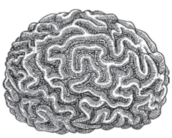
THE SECRET LIFE OF CORALS



Sex, War, and Rocks That Don't Roll

David E. Vaughan, PhD

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Preface

"Through the window of my mask I see a wall of coral,
its surface a living kaleidoscope of lilac flecks, splashes of gold,
reddish streaks and yellows, all tinged by the transparent blue of the sea."

—Jacques Yves Cousteau

Corals are the gems of the oceans, creating the beautiful colors and shapes that form our reefs. Their story, told in the following pages, is unlike any story in the animal or plant kingdoms.

Once you learn about the secret life of corals, you will understand that they serve many vital functions for life on this planet. They create habitat for a large percentage of the seafood eaten around the world. As guardians of our coastlines, they absorb the brunt force of waves and tidal surges, particularly during tropical storms and hurricanes. When we breathe, we can thank corals because they contribute oxygen to the atmosphere. Corals also add significantly to our economy through tourism dollars and related jobs and industries. While they live under the sea, corals are truly important to our lives on land.

Although they are very beneficial to *our* existence, corals are quite precious in their own right. The individual coral polyps are nothing if not charming. The colonies they build and live in can be exquisite, with an amazing array of colors and shapes. These colonies can be large or small, branching, round, mountainous, plate-shaped, and more. Coral reefs can stretch for miles and team with fish and many other creatures such as crabs, shrimp, starfish, eels, rays, and lobsters.

The way corals behave is remarkable too. How they grow, reproduce, coordinate with one another, and even go to war is absolutely fascinating.

Unfortunately, since the 1950s, we have lost over half our coral reefs worldwide, primarily due to climate change and disease. Environmental stressors are devastating coral communities; however, there are corals that do persist. Somehow, they survive warming ocean temperatures, increasing ocean acidity, and various coral diseases. These are the corals we need to grow and replant back onto the reefs. The good news is that we can do it. We now have the technology, including methods to produce corals at scale by the hundreds of thousands—much faster than anyone ever thought possible.

Over the past 50 years I have worked at some of the most prestigious marine research institutions in the world and produced over 50 scientific publications. In 2021 I edited *Active Coral Restoration: Techniques for a Changing Planet*, the first comprehensive book on the subject, geared for the scientific community. Soon after, I realized that the story about corals, what they are exactly, why they are important, what is happening to them, and what we can do to restore them, needed to be conveyed to the rest of the world. For this reason, I was compelled to write this book.

My hope is that you will first fall in love with the crazy creature we call coral, and develop a genuine appreciation for this unique life form. In addition, I hope you will learn why they are so important to the marine environment and to our lives, what threats they are now facing, and how we can work together to "turn the tide" for corals.

—David Vaughan

Introduction: Dave's Journey

Submerged from the Start

When I was young, I didn't know my life's work would be corals, but I did know I wanted to spend it underwater. My fascination with the ocean world started at age 11 when I became obsessed with the thought of becoming a scuba diver like Jacques Yves Cousteau. While other children my age were writing book reports on fighter pilots, football players, and cowboys, I was deeply immersed in the writings of Cousteau and his colleague Frederick Dumas. Both men were instrumental in developing tools and equipment used for exploring the ocean. They are much better known, though, for bringing the undersea world into the homes of millions through television documentaries, movies, and books.

Imagine my disappointment when I discovered that scuba diving was an adult sport, with no serious equipment available for children. Not easily discouraged, I started to teach myself to hold my breath for long periods of time. My teachers undoubtedly thought me odd when they saw me hold my breath at my desk, turn red, and then exhale—as if clearing my imaginary snorkel.

In the summers I practiced holding my breath in our backyard swimming pool until I could hold it for 1–2 minutes—worrying the adults watching and waiting for me to resurface. At my family's summer home along the Jersey Shore, I spent my days underwater at the beach, searching for crustaceans, fish, clams, and seaweed while everyone else was riding the waves. Little did I realize that the trajectory of my life was already set in motion and that I would eventually become a marine biologist and grow many of these same organisms over the span of the next 50 years.

My parents hoped my obsession with scuba diving was just a passing phase. That began to change when my father came down the basement stairs and caught me melting down lead figures of toy soldiers, cowboys, and Indians. Once these favorite childhood toys were melted, I poured the liquid lead into a homemade mold to create my own custom dive weights. These would be used for the weight belt I hoped to proudly wear scuba diving. It was then that he and my mother realized I was not going to give up until someone of a higher authority explained why I was not ready for scuba diving.

So, my Dad took me to the few nearby dive centers. At each one, they confirmed I was indeed too young to learn to scuba dive. Plus, I was much too small to pick up a tank, let alone carry one on my back. I convinced my parents to take me to just one last shop an hour's drive away. It was a new business facility that belonged to a company that primarily built in-ground swimming pools. They also taught scuba diving in a small, deep showroom pool that had a window on the side for observation. At the time I was barely 3½ feet tall and 48 pounds at most. To me, the shop's 6-foot instructor who must have weighed two hundred pounds seemed a giant. My father asked him to teach me a few basic dive skills, hoping he too would agree I was much too young.

When I quickly connected the steel scuba tank to the backpack, attached the regulator, put on the tank that weighed almost as much as I did and jumped into the pool, the instructor gasped. He grabbed his tank like it was a toy and followed me in.

He gave me a workout typically reserved for the final underwater exam. He turned off my air, pulled off my mask and spun me around. My previous practice of holding my breath paid off. I easily waited, casually turned my air back on, cleared my regulator, and replaced my mask. Each time he spun me around, my head came back to the viewing window and I could see the terror in my parents' faces as they thought I might drown. But no, I was having the time of my life! To the instructor's amazement, I then said to him, "Is that all you got?" I'd passed the test. From then on my parents dutifully drove me to scuba lessons each week. In the end they were very proud when I received my scuba certification just prior to my thirteenth birthday.

Soon afterward, I had the opportunity to go on a science expedition to collect and study corals in the U.S. Virgin Islands, an amazing trip for a 13-year-old. My father made it possible and I am forever grateful. As the development officer for Fairleigh Dickenson University, he was responsible for raising funds. Professors from the college approached him about raising a million dollars to search for and develop a new marine laboratory in the Caribbean. (Years later, this endeavor resulted in the West Indies Marine Laboratory, eventually located on Saint Croix.)

My father agreed to try to raise the funds, first for the expedition, and then ultimately for laboratory construction. However, he threw in one condition: they take me along on the expedition. The professors agreed and probably thought I would hang out with the kids of the other professors, enjoying the pool and hotel amenities. But nope, I stayed in a tent on the beach with the college students who hoped they would not have to babysit me.

To my surprise, I was told to pack a geological chisel, hammer, or a prospector's tool for the expedition. Yep, my job was to break off live pieces of coral, and then dry them out in the sun, where they would unfortunately die. These coral samples were then sent back to the university laboratory where they were put in formalin jars and archived. Times have changed and this would not be done today unless you were taking small tissue samples for cloning corals for future restoration.

Each day's activities were memorable and mostly consisted of snorkeling from shore to gather various species of coral for the collection. Wading through the water I searched for an area without coral where I could comfortably sit and put on my fins. This took a while because there were so many staghorn and finger corals, a rare sight today. I vividly remember thinking, "I can hardly wait to get past all of these corals into deeper water to find more interesting corals like brain coral." The reef then was healthy and teeming with life. Sea urchins were everywhere. Sitting or standing on the reef was out of the question lest you impale yourself on one of these long-spined creatures. Naively, I thought that these healthy reefs would be around forever.

The expedition to the Virgin Islands was absolutely life changing for me. As time moved on my interests expanded to all forms of aquatic life, from marine plants and animals to wetland habitats. I saw beauty and intelligence in all creation. College was the next step and I attended a mid-western church college now called Graceland University. Although it may seem strange for an aspiring marine biologist to attend school in Iowa, this school encouraged my reverence for the natural world.

Later, I earned my Master's degree in biology at Fairleigh Dickinson University and worked with both marine algae and shellfish. My interest in micro algae and phytoplankton continued as they were in great demand specifically by shellfish hatcheries near the Jersey Shore. Many shellfish hatcheries were run by zoologists or malacologists that have studied clams or oysters, but did not know how to grow marine plants. And if you can't raise the right type of algae to feed bivalve larvae, they will ultimately starve and die. I knew very little about other marine invertebrates, but I could grow the heck out of algae.

I continued my education as a PhD candidate at Rutgers University. I was in the Botany and Plant Physiology Department and studied seagrasses and the microscopic algae that live on the surface of their leaves. My research led me to the Rutgers Marine Field Station in Tuckerton, New Jersey, to carry out fieldwork. In Tuckerton there was an old U.S. Coast Guard station, complete with a light tower at the tip of a ten-mile-long marsh peninsula. This station was given to the University because it was so remote that the Coast Guard had trouble keeping it manned. Apparently, the university did too, so I was offered the position of "graduate resident" and had the honor of living in the lighthouse-style structure while completing my field work for the next 4 and a half years.

During this time period, my brother, sister, and I had also been running a summer business venture to help finance our respective years in graduate school. We bought and operated an existing farmer's market that sold vegetables, plants, and local seafood. In the first year we had trouble getting the supply of plants needed to fill our orders. Immediately, I was catapulted into plant production and built our first greenhouse. Every year we built a new greenhouse and eventually had an entire greenhouse production system so we could grow and sell thousands (instead of hundreds) of geraniums, marigolds, and petunias.

My life was plants, plants, and more plants, until finally clams became my focus. At our farmers market, we also sold local harvested clams, but one year we could not keep them stocked due to high demand. It did not take long for me to realize, "Hey, when we needed greenhouse plants we grew them, now we need clams. I am a marine biologist, there must be something I can do." I started to thoroughly research how to grow clams. My wife, Donna, would use the term "ad nauseam." One time she came downstairs in the middle of the night to find me and one of my fellow grad students, Joe, staring at a small glass aquarium tank containing just one male and one female chowder size clam and proclaiming we were going to witness them spawn. After a while she gave up and went to sleep. Early the next morning, she found Joe and me still awake staring into a milky white tank now full of clam sperm and eggs. They had done it! I think she knew then and there that our future would change, and she was right—although my in-depth work with clams would come a few years later. My siblings and I kept growing greenhouse plants and selling them at the farmers market over the next several years while also finishing our respective degrees.

Once I had my PhD, my sister and I left the business in the capable hands of our brother who still owns and operates it in New Jersey to this day. If you are ever near Ocean City, stop by Vaughan's Farm & Market and say hi to John. My sister, Pam, went on to become a professor at Stockton University and I followed my interest in clams. First, I formed Aqua-Farms, a commercial clam hatchery, then moved on to Cultured Aquatics on Long Island, and finally went off to Florida to scale up shellfish culture.

For the next 20 years, my work with clams and oysters occurred at Harbor Branch Oceanographic Institute in Florida as Director of the Aquaculture Division. During this time we scaled up clam culture technology by improving the hatchery—spawning tanks where clam larvae, also known as seed, are formed. We went from producing 1 million clam seed per year to producing 1 million clam seed per day, and eventually reached a total of a billion produced before I left. During that time I was given the nickname "Dr. Clam." This production of selected clam seed was so successful that we were able to open "Clam College" which provided education and training in clam farming to displaced fishermen.

We were able to grow out our business to support other research programs, such as the development of culture technologies for the production of marine ornamentals (fish, plants, invertebrates, corals) for the aquarium trade. The impetus for this was to farm these plants and animals in tanks instead of being harvested or taken from the reef. We started our research with clown fish, also known as the anemone fish, a year before the Disney movie "Finding Nemo" came out.

By then we had developed the technology to produce 25,000 fish per month and with demand soaring turned the research hatchery into a for-profit company called Oceans, Reefs and Aquariums, Inc. (ORA).

From this revenue we decided to culture corals for the aquarium trade. At that time, all corals from the Atlantic and Caribbean were protected, so only corals from the Pacific Ocean were legal to buy. It was not long before we scaled up to 100,000 corals cultured for the aquarium trade. We continued to grow and sell these corals with hopes that the process of importing wild coral from the Pacific Ocean would slow down or stop altogether.

It was around this time I had the pleasure of meeting Alexandra and Philippe Cousteau, the grandchildren of my childhood hero Jacques Cousteau. They wanted to tour the aquaculture facilities at Harbor Branch, and I was more than happy to show them around. After the tour they asked why were we growing corals for the aquarium trade? I replied, "To decrease the number of corals taken off reefs in the wild." Philippe then asked, "Why are you not growing these corals *for* the reefs, growing them and putting them back out to sea?"

In that instant my life changed again. Philippe, Alexandra, and I started the "International Coral Restoration Initiative," and a new adventure began. I left Harbor Branch, purchased a warehouse nearby, and started growing corals for outplanting. We continued for three years, but sadly, all our hard work was lost when two consecutive hurricanes, Frances and Jean, struck South Florida in 2004. The area was devastated. Our project came to a halt, and my house was destroyed. In the aftermath, Philippe and Alexandra left for Washington, D.C., and I took a new position at Mote Marine Laboratory in the Florida Keys.

During the next 15 years at Mote Marine Laboratory as the Executive Director of the Tropical Research Lab (now the International Center for Coral Reef Research and

Restoration), I continued my passion for trying to grow corals at scale—hoping to then plant them back onto the reefs for restoration. We focused on coral species found in the waters off the coast of Florida and in the Caribbean, particularly the reef-building coral species which are more massive in size.

At this time people were fragmenting/breaking the one branching coral, known as staghorn coral, and growing them in the field for restoration purposes. To my amazement though, nobody was trying to grow the other 26 species of massive corals, which I termed *orphan corals*. When I asked about hatching (breeding) these corals in a nursery, in addition to breaking and growing them, I was told no one did that. So we decided to try. We worked through a normal marine hatchery process similar to what I used with clams, oysters, and fish. To our amazement we were able to produce a dozen of the first "test-tube baby corals" from elkhorn coral gametes collected in the wild. Although hatching the coral in the lab was successful, the coral larvae grew very, very slowly. At three months they were still too small to see with the naked eye. By six months they were barely visible, and after 1–3 years of age they were still only about the size of a coin.

Frustrated, I realized the growth rate was just too slow to grow these corals at scale in a timely fashion. So, I moved these corals from their perch on the top shelf of a PVC frame to the bottom of the tank. For the better part of a year, I forgot about them.

One day I went to move them so that I could clean the tank. One of the corals was stuck to the bottom. I yanked and yanked until I heard a crack! It broke into a dozen tiny pieces. I thought for sure that I had killed it or at best caused a huge setback in its attempt to grow. But I was wrong! What happened next is what the *New York Times* called "My Eureka Mistake." It turned out to be a game-changer for corals and will be discussed further in Chapter 18 (to keep you in suspense).

My life to date has been serendipitous, and sometimes it has seemed cosmically planned to get me to this point. Although I did not know it at the time, my work with algae, clams, oysters, and fish was essential in helping me to eventually develop technological systems for growing corals in very large numbers (at scale). My Eureka Mistake then paved the way for coral growth and restoration nobody ever thought possible, including myself. I now have a foundation called "Plant a Million Corals" and I am dedicated to growing and planting a million corals before I retire.

The pages of this book represent a lifetime of work and trial and error. My career as a marine biologist has given me an insight into corals that few can match. I am so excited for you to dive in with me and learn about the secret life of corals: what they actually are; their journey from larvae to solid members of the reef; how they eat, have sex, and go to war; their importance to the planet; how they are dealing with environmental stressors; and how new technologies for restoration are providing hope for their future. They are truly remarkable, a creature like no other. Let's learn about and protect them together!

This is the Johnson Sea Link Submersible, the vessel that took Dr. Vaughan on his deepest ocean journey (2,000+ feet) to research deep sea mollusks and corals that could be cultured for biomedical uses (see Chapter 13). Pictured is Dr. Vaughan (right) and family, Dee Dee and Jason.

PART I

What Is a Coral?

Manta ray approaching a coral reef in the Maldives, Indian Ocean.

1

The Importance of Coral Reefs

Despite being mostly water, when it came time to name our planet, land-loving humans thought *Planet Earth* would be best, going so far as to make the word "earth" synonymous with the very soil we cultivate and walk upon. When viewed from space, however, we get an entirely different picture, one where the name *Blue Planet* makes a lot more sense. Oceans cover 71% of the earth's surface—they are the dominant and defining body of our home.

Throughout history, people have roamed, explored, and expanded civilization on Earth into uncharted territories. Historically, ocean-based travel by boat or ship was essentially for commerce and the relocation of people. The world of the seas was known only from the surface and by what was caught and brought aboard for food. Most early seafarers saw the ocean as a mysterious place with sea monsters ready to drag down a ship to its watery grave, perhaps with a mermaid to sing them a siren's song along the way. With occasional glimpses of sharks, whales, rays, enormous jelly fish, and other animals, their imaginations could easily create tales of terror due to their lack of understanding. Coral reefs were dangerous areas close to the surface that could strand or destroy ships and were to be avoided at all costs. The amazing color, variety of life, and unique beauty that abounds below the surface was hidden from their view.

We now know that coral reefs are some of the most diverse and valuable ecosystems on this *Blue Planet* of ours. Healthy reefs are full of unique life-forms, and they can be quite expansive. Coral reefs are actually living rock-like structures. They are made up of distinct coral colonies that are different shapes and colors depending on the species of coral. These coral colonies are made up of individual coral polyps. Their fascinating biology and life history will be explored in future chapters. For now, we will focus on the coral reef as a whole.

A majority of corals that build coral reefs are found in warm tropical waters close to the equator. Different species of corals live in different ocean basins, so reefs in the Indo-Pacific Ocean region can look different from reefs in the tropical western Atlantic Ocean. The Indo-Pacific Ocean region extends from the Red Sea and the Persian Gulf through the Indian and Pacific Oceans to the western coast of Panama. Western Atlantic reefs are found in the waters of Bermuda, the Bahamas, the Caribbean Islands, Belize, Florida, and the Gulf of Mexico.[1] Corals also grow on rocky outcrops in some areas of the Gulf of California. Healthy coral reefs in all these areas can be absolutely striking in color and shape, providing habitat for an enormous amount of marine life.

Although people appreciate that coral reefs are spectacular to see, many are unaware as to how vital they actually are to life on this planet. In fact, throughout my career I have often been asked, "Just how important are coral reefs, anyway?" The answer is more complex than one might think and takes some time to fully explain. Corals and the reefs they create offer so many valuable services to both the marine environment and our own lives that they are among the key drivers of human health, nutrition, safety, economic well-being, and survival on the planet. Coral reefs provide habitat for a large portion of the seafood that we consume. In addition, they provide subsistence living in terms of daily food for almost a billion people worldwide. They protect our coastlines during storm events (i.e., hurricanes) and they even add oxygen to the air that we breathe. They are a major contributor to our economy through tourism and the jobs that support it. And lastly, coral reefs are considered key to finding new medicines for the 21st century. Those who asked the initial question are usually surprised by this answer so we will go into more detail in the following sections.

Corals Produce Oxygen

It is a little-known fact that the majority of oxygen we breathe on land is produced in the ocean. It was originally thought that the vast number of trees and plants in the forest were the major suppliers of oxygen, but that is not the case. We hear that the rain forests are the "lungs of our planet" and they are certainly one of the heavy lifters in the production of oxygen. I would argue, however, that the true lungs of the earth rest beneath the surface of our oceans.

Most scientists believe between 50–80% of the oxygen we breathe comes from the oceans.[2] It is produced by marine plants of all sizes, from microscopic algae like phytoplankton, to giant kelp that can reach up to 65 meters in length. What is surprising is that all reef-building corals have algae that live inside of them, and they produce oxygen as well. This oxygen produced by marine plants is released into the water, which then travels to the ocean surface where it escapes into the atmosphere.

In many of my presentations I ask the audience to take a breath. They usually comply with a half-hearted inhale and exhale. Then I encourage them to take another—bigger and deeper—which usually gets the more energetic response I was looking for. This exercise is not to wake them up and get them to listen more attentively, but to demonstrate one of the biggest, most relatable values of corals to society. We breathe the oxygen that corals produce. I ask the audience to consider that second, deeper breath as a "breath of gratitude" for the oceans and the corals within them.

Habitat for Seafood

Many people do not typically correlate their enjoyment of seafood to corals, after all, no restaurant has coral on the menu. However, coral reefs, which occupy less than 1% of the ocean floor, support 25–40% of our commercial fisheries![3] This translates to food on our plates and dollars pumped into our economy. The National Marine Fisheries Service estimates the commercial value of U.S. fisheries from coral reefs is over 100 million dollars.[4] Around the world, indigenous people in tropical island nations subsist on local seafood caught in and around coral reefs. It is the coral reef that provides places for creatures large and small, solitary or schooling, to survive and flourish.

The huge area that covers the bottom of our oceans is mostly sand or mud bottom terrain, so a dynamic reef ecosystem is like an oasis in the middle of a desert. This unique, diverse, three-dimensional habitat provides structure with nooks and crannies for all types of marine life to thrive. This includes the finfish swimming over the reef, as well as the lobsters, crabs, mollusks, and other invertebrates hidden within it. Many seafood species use the reef as a permanent home, others use the reef to breed and raise their young, and some come to the reef just to feed.

Unfortunately, demand for fresh seafood is rising and ocean harvests are already becoming unsustainable for many of the species that are fished worldwide. In addition, we are losing critical coral reef habitat due to disease and effects from climate change. If you don't like eating seafood this may not seem like a problem, but the impact goes beyond just the unquenchable appetite for seafood shared by many around the world.

Tourism

Tourism is a large component of the economic engine that runs throughout the tropics as tourists like to fish, scuba dive, and snorkel on coral reefs. These reefs are the primary reason why people visit these locations. Many of these areas with local reefs may have thousands of residents and millions of visiting tourists throughout the year. Vacationers help the local economy by eating at restaurants, staying at hotels, and renting boats, kayaks, and dive equipment. They also pay for charter boats, complete with captain and crew, to take them diving and fishing. In South Florida alone, corals are responsible for over 70,000 jobs—estimated by the National Oceanic and Atmospheric Administration (NOAA) to be worth over five billion dollars (with a "B") per year.[5] These values are similar for Hawaii and the Great Barrier Reef in Australia. So, the health of coral reefs is definitively linked to the economy of coastal areas in tropical regions.

Shoreline Protection

Many people don't know that coral reefs provide an amazing amount of shoreline protection, but that is exactly what they do. Coastal wetlands protect seaside communities during hurricanes by breaking up the energy of the waves. Coral reefs behave the same way—they are the underwater defenses for damaging waves in tropical areas. The barrier reefs take the first big waves of a storm, and then patch reefs wear down the waves even more as they approach the shorelines, making them less damaging to the coast.

Irma was a category 5 hurricane that hit the lower Florida Keys in 2017. Oceanographic buoys recorded 35-foot waves just a little over five miles offshore. These enormous waves first crashed over the barrier reef and then were reduced in size as they crossed the miles of inshore patch reefs that blocked and dissipated their energy. When the waves finally made it to shore, they were 4–8 feet high, not the three-story monsters that would have demolished every single structure, including CAT 5 buildings which were built to withstand strong winds but not waves this high.

Even without a hurricane in the forecast, reefs continue their job of protecting our shorelines from rough water caused by normal winds and storms. To illustrate this, NOAA routinely provides weather service marine forecasts which are sent out to mariners, fishermen, and coastal inhabitants in the Florida Keys. They typically go something like this: "Today's forecast is for winds out of the south at 10–15 miles per hour. Waves inside the reef will be 1–2 feet and waves outside the reef will be 3–5 feet." Wait a minute! Did you hear what he just said? The reef caused the inside seas to calm down by 2–3 feet, even when the winds were not very strong.

Although out of sight, coral reefs stand as a bastion of shoreline protection. It is predicted that a loss of one meter of reef height would double annual costs from flood damage all around the world.[6] With coral reefs diminishing and sea levels rising, we will be losing this vital coastal safeguard. Perhaps in the future we will be forced to migrate inland from the coastline. In countries like the Maldives where everyone lives on island atolls, this is a daily worry, not a future concern.

Medicine Cabinets of the Sea

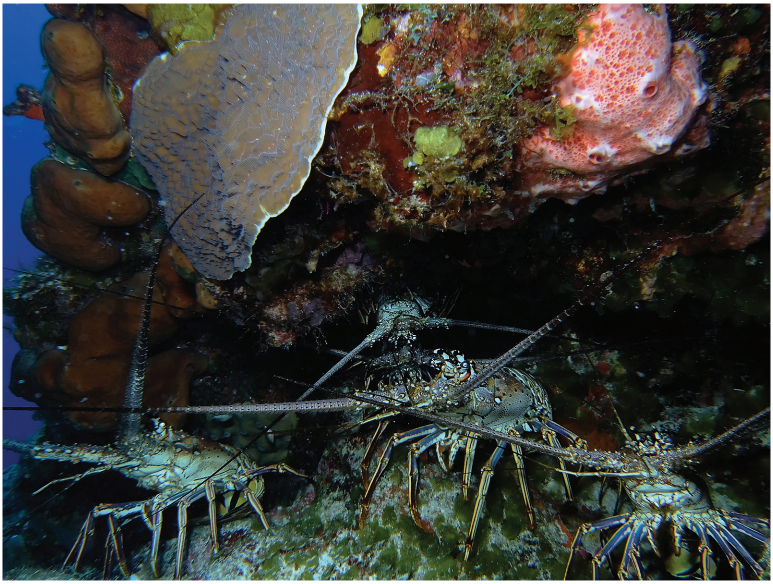
Coral reefs support more species per unit area than any other marine environment, including about 4,000 species of fish, 800 species of hard corals, and thousands of other species. Furthermore, scientists estimate that there may be millions of undiscovered species of organisms living in and around reefs. This biodiversity is considered key to finding new medicines for the 21st century.[7]

Biomedical researchers have been looking to the ocean and marine organisms for new natural products that could be used in medicine. And why wouldn't they? A majority of the medicines that are in use today were originally derived from terrestrial organisms and plants. The ocean is a vast wilderness of possibilities waiting to be explored for medical purposes. The term for seeking out potential medical therapeutics in nature is called *bio-prospecting*. Researchers who are bio-prospecting with various corals have had some remarkable discoveries, including:

- Metabolites derived from corals that have demonstrated significant anticancer activity.
- Products derived from corals have been shown to protect against, and even reverse, bone loss.
- Neuroprotective compounds—believed to be valuable in the treatment of Parkinson's disease—have come from corals. Some of these compounds can be used for relieving neuropathic pain as well.
- Molecules isolated from corals have been shown to greatly inhibit inflammation. They are even being tested to help fight forms of arthritis, including rheumatoid arthritis.[8]

The use of medical compounds derived from corals is still in the early stages, but there is great promise.

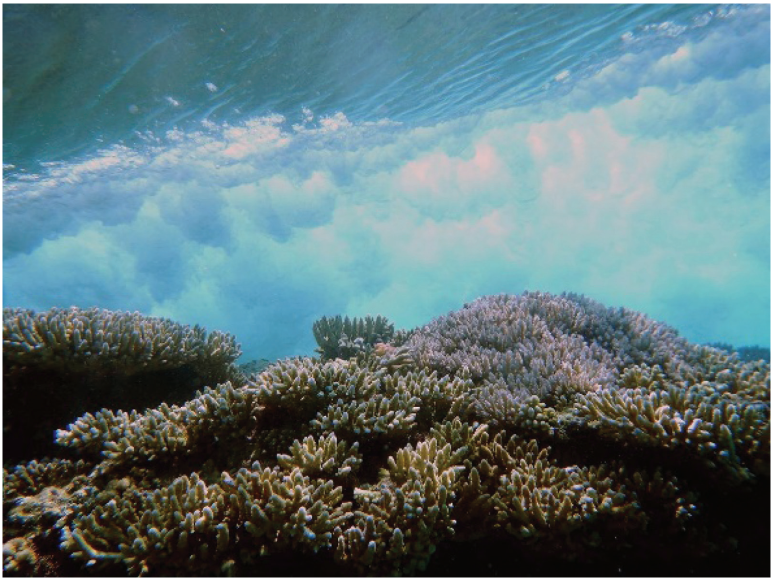
The value of coral reefs is measured in the enhancements they provide to the lives of people around the world. We should all say a heartfelt "thank you" to corals for contributing to the oxygen in the air that we breathe, for the three-dimensional habitat they provide to all the creatures that live on the reef (including the ones we like to eat), for adding to our economies through tourism dollars, for protecting our shorelines from all types of storms, and for offering up new opportunities for medicinal discoveries. It really is amazing to think about how much coral reefs contribute to this *Blue Planet* of ours.



Caribbean spiny lobster sheltering in crevices on a coral reef.

A mixed school of fish, primarily snapper and grunts, under the outstretched arms of elkhorn coral in the Florida Keys, USA.

Scuba diver near a coral wall on the Great Barrier Reef, Australia.



Wave breaking over a coral reef on Kwajalein Atoll in the Republic of the Marshall Islands. The structure of coral reefs can cause waves to break reducing wave energy at the shoreline that can cause flooding, shoreline erosion, and island overwash (photo by Curt Storlazzi, USGS).

A healthy coral reef in the Tumon Bay Marine Preserve, Guam, showing a number of different fish species (photo by Curt Storlazzi, USGS).

2

What Exactly Is a Coral?

WHILE MANY people are familiar with what a coral reef looks like, most do not know what a coral actually is. There are two groups of corals—the stony corals, also known as the hard corals, and the soft corals. Soft corals, like sea fans, sea plumes, and sea whips, are bendable, and resemble plants and trees. However, throughout this book, the word "coral" will refer to the reef-building corals. They are the hard (stony type) corals which produce calcium carbonate skeletons and contribute greatly to the overall reef structure. One of the most absurdly amazing characteristics of coral is that it is essentially a living rock (Image 2.1).

When I am asked, "What exactly is a coral?" I think of one of my favorite childhood games, *20 Questions*. Typically, I turn the question around and ask them: "What do you think it is: an animal, plant, microbe, or mineral?" This usually elicits bewilderment on the person's face, especially when they realize this is actually a trick question because the answer is "Yes, Yes, Yes, and Yes—all of the above!"

Without question, corals are extremely unique. There are no other organisms I know of that can be considered an

Image 2.1

The round boulder form on the right is a hard, or stony, coral called a brain coral, with several invertebrates called Christmas tree worms on top. While the colorful crowns of these worms are visible, most of their bodies are anchored in burrows they have bored into the brain coral. When startled, these worms rapidly retract into their burrows, hiding from would-be predators. On the left is the common sea fan, a soft coral that can move back and forth in the ocean currents.

animal, a plant, a microbe, and a mineral all at the same time. In essence, a coral is a small animal form called a *polyp* that looks like a tiny sea anemone. The polyp is able to create a calcium carbonate skeleton around itself (exoskeleton). It also has marine plants or algae living completely inside of it, as well as a specific community of microbes thriving completely on its outside surface. The coral head that you see on a reef, like a brain coral, is actually the creation of hundreds or even thousands of coral polyps that all live together in a colony.

My personal musings about corals that live in the "inner space" of our ocean planet are that they are strange enough that they might as well have come from "outer space." It doesn't sound so weird if you think of all the unusual pieces, parts, and combinations of diverse creatures that make up the coral life form. Nowhere else on this planet is there such an odd combination of organisms that work together as one crazy rock-like, reef-producing creature.

Symbiotic Relationships Are Key

In nature there are many examples of organisms that work together for a particular purpose or advantage. Most of these relationships are two-way (symbiotic) relationships. Symbiotic relationships include *mutualism* where both organisms benefit, *commensalism* where one benefits but the other does not, and *parasitism* where one benefits and one is harmed.

A famous example of mutualism is the clownfish and the sea anemone. This relationship was made famous in the Disney movie "Finding Nemo," and within their relationship both seem to have advantages, although we are not sure how much each requires of the other to survive. There are anemones that do exist without clownfish, in places like the Atlantic Ocean and Caribbean Sea where there are no clownfish. There are also clownfish that can be grown in captivity without anemones. In the wild however, in places where clownfish and anemones both exist—they do so in mutually beneficial harmony.

The relationship is established when a clownfish brushes up against the stinging tentacles of an anemone. The mucous from the anemone rubs off on the clownfish which then camouflages it from the anemone. The clownfish can survive this self-inflicted abuse because the reward is greater than the cost—it can now safely hide from predators among the anemone's stinging tentacles. The anemone recognizes the mucous on the outside of the clownfish and, consequently, recognizes the clownfish as part of itself.

The clownfish in return brings back bits of food to its landlord, helping to nourish its flexible housing partner. Sounds simple enough but it has its complications. Sometimes absence does not make the heart grow fonder. If the clownfish stays away for too long, the anemone does not recognize its partner anymore and stings it. The clownfish must then repeat the agonizing steps with the sea anemone to once again create the camouflage mucous coat.

Corals have symbiotic (mutualistic) relationships too. These symbiotic relationships are among the polyp itself, the algae, and the community of microbes. They all benefit greatly from each other. These relationships are essential to the health and life of the coral. Today, the scientific term *coral holobiont* is used to describe this multiple assemblage of symbiotic partners, and their fascinating relationships will be brought to light in the chapters ahead.