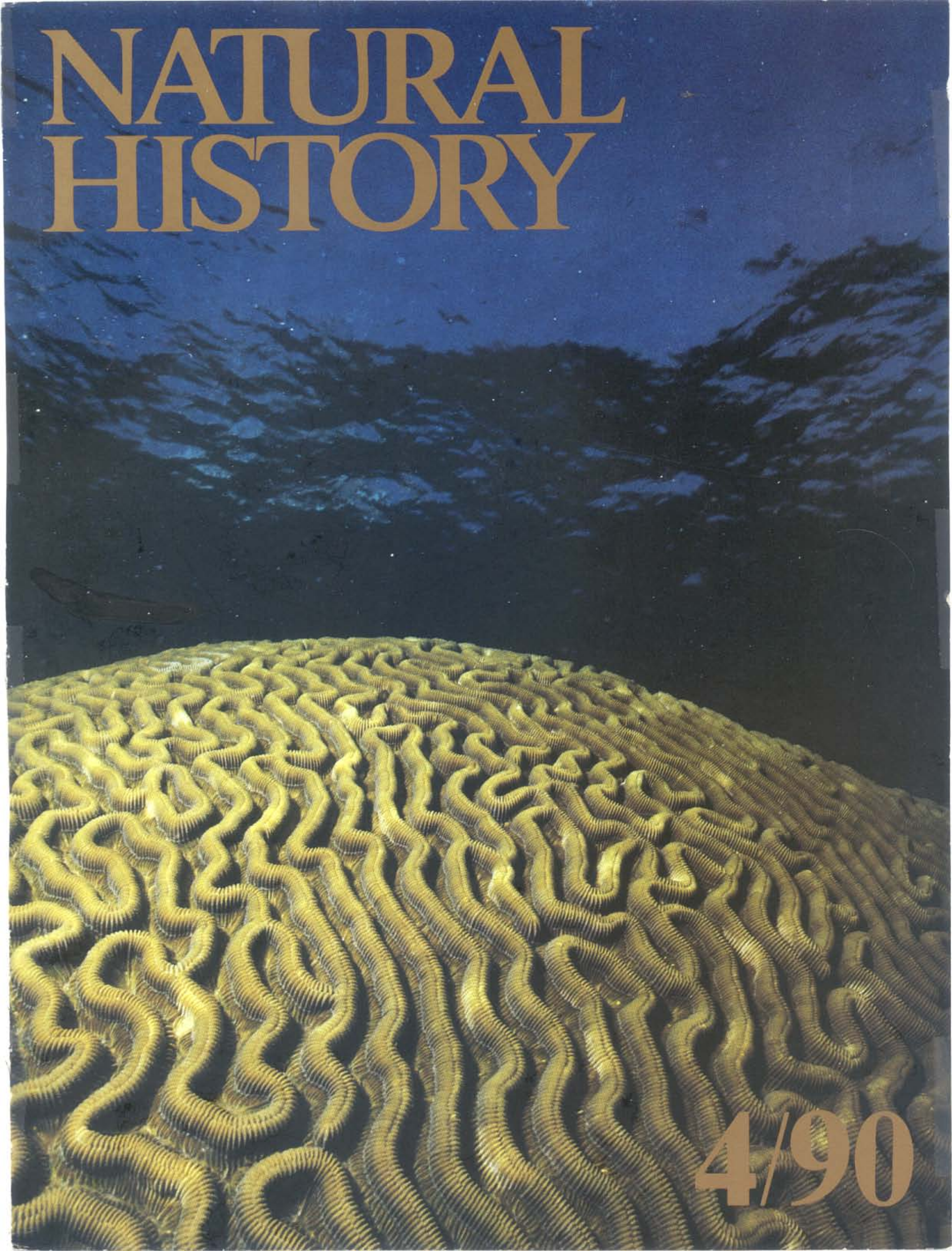
NATURAL HISTORY



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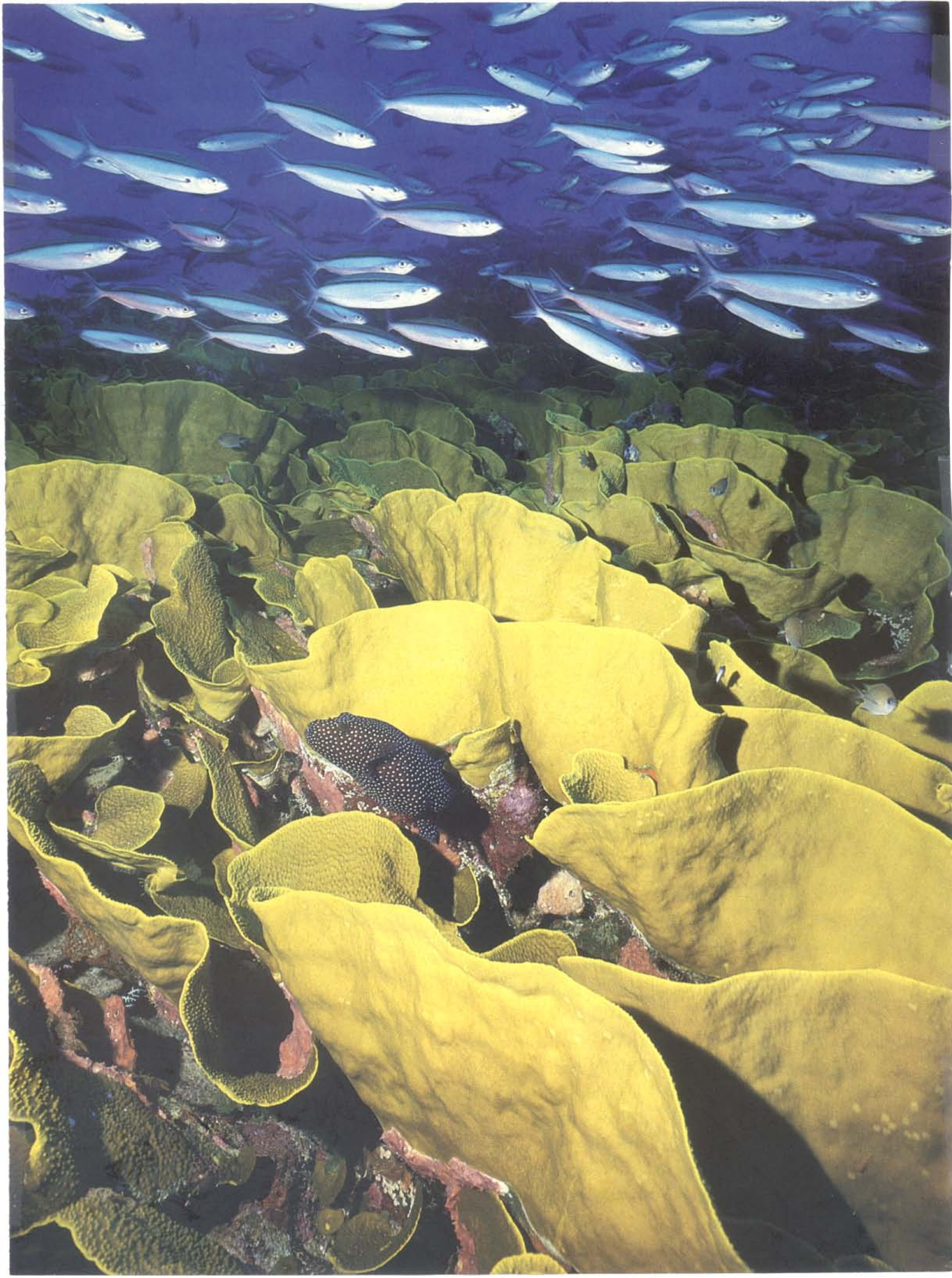


Stephen Frink; WaterHouse

Global Assault on Coral Reefs

What's killing the great reefs of the world?

by Lucy Bunkley-Williams and Ernest H. Williams, Jr.

In mid-September 1987, divers on the southwest coast of Puerto Rico began a routine descent through crystal clear waters to a coral reef. But six feet above the reef, a thick cloud of yellowish brown water blotted out their view of the corals. Unknowingly, the divers were witnessing the collapse of the delicate symbiotic relationship between the coral animals and the single-celled photosynthetic algae, called zooxanthellae, that normally flourish within them. The turbid waters shrouding the reef contained billions of dead and dying zooxanthellae expelled by their hosts into the sea—the first sign that the partnership between plant and animal, so important to the success of coral reefs, was coming unraveled.

Several days later, local fishermen noticed that some of the corals in the area, normally green and brown, had turned a ghostly white. Without their thin layer of inner inhabitants, the corals' pale skeletons were visible. The fishermen assumed that this phenomenon, known as "bleaching," was a local problem confined to shallow waters. Local, small-scale bouts of coral bleaching are not unusual and can be explained by a number of circumstances that put stress on the fragile symbiotic relationship between coral and algae: freshwater runoff from flash floods, which lowers salinity; sediments that cloud the waters; storm surges from hurricanes; extreme low tides, which expose the reefs; high or low water temperatures; disease; and pollution.

After hearing numerous reports of severe bleaching, we began to wonder if this might be more than an isolated blight on the local reefs. Toward the middle of October we decided to have a look for ourselves on the reefs near La Parguera, where the Caribbean Aquatic Animal Health Project (part of the University of Puerto Rico's Department of Marine Science) is located. Even before entering the water, we could tell that the reef had been severely damaged; in the shallows stark white patches were visible from our boat. The fire coral that dominates the reef top had large areas of white. Large mats of zoanthids (animals closely related to corals) had turned white, and the elkhorn corals were blotched brown and white. Once in the water, we found that the deeper parts of the reef had also been affected. The plate corals looked as if they had been dusted by fresh snow. Large brain and star corals, now totally white, resembled grotesque snowmen. As we swam among the bleached corals, we realized that although some of the corals appeared normal or only slightly affected, the extensive white patches covering the reef were far worse than anything we had encountered before.

Since corals retract their polyps during the day, their health is usually easier to assess after dark. Therefore, we decided to take another look at the situation at night. As we approached the reef, our lights illuminated several white coral heads. At first, we could not see the coral polyps waving their tentacles in the current to feed; but by shining our lights from side to side, we could distinguish the delicate, transparent polyps that had been invisible in the direct glare. (The coral's tissue is transparent to allow maximum light to reach the photosynthetic zooxanthellae.) The surface of the coral was clean, indicating that all plankton, or microscopic animal life, caught on the polyps had been eaten and all debris had been removed. But the coral was still alive and function-

Lucy Bunkley-Williams

A garden of healthy lettuce coral, opposite, flourishes on Australia's Great Barrier Reef. The lettuce coral above, however, has turned white with the loss of its symbiotic algae.

ing, despite the loss of its zooxanthellae. We knew, however, that the animal was weakened and might be unable to reproduce or lay down new skeleton without its symbionts.

Once we realized that people all along the south coast of Puerto Rico were seeing bleached corals, we began calling biologists and dive operators on neighboring islands to determine the extent of the problem. To our surprise, people in Jamaica, the Bahamas, Haiti, the Cayman Islands, Saint Croix and the other Virgin Islands, the Dominican Republic, and south Florida had also observed severe bleaching. Prior to our calls, however, they too had assumed that the damage, although serious, was isolated and caused by local disturbances.

We quickly sent a letter to *Science* magazine to alert others to the widespread nature of the bleaching, and we spoke at several international meetings of marine biologists in Puerto Rico. We also sent out questionnaires to gather the specific information we would need to document the problem and possibly determine a cause.

As our questionnaires were returned, we learned that the 1987 bleaching was the most severe and widespread ever observed. Severe bleaching first struck Australia's Great Barrier Reef in January

A Fragile Partnership

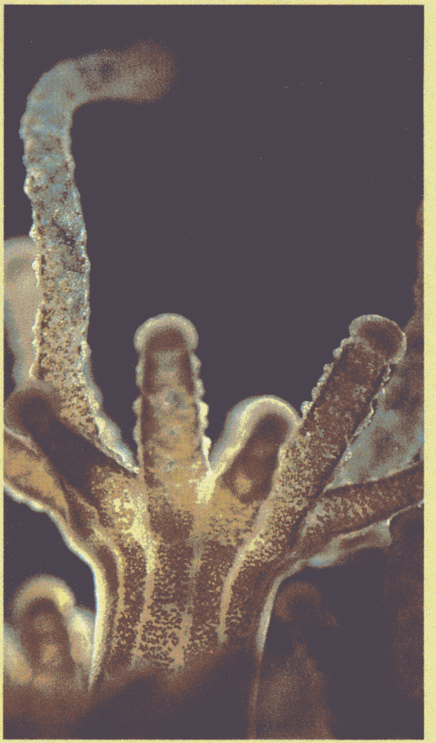
All reef-building corals normally harbor the microscopic algae called zooxanthellae. These one-celled organisms, often numbering several million per square inch, thrive within the cells that line the corals' digestive systems. Protected within the transparent coral tissues, zooxanthellae have everything plants need to photosynthesize and grow: plenty of sunlight and an environment rich in carbon dioxide and other animal waste products. The corals benefit too; the zooxanthellae provide them with oxygen and a portion of the organic compounds manufactured by photosynthesis.

The partnership promotes the coral animals' growth and helps them produce the calcium carbonate skeletons that gradually accumulate to form the reef's framework. Corals lacking zooxanthellae do not build reefs and have to survive solely on the tiny zooplankton that drift into their polyps, a passive and chancy business.

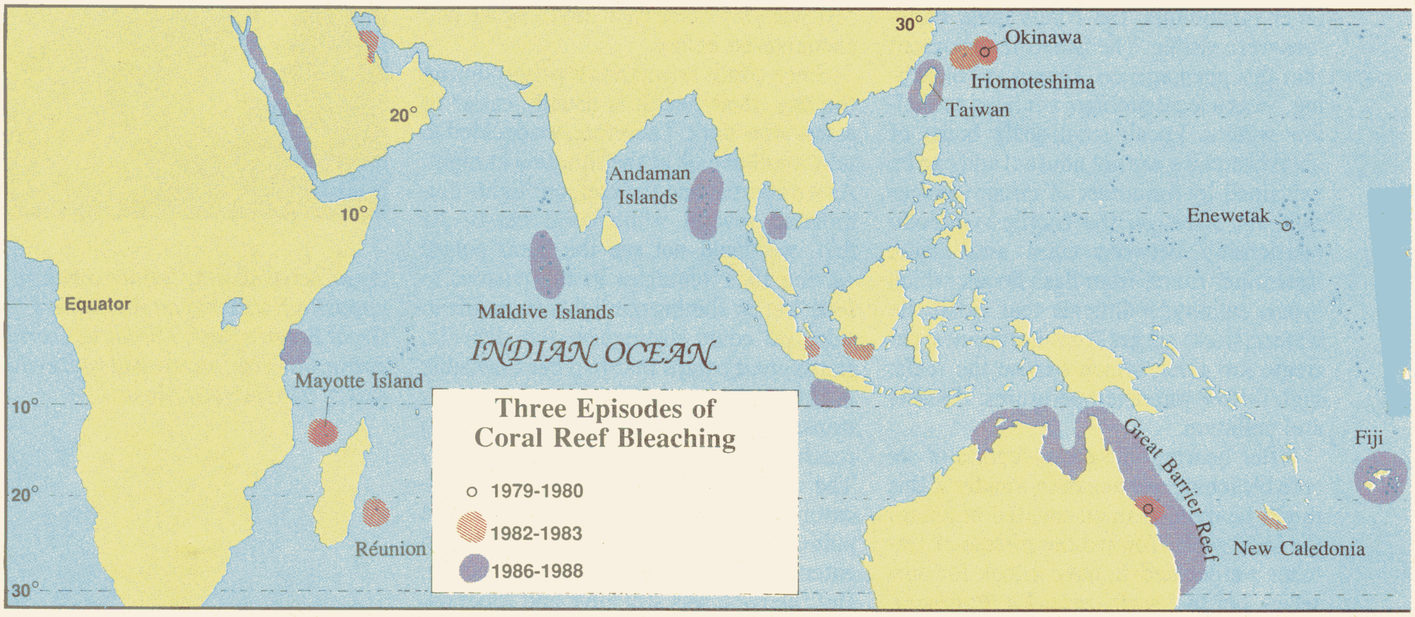
How this vital symbiotic relationship goes awry remains something of a mystery. Some researchers have suggested that the coral polyps actively expel the zooxanthellae when stressed. Ian Sandeman, a professor of biology at the University of Trent, in Ontario, has been working on the mechanisms of bleaching. He proposes that when their rate of photosynthesis is boosted by higher ocean temperatures, the zooxanthellae produce greater amounts of oxygen. In high concentrations, oxygen is toxic to most organisms because extremely reactive compounds are produced that destroy tissue. Because oxygen is produced internally in their cells, corals have well-developed mechanisms for eliminating these toxins and repairing any damage. When too much oxygen is produced by the zooxanthellae, however, the coral cells cannot cope with the excess toxins and may be severely damaged or destroyed altogether.

This hypothesis is supported by the observation that the first species of corals to bleach when water temperatures rise are those in which oxygen production increases the most. In addition, only coral cells containing zooxanthellae are damaged. Sandeman believes that in such cases of severe bleaching, the zooxanthellae are not expelled, but are instead lost along with the other contents of the dead or damaged cells.

Peter Parks; Oxford Scientific Films



Under magnification, thousands of zooxanthellae become visible within the tentacles of this Pocillopora *coral polyp.*



Joe LeMonnier

Overleaf: In the Red Sea, fish circle a soft coral growing amid unblemished lettuce corals.

1987, at the height of the austral summer, and affected most of the northeastern coast, as well as some reefs off north-central Australia and fifteen sites throughout the Pacific and Indian oceans.

In the Atlantic, the most severe bleaching began in late summer and continued into fall, affecting the northern Caribbean, the Bahamas, and southern Florida. Less severe bleaching was noted along the Caribbean coast of Colombia. As the corals in these areas began to recover in late fall and early winter, a second bout of moderate bleaching occurred throughout the southern Caribbean, which had previously been unaffected.

Our questionnaires had also asked for information on previous episodes of bleaching, and we were surprised to find some reports of bleaching in 1986. As our information grew, a pattern of worldwide bleaching in mid-to-late 1986 emerged. While we continued to collect information on past events, another, less intense bleaching event occurred around the world in 1988 when various reefs were experiencing their warmest weather of the year. Now we had a pattern of global bleaching events spanning from 1986 through 1988.

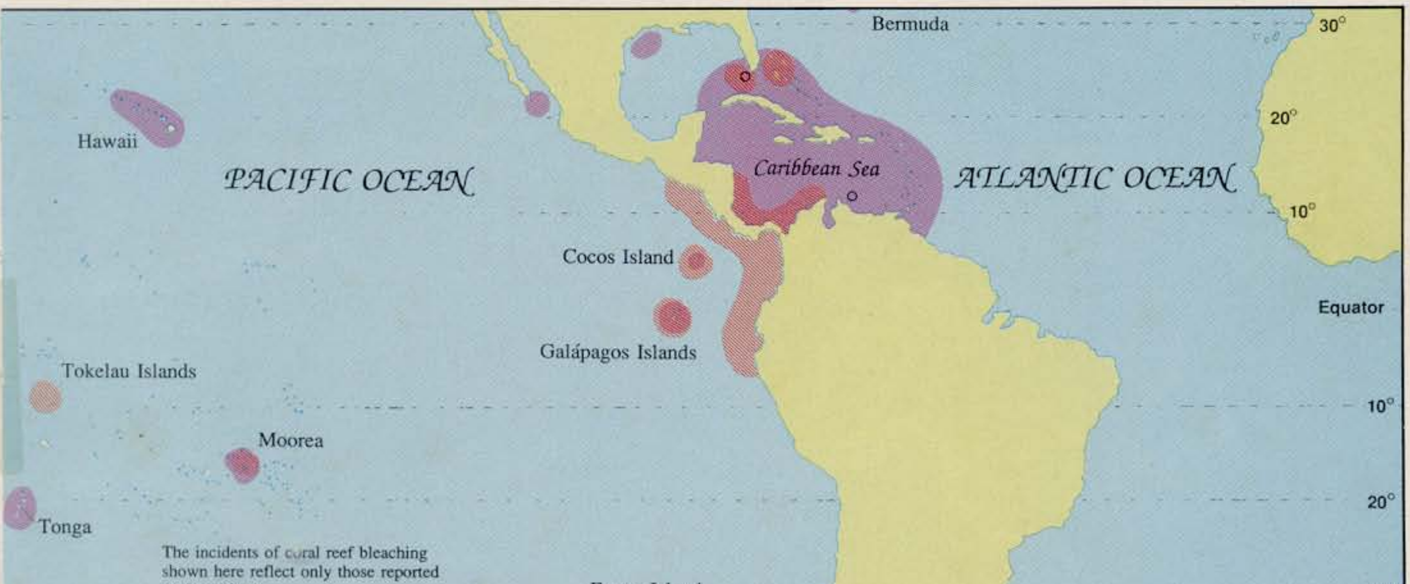
Two other major cycles of global bleaching events, pieced together from responses to our questionnaires and a few published reports, seemed to parallel the severe 1986–88 bleaching: one in 1979–80 and the other in 1982–83. In each case, moderate bleaching occurred one year prior to the most extensive outbreak. (The latest and most severe bleaching stretched into a third year, ending in 1988.) If this general pattern holds, preceding events may allow us to predict major bleaching a year before it strikes.

Although we recognized the cyclic nature of coral reef bleaching, we still needed to determine a cause. As the number of questionnaires returned to us grew, we hoped that the responses to the many questions about the nature of the bleachings, and the conditions that prevailed when they occurred, might point to a single factor capable of affecting the reefs on a global scale. Eventually, we received hundreds of reports, but the character of bleaching in each area differed somewhat, making the search for a common factor seem hopeless.

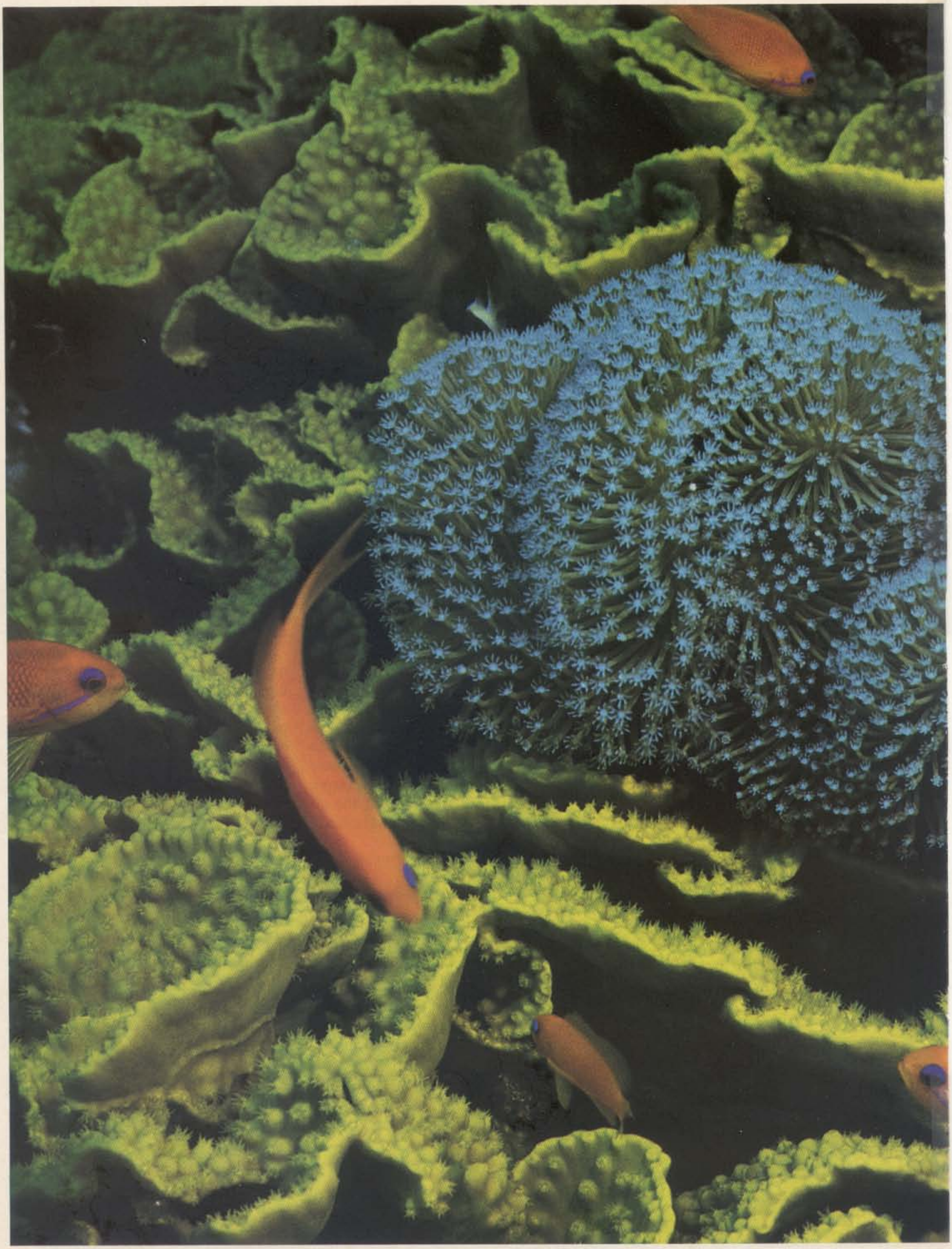
Disease seemed an unlikely cause since most pathogens afflict a particular species or closely related groups. In these bleachings, many different species of corals were affected, as were anemones and sponges. A common thread was that all the affected invertebrates harbored symbiotic zooxanthellae; perhaps some pathogen had spread among the algae. But as the bleaching progressed, animals that supported other photosynthesizing microorganisms, such as blue-green algae (cyanobacteria), also suffered. Overexposure to ultraviolet light was also ruled out; although it causes zooxanthellae to lose their pigment, it does not result in their expulsion from their hosts. High water temperatures became the prime suspect.

In the tropics, seawater temperatures fluctuate only a few degrees from summer to winter. Coral reef animals are adapted to live within this narrow range; even a slight increase above the normal maximum experienced by the reef may cause bleaching. If temperatures remain elevated for prolonged periods or are severely elevated for brief periods, the corals will not only lose their zooxanthellae but they may also die.

Many of the reports that came to us mentioned that water temperatures were high during the period that bleaching was observed. But others reported normal temperatures, confusing the issue of whether or not high temperatures were responsible. Unfortunately, obtaining accurate records of water temperatures on the world's reefs is problematic. Most of the reports only cited sea surface temperature



The incidents of coral reef bleaching shown here reflect only those reported to the authors.



Stephen Frink; WaterHouse

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Angelfish, below, swim above extensive patches of bleached corals in the Gulf of Panama. Ironically, the corals that appear healthy died in a previous bleaching episode and are now covered with algal growth. This damage was caused by high water temperatures associated with the 1983 El Niño. Although the feathery crinoids and red sea fans, opposite, are not affected by bleaching, they depend on the stony corals that build the reef's framework.

Peter Glynn

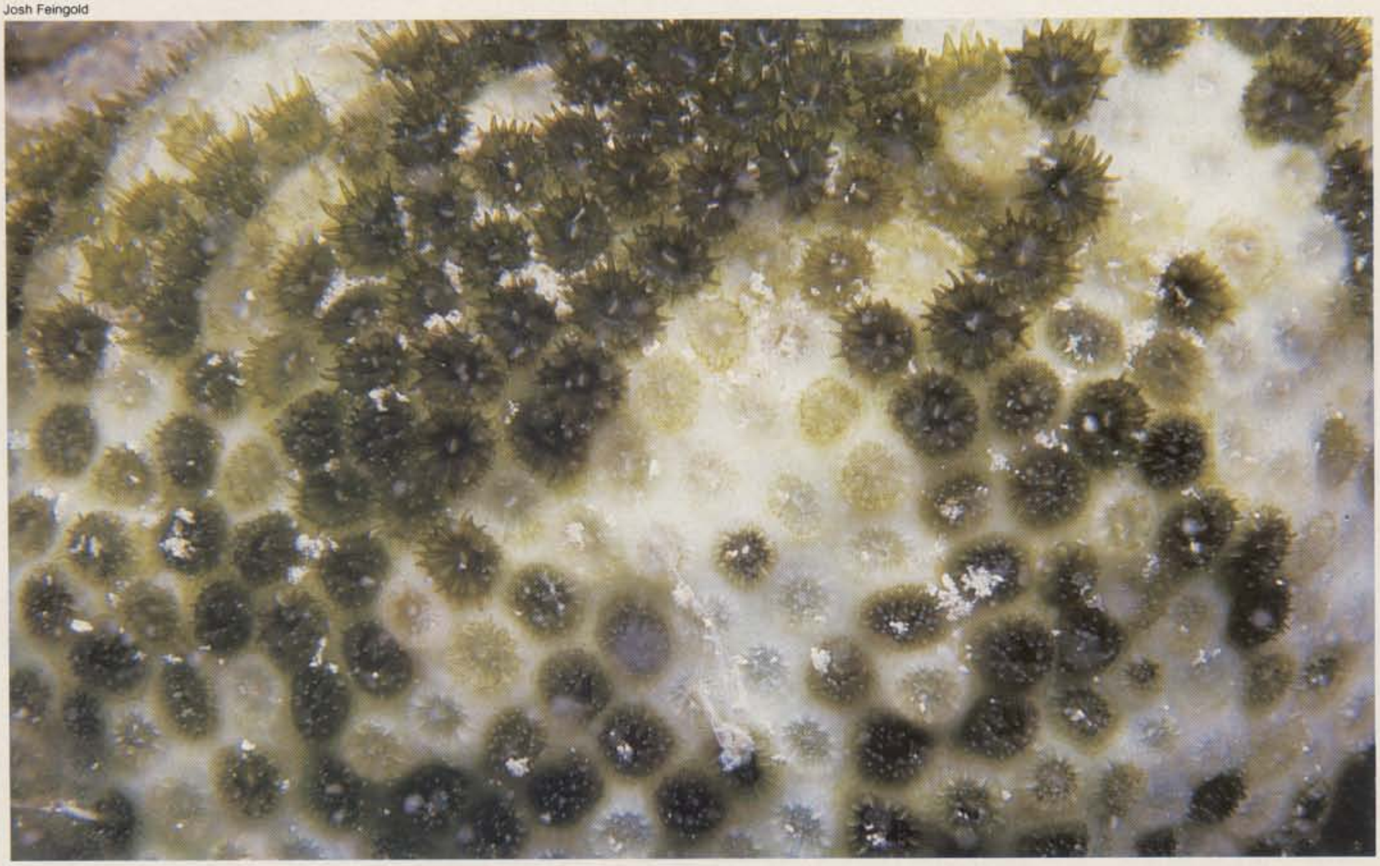
(SST) data, which is routinely recorded around the world. SSTs, however, are measured from ships far offshore and do not always reflect the water temperatures on the reefs. In 1987, this shortcoming became clear when we found that SSTs did not correspond to the temperatures that many observers noted near shore, which were high enough to bleach the corals. Although satellite measurements of sea surface temperatures have been hard to interpret, researchers now believe they can detect a general rise of almost 2° F in Caribbean water temperatures from 1986 to 1987.

In some cases, the severely elevated temperatures were caused by unusually calm weather; with no winds to move cooler waters into the relatively shallow reef areas, water temperatures soared. These weather conditions were associated with the El Niño–Southern Oscillation (ENSO), a periodic oceanic disturbance—centered near the equator in the eastern Pacific—that affects atmospheric circulation throughout the tropics. In 1983, a particularly strong ENSO directly caused the death of 95 percent of the corals on some reefs in the Galápagos Islands and on other reefs in the eastern Pacific by halting the normal upwelling of cold waters. However, while ENSOs directly caused some cases of bleaching and aggravated others, they were not the central cause of coral reef bleaching. The ENSO of 1982–83 had not yet begun when major bleaching occurred on the Great Barrier Reef in early 1982; the ENSO had ended before the 1988 bleaching; and no ENSO was recorded during the 1979–80 bleaching.

We believe that the increasing severity of recent global cycles of bleaching was apparently caused by the general global warming trend in the 1980s, which led to some of the hottest years on record (*see* "Where's the Heat?" *Natural History,* March 1990). During the seasons when the reefs normally experience their highest temperatures, this warming was sufficient to force water temperatures above the limit that corals could tolerate, and bleaching resulted. Overall seawater temperature increases, as well as those limited to areas near shore, were responsible. Most bouts of major bleaching and many of the minor ones happened either during elevated temperatures or during the normal warmest water period of the year.

How damaging to the reefs were all these incidents of bleaching? If the corals can regain the zooxanthellae and are not further damaged, they can recover. Over a period ranging from weeks to months, the depleted zooxanthellae may multiply within the corals and repopulate the hosts, or if they were lost altogether, the microorganisms may enter the corals from the surrounding seawater. Outbreaks of disease, however, often kill weakened colonies recovering from bleaching. Entire colonies may die, and as in the severe 1983

Having lost their zooxanthellae, some of the polyps on this coral are scarcely visible against the stark white skeleton.
Josh Feingold



bleaching in the eastern Pacific, whole reefs may be lost and some species may be eliminated from a region. Because corals may take many years to regain their original vitality, new bleaching cycles may strike before the corals have recovered. Therefore, each cycle may be more damaging than the last.

In the past, when they did not have to cope with other, man-made pertubations, corals may have been resilient in the face of gradual temperature fluctuations. The general deterioration of coral reefs around the world caused by pollution, increased sedimentation, overfishing, and actual physical destruction may have reduced the ability of coral reefs to withstand temperature changes.

In the relatively short time that reef ecosystems have been studied, bleaching on the recent scale has never been seen. Peter Glynn, a biologist at the University of Miami, has examined 400-year-old corals in the severely bleached eastern Pacific and has found no evidence of similar disasters in the past. The severe bleaching indicates that the general warming during the 1980s may have had a drastic effect on the coral reefs and may foretell the future of the reefs if the greenhouse effect leads to even warmer temperatures. Sadly, global warming and environmental deterioration will almost certainly persist and become more acute, increasing the frequency of worldwide bleaching cycles.

Again, in 1989, moderate bleaching occurred in the Florida Keys, and many other areas of the Caribbean were lightly affected. Jamaican reefs, however, suffered prolonged bleaching that extended into this year, causing more damage than in 1987. Whether or not these incidents will be followed by a major bleaching of the world's reefs later this year remains to be seen.

With each bleaching, the coral animals slow their construction of the reef's framework. Growing only millimeters per year, the corals are already racing against the persistent natural forces of erosion that tear them down. Severe episodes of bleaching may tip the balance in favor of erosion. At the very least, reef ecologies will be altered. At the very worst, the coral reefs, which have been able to adapt to gradually changing conditions in the geologic past, may not be able to cope with more rapid climatic changes associated with the greenhouse effect and may perish altogether.

The coral reefs, however, are themselves key players in the greenhouse scenario and may be as important as tropical rain forests in reducing greenhouse gases. As they deposit calcium carbonate for their skeletons, corals remove a large volume of CO_2 from the oceans. Without zooxanthellae, the amount of carbon dioxide corals metabolize is drastically reduced. Ironically, damage to this undersea ecosystem could accelerate the very process that hastens its demise. □

Unlike the scuba divers who visit the coral reefs solely for their beauty, when **Lucy Bunkley-Williams** and **Ernest H. Williams, Jr.** (page 46), plunge into the warm waters, they keep an eye out for parasites, disease, and death. In 1987, Ernest established the Caribbean Aquatic Animal Health Project at the University of Puerto Rico, at Mayagüez, where he is a professor, specializing in marine parasites. Lucy is a research associate at the university and the project's microbiologist. With the other members of the staff, the Williamses cooperate with marine labs throughout the Caribbean to monitor various disturbances to the marine ecosystem, hoping to discover their causes. In addition to their work on global incidents of coral reef bleaching, they are investigating mass mortalities of herrings and brown pelicans in the Caribbean. The Williamses have been diving in the Caribbean for fifteen years, including five week-long missions based at Hydrolab, the undersea habitat at Saint Croix. Living at depths of fifty feet, they can work on the sea bottom for up to ten hours a day. "Corals and Coral Reefs," by Thomas Goreau (*Scientific American,* August 1979), provides more information on how corals use their symbiotic algae to build reefs.

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April 1990

COVER: *Stony corals, which form the framework of the tropical reefs, may be in peril. Photograph by Robert Holland. Story on page 46.*

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