Fragile beauty. Palau's marine protected areas aim to safeguard corals from bleaching.

PALAU COMBATS CORAL BLEACHING

BABELDOAB, PALAU—A giant clam's purplish-green intake valve, big enough to swallow a fist, snaps shut when a diver drifts close. The magnificent meter-wide mollusk in Ebiil Channel is a symbol of survival, whereas a beige, 2-meter-wide table coral nearby is a vivid example of rapid recovery. In the summer of 1998, unusually warm ocean temperatures killed a third of the reefs ringing this tiny archipelago in the western Pacific. But here in the Ebiil Channel Conservation Area off Babeldoab, Palau's main island, underwater denizens have roared back to life with exceptional vigor.

Ebiil's inspiring comeback is the basis for an ambitious experiment. The Nature Conservancy, a U.S. nonprofit, is helping Palau establish the world's first national network of marine protected areas (MPAs) aimed at thwarting bleaching, a phenomenon in which warm ocean waters trigger corals to expel symbiotic algae and starve (see main text). Some corals can resist or recover from bleaching. The Palau network intends to safeguard the hardier varieties—and offer some immunization against future bleaching events as global temperatures rise.

"It's not a new idea, but they are the first to go through with it, and that's great," says Charles Birkeland, a coral specialist at the University of Hawaii, Manoa. "Just limiting fishing isn't going to save our reefs. We need extra protection for the ones that are resisting bleaching, so they can serve as a brood stock for recovery."

Long before the nightmare of '98, Palau had built an impressive record in marine stewardship. The country boasts one of the highest proportions of territory set aside for MPAs in the world, with about a third of its near-shore waters—1300 square kilometers of reefs and lagoons—under varying fishing restrictions. Other Pacific nations are following Palau's lead: In the past decade, the number of MPAs grew from two to 189 in Fiji and from one to 20 in the Solomon Islands. "One village closes fishing in an area, the fish come back after a few years, and soon the next village wants one too," says Michael Guilbeaux

fewer coral species is hardly a 'win.' " Coral abundance is still plummeting, and even resistant corals may succumb in a warmer world, he says. "As climate change accelerates, we will lose an increasing number of coral species, making ecosystems less resilient to other pressures."

A case in point is the widespread bleaching in the Caribbean Sea in 2005–06. At one reef off St. John, part of the U.S. Virgin Islands, "before people knew it, a disease infected the coral that had survived the bleaching. What was left was totally wiped out," Strong says. "You can see how this gets to be a multiheaded monster." NOAA and U.S. National Park Service scientists are now searching for clues to why some corals survived whereas others perished.

In an attempt to boost reef survival, governments have been setting up MPAs, which range from free-for-all recreational parks to no-take zones that bar fishing. Fewer than 3% of the world's reefs lie inside no-take MPAs, says Mora. Many reefs are being fished out. Raising the specter of a pending food crisis, a recent study found that 27 of 49 island countries are exploiting their reef fisheries in an unsustainable way, reports a team led by Nicholas Dulvy of the Centre for Environment, Fisheries, and Aquaculture Science in Lowestoft, U.K., in the 3 April issue of *Current Biology*.

Lax enforcement and lack of local buy-in have undercut many MPAs. "If communities are not involved, they are very unlikely to support an MPA imposed on them," says

Morning commute. Kim Obermeyer (*far right*) leads Earthwatch volunteers on an inspection of a tsunami-damaged reef in the Andaman Sea.

Obermeyer, coordinator for Reef Check Thailand. With volunteers from Reef Check and a second nonprofit, Earthwatch, Obermeyer endeavors to involve villagers—and here near Khura Buri, the Ranong Coastal Resources Research Center of Kasetsart University—in reef monitoring. "This is the only way to succeed," he says.

MPAs and measures such as stanching sewage and runoff cannot prevent bleaching. But resilience—the capacity of a reef to absorb recurrent bleaching and still function—*can* be enhanced, Hughes says. In 2002, more than half of Australia's 40,000-square-kilometer Great Barrier Reef bleached. Two years later, Australia created the world's largest no-take zones, extending fishing bans covering 4.6% of the reef to more than 33%. "This initiative provides real insurance cover against the inevitable impacts of climate change," says Hoegh-Guldberg.

To test this approach, Hughes and colleagues caged some reef sections and left others open to grazing by parrotfish, known by their fused, beaklike teeth. Polyps reestablished on open reef three times faster than on caged sections, they report in the 20 February issue of *Current Biology*. The study shows that reef management after bleaching "has a big effect on the recovery

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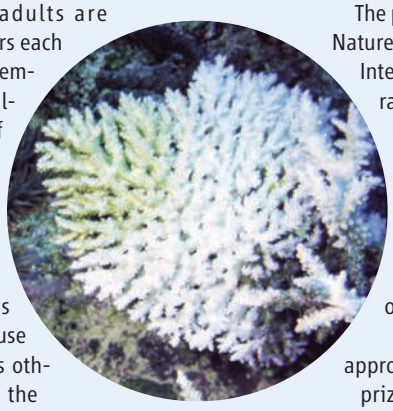
of the Community Conservation Network in Honolulu, Hawaii.

Palau got off to a flying start thanks to a traditional culture that frowns on overfishing and a leader who champions MPAs. "The best way to protect our natural heritage is to use it as a source of income," President Thomas Remengesau Jr. told *Science*. "Tourism is the sustainable thing for us." Palau's prosperity—nearly all adults are employed—comes largely from its 50,000 tourist divers each year. Reefs vibrant with fish are a top priority. Last November, Remengesau sought to export that credo by challenging the rest of Micronesia to set aside 30% of near-shore waters for protection by 2020.

Even for conservation-minded Palau, the massive 1998 bleaching event, which decimated reefs around the world, was a wake-up call. Three-quarters of barrier reef corals at Palau's Rock Islands lagoon, a popular diving site, perished. Ebiil, another barrier reef, was 98% destroyed. Inshore, many reefs fared better because they are accustomed to higher temperatures, whereas others survived because turbid waters and shade limited the sun's damage, says Rod Salm, a marine scientist in the Conservancy's Honolulu office who developed the bleach-resilience project.



Burnt by the sun. Bleaching signals severe stress.

A critical insight led to a bold plan. Most reefs like Ebiil that have bounced back from bleaching are down current from reefs that suffered little, suggesting that coral larvae and fish from healthy reefs fueled the rapid recovery, Salm says. With that in mind, Noah Idechong (pronounced Idda-ONG), founder of the Palau Conservation Society, and others proposed weaving the nation's hodgepodge of MPAs into an ensemble, linked by currents, called the Protected Areas Network. "The key is to protect all the different reef types that survived bleaching or recovered exceptionally fast, because they will provide the larvae that will help damaged areas recover," says Salm. "These reefs don't necessarily have the fish density that would make fishermen want to protect them."

The proposal resonated with Western donors. In 2005, The Nature Conservancy pledged $2 million, and Conservation International $1 million, to a trust, provided that Palau raises $9 million from other sources—which should not be a problem, says Eric Verheij, acting director of The Nature Conservancy's Palau office. The endowment's interest, along with a diver tax, should yield $2.1 million a year for monitoring and antipoaching patrols. Idechong says he expects that the network, with one-third more area under protection than now, will be operational in 2 years.

Ebiil's rainbow reefs testify to the promise of that approach. Gliding past 2-meter strands of black coral, so prized by jewelers that it has been wiped out in many parts of the Pacific, Verheij zeroes in on what appears to be lifeless coral rubble. On closer inspection, the coral skeleton has been melded together by coralline algae and is studded with young polyps: a nursery of tiny phoenixes rising from the ashes of bleaching. Back on the boat, Verheij explains his philosophy. "Since you can't protect everything," he says, "you try to protect the healthiest." That philosophy seems to be paying off in Palau.

–CHRISTOPHER PALA

Christopher Pala is a writer based in Honolulu, Hawaii.

rate," Hoegh-Guldberg says. But the strategy works only in the short run; nations must move rapidly to stem greenhouse gas emissions, he says. "It is next to useless not to do the two things together."

A mortal blow?

Until bleaching reared its head, many experts viewed rising sea levels as the chief peril of global warming for coral—and a relatively toothless one at that. "We thought reefs would respond by just growing higher," says Strong. "Nobody was talking about changing sea chemistry." Then researchers came to the creeping realization that rising ocean acidity is likely to throw a spanner in coral physiology.

The threat is glaringly simple. Currently, ocean pH hovers around 8.1. Carbon dioxide absorbed into the water column lowers the pH, and as it falls, fewer carbonate ions are available for shell-building critters to grab. Even in present conditions, corals are fighting an uphill battle: Erosion removes 80% of the calcium carbonate laid down. Acidification will accelerate that process as rising carbonic acid levels deplete carbonate. Eventually, corals, plankton, and other organisms will fail to form skeletons. And coral skeletons are to reefs what girders are to skyscrapers. "You have a potential world in which reefs and the limestone frameworks they have built are in net erosion," says Hoegh-Guldberg.

IPCC scenarios of global emissions and ocean circulation indicate that by mid-century, atmospheric CO_2 levels could reach more than 500 parts per million, and near the end of the century they could be above 800 ppm. The latter figure would decrease surface water pH by roughly 0.4 units, slashing carbonate ion concentration by half, paleocoral expert C. Mark Eakin, coordinator of NOAA's Coral Reef Watch, testified last month at a hearing in the U.S. House of Representatives. Ocean pH would be "lower than it has been for more than 20 million years," he said. And that does not factor in possible acidification from carbon-sequestration schemes now being considered.

Some coral species facing their acid test may become shape shifters to avoid extinction. New findings indicate that corals can survive acidic conditions in a sea anemone–like form and resume skeleton-building when returned to normal marine conditions (*Science*, 30 March, p. 1811). However, by pH 7.9, says Caldeira, "there would be a good chance reefs would be gone."

The potential for an acid-induced coral cataclysm has cast a pall on the tight-knit community of reef specialists. "The reality of coral reefs is very dark, and it is very easy for people to judge coral reef scientists as pessimists," says Mora. "We're becoming alarmist," adds Strong—for good reason, he insists. "How are reefs going to handle acidification? It's not like sewage or runoff, where you may be able to just turn off the spigot." Queensland's Pandolfi, however, argues that it's "too early to make really definitive doom-and-gloom statements."

No one disputes that urgent action on greenhouse gas emissions is essential. "We could still have vibrant reefs in 50 years time," Hughes says. But these will not be the reefs we know today. "They will be dominated by a different suite of species," says Hughes, who notes that the shakedown is already under way.

More likely, steps to rein in emissions will be too little, too late—and the world will have to brace for the loss of reefs. In Southeast Asia, says Hoegh-Guldberg, the threat of millions of people losing their livelihoods must be factored into policy planning. Coastal dwellings throughout the tropics will have to be strengthened against higher waves. Then there is the intangible, aesthetic deprivation if coral reefs wither and wink out. "Without their sheer beauty," Hughes says, "the world would be an impoverished place." **–RICHARD STONE**

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