



The weather was a scuba diver's dream come true, calm for so long the water was crystal clear. It had been weeks since there was any appreciable wind. The little seacoast town of La Parguera, Puerto Rico sweltered in the tropical summer heat. The weatherman reported record-breaking high temperatures for days on end. Then, something mysterious began to happen. Divers reported crystal-clear waters down to the coral reefs, but thick yellow clouds of water around and 6 feet above the corals.

Little more was thought of this minor annoyance until:

"Ivan says there are white patches all over the reef."

"What?!"

"Ivan says there are white patches all over the reef."

Ivan Lopez, a local fisherman, nat-

uralist, and technician at the marine laboratory at La Parguera, usually knows what is going on in and around the reefs long before any scientist finds out. This time was no exception.

"What kind of white patches? How big? Which reefs?"

"Apparently all the reefs to some extent. He said it looked like a passing oil tanker had dumped detergent and killed some corals and other animals."

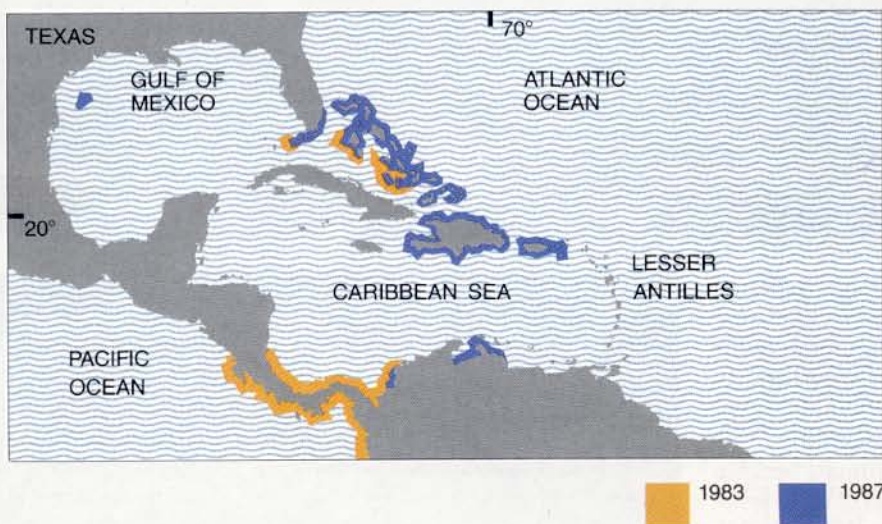
"Well, let's get a boat and go have a look."

White patches, some a square yard in size, were visible from the boat before anyone even splashed over the side. Seen underwater, the white stood out starkly against the blue water and dull green-brown of the reef. The white patches were found in

Facing page: Coral reefs regress from living color to black-and-white with a mysterious ailment called bleaching. Corals and sea fans are not dead, but lose their symbiotic algae, which give them color and nourishment.

Twice in recent years coral-reef bleaching has swept the Caribbean. Much of the Pacific reefs affected in the areas shown died. In 1983 simultaneous bleaching events occurred in the central and western Pacific.

6 feet = 18 meters
1 square yard = 0.8 square meter



CURRENT CRISIS
FUTURE WARNING

CORAL REEF BLEACHING

BY LUCY BUNKLEY WILLIAMS AND
ERNEST H. WILLIAMS, JR.

A ghostly brain coral is afflicted by bleaching. On closer inspection, individual polyps of the colonial animal are resistant and retain their color, while others are bereft.



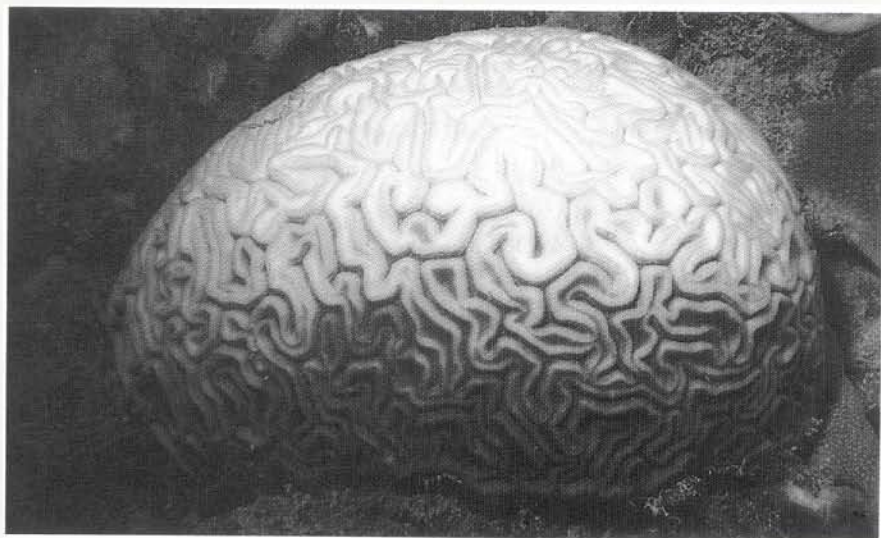
Josh Feingold

the mats of zoanthids that cover large areas of the reef top, and some were found in the stands of fire coral. Some of the other hard corals were turning white.

As with previous bleachings, almost certainly, these animals became white because of the loss of their symbiotic algae—zooxanthellae (now forming the yellow clouds obscuring the reefs). Zooxanthellae live within the soft tissues of and nourish corals, corallike animals, some sponges, and other animals. These algae are photosynthetic (have chlorophyll) and their color shows through the almost transparent soft parts of the host animal. To their hosts, their loss could be life threatening.

Why had these animals lost their zooxanthellae? Was a disaster about to happen? Were other areas affected?

The doldrums continued. Slowly, over a matter of weeks, the affected areas began to enlarge and other organisms began to turn white. The coral reefs turned into a framework of phantoms. Corals, gorgonians,



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zoanthids, and some sea anemones, once dark chocolate brown, tan, or green, began to lose that color and became ghostly white, as if they had been soaked in household bleach. From the surface, looking down into the water, large unnatural patches of white could easily be seen along the reef top, down the reef slope, into the depths.

In Puerto Rico, the event began around the last of August 1987. By the end of September, all inshore reefs were affected to some degree and even the corals at the deep reef at the insular shelf edge had turned white. The shallow zoanthid *Palythoa caribbea*, which covers large areas of the reef top, was the most immediately

visible bleached coelenterate. Also on the reef top were colonies of elkhorn coral (*Acropora palmata*) with blotches of white on the upper surfaces. All species of fire corals, too, were found in patches of white.

On the reef slope, most noticeable were the brain corals, the more massive heads even more impressive in white. The round starlet coral (*Siderastrea siderea*), normally a rusty-brown color, turned a bright shade of lavender, contrasting with the drab surrounding bottom. The most important reef builder, the common star coral (*Montastrea annularis*), looked like a fresh, light snow had fallen on it from above. It was probably the coral most affected.

On the deeper reef, the lettuce corals *Agaricia* and *Leptoseris* were white around the edges of the colonies with only some darker areas near the center, their bright yellow mouths visible over the whole colony, bleached and unbleached. Soft corals were less obviously bleached, but some colonies were definitely lighter than even the lightest "normal" colonies. Sea fans did not seem to be affected along the southwest coast. In Puerto Rican waters, however, approximately 60 percent of the living coral cover was bleached on any reef.

There were also reports of sponges losing or changing color. In Puerto Rico, the authors observed only a few specimens of *Mycale laevis* affected. This usually bright orange sponge became dull gray. Its loss of color was not due to loss of zooxanthellae but of pigment. Why the pigment changed is a mystery.

When the zooxanthellae were lost, many species of corals were left devoid of color, and the white aragonite of their skeletons could be seen. When zooxanthellae are removed, some animals have pigments in their tissues which then become the dominant color, for example, the lavender of the starlet coral, and the bright yellow or rust color of some anemones. Some of the brain corals became completely white, but most colonies retained some zooxanthellae around the edges and in shaded areas of the colony. Why some colonies lost most if not all the zooxanthellae and other colonies little or none might be explained by differences in tolerance to whatever

disturbance caused the loss of the algae in the first place. Whether it was the tolerance of the zooxanthellae or of the corals themselves has yet to be determined.

The threat of disaster

Concern for the fate of the corals was foremost in everyone's mind. During previous bleachings, losses of corals varied from almost negligible to near total destruction. Coral reefs in the eastern Pacific may take decades or even hundreds of years to recover.

In the 1987 bleaching, deaths of whole colonies were reported in Florida waters, and portions of coral heads off Puerto Rico. Reports were received of corals not extending their feeding arms at night, or of extending them and not being able to feed. This is a serious problem, since this is the only means by which corals that have lost their zooxanthellae can feed. Such corals will die.

To confirm these reports, we dove at night to see if the affected corals were extending their polyps. The glare of our dive light reflected off the white surface of the first coral head. At first, no polyps waved out at us; the coral appeared to be dead.

As in all bleached corals, this one had nearly invisible, clear polyps. In the beam of the bright dive light, its clear animal body disappeared, but by shining the light to the side, the extended polyps could be seen. The surface of the coral was clean. Any zooplankton landing on that surface had been eaten, any detritus removed. The coral was doing its housework, and that was a good sign.

Only one colony appeared to have lost the battle against colonizing algae, and it was the territory of the aggressive threespot damselfish (*Pomacentrus planifrons*). This fish is known to nip at living coral to make algae grow. The fish then eats the algae. Except for this single colony, the bleached corals seemed to be holding their own against opportunistic organisms ready to colonize even a tiny spot of bare rock.

The local corals were relatively normal despite the severe bleaching. There were some deaths or abnormal

behavior of corals, but the majority seemed to be healthy. This comforting estimation could change drastically for the worse if the bleaching event continued. How long could the corals survive under these conditions? Which would come first—recovery or mass mortality?

Almost before the seriousness of the bleaching event was established locally in southwestern Puerto Rico, reports of bleaching were received from Ponce, on the south-central coast, and at Humacao, on the east coast. Additional information confirmed an island-wide problem. Saint Thomas and Saint John, U.S. Virgin Islands, sharing the same shallow reef with Puerto Rico, also shared the bleaching problem. Saint Croix, separated by deeper waters, also was experiencing bleaching. Telephone calls and letters eventually confirmed this event at Mona Island, the Dominican Republic, Haiti, the Cayman Islands, Jamaica, the Turks and Caicos, the British Virgin Islands, the Bahamas, Florida Keys, south Florida, and the Flower Garden Banks off Texas. Thus, severe bleaching was experienced over a wide area of coral reefs, in the northern Caribbean, Bahamas, Florida, and the Gulf of Mexico.

The similar and adjacent islands east of the British Virgin Islands were untouched, as were the other islands down the island arc to Trinidad. With the exception of an apparently isolated report from Colombia, the South and Central American Caribbean coasts and offshore islands were not bleached. The corals of Bermuda were also unaffected.

The bleaching also appeared in the Pacific Ocean. It occurred in Australia from January through May 1987 (austral summer) and in the Galapagos Islands in February and March, and is rumored to have occurred in Indonesia and Thailand in the fall of that year. This bleaching event may have occurred worldwide.

Animal-plant partnership

To properly appreciate the significance of the changes taking place during the bleaching, the normal condition of coral systems must be understood. Despite what is seen in curio shops, corals are not naturally bleached white (nor dyed assorted

Highlighted in white, the upper surfaces of this Puerto Rican horny coral (*Plexaurella* sp.) are devoid of zooxanthellae. Victims of bleaching cross phylum lines, including not only corals, but also gorgonians, zoanthids, and sea anemones.

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pastels). Normally, stony corals, fire corals, sea anemones, other corallike animals, and sponges are various shades of browns, green, or some combination. Most of this color is caused by millions per square inch of tiny, single-celled zooxanthellae living in the tissues of these animals.

Like most plants, zooxanthellae need sunlight to function. Hiding inside coral heads seems an illogical abode for such plants, but it is advantageous. The living portions of corals are only a thin veneer on the exterior of the skeleton. Highly transparent, these coral tissues not only protect the zooxanthellae and allow sunlight to reach them, but they provide an environment rich in carbon dioxide and other animal waste products, exactly what these plants need. In turn, the zooxanthellae provide oxygen, nutrition, and energy to the coral tissues. This partnership allows corals with zooxanthellae to grow faster, be stronger, and survive in more diverse habitats.

All of the corals that build coral reefs have zooxanthellae. Corals lacking zooxanthellae have to earn a living solely by catching tiny zooplankton that drift or swim into their polyps, a passive and chancy business. Corals with zooxanthellae have the best of both plant and animal worlds: they are hunters but also farmers. Zooxanthellae are not found just in corals, sea anemones, and sponges. Giant clams depend on these plants and so do some close cousins of the vertebrates—the sea squirts, or tunicates. Zooxanthellae are both widespread and important in the coral-reef environment.

The symbiosis or partnership between coral-reef animals and zooxanthellae is vital for both parties. Only a severe stress can disrupt this association. Loss of zooxanthellae is often expressed as a process of the corals expelling the algae. Often the algae do come out in a cloud or matrix of coral mucus (the previously mentioned yellow cloud). Actually, whether the corals "evict" the algae or the algae "abandon ship" is unclear. Equally mysterious is whether loss of algae means the corals have been damaged or stressed, or the zooxanthellae have been, or both. In either event, both partners suffer.

Most zooxanthellae leaving their hosts are quickly eaten by other animals on the reef, but the host animals losing the algae are not immediately in peril. However, the host is as injured as if a major appendage had been chopped off. If the event lasts for weeks or months, coral polyps contract, corals slough off tissues, sea anemones shrink and some draw into crevices out of sight, and eventually many animals die or are outcompeted by other animals and buried alive.

What causes bleaching?

The 1987 coral-reef bleaching event was the worst and most widespread ever reported in the Atlantic. The next worst was in 1983. Early records of bleaching are far from complete, but such events seem to be increasing in frequency, geographic range, and intensity.

In 1983, coral reefs off the Caribbean coast of Panama, Costa Rica, Colombia, Florida Keys, and Bahamas were partially bleached, but few corals died. At the same time, along the Pacific coast of Central America, corals were bleached, and 70 to 95 percent of the corals died, almost completely destroying the reefs. Similar but less destructive events occurred at the same time in the central and western Pacific Ocean. The history of the West Indies is occasionally splotted with reports of coral-reef bleaching but most events were either more localized, less intensive, or so poorly documented as to be indecipherable.

Many of the earlier coral-reef bleachings are readily explained by exposure to midday heat during extremely low tides, lowered salinity due to rains or runoff, waves generated by hurricanes, or unusually low or high temperatures. The 1983 coral-reef bleaching events may have been caused by the 1982-1983 El Niño warming event, although proof is not complete. High water temperatures may have also contributed to or caused the 1987 event. Although only a moderate El Niño occurred in 1987, the most extensive bleaching event occurred. Could global warming be the culprit, and is bleaching

merely the first alarm bell?

An El Niño warming event, unusually high water temperatures, increased ultraviolet radiation, an exotic disease of the zooxanthellae, or some combination were suggested as possible causes of the 1987 coral-reef bleaching. High water temperatures were suggested by more scientists, but definite proof is lacking. None of the suggested causes are free of contradictions or complications.

Unusually high temperatures were associated with most if not all of the regions where bleaching occurred. Bleaching of the deeper portion of the reef was attributed to heated hypersaline waters sinking to those levels. However, this would not explain deep

almost 300 feet were bleached. Penetration of any ultraviolet radiation through that much seawater is difficult to explain.

Disease organisms usually are host specific. The bleached animals represent two phyla (the sponges and the cnidarians, or coelenterates) and ten orders. It is unlikely that such diverse and large groups could share the same disease. All of these animals do have one thing in common, zooxanthellae. A disease attacking the zooxanthellae

Bleached lavender, the color of the skeleton of this starlet coral (*Siderastrea*) is normally masked by its zooxanthellae. Patches of the masking algae can still be seen at the bottom and right side of the coral. Many species exhibit splotchy bleaching.



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bleaching in areas too exposed for hypersaline waters to form. A long period of raised surface temperatures would increase temperature on the deep reef by a few degrees above normal, and this might be all that was necessary to bleach these corals that prefer deeper and cooler waters. Heat alone should uniformly bleach reef animals, but this was not the case.

Ultraviolet light should more strongly bleach the uppermost and most exposed surfaces of coral-reef animals, and this is what was observed. One could also argue that deep-reef animals are adapted to and tolerate only low levels of ultraviolet light, so any increase might be damaging. In fact, some animals living at a depth of

could, theoretically, injure all of these animals. The slow development, geographic spreading in some areas, partial coverage of some animals, and apparent immunity of some animals circumstantially indicate a disease and not a physical effect.

More field research needs to be conducted to determine under what conditions corals lose their zooxanthellae, before we can speculate with much certainty as to the cause of these events.

Help is needed

The bleachings have not been the only recent disasters on Atlantic coral

300 feet = 91 meters

reefs. In 1980, millions of reef fishes, including many large commercial snapper and groupers, died throughout the Caribbean Sea, Bahamas, and Florida. The surviving fishes were sick for months after the event. The cause is still unknown. Attempts at investigation were limited by lack of early information, lack of coordination, and confusion of goals and responsibilities.

In 1983, a devastating disease of the long-spined black sea urchin (*Diadema antillarum*) began off Panama and spread over all Atlantic reefs by January 1984. Billions of urchins, over 98 percent of the original population, died. Divers who have been stuck by the painfully effective spines of this urchin probably said "good riddance," but this urchin was important in the coral-reef ecosystem. How great the influence of this piece of the whole coral-reef ecosystem may have been and what changes may occur in its absence are still being studied. For example, the algae these urchins would ordinarily have eaten may overgrow and kill many of the bleached and sick corals. But the shortcomings of the fish mass-mortality investigations were repeated in the study of the black sea urchin plague. No one discovered the disease agent, or knows if it was transmittable in seawater, or

proved that it was even a disease!

Numerous small fish kills and marine mortalities occurring in often isolated localities also seem, from the reports we are receiving, to be increasing. No one can be certain, since these events have often been ignored and unreported.

There is a need for a cooperative effort to study such phenomena. A plan that called for a reporting and alert center, a mass-mortality investigation manual, and training workshops for local scientists was formed by a special committee of IOCARIBE (Intergovernmental Oceanographic Commission Association for the Caribbean and Adjacent Regions), part of the United Nations Educational, Scientific and Cultural Organization. The plan was submitted in 1982 for funding, and was re-endorsed during the Second Session of IOCARIBE at Havana, Cuba in December 1986, but it was never implemented. Following the 1987 bleaching event, a special session on coral-reef bleaching was held at the Western Atlantic Turtle Symposium at Mayaguez, Puerto Rico on October 14, 1987. This was followed by a U.S. Senate Appropriations Committee hearing on the subject in Washington, D.C. on November 10, 1987, a special session at the Gulf and Caribbean Fishery Institute

in Curacao on November 14, and a workshop at the National Oceanic and Atmospheric Administration Undersea Research Program at the West Indies Laboratory, St. Croix from December 9-10. Emergency funds to monitor the bleaching event were obtained from diverse research sources.

Possibly a more basic and less expensive first step than that proposed by the IOCARIBE committee is needed. An inexpensive alert and documentation center could monitor the waters of the Caribbean with a 24-hour hotline to call in unusual occurrences that may indicate a mass mortality or beginning of another disturbance. A network of existing field scientists could be established in each country to confirm the existence of a problem and to gather preliminary information. A questionnaire to document each event would enable updated summaries to be prepared to inform the public and the scientific community of the problem.

Epilogue

By early November 1987, the weather had cooled and the trade winds had begun to blow. As if watching a film of the original bleaching being run in reverse, small half-dollar-sized patches of brown or green (no-



The color of the corallike anemone *Ricordia florida* varies naturally in shades of blue or green, as in the normal specimen (above right). At the height of the bleaching event, the anemone is a pale shadow of its former self (above, left). It is hoped that it, and others, will recover their vital colors, as this elkhorn coral (*Acropora palmata*, right) is doing in the Florida Keys.



in fish pathology from Auburn University (Alabama). She is a research associate in aquatic animal health in the Department of Marine Sciences at the University of Puerto Rico at Mayaguez; she also teaches at the Inter-American University at San German. One of her photographs, which won first place in the close-up category of the South Florida Underwater Photography Society's contest, appeared in the July–August 1987 *Sea Frontiers*.

Ernest H. Williams, Jr. is director of the Caribbean Aquatic Animal Health Laboratory, executive director of the Association of Island Marine Laboratories of the Caribbean, and professor of marine parasitology in the Department of Marine Sciences of the University of Puerto Rico. He and Lucy Bunkley Williams have conducted five week-long saturation-diving missions using the undersea habitat Hydrolab, logged more than 1,500 hours of research dives each, and coauthored more than 80 scientific publications.

Related Reading:

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ticeable over time in photographs of individual corals) began to enlarge. The color of the brain corals seemed to seep back up the sides. Slowly, they regained their color. Although some corals were still bleached in January 1988, the immediate crisis was over, and it seemed that most of the corals would live.

Too much is going wrong with the

reefs to be just coincidental. The long-term threat still looms. If coral reefs are to exist in our future, we must dedicate ourselves to solving these extensive and persisting problems.

Lucy Bunkley Williams has an M.S. degree in marine sciences from the University of Puerto Rico and a Ph.D.

Sea Frontiers®

A PUBLICATION OF THE INTERNATIONAL OCEANOGRAPHIC FOUNDATION / UNIVERSITY OF MIAMI



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(ISSN 0886-9448)
is published bimonthly.
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Oceanographic Foundation,
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Virginia Kcy, Miami,
Florida 33149. All rights reserved.
Second-class postage paid at
Miami, Florida and at additional
mailing offices.

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of address correspondence to:
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Front cover: The burning sea. Primeval forces are at work as molten lava from Kilauea volcano on the island of Hawaii spreads into the sea to be quenched. These same forces created the lava-tube structures that today attract divers to Hawaii from around the world to enjoy the delicate splendors of their resident coral-reef community. (See article beginning on page 100.)

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