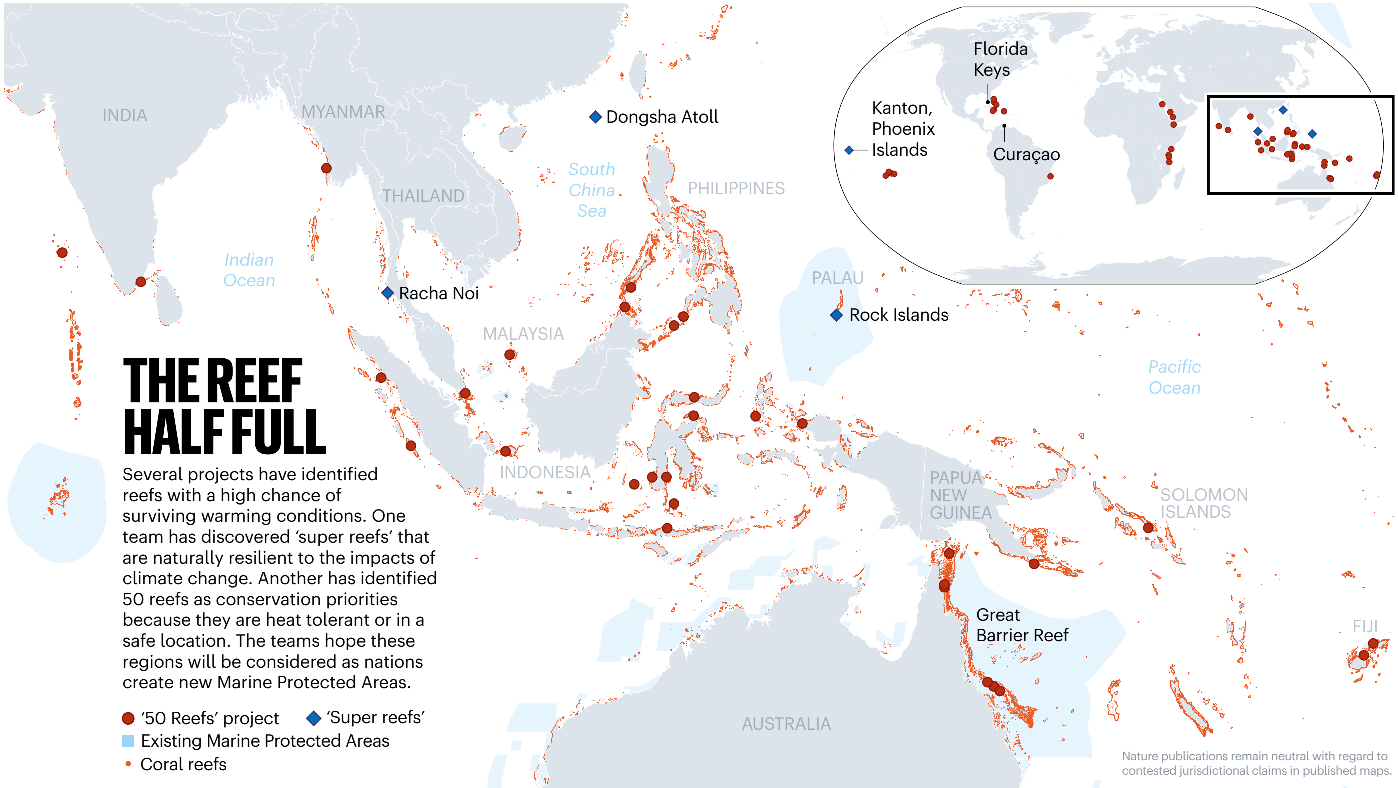
Such places give ocean ecologists hope that even as the climate warms, corals still have a fighting chance. When these scientists hear that 70–90% of reefs could be gone by mid-century, they focus on the 30% that might live. And they're taking action to save those reefs for the future. Around the world, hundreds of millions of people depend on reefs for food, tourism income and protection from ocean storms.

Researchers and conservationists are testing many strategies to help corals. Some approaches — such as breeding or genetically manipulating corals to tolerate climate change, or sprinkling reefs with beneficial microbes[1] — have yet to prove themselves outside of the laboratory.

But scientists are already trying out other ideas in the wild: growing and replanting corals in damaged reefs, for instance, and helping them to breed. And there's another tactic getting attention — finding the reefs that have the best natural chances of survival and helping them to stay alive. There are downsides to both of these approaches, however: breeding is impractical at large scales, and some researchers worry that focusing only on naturally resilient reefs will constrain conservation to a few niche locations.

Conservationists say that it will take a variety of strategies to save coral reefs, but the time is now. "The next decade is really our window," says Lizzie McLeod, who works in reef management at the Nature Conservancy in Alexandria, Virginia.

Half the globe's reefs are already gone. Carbon pollution heats up the ocean and turns it more acidic, making it difficult for the delicate creatures to build their calcium carbonate skeletons. Human activities such as fishing, dredging, pollution and development have



SOURCES: WRI; UNEP; 50 REEFS PROJECT; SUPER REEFS PROJECT: UNEP-WCMC/IUCN: THE WORLD DATABASE ON PROTECTED AREAS

also caused serious harm.

The efforts to save particular reefs are offering some hope, researchers say, but these solutions are only a stop-gap. "Unless we curb carbon emissions, none of this is going to make any difference whatsoever," says Iliana Baums, a molecular ecologist at Pennsylvania State University (Penn State) in University Park.

Helping hands

In the Caribbean Sea, a one–two punch of climate change and disease has hit reefs hard. "The Florida reef tract has been going downhill for the last 40 years or so," says Erinn Muller, science director of the Elizabeth Moore International Center for Coral Reef Research & Restoration at the Mote Marine Laboratory & Aquarium in Sarasota, Florida. "We really haven't seen any natural recovery."

So conservationists from Mote and other organizations are taking matters into their own hands. Over the past several years, the Mote laboratory's reef-restoration teams have planted almost 70,000 pieces of coral from five main species off the Florida Keys. The goal of this project, and others like it around the world, is not to replant reefs entirely, but to provide enough new corals to allow them to reproduce themselves.

Mote's coral nannies start with artificial, ocean-based nurseries. They create tree-like structures by hanging fishing line from buoys and attaching plastic branches. Then they dangle individual corals from those branches.

Once the danglers reach about the size of a basketball, divers carve out softball-sized chunks. Then Muller and her colleagues test the corals, ensuring that some in each batch have the genes to resist dangers such as diseases, heat or acidification, before the restoration crew plants them on the sea floor.

The reef begins to recover within a year, says Muller, and more fish and invertebrates move in. Eventually, the planted chunks will fuse into larger corals. From their experiences with past plantings, the researchers know that the corals will be big enough to spawn within a couple of years.

This works for fast-growing, branching corals. But some mound and boulder corals expand slowly — just a couple of millimetres per year. Mote researchers speed that up by cutting the corals into tiny pieces and affixing them to small, round tiles with stems, like a ceramic flower[2]. In the lab's on-shore tanks, the fingernail-sized fragments grow up to 50 times faster than the full-sized corals, reaching 3 centimetres across in a few months.

To replant them, the restoration team finds a large coral head from which the animals have disappeared but left their limestone skeletons. Divers drill about 20 holes in that dead coral, and poke in the stems of the coral-tile flowers. Eventually, the pieces grow together, 're-skinning' the dead coral and restoring it to spawning in two to three years.

"It's a way to jump-start the reef," says Emily Hall, a chemical ecologist at Mote. The lab places thousands of these coral-flowers every year, says Muller, and typically achieves more than 80% survival.

The microfragmentation approach is promising, says Dirk Petersen, executive director of the coral conservation non-profit organization SECORE International in Bremen, Germany. But he has doubts about re-skinning. The old coral head might have new residents that could harm or compete with the coral-flowers, he says, and organisms that killed the original inhabitants might still be present.

Romancing the reef

Mote, SECORE and others are also helping corals to reproduce. By assisting breeding, reef managers can make not just more corals, but more diverse populations. Some larvae will be heat-tolerant, some resistant to acidified waters. Nature will select those that match a given reef's conditions.

It was in pursuit of this diversity that Baums went to the Caribbean island of Curaçao in August. She and her colleagues from SECORE teamed up with local conservationists to perform *in vitro* fertilization for elkhorn coral (*Acropora palmata*).

The affair began a couple of hours after sunset, under a full moon. Corals spewed their gametes into the water. Sperm and eggs were so thick, they formed a slick on the surface. Baums and the other divers secured nets over the colonies to collect the gametes.

Because gametes are viable only for a few hours, the team had to race to pair up compatible eggs and sperm. "We have used a bench on the beach as an improvized laboratory," says Petersen. The low-tech lab can boost fertilization rates to 90% or higher.

Then, SECORE placed the embryos in the nursery, a floating pool in the sea that is protected from predators. A few days later, larvae settled on 3D-printed, starfish-shaped structures. When the corals reach about fingernail size, divers will wedge these substrates into the crevices of needy reefs. Petersen says this approach has also been tested in reefs off Mexico, Florida, the Bahamas, the Dominican Republic, Bonaire, Australia, Palau and Guam.

Although these restoration measures are beneficial in deeply damaged reefs, they are difficult and costly to deploy at scale. Consider Australia's Great Barrier Reef, which is close to the size of Italy. Heatwaves in 2016 and 2017 bleached half the corals. Although some restoration is happening, surviving corals in larger areas have to help themselves, says Terry Hughes, director of the Australian Research Council Centre of Excellence for Coral Reef Studies at James Cook University in Townsville. "Billions of tougher corals survived, and they're breeding."

Come hell or hot water

Fortunately, the Great Barrier Reef's neighbourhood is better off than the Caribbean's. "The Indo-Pacific is still in great shape," says Emily Darling, a conservation scientist at the Wildlife Conservation Society in Toronto, Canada.

In August, a large team led by Darling published an analysis of 2,584 Indo-Pacific reefs[3]. The good news is that 86% of those reefs were dominated by large species such as branching, plating and boulder corals, the types that create fish habitats and shield shorelines from storms.

The bad news is that these species are also the most sensitive to heat.

Darling and her colleagues identified a group of almost 450 reefs that had been affected very little by recent warming events and had retained more than 10% coral cover — the minimum at which the reef can build more skeleton than it's likely to lose (but still well below the area's coral cover in decades past). "Right now, I would really target those to save," says Darling.

Cohen, too, is on a quest to find resilient reefs and make sure they are protected in her Super Reefs project (see 'The reef half full').

Her team has found three ways in which reefs beat the heat. Some corals live in naturally warm environments and are genetically adapted to deal with scorching temperatures. For example, reefs off Palau's Rock Islands withstood major heatwaves in 1998 and 2010. In the nearby barrier reef, where the water is typically cooler, coverage dropped to 5–6%. Other reefs are simply lucky in location. Some benefit from cold currents that protect them from hot spells[4]. Others are served by currents that provide a constant plankton buffet. Even if they bleach, these corals remain well-fed and survive.

"So far," says Cohen, "most of the super reefs we've found have been by accident." To find more, she's using hydrodynamic modelling of currents to identify likely spots, and developing underwater robots that can identify areas with living corals and hover over them to gather data. "I'm convinced there are super reefs in most places," she says.

The next step will be to protect them. For example, Cohen is working with the Nature Conservancy and the government of the Marshall Islands to identify resilient reefs in the nearby waters, and to ensure that the nation includes some of these corals in any new marine protected areas.

Another researcher on the hunt for resilient reefs is Ove Hoegh-Guldberg, a marine scientist at the University of Queensland in Brisbane, Australia. He borrowed an algorithm from the world of finance to find them.

Investors want a diverse portfolio that balances risk and reward. Hoegh-Guldberg joined forces with other coral specialists and economists to apply the same logic to the world's reefs. For example, being in the predicted path of cyclones might put a reef at high risk, but having good tolerance for climate change, or being well-connected to other reefs that could need re-seeding, would give it a high benefit profile.

"I'm convinced there are super reefs in most places."

Considering 30 such factors, the group identified 50 ocean regions scattered throughout the tropics, each about 500 square kilometres, as conservation priorities[5]. If the rest of the world's reefs are wiped out, these reefs might be able to kick-start repopulation, assuming the climate stabilizes, Heogh-Guldberg says.

Some find the idea of singling out survivors troubling. "I hope it doesn't come to the point that we have to pick and choose one reef over another," says Hall. "I think all reefs are important."

Mónica Medina, a coral-reef biologist at Penn State, called the idea of relying on naturally robust corals "dangerous" at an October meeting of science writers held at her university. Corals that are resilient in one habitat might not thrive elsewhere, she pointed out, and the idea can lull people into thinking that reefs don't need other assistance.

Both Heough-Guldberg and Cohen stress that they don't intend for only these special reefs to receive conservation attention. In his '50 Reefs' project, Heogh-Guldberg is simply hedging his bets by identifying some promising targets. "You have a good chance of winning, no matter what."

Social science

In one of his 50 regions, off Madagascar, the wildlife charity WWF is helping protect a beautiful reef. Broad table corals rise in layers, and sea turtles prowl the clear waters. Although there are some signs of bleaching from past stress, the reef has mostly recovered, says Gabby Ahmadia, a marine conservation scientist with the WWF in Washington DC. But there aren't quite as many fish as there ought to be.

The way to solve that fish deficit is as much about local people as it is about marine ecology, she says. Conservation groups have helped locals to set up boutique tourism. The Nosy Hara marine national park pays community rangers to keep an eye on the corals. Fishers across Madagascar teach each other protective practices.

Conservationists are applying similar strategies in several places, customized to the people and the environment. It's societal action, not biology, that will ultimately save reefs, Hughes says. "They'll die again if we don't first fix water pollution, overfishing and ever-rising emissions."

Nonetheless, conservationists cling to hope for the future — albeit tempered with realism. "I think we can resolve this crisis," says Petersen. "I'm also sure that reefs will look different than they do now." Coral ecologists might have to sacrifice species diversity to rescue the whole ecosystem. Petersen compares future reefs to modern, managed forests, which host a narrower mix of trees than untouched forests, but still provide habitats for wildlife and help to cleanse water and air.

Another reason for hope is that reefs have made it through other challenges. Reef-building corals are part of a lineage that is more than 400 million years old. They've endured global water temperatures that have swung between 10 and 32 °C, and carbon dioxide levels up to quadruple those of today. But they've never before had to endure such rapid warming.

The current pace of climate change could stretch corals beyond their adaptive limits. Even if nations succeeded in limiting global warming to 1.5 °C above 1990 levels, the target of the 2018 Paris agreement, 70–90% of reefs would be lost, according to the Intergovernmental Panel on Climate Change. And that target is looking more and more unrealistic. If the climate warms by 2 °C, the panel projects[6] losses of greater than 99%.

Still, researchers are confident that with human assistance, and a global drop in emissions, reefs can rise again. "Corals 'know' how to recover, they know how to regenerate themselves," says Hoegh-Guldberg. "Corals are almost made for this."

Amber Dance is a freelance writer in Los Angeles, California.

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