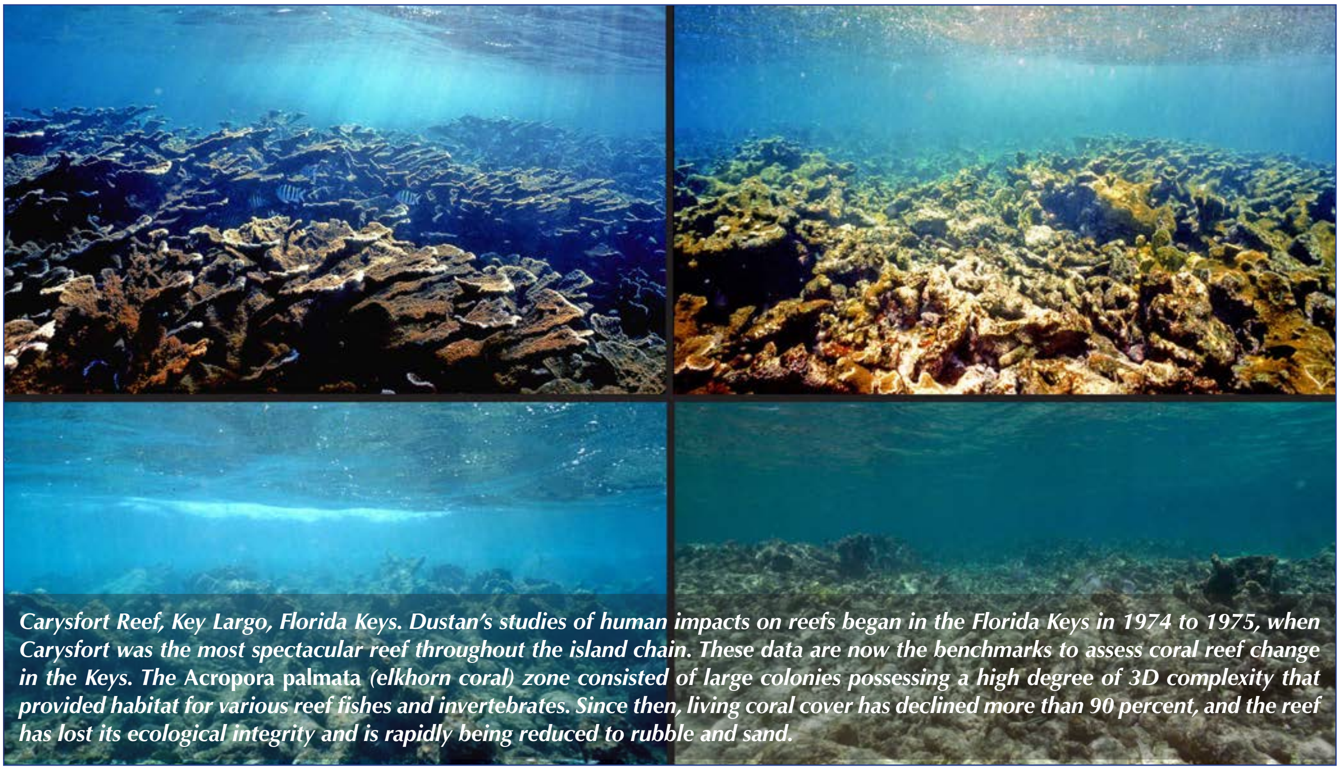
The Decline of Caribbean Coral Reefs

Photographic Tracking From 1972 to 2013 Reveals Ecological Crisis

By Dr. Phillip Dustan



Carysfort Reef, Key Largo, Florida Keys. Dustan's studies of human impacts on reefs began in the Florida Keys in 1974 to 1975, when Carysfort was the most spectacular reef throughout the island chain. These data are now the benchmarks to assess coral reef change in the Keys. The Acropora palmata *(elkhorn coral) zone consisted of large colonies possessing a high degree of 3D complexity that provided habitat for various reef fishes and invertebrates. Since then, living coral cover has declined more than 90 percent, and the reef has lost its ecological integrity and is rapidly being reduced to rubble and sand.*

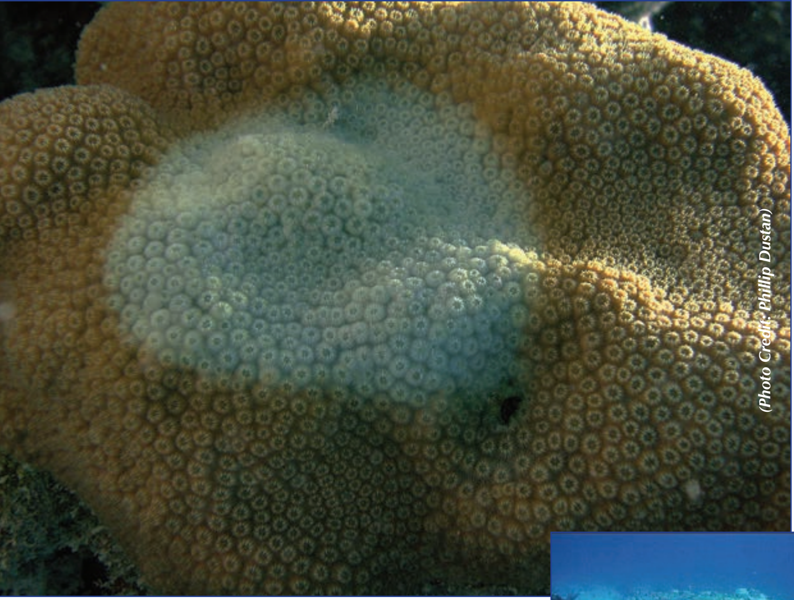
In 1975, as a young scientist, I worked with Captain Jacques-Yves Cousteau to make a film about Caribbean coral reef ecology, "Mysteries of the Hidden Reefs." It was the last of 36 films in Cousteau's "Undersea World" series that inspired a generation to love the sea. We dove tirelessly around the clock shooting film of the reef and its creatures, especially the lush overabundance of corals, which form and build the reef.

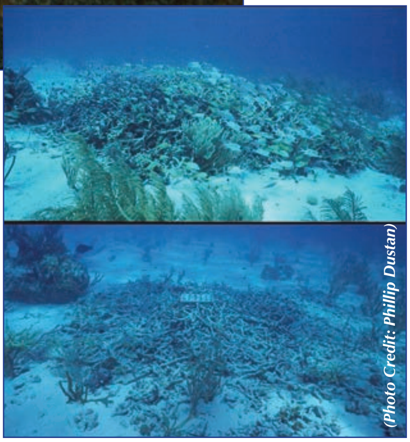
One day, after a sumptuous lunch on board *Calypso* in Belize, Cousteau and I began a discussion about the health of coral reefs that continued throughout our long friendship until his passing in 1997. He was concerned that humans were beginning to cause their decline, and he told me reefs in the Red Sea near Jeddah, Saudi Arabia, were dying. I can remember thinking that he was out of his mind—and that reefs were so stable and robust that little could hurt them. After all, they are the richest, most productive ecosystems in the sea, the largest construction project on Earth.

Fast forward to 2014 and a much changed world populated with more than 7 billion people. We still marvel at reefs, and millions scuba dive with regularity. Books and movies abound with exquisite pictures of turtles, sharks, bikini-clad divers, and spectacular macro shots of the smallest fish or the most colorful shrimp nestled within psychedelically glowing coral tentacles. But the sad fact of the matter is that we must range ever farther from human habitations to find these marvels.

Dancing Lady Reef

I visited the Discovery Bay Marine Lab in Jamaica in October 2013 to record changes in the ecology of Jamaican reefs since my time there as a graduate student. Specifically,





(Top) Coral bleaching, or the loss of a coral's symbiotic algae, is a reaction to a wide variety of stressors that uncouples the symbiotic bond between coral and zooxanthellae. No one knows if the algae leave or are expelled by coral, but bleached corals grow slower and are more vulnerable to diseases. Mass bleaching began in the 1980s and is increasing throughout the tropical seas as the oceans continue to warm. (Bottom) Coral create complex habitat for fish that become reduced to rubble fragments when the colonies die. The remains of a lobster trap in the middle of the fragment pile indicates the demise of this patch of staghorn coral, Acropora cervicornis.

my diving partner, Liv Wheeler, and I were there to redocument Dancing Lady Reef, which I had come to know like my own backyard in the 1970s. Since then, there had been two serious hurricanes, chronic overfishing, large-scale coastal development, and mass mortality of the long-spine sea urchin, *Diadema antillarum*, the reef's principal herbivore, along with a changing global climate.

On a glass-smooth sea our coxswain dropped us on Dancing Lady. We descended with excitement and apprehension. The reef topography told me we were in the right place, but almost everything else was different. The once incredibly lush coral community was an algae field encrusting dead coral skeletons. Large areas once covered with vast piles of delicate branching staghorn coral were now piles of eroding rubble. Deeper, corals exposed to the rain of sediments and organic snow from above were dead, dying or badly damaged. Fish were nonexistent, and many of the colorful invertebrates that dwell among the corals were absent. More alarming, we found that the local fishermen and Discovery Bay townspeople had no idea of the treasure they had lost. We started asking around and showing before and after pictures to the regional fisheries council and local organizers, who were shocked at the discrepancies between the photos. Nobody knew. Nobody had even thought to look.

Earth's Largest Biological Construction Project

Long before there was life on land, there were reefs in the sea that evolved into the vibrant, underwater fantasy worlds we were introduced to by the "Undersea World of Jacques Cousteau." Their biodiversity holds potential for advancing medical science and understanding life. More practically, reefs protect shorelines, are a major source of protein for more than a billion people, may be co-located with oil and gas fields, and, tragically, become the final resting grounds of hapless ships.

Reefs are shallow, underwater living mountains that grow towards the surface. Seen from space, reefs are the largest biological construction projects on the planet. Paradoxically, corals that build reefs are among the simplest animal forms known. Corals form the framework, algal and animal sediments get trapped in the cracks, and submarine cementation turns the mix into hard limestone rock.

Reefs have the greatest biodiversity on Earth. Energy and nutrients flow through their elaborate food webs. Intricate life cycles flip between pelagic and sessile forms, while roving predators exert a top-down control on reef fish. Healthy reefs have a full complement of sharks, groupers, snappers and other predators, along with the trophic levels beneath. But an abundance of fish is not a sign of boundless harvest because virtually all the ecosystem's production is utilized by the reef community.

Sadly, the decimation of Dancing Lady Reef is not an isolated case; reefs worldwide are fast deteriorating. Seventy-five percent of the Earth's coral reefs are threatened, especially in the Indo-Pacific and Caribbean, where most reefs are undergoing an underwater catastrophe rivaling the global deforestation of tropical rainforests. Scientists and resource managers are scrambling to find ways to assess coral reef health, identify the causes driving reef deterioration, and stop their slide to extinction.

The Coral Colony

Most reef-building corals are colonial animals with their tissues intimately in contact with the sea, like the roots of plants. Their bodies are just three to six cell layers thick, covering the surface of their stony calcium carbonate skeletons; less than the thickness of a credit card. They are both animals and plants. Coral polyps expand into the water column (usually at night) in search of zooplankton prey, while the photosynthetic activity of millions of microscopic symbiotic algal cells, *zooxanthellae*, within the animal tissue recycles metabolic animal waste to provide nutrition and enhance skeletal growth. Additionally, tens of millions of bacteria and viruses living on the coral colony's surface provide an interface with seawater. While we don't yet understand the function of this microbiome, it may play an active role in the nutrition, metabolism and immunity of healthy corals. Studies have shown that some coral diseases on overfished reefs correlate with changes in these microbial communities. The efficiency of the polytrophic coral organism provides the ecological infrastructure that enables complex, highly diverse ecosystems to thrive in virtual oceanic deserts.

Anything that affects the integrity of the coral tissue will impact coral, and possibly ecosystem, health. Fish bites, a

(Top) White Plague, a coral disease discovered by Dustan in 1974, is caused by a microbial infection that kills coral tissue. In a short time, the bare skeleton becomes encrusted in algal turf and boring sponges begin to degrade the skeleton. Since then, many more diseases have been discovered and their pathogens identified, many related to decreased water quality, overfishing and land-based sources of pollution. (Bottom) Dancing Lady Reef 1972 to 2013. The fore-reef terrace is now a shell of its former existence. Once almost entirely covered with staghorn coral,* Acropora cervicornis*, and star coral,* Orbicella annularis*, the reef has lost more than 90 percent of its living coral to storms, algal overgrowth, disease, pollution, and, perhaps, global warming.* A. cervicornis *and* Montastrea annularis *corals no longer exist in the pictured area as they once did.

careless diver's fin kick, a ship grounding, excess amounts of sediment, or algal overgrowth all can generate a lesion. An open wound can easily become infected by a disease that can kill a century-old colony in weeks to months. In other situations, the skeleton exposed by the wound is colonized by algae that can grow unchecked due to the loss of herbivores through overfishing and/or disease. Corals have no second line of defense once the herbivores disappear.

Reefs develop to their highest expression in nutrient-poor, crystal-clear tropical waters. Ironically, the adaptations that have evolved to scavenge and conserve limiting nutrients enabling corals to be so successful for hundreds of millions of years now make them acutely vulnerable to human activities that take, break or indirectly interact with reefs. Reefs are more sensitive to environmental change than our finest oceanographic instruments, responding to increased nutrients at levels we can barely measure or shifting community composition at the earliest stages of overfishing. They are present day harbingers of ocean change.

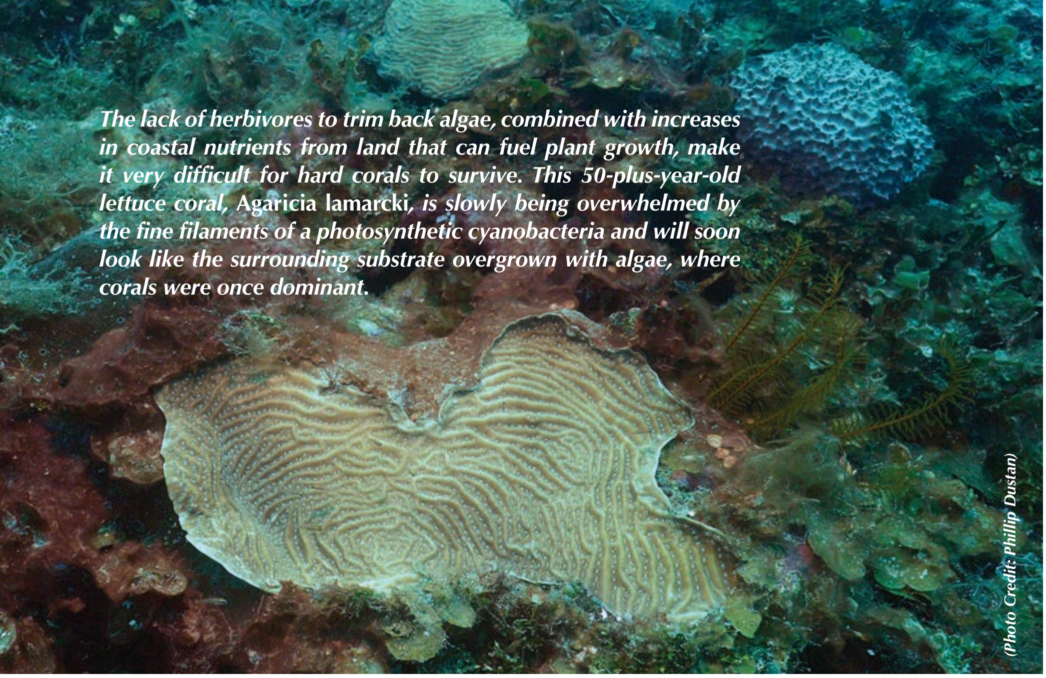
Stresses

Reefs in all the tropical seas are threatened by degraded ecological conditions that originate locally, regionally and from the shores of distant continents. The question is frequently asked: What factors are responsible for the destruction of coral reefs—sediments, nutrients, pollution, overfishing, climate change or something unknown? In reality, it is the accumulation of stresses, which are as local as fishing and tourism; as regional as cities, agriculture and industry; and as global as deforestation, the hole in the ozone, rising atmospheric carbon dioxide and African dust. Fishing removes important ecological components of the reef, increased sedimentation smothers corals, increased nutrients promote algal overgrowth, elevated temperatures cause bleaching, and diseases are more prevalent in areas close to civilization. On a large geographic scale, the over-addition of nutrients, organic carbon and sediments from land-based sources of pollution generates coastal dead zones at river mouths, where they are picked up by ocean currents and circulated throughout the seas. Additionally, vast quantities of iron-rich African dust laden with pesticides, heavy metals, and viable mold and fungal spores are transported across the Atlantic to the Caribbean on stratospheric winds.

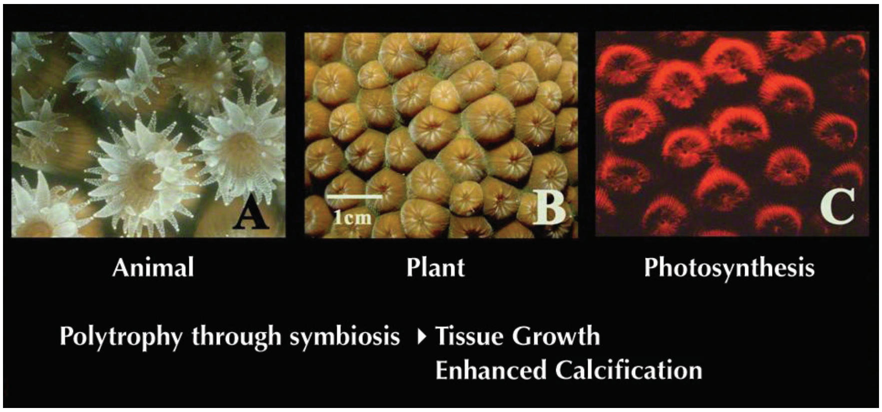
In the Caribbean, the three big stressors appear to be overfishing, which interrupts the food web by removing predatory and herbivorous fish; loss of urchin herbivores due to an unknown factor in the early 1980s; and massive land-based sources of pollution. Global warming is a close fourth. Work on rebuilding urchin populations has been slow to nonexistent. Development, deforestation and other forms of land use bleed nutrients and sediments into the coastal seas. Current forms of wastewater treatment, if in use at all, decrease the biochemical oxygen demand but do not reduce nutrient level in wastewater, nor kill all the potential pathogens in their discharge. A major unknown in this story is the impact of ocean development. Since the 1980s, there has been an explosion in the exploitation of ocean resources. The global shipping fleet has doubled, hydrocarbon exploration and extraction has ballooned, fishing efforts have grown by a factor of six and cruising tourism by an order of magnitude.

Ways Forward

The oceans have swallowed up vast amounts of pollutants, sewage, relict ships and even railroad cars, but the collapse of coral reefs is telling us that the oceans' ecological goods and services are stretched to the breaking point. Many of the issues I have raised, however, could be fixed if political will is present to better manage the impacts because the best way to manage reefs is to manage people. We can build tertiary sewage treatment and/or wastewater gardens that turn sewage into a valuable resource. We can improve fisheries through marine protected areas and education. We can restore herbivore populations, apply soil



The lack of herbivores to trim back algae, combined with increases in coastal nutrients from land that can fuel plant growth, make it very difficult for hard corals to survive. This 50-plus-year-old lettuce coral, Agaricia lamarcki, *is slowly being overwhelmed by the fine filaments of a photosynthetic cyanobacteria and will soon look like the surrounding substrate overgrown with algae, where corals were once dominant.*



Coral are both animals and plants, forming a symbiotic relationship that has evolved to trap and retain nutrients in the nutrient-poor conditions of tropical seas. Their animal polyps expand at dusk, using tentacles to capture zooplankton. During the day, the* zooxanthellae *living inside the contracted coral's cells use the animal's waste products and sunlight for photosynthesis to enhance tissue and skeletal growth. (Photo Credit: Phillip Dustan)

conservation techniques and reduce pollution levels. But there are no quick fixes.

For instance, no-take marine protected areas work over time because all natural populations overproduce. Decreased fishing pressures promote overcrowding, which naturally pushes fish out of the protected area into waters where fishermen ply their trade. Given suitable environmental conditions, most reefs could regenerate.

While many of these ecological problems may seem global, local action is required. Local fishers must agree to honor the integrity of marine protected areas, and local populations must agree to recycle their plastic, collect their garbage, and control their waste. Corporations can act regionally through the actions of local stakeholders.

Coral reefs have weathered global climate shifts, plate tectonics, typhoons and volcanic eruptions. Evolution has produced an astonishingly complex system adapted to a nutrient-impoverished ocean whose design for ultimate conservation ironically now contributes to its steady and rapid decline. As the coral reef crisis deepens, we must redouble our efforts to develop more committed public policy, engage stakeholders and utilize economic models to save reefs. As we move into the Anthropocene, with barely any wild place left, the marine industry, capitalized at more than $3 trillion while extracting biological and mineral riches, would be well-served by assuming more of a leadership position in the stewardship of the sea from which it derives its wealth.

Acknowledgments

Support provided by the Waitt Foundation and the Discovery Bay Marine Laboratory, with significant diving assistance in Jamaica from Liv Wheeler (TreestoSeas.org), Gene and Pat Shinn on board *Papa San*, and John and Judy Halas in the Florida Keys. ■

Dr. Phillip Dustan, professor of biology at the College of Charleston, studies coral reef vitality throughout the tropical seas. He worked closely with Captain Jacques-Yves Cousteau and the Cousteau Society, has testified to the U.S. Senate Subcommittee on Oceans, and helped design and implement the USEPA Coral Reef Monitoring Project for the Florida Keys.