CORAL | THE REEF & MARINE AQUARIUM MAGAZINE

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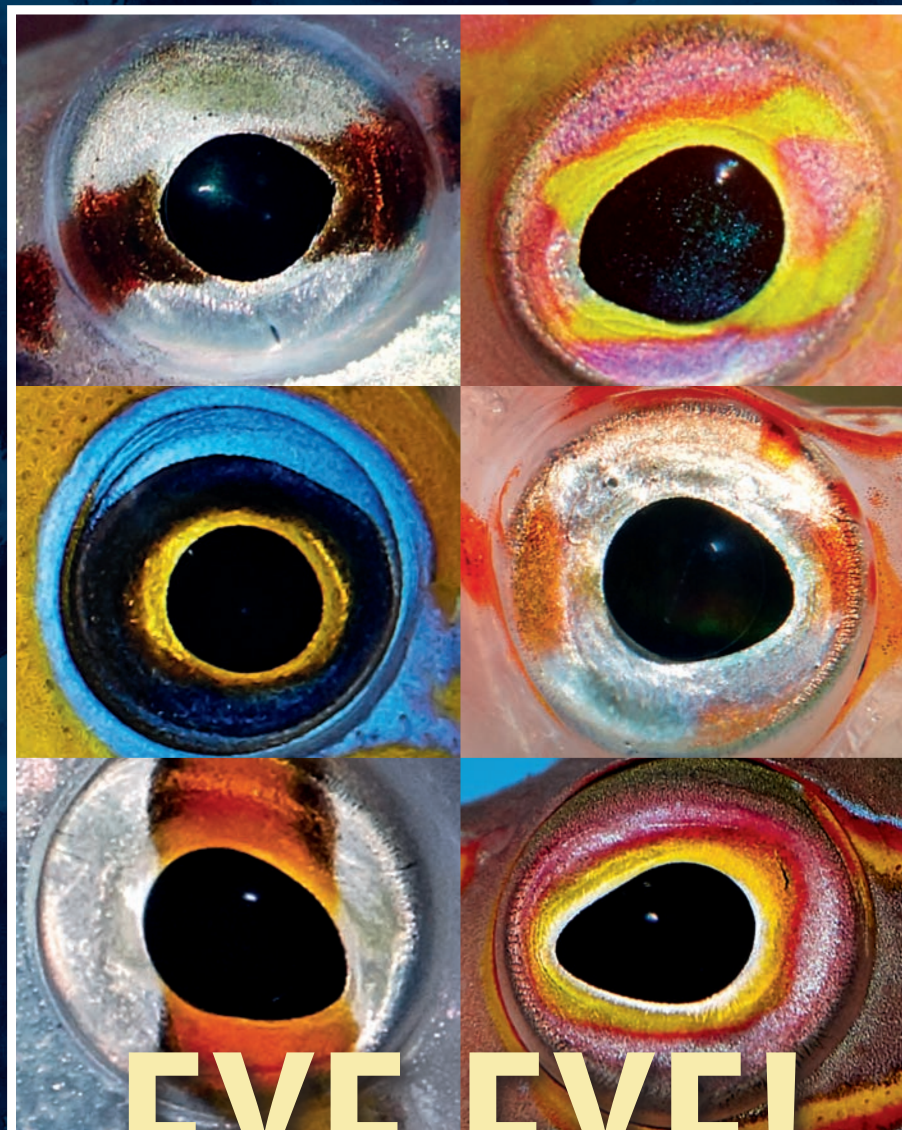


EYE EYE!

Looking at the astonishing vision of marine animals

- **Rule-Bending Reef**
- **Boxfish Bonanza**
- **Thermoplastic Fragging**

SEPTEMBER/OCTOBER 2017

REEF STEWARDSHIP |

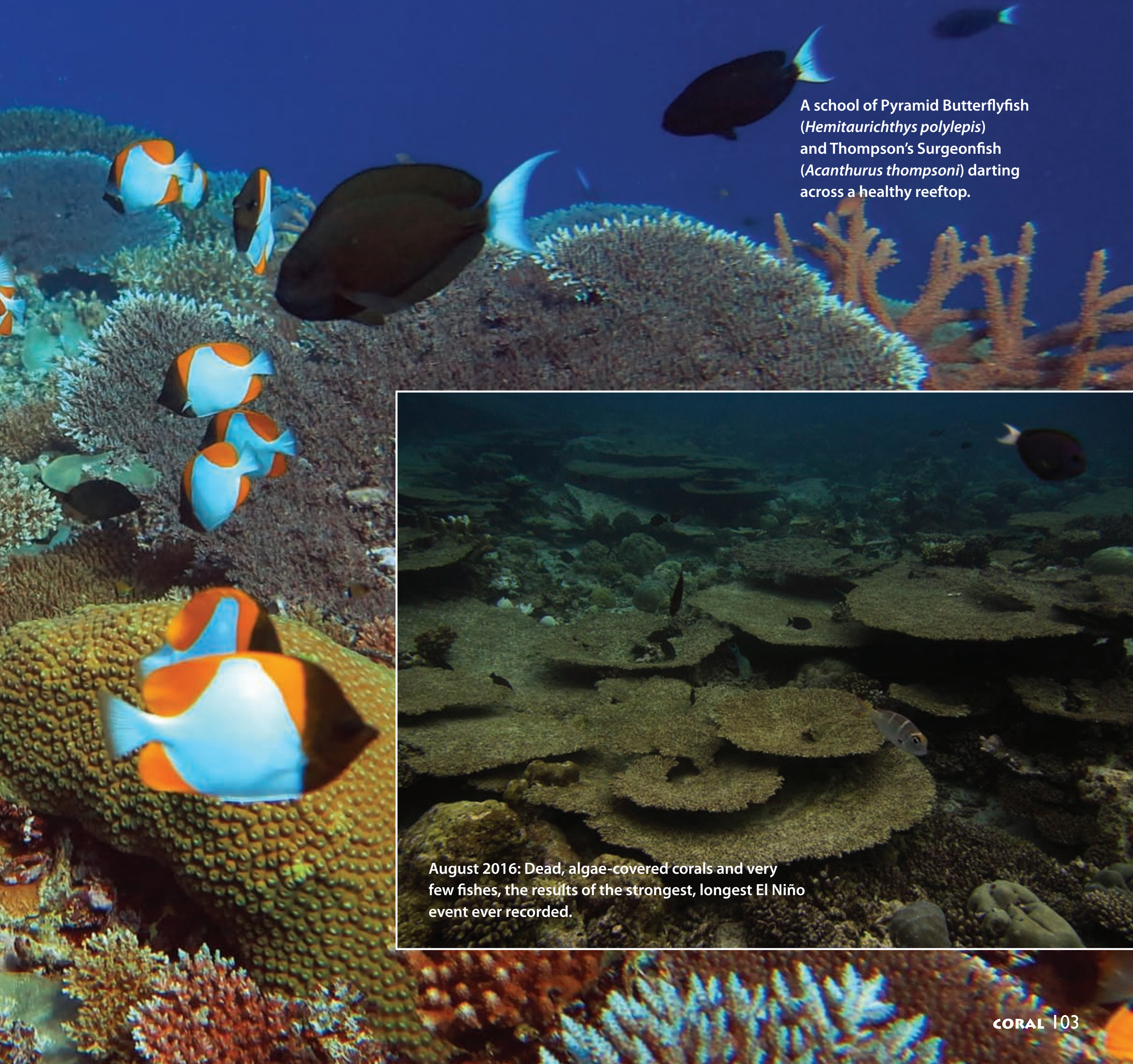
GEORGIA COWARD & ANDREW BRUCKNER, PH.D.

Corals in Crisis

Do we have the willpower to save them?

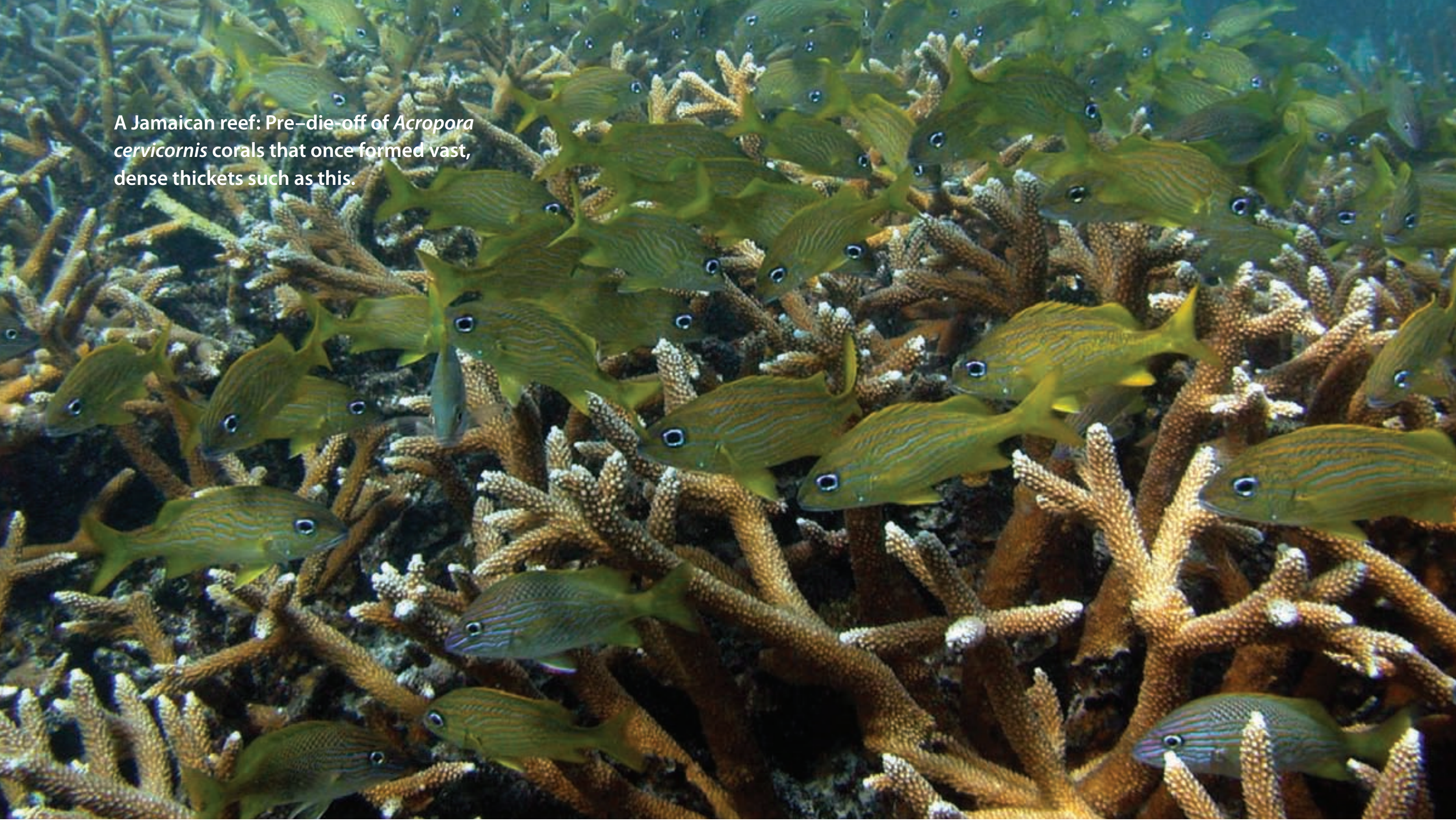
ALL: A. BRUCKNER, PH.D.

Current predictions using global climate models suggest that severe bleaching will occur annually on 99 percent of reefs worldwide within this century if we fail to reduce greenhouse gas emissions, while some locations will start to experience annual bleaching by 2043. Are there ways we might still save the reefs?



A school of Pyramid Butterflyfish (*Hemitaurichthys polylepis*) and Thompson's Surgeonfish (*Acanthurus thompsoni*) darting across a healthy reeftop.

August 2016: Dead, algae-covered corals and very few fishes, the results of the strongest, longest El Niño event ever recorded.



A Jamaican reef: Pre–die-off of *Acropora cervicornis* corals that once formed vast, dense thickets such as this.

The Jamaican reef today: Fish populations are sparse, and the remaining corals are struggling. Some hope that restoration is possible.

Forty years ago, during my first dive trip to the Caribbean, reefs still displayed the classic zonation patterns described in 1959 by Tom Goreau. Large spurs sloped gradually from the reef crest into deep water. Dense thickets of Elkhorn Coral (*Acropora palmata*) covered the tops of the spurs, extending from just below the water's surface to about 16 feet (5 m) deep, while the sides were constructed of massive star corals (*Orbicella* [formerly *Montastraea*] *faveolata*). These mountainous structures were 10–15 feet (3–5 m) or more in diameter, centuries old, and often had coalesced with neighboring colonies to form an extensive cave system. Monospecific stands of Staghorn Coral (*Acropora cervicornis*) began at the bases of the spurs and continued along the coastline as far as the eye could see. On the deeper reef, foliaceous and sheeting agaracids and other species covered 60 to 70 percent of the sea floor, extending down the slope well beyond diving depths. In early literature, this was described as a climax community.

CHANGES IN THE CARIBBEAN REEF SYSTEM

The reefs of Jamaica, which were the most thoroughly studied at the time, had already begun to experience changes when I first began diving. Although the coral community was flourishing, intense fishing pressure since the 1950s had depleted the top predators; grouper and snapper were uncommon. Fishermen were targeting parrotfishes using small-mesh fish traps, and the size and density of these fishes were also in decline. The effects of overfishing on the corals and the reef system as a whole were not yet apparent, largely because populations of Long-Spined Sea Urchins (*Diadema antillarum*) had expanded and were occupying the critical niche of herbivores, keeping macroalgae under control. During the 1980s, these reefs experienced a rapid phase shift from coral to macroalgae as a result of a disease that quickly eliminated most of the *Diadema*, several severe hurricanes, and chronic outbreaks of White Band Disease (WBD) that led to the demise of the acroporids. By 1985, the reef was a graveyard of Elkhorn and Staghorn Coral skeletons, and the few survivors were under attack by coral-eating snails (*Coralliophila abbreviata*).

Concerned about the dramatic changes I witnessed in Jamaica, I began to look at the impact of disease, coral predators, and hurricanes in other Caribbean localities. Everywhere I dove, the acroporids were disappearing, and reefs that experienced heavy fishing pressure also began to succumb to overgrowth by macroalgae. I also observed the first two Caribbean-wide bleaching events (1982–1983, 1987–1989), but fortunately the corals mostly recovered.

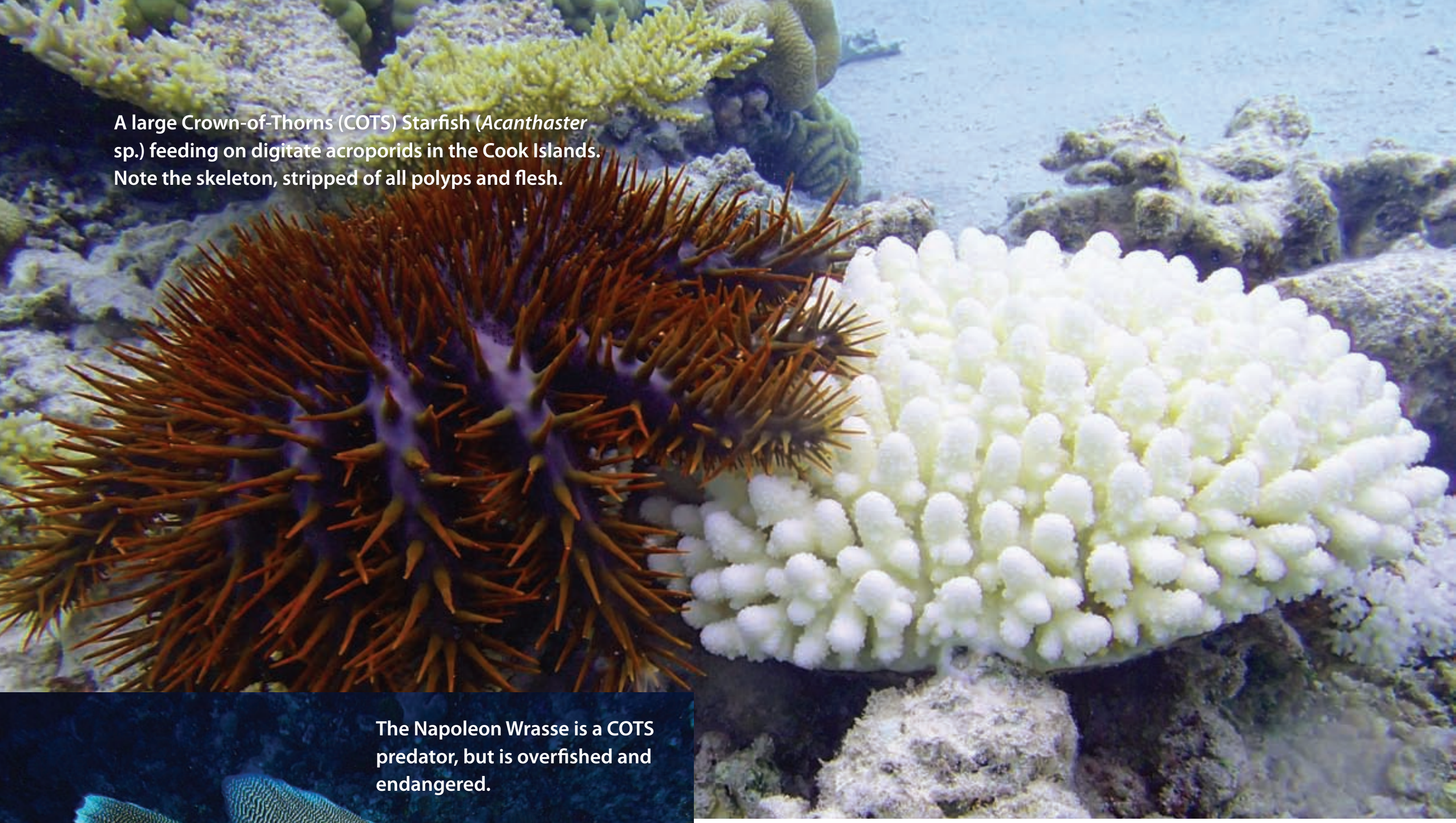
The deleterious impacts of bleaching were not fully understood until the mid-1990s, when we began to link these events to abnormally high seawater temperatures. Concurrently, this decade was marked with the emergence of new coral diseases. In 1995, I documented the effect of two particularly virulent diseases, White Plague and Yellow Band Disease, which emerged after a mass bleaching event. Unlike WBD, these diseases targeted massive corals, especially the star corals (*Orbicella* spp.), which were the dominant and most important frame-building corals on these reefs. Through subsequent mass bleaching events in 1998, 2005, and 2009–2010, Caribbean reefs exhibited a stepwise decline, but the timing of coral loss varied between locations. The Eastern Caribbean was most affected following the 2005 bleaching event, mainly due to outbreaks of White Plague and the rapid death of many of the largest remaining star corals. Between 2009 and 2010, I noted a similar pattern of coral loss in the Cayman Islands, Belize, Curaçao, Bonaire, and other locations. These reefs bleached and began to recover; however, shortly after the corals regained their symbiotic algae (*Symbiodinium*), outbreaks of disease spread throughout the reefs. By 2010, coral cover had declined to less than 15 percent on most reefs in Florida, the Bahamas, and the Caribbean.

As Caribbean reefs have experienced catastrophic losses of coral, resource managers and conservation groups have implemented numerous strategies and programs to abate the crisis. Some of the challenges include the high population density within a relatively small ocean basin and the related unsustainable coastal development, land-based pollution, and continued intensive fishing pressure. Nevertheless, even remote Caribbean reefs far removed from direct human activity have suffered large losses of corals as a result of climate change–related stressors, such as elevated water temperatures and increased storm frequency and intensity. Consequently, both bleaching and coral disease have grown in severity. Surely the difficulties in reversing negative trends should have served as a lesson to us?

INDO-PACIFIC AND RED SEA

I began working in the Pacific in 1997, one year before what would turn out to be the most severe bleaching event recorded at that time. I had been asked to assist the international community in addressing the perceived threat of the aquarium trade. I joined coral and sea cucumber fishermen in Indonesia, where I surveyed the health of the reefs and evaluated impacts from localized harvest. At first, I was overwhelmed by the diversity of species and the high coral cover, based on my experiences in the Caribbean. Although coral-collecting fishermen were removing over a million colonies per year from reefs in Indonesia, the coral seemed endless, and many of the other stressors were much more destructive. Diving within a national park in Bali, I was shocked at the number of explosions I heard and felt while underwater. Using homemade bombs to capture fishes, “blast fishermen” were turning large areas of reef track to rubble, and dead fishes littered the sea floor.

While it was apparent that densely populated areas in Indonesia, the Philippines, and elsewhere in southeast Asia were exposed to high stress from the pressures of human populations, 1998 provided the first evidence that climate change has the potential to cause global changes to coral reefs. Throughout much of the Pacific and Indian Oceans, an unusual El Niño event triggered widespread bleaching; by the time the waters cooled, many reefs had lost most of their coral. Reefs I surveyed around Fiji and neighboring central Pacific locations appeared to have escaped the worst effects, but two years later they suffered a similar fate, and most of the shallow-water branching corals died.



A large Crown-of-Thorns (COTS) Starfish (*Acanthaster* sp.) feeding on digitate acroporids in the Cook Islands. Note the skeleton, stripped of all polyps and flesh.

The Napoleon Wrasse is a COTS predator, but is overfished and endangered.

Over the next decade, the reefs exhibited a slow but progressive recovery as corals rebounded. Many returned to their pre-1998 baseline, although this was not always the case for reefs that were near urban centers—the pressures of human habitation continued to rise.

Beginning in 2008, I embarked on a six-year Global Reef Expedition (GRE). My task during this mission was "simple": identify the healthiest and most resilient reefs, as well as tangible actions that countries could take to reverse the coral reef crisis. Working with coral reef experts from universities and government agencies and local scientists, I dove on more than 1,000 reefs in 22 countries. One of my most unexpected findings was that the condition of reefs varied dramatically, both between and within individual countries. We found a mix of healthy, diverse sites with high coral cover and abundant fish populations, but neighboring areas a few kilometers away could be badly degraded. These differences were often apparent within individual reef systems, even in remote locations with an absence of direct human pressures.

CROWN-OF-THORNS THREATS

One of the most widespread causes of coral loss in every country I visited was the Crown-of-Thorns Starfish, or COTS (*Acanthaster planci*). The harmful effects of these starfish have been recognized for decades, but outbreaks appear to be increasing in frequency and severity. Historically, these starfish feed on fast-growing corals, such as *Acropora* and *Montipora*, and recovery once the COTS disappear can be relatively quick. But I was alarmed when I identified many locations that had lost most of the fast-growing corals during previous outbreaks, and the starfish had re-invaded and were consuming the long-lived boulder corals, including *Porites* and other less-preferred species. Entire reef systems in French Polynesia (Society Islands and Austral Islands) and the Cook Islands had been destroyed a decade before my arrival, yet minimal recovery had occurred and secondary outbreaks were underway on neighboring atolls.

The reefs of Australia and Japan have the longest history of Crown-of-Thorns damage; persistent outbreaks have occurred over the last four decades. In fact, the Great Barrier Reef lost 50 percent of its coral cover between 1985 and 2012, and nearly half of this was attributed to Crown-of-Thorns. Given the voracious diet of these corallivores, the appearance of hundreds of thousands of starfish during outbreaks, and their potential to eliminate most corals from an affected reef—combined with the occurrence of COTS outbreaks in every Indo-Pacific country I examined during the expedition—I believe that this is the second-greatest threat facing these reefs today. COTS population explosions have been found to correlate with overharvesting of predatory fish species and deforestation, which allows nutrient runoff to enter coastal waters, fueling the growth of the phytoplankton on which the starfish larvae feed.

GLOBAL BLEACHING

A general consensus among most coral reef scientists, myself included, is that global climate change remains the largest threat to coral reefs worldwide. We have recently witnessed the third and most significant global bleaching event, far exceeding the impacts of both the 1998 and 2010 global events. Heat stress caused by a severe El Niño event, the first ever to last for two years, triggered bleaching on reefs that have never before bleached, and some reefs bleached three years in a row. The event began in the North Pacific in 2014, and reefs around the main Hawaiian Islands, Guam, CNMI, and the Marshall Islands exhibited extensive bleaching. This was followed by reefs in the Florida Keys, Bahamas, and wider Caribbean in August and September 2014, and again in September and October 2015. Following the onset of the 2015–2016 El Niño, warm water masses spread to the Central Pacific and Southeast Asia during the first half of 2015, causing severe bleaching around Fiji, PNG, Kiribati, and the Samoas; mass bleaching was also recorded in parts of the Indian Ocean. By October, one-third of the world's reefs were exposed to abnormal thermal stress and widespread bleaching was reported from the Pacific, Indian, and Atlantic Ocean basins.

From January to May 2016, thermal stress and bleaching occurred again in the southern hemisphere, and reports of bleaching extended from French Polynesia to the Northern Great Barrier Reef, New Caledonia, Fiji, Tanzania, and the Maldives. Water temperatures cooled in most tropical areas in 2017, but the Great Barrier Reef experienced its second consecutive year of bleaching, and reports came from areas that were not affected in 2016.

Prior to the onset of the 2015–2016 El Niño event, my new non-profit organization, Coral Reef CPR, established permanent sites to document and monitor changes to Maldivian reefs. We recorded temperatures that exceeded their normal annual maximum throughout the months of March and April 2016, climbing to 90°F (32°C) in exposed fore reef communities and up to 95°F (35°C) in lagoonal reefs, with no relief to 100 feet (30+ m) deep. Compounding the temperature stress, the region experienced doldrum-like conditions with an absence of wind, a breakdown of water currents, and crystal-clear visibility, all of which dramatically increased photo-oxidative stress to the corals. Branching pocilloporids were the first to bleach in early March, followed by the acroporids. Plating, foliaceous, and massive corals resisted bleaching initially, but by early May nearly every coral was bleached and many began to die. By the time the water cooled, most table *Acroporas*, staghorn corals, and other branching and foliaceous species were dead and carpeted in turf algae. Many of the boulder corals survived, but they lost large portions of their tissue. Coral death extended to depths of over 100 feet (30 m).

There is now a general consensus that the 2015–2016 El Niño bleaching event was the longest, most widespread, and most damaging on record. Nevertheless, conditions are expected to worsen in the future. Current predictions using global climate models suggest that severe bleaching will occur annually on 99 percent of reefs worldwide within this century if we fail to reduce greenhouse gas emissions (RCP8.5*), while some locations will start to experience annual bleaching by 2043.

Bleaching in large table acroporids, the corals most affected during the 2016–2017 El Niño event.

Healthy large table acroporids host thousands of organisms large and small.

Thriving plates of *Merulina* sp. large-polyp corals on a still-pristine reef.

ity of corals to rebound through novel restoration programs may provide reefs with the capacity to adapt to climate change.

ECOSYSTEM LINKAGES

During the Global Reef Expedition, we surveyed reefs using a holistic approach that incorporated corals and other invertebrates, reef fishes, and substrate characteristics to better understand factors and processes that control the health and resilience of reefs. In densely populated areas, signs of overfishing were usually apparent, and some of the changes we observed could be attributed to the depletion of certain target species. For example, on Caribbean reefs where herbivorous parrotfishes were absent, reef communities were dominated by turf algae and fleshy macroalgae. The rare occurrence of macroalgal overgrowth of corals in Indo-Pacific locations could be attributed to the higher number and biomass of herbivorous species, and it became clear that functional redundancy was important in areas where certain species were targeted by fishermen. More commonly, many of the top predators, notably sharks, were uncommon near urban centers, and the loss of these apex predator species had cascading impacts on lower trophic levels. What was surprising was our finding that even many of the very remote coral reefs had few sharks and large groupers. One exception was the Chagos Archipelago, where we observed a fish biomass that was five to ten times higher than that reported from many marine protected areas. Interestingly, these reefs also showed a remarkable ability to rebound from bleaching, which caused catastrophic losses in 1998 and is still apparent in many other Indian Ocean locations. Healthy fish populations, it appears, help prevent the smothering overgrowth of algae that can follow in the wake of a bleaching event.

Because it takes a reef a minimum of about five years to rebound from bleaching in situations where only the fastest-growing corals that exhibit the highest recruitment are affected, annual bleaching may facilitate a permanent loss of these species.

VIOLENT WEATHER AND RISING ACIDITY

If rising seawater temperatures aren't enough of a concern, reefs are concurrently exposed to more frequent storms and seawater is becoming more acidic. Nearly 25 percent of the carbon dioxide generated as a result of the burning of fossil fuels is absorbed by the ocean, reducing pH and altering seawater carbonate chemistry. For marine calcifiers, such as mollusks, corals, and other invertebrates, current and future predicted CO_2 emissions will dramatically lower the saturation state of calcium carbonate, inhibiting their ability to deposit their skeletons. Under a "business as usual" scenario (RCP8.5), calcification rates in corals are predicted to decline by 130 percent by 2100, shifting from a net positive accretion to net dissolution. Conversely, if we reduce emissions (intermediate emissions scenario; RCP4.5), calcification in corals will still be suppressed by around 50 percent, whereas reef calcification under present-day conditions has been experimentally measured at rates that are already 25 percent less than those under preindustrial conditions.

Climate change stressors, including ocean warming and acidification, compound localized human impacts, and together these may overwhelm the resilience of coral reefs and undermine their ability to recover. However, steps taken to protect and enhance the resilience of reefs by reducing human pressures, protecting other key species and bleaching refuge sites, and improving the abil-

REEFS OF THE FUTURE

Studies illustrate the ability of a coral reef to rebound from a barren, low-relief hard bottom habitat to a climax community dominated by coral within a decade. This suggests that coral reefs can exhibit unusually high resilience. Many reefs in the Caribbean have plummeted from 60 to 70 percent living coral in the 1970s to less than 5 percent today, but recovery is still possible.

Jamaica, the textbook example, was the first to lose many of the dominant reef-building species, and its reefs were transformed into macroalgal communities. Over the last 10 years these reefs have started to


Two distinct forms of *Acropora* spp. corals and their associated fish populations. Many healthy corals are tan-colored in nature.


Coral-eating snails, *Drupella* spp., devouring a *Montipora* colony in the Solomon Islands.

show rapid increases in coral cover. Yet the taxonomic composition is very different. Instead of a community of acroporids and star corals, the "weedy" species are now flourishing. Early colonizing brooding corals, such as Mustard Hill Coral, *Porites astreoides*, and Lettuce Coral, *Agaricia agaricites*, cover as much as 30 percent of the bottoms of shallow fore reefs. The persistence of diseases and corallivores has limited recovery of the acroporids, but these corals have the potential to rebound within one to two decades if conditions improve. Early successional changes are underway, but it will take centuries for the large, long-lived star corals to return, due to their slow growth and low recruitment. These reefs can still provide important habitat for other reef species and numerous ecosystem services.

While most of the countries with coral reefs are small and contribute little to global climate change, they can take tangible steps to help their reefs acclimatize and adapt to climate change. It is the responsibility of the large countries with high dependency on fossil fuels to commit to reductions in emissions. Global climate models indicate that by meeting or exceeding pledges made by countries under the Paris Agreement, coral reefs would have an additional 11–25 years to adapt to rising sea temperatures before annual bleaching occurs.

FARMING THERMALLY TOLERANT CORALS

On a localized scale, recovery following a bleaching event relies on the survival and regrowth of some corals, successful recruitment of the species that were eliminated, and the presence of bleaching refuges. This process can be expedited by man through the establishment of coral nurseries. While many models suggest that coral reefs will not survive current projections for global warming, researchers are identifying species and strains that have adapted to withstand thermal stress and subsequent bleaching, as well as sites that provide refugia from bleaching.

When developing coral nurseries, you cannot just grow any coral. Instead, we need to consider strategies for fragmenting, propagating, and transplanting thermally tolerant corals and locating and protecting bleaching refugia. Concurrently, we need to enhance the quality of the habitat, reduce manageable stressors, and eliminate pest species to give corals that survive bleaching events, as well as corals raised in nurseries, a better future outlook.

HANDS-ON REEF RESTORATION

My team at Coral Reef CPR is working with partner resorts and safari dive operators in the Maldives to speed up the recovery of reefs following the 2016 bleaching event and to develop restoration protocols. Our research documented a precipitous country-wide decline in coral, but we also found bleaching refugia—areas with concentrations of surviving corals and selected colonies that resisted bleaching. Of note, many of the reefs exhibited high survival of juvenile corals that had colonized these reefs prior to the bleaching event, but these are now being targeted by coral-eating snails (*Drupella*), as well as *Acanthaster* starfishes and cushion stars (*Culcita*). These corallivores are also attacking many of the frame-building species that were less affected by bleaching. To mitigate further losses, we lead dedicated predator removal trips for recreational divers, targeting sites that are experiencing persistent outbreaks of Crown-of-Thorns Starfish.

We have also introduced a new approach to coral mariculture in the Maldives. Traditionally, resorts grew corals on metal frames that were placed in shallow lagoonal areas. These are easy targets for corallivores, and most experienced near-total mortality during the bleaching event; it is also very difficult to remove corals that have been grown on metal for use in restoration projects. As an alternative, Coral Reef CPR is growing corals on ropes that are suspended in the water column. These ropes are inaccessible to bottom-oriented corallivores, they will not be buried by sand, and they are exposed to higher water movement, providing conditions that are more conducive to coral growth. It is also easy to remove the corals and subsequently transplant them to degraded reefs. Furthermore, all of the corals used in our nurseries are rescued from construction sites or sand mining sites or are fragmented from colonies that are being attacked by corallivores or affected by disease. In this way, we avoid causing any damage to healthy corals or healthy reefs.

While both global and localized stressors continue to increase and many reefs worldwide have been badly damaged, it is not too late to reverse this trend. We have the technology to tackle the global carbon emissions challenge, and we have the knowledge to address local management needs—we just need the willpower.

YOU CAN HELP

Marine aquarists have a vested interest in the health of the world's reefs. You can help by lending your support to reef restoration initiatives that are doing important work and research. (See the list below.) For example, you can help fund coral gardening initiatives in the Maldives by sponsoring your own rope of corals or a restoration plot. Sponsors receive certificates of sponsorship and regular photo updates on the progress of their corals. This small act of generosity will go a long way toward restoring reefs in the Maldives. You can find out more about coral restoration programs online (www.coralreefcpr.org, https://coralrestoration.org and on our Facebook page (@CoralReefCPR).

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Global Reef Expedition: https://www.livingoceansfoundation.org/global-reef-expedition

Reef scene in the Bismarck Sea, Papua New Guinea.

See page 100.