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DEDICATION

For students, teachers, and communities nurturing and nurtured by the environments of their Pacific islands.

NOTE TO READER

The main goal of this book is to help you know the reefs better and understand the complex processes that create and sustain reefs. This book draws upon different scientific concepts to describe and explain these processes, but you are encouraged to constantly think about and reflect on the stories you have heard and lessons you have learned from your elders about your reefs. Traditional and local knowledge have their rightful places alongside science, and we invite you to help us create those places together.

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Do you see the two children walking on the reef? What do you think they are doing?

These children—and perhaps you—are part of a community that is deeply connected with reefs. They may be out to find food for their families—maybe to collect something in the shallow pools at low tide or to fish in deeper waters. Or maybe they are there to enjoy the sight and sound of waves breaking against the edge of the reef. Maybe they are headed snorkeling to observe the plants and animals living on the reef. Or perhaps they just wanted a quiet place to walk, talk, and relax.

Or maybe—just maybe—they are out there to get a closer look and learn about the reefs that have protected and provided for our communities for generations.

This book is an invitation for you to join the children in the picture and to explore the reefs and the ways they are important to us.

Let’s learn what the reefs are, what they are made of, and how they form. We will explore the reef environment, the great variety of creatures that make their homes there, and the countless ways they interact with one another and with the reef itself. We will think about all the ways reefs are important to people. Reefs protect our islands from the destructive power of waves and storms, give us food, and provide other resources and services. We will even discover that many islands would not even exist without reefs. Then, we will look at things that threaten our reefs and explore ways to minimize harm to reefs. When we know more about reefs, we will better appreciate, enjoy, utilize, and protect these vital parts of our islands.
Since our ancestors first arrived to our islands, Pacific Islanders have honored the important roles coral reefs play in protecting and supporting life on land and in the ocean. This respect is reflected in our culture, especially the ways we talk about our traditions—stories, songs, chants, and proverbs. For example, elders on the island of Pohnpei tell the legend of *Sapwukini*, a powerful navigator who sailed out far from the known lands and discovered a shallow reef. On that reef, he tirelessly worked with his friends to build up a stone altar that would rise above the water and become a new island. Stories from Chuuk describe the origin of the islands as the work of the goddess *Nikowupwuupw Fénú*. She made the islands and added a giant reef around them to protect her creation from waves and storms. In Hawai‘i, the creation chant *Kumulipo* describes coral as one of the most basic and important things in the world. It says that coral was the first living thing created, followed by all other life. Based on these beliefs, how do you think our ancestors treated our coral reefs?

The reef is fundamental to supporting life and communities in the Pacific. The stories and chants mentioned here are just some of the many examples throughout the Pacific that illustrate how our ancestors have honored and respected our reefs throughout history and viewed them as a part of the natural world that is linked to the spiritual world.
WHAT IS A REEF?

A reef is a shallow place just above or below the surface of the sea. The majority of reefs around tropical Pacific islands are coral reefs.

Strictly speaking, any kind of shallow place in the ocean, especially if it represents a hazard to passing boats, can be called a reef. It can be made of rock, sand, or coral and other living things. In the tropical Pacific islands, when we talk about reefs, we generally talk about reefs made of coral and other living things. A reef made of coral and other living things is called a coral reef.

Coral reefs are true wonders of nature. They are large enough to be seen from an airplane, yet they are created by corals, which are relatively small living things. The photos on the opposite page show various reefs as seen from flying airplanes. You can see that coral reefs are huge underwater structures of various appearances.

Only a very small part of the ocean floor, less than 1%, is covered by coral reefs. That is a relatively small area compared to the entire ocean, yet the importance of coral reefs is immense. They are especially important in the Pacific islands, where they are an essential part of life and environment. They produce unique resources for people, provide vital services to the environment, and are home to about a quarter of all kinds of living things in the ocean. More kinds of living things are found on coral reefs than in almost any other ecosystem. Coral reefs are some of the most diverse, beautiful, and precious places on our planet.
Corals are living organisms. They live in the ocean. Many kinds of corals produce hard, rock-like material that is often also called coral.

When you walk along the beach or out on the reef at low tide, much of the hard material beneath your feet is coral. Many people think of just rocks on the beach or in water when they say the word “coral.” But to really understand what coral is, we should ask, “What exactly made these rocks, and how?” Rocks that we think of as coral are made by living things. Those living things are also called corals.

If you walk out farther on the reef and look below the water’s surface, you will see many living corals. They are living things, just like trees, birds, and people.

**WHAT IS CORAL?**

**Corals are living things.**

What is coral? Is it a rock or a living thing, plant or animal? In some ways, coral can be a little bit of each. How is that? Let’s see!

**A ROCK? A PLANT? AN ANIMAL?**

**Corals are ... rocks?**

Pick up a piece of coral from the beach. It may have a unique shape and texture or color, but its general feel is very much like a rock. It is not alive, it does not move or eat, and it is hard and heavy just like a rock. It is not a surprise that some of the first people who studied corals, many centuries ago, classified corals as a type of rock. However, coral is not only a rock. The coral rock is a part of the skeleton of a coral that used to be alive, but died and was washed up on the beach.

**Corals are ... plants?**

Before broken pieces of coral wash up on the beach, they are found in the ocean. At some point, those pieces were part of a larger living thing. Corals live in the ocean. Though they stay in one place and do not move around, they grow, reproduce, and die. A living thing that lives its whole life in one place sounds like a plant to some people. Indeed, about 300 years ago, some scientists thought of corals as a type of plant. Today we know that corals are not really plants, but if you thought they were, you are not far off. Many corals actually contain tiny plant-like living things inside their bodies and get food from the process of photosynthesis, just like plants (see page 15).

**Corals are ... animals?**

Corals do not just grow, reproduce, and die; they also eat. Plants do not eat, but animals do. Corals are animals. They are relatively small, soft-bodied creatures related to jellyfish and sea anemones.
When we look closely at the reef, we see that it consists of many different kinds of corals. They have different shapes and colors. But if we take an even closer look, we will see that what seems to be a single coral is often a group of many tiny animals that live together, closely packed and appearing as one. That is called a **coral colony**.

Each tiny coral animal in a colony, or in some cases, living on its own, is called a **coral polyp**. We can see polyps if we take a close and careful look at coral. Seen from above, polyps look like little stars.
Corals get food in two ways: from algae that live inside them, and by catching food from water.

An individual coral animal, a coral polyp, is a simple animal shaped like a cup. It consists of a bag-like stomach with a mouth on top. The mouth is surrounded by tentacles.

A STURDY HOME

Corals are broadly divided into two groups—soft corals and hard corals. The hard corals are also called stony corals because their polyps build rock-like skeletons. The skeleton is shaped like a cup in which the polyp sits. It supports and protects the polyp. A polyp creates its skeleton from material dissolved in water. It makes the same hard substance that a clam makes for its shell—a mineral called calcium carbonate. A polyp keeps adding layer upon layer of this mineral underneath its body. Its cup-shaped skeleton keeps getting taller and taller, but the polyp keeps rising above the added layers and always stays on the outer edge of the cup. As long as the polyp is healthy and can get the material it needs from water, it continues to build its skeleton.

What gives polyps the energy for all this home-building? Let’s see on the next page how corals obtain food.

A polyp is a simple, soft-bodied animal, similar to an upside-down jellyfish.

Polyps of hard corals build rock-like skeletons.

CATCHING FOOD

Polyps cannot move around to find food. Instead, they stick out of their skeleton cups at night and stretch out their tentacles to snatch tiny pieces of food from the water. Each tentacle is lined with thousands of special cells called nematocysts. Polyps use them to catch food. Some nematocysts contain tiny poisonous spears that shoot out and pierce the creatures that polyps eat, from microorganisms to baby fish. Some nematocysts shoot out strings that stick to or wrap around the food. A polyp then pulls the prey into its mouth. Also, the outside “skin” of corals can be sticky. Food and any minerals that corals need might stick onto a polyp and then get pushed into the polyp’s stomach.

HELPERS INSIDE

Water on coral reefs is often crystal clear. It does not seem to have a lot of food floating around. That is true, and most corals would probably starve if they did not have a secret food supply. Inside the polyps of stony coral are thousands of tiny algae called zooxanthellae. They live just under the “skin” of the polyps. Like other algae and plants in general, they use the sun’s energy for photosynthesis. They make their own food. They share that food with the polyp in which they live. Some corals get 90% of their food from the algae inside their bodies. Algae also give off oxygen that corals need and help speed up the process by which corals build their skeletons. This is a kind of rent payment that algae give to polyps in exchange for the safe places to live. In addition, polyps give off carbon dioxide and some important nutrients that algae need. They are partners that work together to survive.
Polyps of some kinds of coral live alone, but most live together in big bunches we call colonies. Each polyp is an animal, but a colony of hundreds or thousands of polyps functions like one large organism. Polyps in a colony depend on one another. In many kinds of corals, stomachs of individual polyps are interconnected, allowing for the sharing of food across the colony. Polyps of hard corals are also bound to one another by their tough skeletons. This makes the colony stronger and holds it together.

**ALL COLORS AND SHAPES**

Coral colonies come in many colors and shapes. Their bright colors—orange, yellow, green, blue, red, purple—are not only from polyps, but also from the tiny algae that live inside them. Without the algae, many corals would be white. Each species of coral makes its own kind of colony. Each species has its own scientific name, but we often refer to corals by simpler names based on their general shape. Some coral forms are named after things they remind us of—but are in no way related to, such as horns of animals, fingers, cactuses, mushrooms, or even brains. Coral forms include:

- Branching coral
- Massive coral
- Tabular coral
- Foliose coral
- Encrusting coral
- Pillar coral
- Laminar coral
- Mushroom coral
- Antler coral
- Cauliflower coral
- Brain coral
- Lace coral

**IN TUNE WITH LOCAL CONDITIONS**

The shapes of coral colonies depend mostly on the species, but also on the place where a coral lives. The same species can have colonies that differ in shape depending on local conditions. The key conditions are available light (because algae inside the coral polyps must have enough light for photosynthesis), movement of water (because corals need some current to bring food to the polyps), and wave strength (because coral colonies must be strong enough not to break).

For example, corals in shallow places with lots of light might have many dense branches, to ensure that the sunshine is not too strong as to hurt the colony. Corals in deeper, darker water might be shaped like bowls or have branches wide apart to catch all the light from above. Corals in calm places may grow tall and fragile, but corals exposed to rough surf are low and tough.

**GROWING FAST OR SLOW**

The species and local conditions also influence how fast a coral grows. Under good conditions (see page 21), branching corals can grow 4 inches (10 cm) or more per year, whereas massive corals grow more slowly, around half an inch (1 cm) per year. If conditions become bad, coral growth slows down and coral may even die if the situation gets worse.

**FROM COLONIES TO ROCKS**

Coral skeletons are tough. Even when corals break and polyps die, especially in rough waves and during storms, their skeletons remain. Many pieces of rock we see on Pacific island beaches are remains of coral colonies. The many holes you see on them are the little cup-shaped homes in which individual polyps used to live.
As polyps grow and create cup-shaped skeletons, their colony gets stronger and bigger overall. A colony will grow as long as its polyps are alive and keep building. Polyps eventually die, but their skeletons last. New colonies grow on top of the remains of the older ones. Over the years, layer upon layer of coral colonies build up the large, complex rock-like structures we call coral reefs.

Day after day, for hundreds, even thousands of years, coral polyps build their skeletons and colonies. Each little cup-shaped skeleton is a tiny building block. The skeletons are anchored to the reef and remain attached even as their polyps die and new polyps make their own cup-shaped homes on top. As the reef grows, corals are alive only at its surface. Inside the reef are remains of older, long-dead corals. The whole reef structure can be many thousands of years old, though its outermost layers are brand new, being built bit by bit, every day. Thus, while many small corals you see on the reef are younger than you, the reef itself is ancient. Most reefs that surround Pacific Islands have been there long before the first people arrived.

Because polyps need ocean water, the reef can only grow up to the ocean surface. Also, as the reef builds up, waves, storms, and some living things tear it down. New colonies of corals and some other organisms, especially certain algae, build upon broken coral pieces and cement them together. The reef naturally breaks and repairs itself (see pages 52–53).

As the reef builds up, layer after layer, old coral skeletons in deeper layers gradually get crushed by the reef’s weight. Gaps get filled with sediments—sand and smaller grains called silt and mud. The reef becomes a tighter, denser body of rock we call limestone. Limestone is a rock made of calcium carbonate originally produced by corals and other living things.

The sea level changes over long periods of time. When the sea level goes down, reefs may become dry land. Many islands are made of limestone that was originally coral reef. Large parts of Guam, Palau, and other islands are composed of limestone that used to be coral reef long ago.
**WHERE DO CORAL REEFS FORM?**

Coral reefs typically form in warm and shallow parts of the ocean.

Corals grow best in warm and shallow ocean waters near islands or continents, and also in relatively shallow spots in the ocean far away from land. Warm, shallow ocean areas with healthy reefs occur mostly near the Equator in the region of the world between the Tropic of Cancer and the Tropic of Capricorn. The climate in that region is tropical (warm throughout the year). Coral reefs also grow where ocean currents transport warm tropical water to areas outside the tropical region. Note that the Equator, the Tropic of Cancer, and the Tropic of Capricorn are imaginary lines drawn on globes.

**Like all living things, corals require certain conditions in order to survive. Conditions that most corals require are the following:**

**a. SALTY WATER**
Corals live in seawater. No coral can grow in fresh water. That is why we do not see corals near mouths of rivers and other places where lots of fresh water mixes with seawater.

**b. WARM WATER**
Corals prefer warm water temperatures. Many species live in waters that are as warm as they can tolerate. That means if the water becomes even just a little warmer, it can harm corals.

**c. SUNLIT, SHALLOW WATER**
Corals with algae inside them need sunlight in order to survive. This is because algae cannot produce food without enough light. Corals with algae inside them cannot grow in deep water because of its darkness.

**d. CLEAR, MOVING WATER**
Corals like clear water with some currents. Water that is too quiet may not bring enough food and oxygen to the corals. Water that is not clear blocks sunlight from algae inside the corals. Mud in the water smothers the corals and kills them.

While coral reefs mostly grow in warm and shallow waters in tropical areas, some corals can grow in other places in the ocean, including nearly freezing, completely dark, and very deep waters. Corals that live in cold, deep waters and the reefs they form are very different from the reefs we normally see. They require different environmental conditions and grow extremely slowly because they do not have algae partners inside them. Scientists are only beginning to study deep-water, cold-water reefs, and many people do not know that they even exist. In this book, we talk about shallow-water, warm-water reefs that we see around Pacific islands and other tropical places.
Reefs differ from one another. There are many kinds of reefs. The three basic types are fringing, barrier, and atoll reefs.

No two reefs are the same. Every aspect of reefs, from the kind and amount of corals, to the overall structure and size, depends on local conditions. We can classify the immense variety of reefs mostly into three kinds based on their general shape and setting.

### WHAT KINDS OF CORAL REEFS EXIST?

Understanding the shape and setting of coral reefs is important because different kinds of reefs face different problems. For example, fringing reefs are right next to the land, so they are most exposed to what happens on land, such as pollution by people.

#### Fringing Reef

Fringing reefs form next to the coasts of islands or continents. They grow along the shoreline and are attached to the land.

- **Pacific Island Examples:**
  - Most high islands (islands with mountains or hills) have fringing reefs. Among them are Babeldaob in Palau; Guam; Saipan, Tinian, and Rota in the Commonwealth of the Northern Mariana Islands; Yap, Kosrae, Chuuk, and Pohnpei in the Federated States of Micronesia; O‘ahu and Molokai in Hawai‘i; and Tutuila and Manua in American Samoa.

#### Barrier Reef

Barrier reefs are like fringing reefs that got pushed away from the coast. A barrier reef is separated from the land by an area of water called lagoon.

- **Pacific Island Examples:**
  - Some Pacific islands have barrier reefs. Nearly all of Palau, specifically Babeldaob, Koror, Rock Islands, and Peleliu, is surrounded by a huge barrier reef. Chuuk and Pohnpei in the Federated States of Micronesia are each surrounded by outstanding barrier reefs. Smaller barrier reefs also exist in Guam, Saipan, and O‘ahu and Kaua‘i in Hawai‘i.

#### Atoll Reef

Atolls are like barrier reefs that wrap around an area of the ocean and make closed rings. An atoll reef encloses a lagoon.

- **Pacific Island Examples:**
  - There are hundreds of atolls in the Pacific. In Palau, Kayangel, Ngaparou, and Helen’s Reef are atolls. Almost all outlying islands (called “Outer Islands”) of Yap, Chuuk, and Pohnpei in the Federated States of Micronesia are atolls. Many islands in the Marshall Islands are atolls. Some Northwestern Hawaiian Islands are atolls.

#### Other Types

Do not be surprised if a reef you see does not fit in the three basic types. There are others. For example, a relatively small, isolated reef inside a lagoon is called a patch reef.

In contrast, an isolated reef in the ocean is called a bank reef. It has no lagoon. Small sandy islands can form on top of bank reefs.

- **Pacific Island Examples:**
  - Bank reefs are shallow spots in the ocean, with no lagoons. Some of them have islands. Bank reefs with islands are Toa and Sonsorol in Palau; Fais, Satawal, Pikelot, and Gaferut among “Outer Islands” of Yap; Nama and East Fayu among “Outer Islands” of Chuuk; Kilu, Jalu, Jalewe, Senn, and Mey in the Marshall Islands; and Laysan in Hawai‘i.
Most islands in the Pacific can be classified either as high islands or low islands. High islands are those where there is at least some land remaining from the volcano that originally made the island. When they are young, such as parts of Hawai‘i, high islands may not yet have developed reefs. Later, they develop fringing reefs, and even later, barrier reefs. Below is a view of the island of Pohnpei, seen from an airplane. It shows the types of reefs typical of high islands in the Pacific.

Low islands are those where no land from the original volcano remains. There are only reefs and small sandy islands on top of them. Below is a view of Sapwuahfik Atoll, seen from an airplane. It shows the types of reefs typical of low islands in the Pacific.
An island has various kinds of places, from hot sunny beaches to cool shady forests, from quiet wetlands to busy streets. These places look and feel different from one another and are home to different living things. The coral reef also has various kinds of places, from peaceful lagoons to wave-splashed and rough edges of the reef, from shallows near the beach to deep water away from shore. These various places are homes to corals and other living things. That is because various parts of the reef have different conditions that may be good for some living things but not suitable for others. These conditions include water depth, strength of waves, amount of light, temperature, and salinity (amount of salt in water). If we know the different parts of the reef and their conditions, we can better understand and appreciate the coral reef as a whole.

**What Are the Different Parts of a Coral Reef?**

Fishermen have the best understanding of the different kinds of places on the reef and the different conditions and living things there. Ask the fishermen you know about this. You will be amazed by their expertise. Write down what you learn, and share with your classmates.

### Reef in Your Language

Don’t be discouraged by the new terms on these pages. Many are familiar to you in your own language. Check the local names for lagoon and reef flat shown above, and ask your family to teach you other words for different parts of the reef. Write down these words and compare with those that your friends find.

**Reef Flat**
- **Carolinian:** matamat
- **Chamorro:** kánton ma’tingan
- **Chuukese:** wóón anang
- **Kosraean:** fin kap
- **Marshallese:** pedped
- **Palauan:** merek
- **Pohnpeian:** nanmad
- **Ulithian:** masowchael
- **Woleaian:** niperou
- **Yapese:** dakean ea náaq

**Lagoon**
- **Carolinian:** ióómw
- **Chamorro:** laguna
- **Chuukese:** nóómw
- **Kosraean:** luhluh
- **Marshallese:** majo
- **Palauan:** uet
- **Pohnpeian:** nanamw
- **Ulithian:** Foamw
- **Woleaian:** laamwo
- **Yapese:** nguyu

**Back Reef**
- **Carolinian:** lóómw
- **Chamorro:** lóówm
- **Chuukese:** lóólm
- **Kosraean:** lóólm
- **Marshallese:** majo
- **Palauan:** uet
- **Pohnpeian:** nanamw
- **Ulithian:** Foamw
- **Woleaian:** laamwo
- **Yapese:** nguyu

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- **Ulithian:** masowchael
- **Woleaian:** niperou
- **Yapese:** dakean ea náaq

**Reef Crest**

**Reef Slope**

Note: This picture shows the parts of a typical barrier reef. A fringing reef does not have a lagoon or back reef.
The lagoon is an area of water that is partly separated from the rest of the ocean by coral reefs or land. It can be big or small, shallow or deep. It can contain areas with sand, patch reefs, seagrasses, or mangroves. The lagoon can be connected with the surrounding ocean by one or more channels, where water flows in and out with the tides.

The water in the lagoon feels different from the surrounding ocean. It is always calmer and less deep. In small, shallow lagoons, water can get much warmer than the ocean. In lagoons beside large islands with big rivers, water can be muddy and not clear. That is because rivers bring mud, soil, and even dirty water and waste from people and animals.

Not all islands have lagoons. Lagoons are always found in places where there are barrier reefs and atoll reefs. They are not found on islands that have only fringing reefs, as the reef is right next to the land.

The ocean and the lagoon are separated by a shallow reef. The part of the shallow reef that slopes down to deeper waters of the lagoon is called the back reef. The back reef is on the opposite side of the reef from where the waves are breaking and thus is mainly calm except during storms.
The reef flat is the relatively flat and shallow part of a reef. It is usually also the widest part of the reef. When we look at the reef from land, most of what we see is the reef flat. The width of the reef flat varies. On some islands, it can be miles wide; on others, it can be so narrow that you could throw a stone across it.

In addition to being wet at times and dry at times, organisms that live on the reef flat must tolerate a wide range of salinity and temperature. On rainy days, the fresh rainwater makes the reef flat water much less salty. On sunny days, the reef flat can become very hot, and the organisms must struggle with the heat and with getting enough dissolved oxygen to breathe. The problem with oxygen happens because warm water holds less dissolved oxygen than cool water.

Due to such difficult living conditions, fewer kinds of living things can survive on the reef flat than on other parts of the reef.

Water on the reef flat is very shallow, from inches to a few feet deep. This varies a lot with the tides. You have noticed that the level of water around your island is not always the same. It is higher when the tide comes in. That time is called the **high tide**. The level is lower when the tide goes out. That time is called the **low tide**. When the tide is high, the reef flat is covered with water. When the tide is low, parts of the reef flat become dry.
The reef crest is the edge of the reef flat, where it faces the ocean. It is the highest point on the reef and is often dry at low tide. The reef crest is fully exposed to surf. In many places, especially areas that face the dominant wind direction, the reef crest is nearly constantly battered by waves. Few living creatures can survive in this harsh place. If you visit the reef crest on a calm day at low tide, you will not see many corals. Most corals cannot withstand such intense wave action. If corals do not grow well here, what builds up this part of the reef?

The reef crest is built by another kind of living thing: coralline algae. These simple organisms make hard material similar to corals. They come in many shapes and colors, but most often look like tough pinkish or brownish crusts. The coralline algae resist the force of waves and thrive where waves hit hard and corals cannot grow.

The reef slope is the part of the reef that is farthest away from shore and faces the open ocean. There, the reef slopes down into the ocean depths. Sometimes the slope is so steep that it is like a giant underwater wall.

The greatest variety of corals is found on the reef slope, particularly in places that are just deep enough to not be affected by waves, but still shallow enough to have plenty of sunlight.

The deeper the place on the reef slope, the fewer the corals that live there. That is because there is less light available in deeper water. Reef-building hard corals are not usually found more than about 150 feet (50 meters) deep, because it is too dark there for algae inside corals to have enough light.

Deep parts of the reef have many soft corals. Soft corals do not have algae inside them and thus do not need sunlight.
WHO LIVES ON A CORAL REEF?

The coral reefs are full of all kinds of marine life. Thousands of species live, find food and shelter, and reproduce on coral reefs.

Not only corals, but numerous other living things make their home on coral reefs. Many kinds of algae (seaweeds and other plant-like organisms) thrive in places reached by sunlight. A few plants known as seagrasses are adapted to life in salty water and grow in shallow sandy spots. A stunning variety of animals of all shapes, sizes, and colors can be found all over the reef. There are living things even where we cannot see them. Huge numbers of microorganisms (tiny living things that can be seen only with a microscope) float around in every drop of water, thrive between grains of sand, live on and inside the reef, and even on and inside other creatures.

Coral reefs are bursting with life. Every bit of the reef surface is covered by some living thing, from familiar animals to strange growths and crusts that you can barely tell are alive. And within the reef itself, every hole and crack has some organisms living there. Coral reefs are complex structures, full of open spaces, from tiny pores to large tunnels and deep cracks. They provide excellent shelter for a variety of living things we rarely see. Some creatures even spend their entire lives in darkness deep inside the reef.

There are more kinds of living things on reefs than anywhere else in the ocean. Scientists are still discovering previously unknown reef creatures every year. Most of the large animals have already been found and named, but you can be sure that right there, on your own island, on the reef where you play and fish, you can see some creature that no scientist has described.
Let's get our faces wet and take a look under water. Use a snorkeling mask to see reef creatures in their habitat (natural home). As you swim out from the beach, you might see patches of seagrass and many kinds of algae, of which the seaweeds are the easiest to note. If you take a closer look at the surfaces of rocks on the reef flat, you may also notice coralline algae, which make rock-like crusts over the reef. In deeper water, you cannot miss the hard corals in their multitude of shapes and colors. Among them are sponges, sea anemones, and soft corals such as sea fans. They are attached to the reef and gently sway back and forth as the water moves. Worms hide under sand or burrow into coral. Some live in tubes from which only their feather-like legs stick out to catch food. Sea urchins, sea cucumbers, sea stars (including the coral-eating crown-of-thorns), and feather stars cling to the reef and creep along ever so slowly.

You will see bivalves that live in the sand or, like giant clams, live inside holes that they themselves make in the reef as they grow. Their relatives, gastropods (snails) have beautiful spiral shells and creep along the seafloor. Among them are conchs, cowries, and colorful nudibranchs, which are a special kind of snail with no shell. Octopuses sit in holes and squid swim in schools in the water above. Crabs and lobsters hide under rocks or scramble around. Hundreds of kinds of fish swim above the reef, dart among corals, or lie low on the bottom. Among them are damselfish, butterflyfish, parrotfish, squirrelfish, triggerfish, surgeonfish, porcupinefish, snappers, and sharks. Turtles glide gracefully through the water and rest among corals at night. Birds, especially reef herons, wade in the shallows in search of food. All of these living things depend on the coral reef for survival.
Living creatures on a reef have many relationships with one another and with their environment.

Coral reefs are some of the most colorful, diverse, and active places in the world. A lot goes on in there, much more than meets the eye.

A fish or clam or crab that you see on the reef is not just an individual creature. It belongs to a particular species, and it can make offspring with other individuals of its species. It is also a member of various groups of living things that interact with one another in different ways. It looks and behaves as it does in order to succeed in its environment. It is affected by other organisms and its environment and, in turn, it affects other organisms and its surroundings. A reef organism is like a small piece of a gigantic, living, ever-changing jigsaw puzzle.

Similarly, the reef is not a dead, giant rock-like structure. It is made by and of living beings. A reef grows and changes as its residents grow and change.

Pacific island cultures and modern science both teach us that everything in nature is connected, and that every single living thing in the world is a part of something bigger. Each organism (a single living thing) is part of a group of others like it that live in the same area. They make up a population. Together, all the populations of various species in a certain area make up a community.

A community is closely connected with the environment in which it lives; together, a community and its environment form an ecosystem. Coral reef is an ecosystem that consists of the coral reef environment and all of the living populations of organisms there. It is itself part of an even bigger system—the ocean biome and the entire biosphere.

### From one living creature to the entire world

<table>
<thead>
<tr>
<th>Level</th>
<th>What this is</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>One organism. One living thing. Any one member of a species.</td>
<td><img src="fish.png" alt="Fish" /></td>
</tr>
<tr>
<td>Population</td>
<td>Many individuals of the same species. All members of a species living in the same area.</td>
<td><img src="fish_population.png" alt="Fish population" /></td>
</tr>
<tr>
<td>Community</td>
<td>Many populations of different species, all living in the same area and interacting with one another.</td>
<td><img src="fish_community.png" alt="Fish community" /></td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Community of organisms considered together with their physical environment.</td>
<td><img src="fish_ecosystem.png" alt="Fish ecosystem" /></td>
</tr>
<tr>
<td>Biome</td>
<td>Group of ecosystems that together cover a major part of the world.</td>
<td><img src="fish_biome.png" alt="Fish biome" /></td>
</tr>
<tr>
<td>Biosphere</td>
<td>All the living things in the world and all parts of the world where they live.</td>
<td><img src="fish_biosphere.png" alt="Fish biosphere" /></td>
</tr>
</tbody>
</table>
Coral reefs have some of the largest biodiversity (variety of species) in the world. How are coral reefs so rich with life? Every living thing needs its living space and has basic needs for food, shelter, and reproduction. How is it that so many creatures can fit on a coral reef?

The “space” every living organism needs includes not just the actual place to live but also opportunities to meet all its needs. Such “space” is called a niche. Every species occupies some niche, as determined by its unique way of life, where it lives, what it eats, when it is active, how it behaves, and how it interacts with other living things and the environment. If two species have an almost identical way of life and seem to have the same niche, over time, one of the two will either die out, move to another place where no other species shares its niche, or change and adjust to live in a somewhat different niche.

The reefs can support so much biodiversity because the various living creatures there are specialized to many different niches. Being highly specialized allows all these species to share the wonderful underwater world that is coral reef. Being highly specialized also means that many reef organisms would not be able to survive anywhere else.

A niche is a species’ place and role in its community. It is where it lives and what it does.

EACH LIVING THING HAS A ROLE

Each organism on the reef has its habitat, its natural home. It refers to the kind of place where an organism feels comfortable and can find what it needs. Knowing the place where something lives does not mean we understand how it fits in the big picture and how it interacts with other living things and its environment. The niche tells us not only where something lives, but also what it does. In a way, habitat is like the “address” of an organism, and the niche is like its “profession.”

Consider a parrotfish. It lives on the coral reef. The reef is its habitat. If you were sending a letter to a parrotfish, the “address” would be:

Madame Parrotfish
The Coral Reef
Pacific Ocean

What does a parrotfish do? If you can answer that question, you know the parrotfish’s “profession.” You might think that a parrotfish just swims around until someone catches it and eats it, but that is not so. A parrotfish does many things:

1) scrapes coral surfaces to feed on polyps and algae
2) eats algae and does not allow them to get out of control
3) grinds up coral and turns it into sand, which fills holes in the reef and makes it stronger and piles up and adds to beaches and islands
4) becomes food for larger animals on the reef and people

The roles above are the key points of the parrotfish “profession,” or the niche of the parrotfish. You can think of it as being a kind of job description—including the kind of environment to which it is adapted and its role and relationships in that environment.

If the parrotfish were hunted out or disappeared for another reason, they would no longer be doing their job on the reef. This would have a disastrous effect. The reef could become dominated by algae instead of corals. The habitat would change, and many of its organisms would die. Even land would be affected; islands would get smaller because less new sand would come to the beaches.
So many living things can live closely together on the reef because they are specialized to different niches. But how does a species specialize? With each generation, a species changes slightly. Just as how young people today are not identical to their parents or grandparents, each generation of any organism is not exactly the same as its ancestors. Everything changes over time, so living things also change to better fit their environment. Each such successful change is called an adaptation.

The ability to adapt is an amazing property of life that makes life so resilient. Throughout its long history, our planet has gone through many changes, and life was able to adapt. The process of adaptation is what allows a species to become better suited to its environment, to find a successful way of life in a given place and to “fit” its niche. Nearly every trait of a living creature is an adaptation:

★ The way it lives, → see pages 44–45
★ how it relates to other living things, → see pages 46–47
★ how it gets food, → see pages 48–49
★ what role it plays in the ecosystem, → see pages 50–52

and all other aspects of what they are and how they live are adaptations to allow it to find food, shelter, or something else it needs, and to better survive, grow, and reproduce.

The flattened, pancake-like body of the angelfish is an adaptation that allows it to make sharp turns. The long, snake-like body of an eel is an adaptation that allows it to live in holes in the reef.

The strong beak of a parrotfish allows it to scrape coral and feed on small algae. The gaping mouth of a grouper allows it to swallow fish by sucking them in. The sharp teeth of barracuda enable it to bite on fish. The thin, tweezer-like mouth of butterflyfish lets it pluck out coral polyps and eat them.

A shark's eyes in the front of the head help it focus on fish that it chases. Soldierfish's big eyes on the sides of its head help it see in dark holes and look around for danger.

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MANY LIFESTYLES

Some reef animals are easy to notice, but many stay hidden most of the time. Some are slow and some are quick. Some are active during the day, others are out and about at night. They may swim, drift, bounce, crawl, slide, dig, or barely move at all. No two kinds of animals live in exactly the same way.

DOES IT SWIM?

As strange as it sounds, many animals that live in the ocean cannot swim. The coral reef is full of nonswimmers that rest on the bottom. These bottom-dwelling reef animals include corals, worms, clams, snails, crabs, sea cucumbers, sea urchins, and sea stars.

Other nonswimmers in the water simply float around or swim a little, but too slowly to be able to choose where to go. They are carried by currents and drift wherever the water takes them. Such living things are collectively referred to as plankton. Most plankton are so small that they cannot be seen by the unaided eye. Plankton includes microorganisms, small algae, simple animals, and eggs and larvae of various reef animals.

Finally, there are the swimmers. The majority of swimming animals on coral reefs are fish.

DOES IT MOVE?

Not all animals move around. Many stay in one place their entire lives, permanently attached to the bottom. They cannot leave to look for food. They have other ways to feed (see page 49).

DOES IT DIG?

Some animals live inside the bottom of the sea floor. They make holes and tunnels in sand and other sediments and even get into hard rock and coral.

Describe my lifestyle

2. Observe it and/or ask people about it. Read about it.
3. Does it move? Does it swim, float, or live on the bottom? Does it dig into the bottom?
4. Repeat with one or more other reef animals that have a different lifestyle.
5. Make an illustrated report about these reef animals.
6. Share your report with friends, family, or class.
The many relationships between different living things can be classified as three basic types: predation, competition, and symbiosis. Predation is when one living thing eats another. Competition is when living things try to get the same resources, especially food and space.

**DOES ONE EAT ANOTHER?**

Animals are constantly trying to find food while avoiding being eaten. When an animal eats another, it is called a predator, and the victim is its prey.

**DO THEY COMPETE WITH EACH OTHER?**

Food, space, and other resources are limited. Living things that need the same things are natural competitors. Space is especially scarce on reefs, and living things compete or even attack one another to get or protect a good spot to live.

Symbiosis is a close, often long-term relationship, between living things of different species. This relationship can help both species. It can be beneficial for one species and not important for the other. It can also be good for one species, but bad for the other species.

**DO THEY HELP EACH OTHER...**

Coral polyps and the algae that live inside them (see page 15) are not the only partners on the reef. There are numerous other relationships where different organisms team up to help each other survive. They mutually benefit from their relationships.

**...OR IS ONE NOT GETTING ANY BENEFIT?**

Sometimes one partner benefits but it does not do anything for its partner. The other partner is not affected.

**DOES ONE HURT THE OTHER?**

One organism may benefit and also cause harm to the other. Such an organism is called a parasite. The victim is called a host and only suffers from the relationship.
Animals must eat to survive. What do they eat? If all animals on the reef ate the same food, there would be so much competition that the food would quickly disappear. Instead, most animals specialize to have unique ways of obtaining food. They differ in the kind of food they eat, the places they find it, the times they feed, and especially how they get food. These differences help them avoid competition and get enough food.

**WHAT KIND OF FOOD?**

Some reef animals eat only algae. Some animals eat only other animals. Some animals can eat algae as well as animals. Finally, there are animals that eat dead things and waste.

- **Herbivores** eat algae. Examples include snails, sea urchins, and fish like surgeonfish and damselfish.
- **Carnivores** eat other animals. Examples include pufferfish and some crabs.
- **Omnivores** can eat both plants and animals. Examples include fish like pufferfish and some crabs.
- **Scavengers** eat dead things and waste. Many animals that feed on the bottom, such as worms and sea cucumbers, are scavengers.
- **Detritivores** eat waste. Examples include sponges, many worms, and sea cucumbers.

**WHERE DOES IT FEED?**

Animals that eat similar things may feed in different areas to avoid competition. Different feeding areas include the bottom, just above the bottom, near the water’s surface, or somewhere in between.

**WHEN DOES IT FEED?**

Living creatures on the reef are active at different times. Some are active during the day, others at dawn or dusk, others at night. Many animals we rarely see during the day are very active at night.

Animals specialize in eating certain things and have different strategies to get what they want. There are a few key approaches.

- **Grazer**s nibble on tiny algae on the reef surface. **Browsers** pluck coral polyps and bite snippets off algae and sessile animals. **Scrapers** scrape coral surfaces, and **excavators** bite off chunks of dead (and sometimes living) coral to eat algae living inside. Some animals crawl around and scour the bottom for food. Some sift through sand to find edible morsels. **Hunters** pursue or ambush prey. **Crunchers** force open the protective skeletons of prey. **Cleaners** pluck parasites off fish.

**Suspension feeders** use tentacles to snatch food from the passing water. **Filter feeders** pump water and sift through it for plankton and nutrients. **Deposit feeders** swallow mud and sand, pass it through their guts, and digest any food in it.
Every living thing needs energy to stay alive. Only some living things can get their energy through photosynthesis. They use energy from the sun to make food from water and carbon dioxide (a gas dissolved in water). They live and grow with food that they themselves produce (make). All living things that can do this are called producers. The main producers in the world are plants, but we do not see many of them on the reef. So who on the reef makes the food? The producers on the reef are mostly algae: seaweeds, coralline algae, and many other algae that are so small that we cannot see them without a microscope. Though not easily seen, microscopic algae are the key producers on the coral reef. The microscopic algae include zooxanthellae inside coral polyps and also tiny algae that float around as plankton. Tiny floating living things that make food by photosynthesis are called phytoplankton.

All other living things depend on producers for food. They must consume (eat) something to stay alive. They are called consumers. They consume producers or other consumers. They include all animals, even very tiny ones that float around as plankton. Tiny floating living things that must feed to survive are called zooplankton.

Some animals and many microorganisms get energy by eating things that died. They decompose (break down) dead material. They are called decomposers. They feed on dead producers and consumers. Decomposers recycle the tiny remains from food back into the ocean water.

The relationship of who eats whom is called a food web. It connects all the living things in a community into a complex pattern that shows the flow of energy as food from producers to various consumers to decomposers. At every step in the food web, some energy is lost because living things use it for their life activities. Because they continually lose energy, animals need to feed again and again. Producers capture more energy from sunlight and continually produce food that keeps the system going and the coral reef communities alive.
Corals build up most of the coral reef structure. However, other living things also help build and shape the reefs.

The second most important reef builders are algae. Typical algae are soft and squishy, but some are very different. Coralline algae are rock-hard. They also produce skeletons from calcium carbonate, the same mineral as in corals. We call them “coralline” because they remind us of corals, but they are not related to corals. They may look like small corals, but more often they appear as tough crusts, almost like spread-out cement. They even act like cement. When parts of the reef crumble, coralline algae grow over and glue them together. These algae are so tough that they resist very strong waves. The reef crest (see page 32) and other places where big waves crash are made mostly of coralline algae.

Some other living things also produce calcium carbonate. These include various microorganisms, some additional algae, certain sponges, some of the corals’ relatives known as hydrozoans, most snails and clams, and many worms and echinoderms. All of them contribute material to the reef because when they die, their hard parts—skeletons, shells, tubes, spines—remain behind. These hard parts become part of the reef structure or become sand that fills in holes in the reef.

What some create, others tear down. Many animals make a living by wearing down the reef. Various sponges, worms, clams, crabs, sea urchins, and fish dig holes to hide in or scrape reef surface as they feed. Some of them use acid to break down calcium carbonate.

The actions of the various living things that erode (wear away) the reef are actually good for the ecosystem. Creating holes in the reef makes a more complex structure and makes more living space for a greater number of creatures. Scraping of reef surfaces keeps algae in check. Algae grow much faster than corals and would take over the reef if not controlled. Very importantly, breaking of the reef by living things creates sand. The sand collects between coral colonies and toughens up the reef, covers the floor of lagoons, and piles up to create beaches and islets. Grains of broken reef are what make up most of our beaches and small islands, including all islands on atolls.

As some living things break the reef, all the corals, algae, and other reef builders keep growing to repair damage and strengthen and enlarge the reef. The reef is always in fine balance between organisms that build it and others that break it.
WHY ARE CORAL REEFS IMPORTANT?

Coral reefs are unique places unlike any others in the world. They are habitat for thousands of species of living things. They protect shorelines from waves and erosion and provide the sand and rocks that make up our beaches and small islands. They are the vital source of food for people and are very important to our way of life, culture, and economy.

1 HABITAT AND BIODIVERSITY

Coral reefs are known for a stunning variety of marine life. Though they cover only a tiny bit of the ocean floor, about 25% of all ocean life depends on them. Scientists who study reefs believe that important discoveries are yet to be made, such as medicines from chemicals found in various reef organisms.

2 FOOD SOURCE

Coral reefs have been providing food to Pacific Islanders for thousands of years. Animals like fish, octopus, lobster, turtles, and various crabs and mollusks continue to be vital sources of protein on many islands.

3 COASTAL PROTECTION

Large waves from storms and typhoons can damage homes, roads, buildings, and farmlands. Healthy reefs provide protection from these hazards. As waves arrive from the ocean and hit the reef crest, which is the shallowest part of the reef, the waves break and lose 90% of their height and power.

4 ISLAND BUILDING

Old coral skeletons and hard parts of other reef organisms naturally break down to smaller grains. This is done by certain fish and other living organisms that scrape and crush coral, and also by waves, especially during storms. These broken pieces of reef range in size from sand grains to large rocks. They pile up in different places and create beaches and small islands. On low islands (atoll islands and similar), all land is made of sand and rocks that came from the reef. Without reefs, there would be no land or human life on atolls.

Most of the food I get for my family comes from the reefs around our island.
NATURAL RESOURCES
Reefs provide resources to communities. Pacific Islanders have used coral rock to build homes, walls, fish traps on reef flats, roads, and other structures. Sand that started as coral skeletons and shells of reef creatures is used to make cement. Traditionally, shells of various marine animals were fashioned into tools, fishing hooks, jewelry, and other objects of value; they are still a key material for handicrafts.

CULTURE AND IDENTITY
People from islands across the Pacific have strong cultural connections with reefs and sea life. Many clans are represented by important reef animals, which are symbolic ancestors and a part of people’s identities. Island cultures and traditional ways of life are connected with fishing and uses of marine resources. To this day, numerous stories, legends, proverbs, and chants bring knowledge of the reefs, including secrets, to new generations of Pacific Islanders.

RECREATION AND TOURISM
Small islands on reefs are perfect places for weekend camping, picnics, and family retreats. People relax on walks on reef flats at low tide and children play there. Some love to swim and snorkel. For most people in the world, however, coral reefs are exotic places they know only from television and the Internet. That is why tourists, especially scuba divers, travel from far away to experience coral reefs.

JOBS AND INCOME
Reefs support island economy by enabling fishermen to make a living and support their families. Many jobs in hotels, restaurants, and stores are made possible by money spent by visitors who come for the beaches and coral reefs. That income represents a large part of the economy for many islands. Some local jobs are dedicated to managing and protecting reef resources.

Children, don’t ever forget, we have this peaceful lagoon only thanks to the coral reef blocking the waves.

We don’t have such beauty back home. Traveling all the way to the Pacific was worth it!
Many reefs, including all fringing reefs, are located next to land. As close neighbors, the reef and the land affect each other and exist in balance. Big changes on the reef will also be felt on land, and big changes on land will be felt on the reef. To keep our land healthy, we must not harm the reefs. To keep the reefs safe and healthy, we must also be good stewards of the land.

**THE REEF PROTECTS THE LAND**

Coral reefs perform a vital service to the land by weakening waves coming from the ocean. As a wave hits the reef crest, it is forced to break because the water gets less deep. One wave after another breaks, and we see the white foam from breaking waves. We don’t see big waves on the reef flat and in the lagoon because the reef has reduced waves’ height and power. When these waves finally meet the land, they are not too strong. On many islands, mangroves grow in the quiet parts of the lagoon along the shore. The mangroves make any waves even smaller before they get to the shore. Thanks to this, the water at the shore remains relatively smooth even when the reef is experiencing large waves.

Every time it rains, the rainwater washes the land and flows down to the ocean. Anything the water picks up on land can flow into seawater and reach the reef. That includes many things that are harmful to corals and other marine organisms: too much sediment, waste, and chemicals.

Fortunately, forests on land protect the soil and prevent it from being washed as sediment. Mangroves are especially important because they grow in shallow coastal waters and filter the dirty runoff from land before it gets into the ocean. The tangled roots of mangroves slow down water that runs off land. The slower flow causes materials carried by the water to be deposited among the mangroves. That includes mud and other sediment, as well as pollutants made by humans. In addition, many filter-feeding organisms that live in the mangrove swamp remove various particles from water and eat them. Thus, the water that runs off from land and passes through mangroves is a lot cleaner when it gets to the sea. This filtering of water helps corals stay healthy and grow. The forests and mangroves protect the reefs from harmful runoff. Thus they return the favor to the reefs, which protect the land from big waves.

**OCEAN WAVES**

*Rough seas and storm surges*

**SEDIMENTS, POLLUTANTS**

*Soil, mud, other sediments, waste, and harmful chemicals*

**THE REEF AND THE LAND ARE CONNECTED**

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How do we go about being good stewards and keeping the reefs safe and healthy? The key to that challenge is knowledge. We must know and understand something if we wish to take care of it and benefit from it without causing harm. People cause great harm to reefs due to a lack of knowledge and care (see pages 62–65). We gain the needed knowledge from everywhere we can—direct observations, school, books, but especially, and most importantly, elders in our own communities.

THE REEF AND THE PEOPLE ARE CONNECTED

Fishermen in Chuuk tell about an octopus that crawls out of the ocean at night and even climbs trees to catch lizards to eat. Such a strange creature is not known to science. Does it exist? Can it be that fishermen know something that scientists do not? Absolutely. Like scientists who increase scientific knowledge by building on discoveries of others, local experts like fishermen, farmers, navigators, weavers, and others build on the knowledge gathered by the previous generations. Local knowledge—especially about the connections that living things have to the world—has allowed people to use reefs sustainably for thousands of years.

For example, to be a master fisherman and reliably provide food for his family, a man learns all he can from his parents, grandparents, and other members of his community. He also learns from his own experiences and observations of the ocean, reefs, land, weather, animals, and plants.

Over time, this fisherman will gain deep knowledge about the behavior of organisms in the ocean, their relationships with their habitats and other species, their roles in the ecosystem, seasonal changes, and many other aspects of the environment. If this master fisherman is from Hawai‘i, he may know that a very wet season causes an increase in populations of akule (bigeye scad) and certain other fish in two years’ time. Or if he is in Chuuk, he may know that the appearance of seiwaanú (a kind of eel) on the reef is a signal that breadfruit has become ripe.

Our master fisherman would also learn from his elders about the traditional taboos or rules established to help the entire society manage its limited resources. For example, on Ulithi atoll in Yap, a single clan owns all wool (turtles) in the ocean. A turtle can only be killed with proper permission.

In the Marshall Islands, the chiefs set aside reef and other areas as moy—preserves that are off limits for harvesting or fishing. This allows depleted resources to recover before the area can be used again.

All of this knowledge helps the master fisherman make predictions and choose the best places, times, and methods to fish. It connects the men and women of our families, clans, and communities with our islands and the ocean and allows us to live sustainably from our lands and reefs. It is a part of our culture as Islanders.

We must remember, however, that this accumulated knowledge from our ancestors is not automatically transferred from parent to child like a genetic trait. Elders teach their children, and children learn from elders. It is a lifelong process supported by families, clans, and communities working together.
WHAT HUMAN ACTIVITIES HARM CORAL REEFS?

The forces of nature sometimes damage reefs. Powerful waves from storms break coral. You can see evidence of that when big boulders of broken reef are scattered after a typhoon. But corals and other living things are adapted to this danger; they survive and repair the reef. Unfortunately, there are threats that corals cannot easily deal with that can make a reef die out.

People cause a lot of harm to reefs. The climate change driven by human activities (see pages 76–81) is the single greatest threat to reefs. Other harmful things we do make the reefs weaker and less likely to recover from damage by the forces of nature and from impacts of climate change. When we harm reefs, we hurt ourselves because we risk losing all the benefits that reefs provide for us.

**TOO MUCH SEDIMENT**

Human activities on land are another source of sediment that kills coral. When people cut trees to clear land for farming and construction, the soil becomes exposed to rain. Rain washes away the land. Streams and rivers carry the sediment downhill to the ocean. The sediment makes photosynthesis difficult and smothers coral.

When we cut trees and make sediment, we can harm reefs even if they are far away. We can cause great damage and not even notice it until it is too late.

**POLLUTION**

The waste we produce—sewage (such as in the photo to the right), manure from domestic animals, and other chemicals from our homes, fields, cars, and trash—wash into the ocean. They can have terrible effects on reefs and other habitats in the water. Some chemicals are poisons that directly kill sea life. Others are nutrients that some ocean organisms use to grow and quickly reproduce. When water on the reef has too many of these nutrients, especially fertilizers from farms and human and animal waste, small algae and seaweeds grow very quickly. They cover up the coral and take over the reef. The ecosystem changes completely. Rich marine life that lived there disappears, and the reef breaks down.

**DREDGING**

In some places, people dredge the reef. They dig holes and canals to open boat passages, to build, or to gather broken coral to use as building materials.

Large machines that dig up the reef destroy corals, other living things, and their habitat. They also stir up a lot of sediment and make water cloudy in a wide area. Less light getting through water means that zooxanthellae can do less photosynthesis and corals go hungry and suffer. Even worse, sediment settles as a muddy or sandy layer over the reef. Covered corals die because they cannot make or get food.
OVERFISHING
If people harvest too many fish or other living organisms, that weakens the entire coral reef ecosystem. Some islands export hundreds of coolers full of frozen fish and other living things every week. Reefs can get overfished because of that. Many kinds of fish and other living things become rare.

Different species perform different jobs on the reef (see page 41), and their loss harms coral and other organisms. For example, catching too many herbivorous fish, such as parrotfish and surgeonfish, causes seaweeds to multiply, cover up coral, and ruin the reef. Catching too many parrotfish also reduces the amount of sand available in the area and increases erosion of the land along the coast (see pages 52–53).

SOLID WASTE
Trash, such as plastic, metal, rubber, and other garbage, litter coral reefs in some places. These things rarely break down naturally, and they remain over long periods of time. They cause physical damage to reefs by breaking coral when they are first dumped or as they roll around with tides and waves. Cut pieces of fishing line and nets become entangled on reefs and stay there, killing living things. Many animals, especially sharks, turtles, and seabirds, die after they swallow plastic bags and other trash, thinking they are food.

DESTRUCTIVE FISHING
Some people do terrible things, such as using poison or dynamite to catch fish. This destroys all life in an area—not just the fish people want to eat, but also young fish and many ocean organisms that people do not eat. Even worse, dynamite destroys the reef itself and leaves a rock rubble in its place. Most organisms that lived there disappear. A destroyed reef may take decades to recover. It may never recover at all.

CARELESSNESS
People also damage reefs by being careless and walking over coral at low tide, touching and breaking marine life, and anchoring on the reef and dragging anchors. Fishermen may damage corals with nets and traps that get caught on the reef, or they break coral when spearfishing and trying to get fish that hide in holes and cracks. Careless tourists can trample the reef or accidentally break pieces of coral when snorkeling or scuba diving. Every coral colony is a building block of the reef. Damaging just one colony damages the reef as a whole.
HOW DOES CLIMATE CHANGE AFFECT CORAL REEFS?

Earth’s climate is changing because humans are changing our planet’s atmosphere. We burn lots of gas, oil, and coal. That produces gases (especially carbon dioxide) that trap heat in the atmosphere. This is causing Earth’s climate to get warmer and change in other ways. You can learn more about climate change on pages 76–81.

A warmer climate is changing our planet. We are seeing increasing temperatures of water at the ocean surface, and a change in rain patterns. In distant cold parts of our planet, the warming is causing polar ice caps and glaciers to melt. Water from the melting ice flows into the ocean, and causes the water level to rise all over the world. The sea level rise will flood some low-lying areas and erode coastal lands. Tides and surging water that comes with storms will reach higher than before and hurt plants by bringing salty water onto land and into groundwater.

In addition, the chemistry of the seawater is changing because the ocean is absorbing extra carbon dioxide that humans put into the atmosphere. This change is called ocean acidification and makes it more difficult for corals and other reef-building organisms to create calcium carbonate and maintain their skeletons and shells. In combination with higher ocean temperatures, ocean acidification is a major climate change-related threat to coral reef ecosystems.

Climate change can also harm nearby ecosystems, and this ecosystem damage can then harm coral reefs. If changing rainfall patterns damage mangrove ecosystems, then more sediments and pollution will flow into the ocean and harm coral reefs.

One way we see that a reef is in danger is when it experiences coral bleaching (see pages 68–69). This is a serious problem from which a reef may or may not recover. The climate change will affect the most those reefs that have already been harmed by human activities. Reefs damaged by people are likely to succumb to problems related to climate change. Reefs that are in better shape to begin with are much more likely to recover from tough times.

Coral reefs have existed for 500 million years. They have survived many past changes in our planet’s climate. Coral reefs are in trouble now because this man-made climate change is happening quickly, and because many reefs are already threatened by other human activities.
Coral bleaching is when coral colonies lose their color and become white. This is a sign of extreme stress and corals may die.

Coral and zooxanthellae—the microscopic algae inside coral polyps—depend on each other to survive. In abnormal conditions, especially when water gets too warm for too long, coral polyps and zooxanthellae panic and their partnership falls apart. Zooxanthellae are kicked out by polyps or leave on their own. Coral colonies then turn white. Their polyps cannot get enough food or build skeletons. They are weak and vulnerable to disease. If conditions return to normal soon, corals may take on new zooxanthellae and recover. But if bad conditions continue, polyps die. Coral skeletons get covered with seaweeds and the reef begins to break down.

**Coral bleaching in American Samoa.** The picture on the left was taken in December 2014, and the picture on the right was taken three months later. The bleaching happened due to water getting too warm. Reefs that are already damaged by people in other ways recover slowly or do not recover at all.
How Would Damage to Reefs Affect Your Island?

Damage to coral reefs can have terrible effects on the local area or even the entire island.

As we learned, coral reefs provide habitat, food, coastal protection, and other resources and services to living organisms, including people, and the environment as a whole. Damage to reefs can be very dangerous and can cause a series of negative changes on the island.

We Would Lose Land

Damaged reefs could not shelter the island well from waves and storms, and the ocean would erode the coast more easily. Waves would crash against the shore, and water would penetrate farther inland, especially during storms. Some land would be flooded, groundwater would get saltier, and plants would die. Without healthy reefs to provide new sand, there would be not enough material to add to beaches and atoll islands. Many places would get wiped out by the ocean and disappear.

We Would Lose Biodiversity

Most reef organisms cannot survive anywhere else. If reefs are damaged, they would lose their home and disappear. Without healthy reefs, the ocean around Pacific islands would have much fewer kinds and amounts of fish and other organisms.

We Would Have Less Food

Reefs are home to fish and other animals that people depend on for food. When a reef is degraded (made worse than it was), people fishing there can get far less seafood would be provided by a healthy reef.

Our Communities Would Suffer

When coral dies and reefs decay, people suffer. They cannot eat healthy local food from the sea, they cannot continue working as fishermen or boat captains, and they may lose jobs at hotels, restaurants, and other places that depend on fishing and tourism. Culture and society would change as people lose their ancient connection with the reef and the ocean. People would not know how to care for their island and would do even more damage through destroying habitat, oversusing resources, and polluting. They would not be able to make a living from their island anymore and would depend on outside help to survive.
WHAT CLIMATE ADAPTATIONS CAN HELP PROTECT THE REEFS?

A living thing that is hurt or weak is less likely to survive trouble than a living thing that is healthy and strong. What is true for individual creatures is also true for ecosystems. A coral reef can be weaker or stronger depending on its specific conditions. If a reef is harmed by human activities, such as dredging, sedimentation, pollution, overfishing, or other problems, it is more susceptible to damage from climate change and will likely suffer more and recover slowly or not at all.

In contrast, a healthy reef that has been protected from damaging human activities will generally be more resilient in the face of climate change and will likely experience fewer negative impacts and recover more quickly and fully. For example, when there is coral bleaching due to high surface water temperatures or very low tides, corals on reefs that have been already harmed by people may die, whereas corals on other reefs can recover.

We cannot easily control climate change, but we can control our local conditions. We can ensure that our reefs are robust and resilient to changes. There are ways we can act to help our reefs be tough and in good shape to better resist problems associated with the changing climate. By helping coral reefs survive into the future, we ourselves are adapting to the climate change and reducing its impacts on our islands and communities.

HOW CAN A COMMUNITY START TO ADAPT?

We use the term climate adaptation to describe the things that individuals, communities, and governments can do to help protect local ecosystems from harmful climate impacts. The best ecosystem climate adaptations are activities that help ecosystems return to and keep their natural conditions.

If human activities are damaging coral reefs, people need to decide as a community what to do about that. We know that healthier ecosystems are more resilient with respect to climate change. Healthy coral reefs generally recover faster and better from impacts of climate change than reefs that are already damaged by people.

As important members of society, schools and students can share information about coral reefs and climate change with their communities. For example, pages 62–65 describe seven types of human activities that can damage coral reefs: dredging, too much sediment, pollution, overfishing, destructive fishing, solid waste, and carelessness. Using their lifelong knowledge of the local reefs and the kinds of information in this book, communities can start by identifying the most damaging human activities that need to be managed and reduced.

Communities can also identify the most important reef areas on their island and work to protect them from any harm from people (create Marine Protected Areas). Having broad areas of healthy and well-protected coral reefs can help make an entire island and its communities much better prepared for changes that the future will bring.
**BIG IDEAS**

**KEY BENEFITS OF CORAL REEFS**

Coral reefs provide habitat, food and resources, and services.

Habitat:
- ★ home to many living things
- ★ some of the highest biodiversity in the world

Food and resources:
- ★ source of fish and other seafood
- ★ source of sand, rocks, shells

Services:
- ★ protection from waves and storms
- ★ sediment that makes beaches and small islands
- ★ important to culture, recreation and tourism, economy

**MAIN THREATS TO CORAL REEFS**

Human activities can directly harm coral reefs. Human-caused climate change also harms coral reefs.

- ★ destroying habitat
- ★ producing too much sediment
- ★ polluting
- ★ overfishing
- ★ climate change
  - ★ increasing temperatures
  - ★ sea level rise
  - ★ ocean acidification
  - ★ ecosystem damage

**STRATEGIES TO REDUCE THREATS TO CORAL REEFS**

The best climate adaptations for any ecosystem are activities that help that ecosystem return to and keep its natural conditions. That makes an ecosystem more resilient to threats, including climate change. Activities that can make coral reefs more resilient include preventing sediment and pollutants from getting to reefs, creating and securing Marine Protected Areas, and restricting human interactions with reefs everywhere: eliminating dredging and destructive fishing, managing fisheries to prevent overfishing, and protecting rather than destroying corals and other living things.
WHAT IS CLIMATE CHANGE?

Many times in our planet’s long history, Earth had a much colder climate than today. During an Ice Age, huge glaciers cover large amounts of land on continents. For example, 20,000 years ago, the area where New York City is located was covered by ice that was about 9,000 feet thick. The ice was six times taller than today’s tallest buildings. So much of Earth’s water was locked up in ice that the sea level was about 360 feet (120 meters) lower than today. Your island would be much bigger if today’s ocean was that low.

During other times in our planet’s long history, Earth had a much warmer climate than today. Even the poles had little or no ice covering them. During those warm times, the sea levels were much higher than today.

We use the term global climate to describe the general climate of the planet as a whole. For the past 10,000 years, the global climate has not changed that much.

Plants, animals, and other living things have all adapted to the climate conditions where they live. Different kinds of ecosystems depend on the different climate conditions in various places. In addition to different organisms and ecosystems, human communities are also adapted to climate. People have built their homes, agricultural areas, cities, and transportation systems to work well in the conditions of the local climate and geography, including the sea level.

Humans did not cause climate changes that happened previously in Earth’s history. However, the current global warming is man-made. It is happening mostly because we burn huge amounts of fossil fuels. We use oil to make the gasoline that provides the power for cars, boats, and trucks. People also burn coal, oil and gas to keep warm, cook, and make electricity. This burning produces gases (especially carbon dioxide) that trap heat in the atmosphere.

Other activities, notably massive production of cattle for meat, also release harmful gases into the atmosphere. Trapping of heat by carbon dioxide and other gases is causing Earth’s climate to get warmer.

The graph of average global temperature since the year 1880 shows that the global temperature has been increasing. Over the past 100 years, Earth’s temperature has increased about 1.6 °F (0.9 °C). We are already seeing changes such as higher sea levels and more flooding. In this century, sea levels could rise three or more feet.

▲ When we burn fossil fuels (oil, coal, and natural gas), they produce gases that stay in the atmosphere and trap heat, causing global warming. A) Oil is used to make gasoline to run cars and trucks. B) Oil, coal, and natural gas are burned for heating, cooking, and to make electricity.
As shown in the diagram below, the increasing amount of CO₂ in the air is heating our planet and causing many other changes. As the ocean gets warmer, it increases in volume. In addition, melting land ice flows into the ocean and adds to the volume of the ocean. The resulting rise in sea level causes some of the biggest climate change problems for island ecosystems and communities.

Higher air and ocean temperatures also cause changes to the patterns of rainfall. Some places may experience more drought, while other island locations may have increased rainfall, especially heavier downpours. Scientists have some evidence that tropical cyclones in the Pacific may increase in strength but occur less frequently.

While there are other impacts of global climate change, we have focused on the four impacts that affect coral reefs and island communities the most:

★ Higher air and ocean temperatures
★ Higher sea levels
★ Changing rain patterns
★ Ocean acidification

Each of these impacts of global climate change can directly harm at least some important island ecosystems. These ecosystems provide many services—such as support for cultural values and traditions, food and other resources, and opportunities for income from fishing and tourism. All four of the climate change impacts can decrease the benefits that humans get from island ecosystems.

In addition, much of the extra carbon dioxide in the air dissolves in the ocean. This extra dissolved carbon dioxide forms a weak acid, and changes the ocean’s chemistry. The extra acidity harms marine organisms that have calcium carbonate shells (such as corals and clams). Ocean acidification is included as a harmful impact of climate change because many activities that cause climate change also cause ocean acidification.
We humans have been able to live in so many different places on the planet because we have developed construction systems that provide us with homes, and agricultural and fishing systems that provide us with food. We have also developed other systems that provide us with fresh water and transportation. Rising sea levels can harm each of these human systems. Because of their effects on ecosystems and agriculture, all four of these climate change impacts can make it harder for people to get food. Changing rain patterns can also make it harder to have a secure supply of fresh water.

Humans can reduce the amount of climate change by burning less fossil fuel and reducing other activities that put heat-trapping gases into the atmosphere. Communities can also reduce the harm caused by climate change by planning and practicing climate adaptations. For an ecosystem, the most effective climate adaptations are activities that help an ecosystem stay as close to its natural state as possible. These climate adaptation activities mostly involve protecting the ecosystem from other human activities that can harm the ecosystem. Climate adaptation activities include preventing and removing pollution, and carefully managing how we fish, cut trees, build roads, and develop on our lands. A healthy ecosystem is resilient to climate change; it tends to suffer less damage from climate change, and recovers more quickly from damages that do occur.

Pages 66–73 in the main text describe the effects of climate change on coral reefs and ways that humans can help protect these essential island ecosystems.

EXPLORE MORE ABOUT CLIMATE CHANGE

You can explore three “interactives” to learn more about the science of climate change and its impacts on Pacific island communities. An “interactive” is an educational resource on the Internet where you can interact with diagrams, images, and text to get more information.

Start exploring the “interactives” by going to: http://pcep.prel.org/resources/?collection=interactives

1 “Carbon Dioxide and the Carbon Cycle”
   – how human activities change the carbon cycle and cause atmospheric carbon dioxide to increase

2 “Earth’s Energy Flows and Climate”
   – how higher carbon dioxide levels cause global warming

3 “Impacts of Climate Change in the Pacific Region”
   – climate change impacts and adaptation strategies for ecosystems and human communities

You can also find these interactives and associated lesson plans at: http://pbslearningmedia.org and search for “PCEP.”
A
Adaptation – way in which a living thing changes over time to better survive in its environment
Algae – seaweeds and other organisms, including microscopic ones, that live in water and make food by photosynthesis
Atoll – ring-shaped or irregularly shaped enclosed coral reef that surrounds a lagoon
Barrier reef – wall-like coral reef that goes along the coast but is separated from it by deeper water
Biodiversity – variety of living things; the number of different kinds of organisms in a particular place
Calcium carbonate – material that coral and many other marine organisms make from minerals dissolved in seawater and use to produce their hard body parts
Carbon dioxide – gas that animals breathe out and plants use for photosynthesis
Carnivore – animal that eats other animals (from carnis, which means “flesh” and vorus, which means “eater” in Latin)
Climate – overall weather patterns of a place over a relatively long period of time
Climate adaptation – actions people can take to help an ecosystem or their community become more resilient to climate change
Climate change – long-term change in the climate of a place, including change that is caused by the increase in the temperature of the atmosphere
Community – all plants and animals living and interacting in an area
Consumer – organism that cannot make its own food and has to eat producers or other consumers
Coral – polyp animals and their hard skeletons
Coral bleaching – when corals turn white after losing the algae that live inside them
Coral reef – rock-like structure found in shallow warm ocean waters, made by colonies of corals and other organisms

B
Decomposer – type of organism that breaks down waste and parts from dead plants and animals into simpler substances
Detritivore – animal that eats plants and animals after they have died (from detritus, which refers to loose and worn material and vorus, which means “eater” in Latin)
Echinoderm – sea urchins, sea stars, sea cucumbers, and similar animals that have spiny skin and bodies with a central point
Ecosystem – community of all the living organisms in an area together with their interactions with one another and with all the nonliving parts of the area
Equator – imaginary line that goes around the Earth and divides it into a northern half and a southern half
Erosion – process by which land is worn away by water, wind or living things
Filter feeder – animal that feeds on small bits of food obtained through filtering water
Food web – feeding relationships where energy and matter are transferred from plants to herbivores to carnivores to decomposers
Fringing reef – reef that lines a coastal area
Gills – body part that many animals have and use to breathe underwater
Global warming – increase in the overall temperature of Earth that is currently caused by human activities, especially the burning of fossil fuels
Habitat – area where a certain living thing finds food and shelter
Hard corals – corals that build hard skeletons
Herbivore – animal that eats plants (from herba, which means “grass” and vorus, which means “eater” in Latin)
Invertebrate – animal that does not have a backbone, such as corals, worms, crabs, clams, squids, and sea urchins; the vast majority of marine animals are invertebrates (but fish and turtles are not because they have backbones)
Lagoon – area of calm water surrounded by reefs, or reefs and land

Crustacean – shrimp, lobsters, crabs, and similar animals that have a body divided into segments and protected by a hard skeleton

Crustacean – shrimp, lobsters, crabs, and similar animals that have a body divided into segments and protected by a hard skeleton
**Marine Protected Area** – reef or another marine-related area where fishing and the use of other resources is controlled in order to protect the living things and the environment

**Microorganism** – living thing that is so small it can only be seen with a microscope

**Mollusk** – animal with a soft body and usually a hard shell, such as clams, snails, octopuses, and squid

**Niche** – particular place that a living thing has in its community, including the space in which it lives, its role in the food chain, and its behavior

**Nutrient** – substance that animals need to eat in order to live, and that plants need to absorb in small quantities to help them with their living processes (including production of food through photosynthesis)

**Omnivore** – animal that eats both plants and animals (from *omnis*, which means “all” and *vorus*, which means “eater” in Latin)

**Oxygen** – gas that plants release through photosynthesis and that animals need to breathe

**Parasite** – organism that lives inside or on another organism and benefits at the other’s expense

**Photosynthesis** – process by which plants and algae use energy from sunlight to make food from carbon dioxide and water

**Phytoplankton** – plankton that make their own food through photosynthesis

**Plankton** – tiny living things that drift in the water

**Pollution** – harmful substances in the water, air, or soil

**Polyp** – individual coral animal, a small bag-like organism with tentacles, mouth, and stomach

**Predator** – animal that hunts other animals for food

**Prey** – animal that becomes the food of another animal

**Producer** – plant or any similar organism that can make its own food

**Reef** – large, rocky formation underwater or near the water’s surface

**Reproduce** – how existing organisms make young copies of themselves, such as animal babies and plant seedlings

**Resilient** – to resist damage and recover quickly after difficult conditions

**Scuba** – equipment used by people to breathe underwater

**Sea anemone** – animal related to a coral; it looks like a large coral polyp without a skeleton

**Sea level** – height of the water’s surface in the ocean

**Sediments** – small pieces of soil, rock, and matter from organisms, often moved by flowing water from one area to another area, where they settle to the bottom

**Soft corals** – subgroup of corals whose members do not build hard skeletons

**Species** – group of organisms that are very similar to one another and can produce young together

**Symbiosis** – literally means “living together,”—any close relationship between two different species, in which at least one benefits

**Tropical** – kind of climate or place that is usually warm throughout the whole year

**Vertebrate** – animal that has a backbone, such as fish, lizards, birds, pigs, bats, and people

**Zooplankton** – plankton that gets its food by eating

**Zooxanthellae** – microscopic algae that live inside coral polyps, but also inside some other animals (sea anemones, giant clams, sponges)
TEACHING TIPS

QUICK TIPS

When learning and discussing coral reefs, students and teachers in the Pacific islands have the advantage of visiting reefs in their local environment. It is important that students go outdoors and explore the reefs. This will make it easier for them to connect concepts from this book with real life and understand the relevance of the reefs to their own island. To take advantage of the local reefs surrounding your island, visit nearby reefs with your students. Talk with fishermen and other people with direct experience of reefs, and help students observe organisms on the reef flat, at low tide and when it is safe.

1. Students find different corals and compare growth forms when walking along a local reef during low tide and when the ocean is calm. Note that they may not see many different coral species on the reef flat itself, and it may be necessary to look along the edge of the reef or inside any deeper holes on the reef flat. After they examine corals, have students look for other living organisms and identify algae, *invertebrates*, and fish they see. Schools in different parts of the island, state, or country can communicate and compare their findings.

   Note: Always use caution when near or in the ocean, as conditions can change quickly and a place that is fine at one time may not be safe at another time. Make sure there are enough teachers and parents with you to ensure that the place and time is safe for students to explore.

2. Students create a coral reef poster or mural. They draw different corals and other reef creatures and explain why they chose those creatures, and how they decided where to place them on the reef.

3. Students describe the concepts of coral polyp, coral colony, and coral reef. They describe how reefs are made of many colonies, which in turn are made of many polyps. They communicate this to others visually, orally, and by written report.

4. With a partner, students select a reef organism to personify (give it human characteristics) and create a story with the organism as the narrator. The narrator tells a story of life on the reef.
VISUAL BRAINSTORM ABOUT REEFS

In this activity, students will use visual brainstorming techniques to generate ideas, record what they know about coral reefs and interdependency, identify questions for further inquiry, and engage in research and writing processes. They explore the idea that coral reefs are created by living things and are—at the same time—habitats for living things. Students also consider how some living things build reefs, while others erode them, and how these activities exist in balance. Students determine the interdependence between reefs and various living things, and connect that relationship to human interactions with reefs.

1. In small groups, students investigate topics about coral reef interdependency by brainstorming ALL of their ideas about coral reefs as quickly as possible. When the ideas slow down, the group tries to reach a consensus about the main idea of their research based on the ideas shared.

2. Students create a concept map with the main idea in the middle and then brainstorm all they know about that main idea (draw lines back to the main idea to link them), including possible areas for further research. Alternatively, they can visually represent the main idea and related details with a combination of drawings and words. The teacher explains to the students that the purpose of the concept mapping is to facilitate brainstorming concepts the students will want to research and learn more about.

3. Once many ideas are recorded, students review and revise the links between ideas.

4. New links and layers (subcategories) can be added during the brainstorming process.

5. The teacher has students add or draw visuals of the ideas represented in the concept map to help them better understand concepts and remember details. Drawing can also provoke thinking and new ideas, as they determine which visuals and what details to include.

6. Once the group’s main research idea becomes clear and is approved by the teacher, they can proceed to frame their main topic idea as a question for inquiry. For example, students might ask: What creatures live on coral reefs? What do they do, and how do they give back to the reefs? How do reefs provide for and protect human beings?

7. Before students commence their research, they should consider the possible sources of information. These include family and clan members, community members (especially fishermen and others who spend much time around reefs), the Internet, school textbooks, and any other relevant books available from the school library or elsewhere on the island. The teacher can point out to students the difference between primary and secondary sources of information. At higher grade levels, the teacher may request that students rely on primary sources in their research.

8. The concept map (or visual representation) is ready to be used as a graphic organizer to facilitate research. The students will use it as a tool to record: 1) strategies for collecting information and defining critical questions and sources; 2) actual new information collected; 3) sources of that information; and 4) plans for further research. The teacher emphasizes that the concept map used to brainstorm knowledge and identify research questions has now become the graphic organizer for the actual research process.

EXPLORING REEFS USING SATELLITE VIEWS

Coral reefs are often gigantic structures, and it may be difficult for students to grasp the overall shape of reefs by looking at them from ground level. If you have access to a computer or smartphone with Internet in your school, students can view satellite images of their own island and the reefs that surround it, as well as other islands and reefs. To do that, follow these steps:

1. Go to [https://www.google.com/earth/](https://www.google.com/earth/) in your browser and download and install free software called Google Earth™.

2. Start the program and show the globe on the screen to the students. Type the name of your island in the search box, and watch the globe rotate and zoom in.

3. Ask students if they recognize their island and point out some of the key features (ocean, land, coast, main town). Use the commands on the screen to zoom in and out and move around the image. Explain that this is an actual photo of the island taken from a satellite high above the Earth’s surface. Find other islands and explore their key features as well.

4. Work with students to identify different types of reefs. Find examples of fringing reefs, barrier reefs, and atolls (an example of each is shown in the pictures to the right). Try to find patch reefs in lagoons, and identify different reef zones (reef flat, reef crest, etc.).
FISHING METHODS AND RESOURCE USE

There are many ways to obtain food from coral reefs. Fish, crabs, mollusks, urchins, sea cucumbers, seaweed, and other things are caught or collected using a variety of methods, many of which are learned from elders as they are passed down from generation to generation. Depending on the island, there is still a variety of traditional methods in use.

Part I. Students make a list of all kinds of edible things from coral reefs, including things that are collected, such as various clams and sea cucumbers, as well as things that must be caught, such as various species of fish and crabs. For each animal, students brainstorm and record their ideas about the following:

- a) who obtains it (men, women, children, communities working together)
- b) how they do it (methods of capture, tools for hunting)
- c) when they do it (time of the day and month/season)
- d) what they do with it (methods of food preparation)
- e) any other relevant aspects that interest the students

Inviting 3–5 community elders who use the reef to the classroom. Ask them to each respond to a–e. Students share their brainstorm, then work together with a teacher or elder to add or revise and create a collective response.

Part II. Students consider the importance of the practices described in Part I in understanding their environment and cultural links with the ocean and reefs. Human activities and climate change impact coral reefs. Students reflect on human activities that protect the reef and activities that hurt the reef. For example, students consider the following:

- a) Which reef organisms are harvested more than others, and why
- b) Which organisms were more common in the past, and why
- c) How their ancestors regulated the taking of different organisms to avoid overharvesting (e.g., limiting fishing rights, limiting fishing at different seasons, clan ownership of reef areas, taboos imposed by chiefs).

Students come up with plans to support practices that protect the reefs and prevent overharvesting, ensuring that all kinds of organisms continue to exist on their reefs in ample numbers in the future. Students also consider how changes in society, the introduction of new fishing methods, and the sale of catch for cash is both helping and harming the reefs. What are the impacts on society and the environment? What can be done to maximize protection and minimize harm? Students invite community elders back to the classroom to share their findings and identify potential solutions together. Solution-based actions should include the role of youth in agreed-upon actions.

RELATIONSHIP BETWEEN ENVIRONMENTAL CONDITIONS AND ORGANISMS’ ADAPTATIONS

Students go out to explore the reefs and observe how different parts of the reef have varying conditions, how the location of the place influences the conditions, and how the conditions influence the types of organisms that live there.

- What are the different zones on a reef?
- What makes the zones different from one another?
- What organisms live in different zones?
- How do the organisms’ adaptations help them live in certain reef zones? (For example, sea cucumbers living on the reef flat must be able to survive short periods of being exposed to air during low tide.)
- How is the changing climate impacting the conditions, and what is the effect on organisms? Will they continue to adapt?

Students use their observations, discussions with users of the reef, and readings to prepare for an interactive exchange with peers or younger students about how organisms adapt to the conditions of the reef where they live. Additional questions are generated during the discussions for further research.
FEEDING ADAPTATIONS OF REEF ANIMALS

This activity helps students grasp the variety of adaptations that reef animals developed to find food.

Part I. Students identify and compare producers and consumers on the reef to understand the differences between them. Emphasize that this activity deals with consumers only—the organisms that must eat food to survive. Using a graphic organizer, such as a table, students distinguish between various plants and animals using pictures shown on pages 36 and 37 and describe their respective feeding habits: predation, scavenging, deposit feeding, suspension feeding, filter feeding, and other ways.

Part II. Students engage in an expert-novice activity to learn about the feeding habits of animals on the reef. In pairs or small groups, students research a reef animal that they find particularly interesting. Each group chooses an animal, such as a fish, clam, coral, brittle star, hermit crab, or snail, etc., and learns about its feeding habits and instructs the other students about what they have learned about their chosen animal. This activity appeals to students’ curiosity through hands-on participation and interactive instruction. It can be combined with personal stories from students about why they chose a particular animal to discuss, when and where they have seen it, its role in the ecosystem, and other aspects.

Part III. (Extension Activity) In the next part of the activity, students can be divided into four separate groups. Each group gets assigned one feeding habit (e.g., predation, deposit feeding, suspension feeding, filter feeding) and one color. To represent food, the teacher prepares several handfuls of cut-up pieces of paper in four colors. The goal of each group is to get the pieces of paper in their color and demonstrate to others a particular feeding method. Members of each group are allowed to get their food (their pieces of paper) only by the feeding method they have been assigned. Brainstorm with the students as to how best to represent this. For example, predators can walk around the classroom and locate and grab pieces of paper placed in various parts of the classroom. Deposit feeders must creep slowly and can only pick up pieces of paper on the floor. Suspension feeders must stay in one place and use a stick with sticky tape to snatch pieces of paper placed near them. Filter feeders also stay in one place and use their hands or pieces of cloth or nets to capture small pieces of paper blown toward them using a hand fan. Let the activity go on for a few minutes, and then regroup students for a discussion. Ask the students “What limitations did you feel while using a particular feeding habit? How is this feeding habit helpful for organisms? How would this feeding habit affect where an organism can live in a reef environment?”

Note: This activity is based on a game developed by Marine Discovery, University of Arizona

EXPLORING BIODIVERSITY OF CORAL REEF

Students work as a group to organize their results from the “Fishing Methods and Resource Use” activity (page 90) and “Feeding Adaptations of Reef Animals” activity (page 92) into a chart similar to the one shown below. The chart organizes the knowledge that students already have and provides a framework for students to identify gaps in their knowledge. Students then fill those gaps in knowledge together through class discussion, homework involving talking with elders, referencing this book, and library/Internet research.

The first row in the chart lists different reef organisms. Aim to have at least two organisms per student so that students can make their own conclusions about the reef’s complexity and diversity. In each row of the chart, students frame their own questions about the environmental and biological conditions related to the specific creature. The chart below is an example of the types of organisms and questions that students can explore.

<table>
<thead>
<tr>
<th>Giant clam</th>
<th>Sea cucumber</th>
<th>Octopus</th>
<th>Parrotfish</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is it called in your own language?</td>
<td>Have you ever seen it?</td>
<td>Where have you seen it?</td>
<td>Where does it live?</td>
</tr>
<tr>
<td>What does it eat?</td>
<td>How does it get food?</td>
<td>Does it make any hard parts (shell, skeleton)?</td>
<td>How does it interact with the coral reef?</td>
</tr>
<tr>
<td>Is it a producer, consumer, or decomposer?</td>
<td>If animal, is it a vertebrate or invertebrate?</td>
<td>What group does it belong to?</td>
<td>(use pages 94–95 as aid)</td>
</tr>
</tbody>
</table>

Once the chart has been completed, students select one organism and create a 1- to 2-page fact sheet with images and detailed descriptions of the organism based on information gathered. The fact sheets become reference material for the class and reading material when students present and share with younger grades and to community.
CLASSIFYING LIVING THINGS

Scientists classify (group) closely related living things together to make them easier to study. Like people in families and clans, groups of living things share ancestry and certain characteristics that make them more similar to one another, than to things outside of their group.

In this activity, students look at the key groups summarized here and for each group, they give examples of what they have observed on coral reefs and discuss the characteristics that the organisms have in common.

**MICROORGANISMS**
Microorganisms live in different ways and belong in different groups. They are not all closely related to one another, but we tend to think of them as a group because they are so small we need microscopes to see any of them. Some of them are like animals because they have to eat to survive. Some are like plants because they use sunlight to make food from water and carbon dioxide. Zooxanthellae that live inside coral polyps are plant-like microorganisms.

**ALGAE**
Algae are plant-like organisms that live underwater. Some algae are microorganisms, but many algae are larger and very visible.

**PLANTS**
Seagrasses are the only real plants adapted for underwater life in the ocean. They grow in sandy areas on the floor of lagoons and on reef flats. They can grow only in places that get enough sunlight. They can cover large areas and turn them into underwater gardens, where small animals can hide and grow up.

**SPONGES**
Sponges are very simple animals whose bodies are full of holes. They are attached to the sea floor and cannot move away. They allow water to pass through the holes in their bodies. They eat bacteria and other bits of food that they remove from water as it filters through them.

**WORMS**
Worms have long, soft, and slender bodies. They live mostly hidden under sand or rocks, or inside coral and even inside other animals. They belong in many different groups. Some worms build protective tubes for their sensitive bodies, including some whose tubes are hard and contribute to reef building.

**ANIMALS**

**SPONGES**
Sponges are very simple animals whose bodies are full of holes. They are attached to the sea floor and cannot move away. They allow water to pass through the holes in their bodies. They eat bacteria and other bits of food that they remove from water as it filters through them.

**CNIDARIANS**
Corals and their relatives belong to a group of animals known as cnidarians. They have a similar basic form of a bag-like body with a mouth surrounded by tentacles.

**JELLYFISH**
Jellyfish have soft, bell-shaped bodies and long, stinging tentacles that they use to catch food.

**CORALS**
Most corals consist of small polyps that live in colonies. There are also solitary corals that live on their own.

**SEA ANEMONES**
Sea anemones are shaped like coral polyps, but are much larger. They are attached to the sea floor. They eat fish and other food they catch with their tentacles.

**ALGAE**

**SEaweeds**
These are typical algae that are large enough to be seen without a microscope. They are usually soft and squishy and can have green, brown, red, or other colors.

**CORalline algae**
These algae are a special group that make hard, coral-like skeletons. They look like tough crusts or small corals.

**SEa stars**
Sea stars have five or more arms. They feed mostly on bivalves. Sea stars with very fine, flexible arms are considered a separate group called brittle stars.

**FEathering stars**
Feather stars have many feather-like arms that give the overall impression of a flower. They use the arms to filter small particles of food from seawater. They hold onto the reef and can slowly move around using small legs.

**ECHINODERMS**
This is a diverse group of animals that look quite different from one another but share some key traits, especially spiny skin and a body shape that has a central point.

**SEA Urchins**
Sea urchins have a round, hard body with many spines. They use the spines for protection and for movement. They feed mostly on algae, which they scrape off reef surfaces.

**SEA Cucumbers**
Sea cucumbers have leathery skin and elongated bodies they can make soft or hard as needed. They live on the bottom and feed on detritus.

**SEA STARS**
Sea stars have five or more arms. They feed mostly on bivalves. Sea stars with very fine, flexible arms are considered a separate group called brittle stars.

**FISH**
Fish are the only vertebrates that live their entire lives in the ocean and breathe underwater. They are the most important food we have from the sea.

**CRUSTACEANS**
Crustaceans are animals with outside skeletons, legs with joints, and bodies divided in three segments: head, chest (known as thorax), and belly (known as abdomen).

**CRABS**
Crabs have well armored bodies, short tails, and strong claws. There are many kinds of crabs. Some crabs live on beaches and some even on land. They are a popular food for people.

**SHRIMPS**
Shrimps are small, fast crustaceans that often live in groups. There are many species. Some eat algae, some hunt, and some eat dead things.

**LOBSTERS**
Lobsters live in holes in the reef. They walk slowly but can also quickly swim backward when they need to escape. People like to eat lobsters.

**BARNACLES**
Barnacles live in hard shells stuck to rocks and other things, even to turtles. They are related to crabs, shrimps, and lobsters, but do not look anything like them.

**VERTEBRATES**
Vertebrates are animals with spinal cord and bones (or cartilage) inside their bodies. The key vertebrate groups are fish, reptiles, birds, and mammals, including humans.

**MOLLUSKS**
Mollusks are a very diverse group of animals and include clams, snails, octopuses, squid, and certain other animals. Their soft bodies are often protected by hard shells.

**VERTEBRATES**
Vertebrates are animals with spinal cord and bones (or cartilage) inside their bodies. The key vertebrate groups are fish, reptiles, birds, and mammals, including humans.

**BIVALVES**
Bivalves have hard shells that consist of two matching parts. They live on the bottom. They pump water through their bodies and sift out small bits of food.

**GASTROPODS**
Gastropods are better known as snails. A snail carries its coiled shell on its back, as it slowly slides along on its “foot.” Some snails do not have shells.

**CEPHALOPODS**
Cephalopods have “arms” attached to their heads. Best known cephalopods are octopuses and squid. They can quickly change their body color.

**CRUSTACEANS**
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Fish are the only vertebrates that live their entire lives in the ocean and breathe underwater. They are the most important food we have from the sea.

**REPTILES**
Reptiles live mostly on land, but some species have adapted to life in the ocean. Sea turtles and sea snakes are reptiles that live around reefs.

**BIRDS**
Many birds eat fish and live only near the ocean. They generally feed on fish schools in deep water, but some species spend time around coral reefs and find food there.
Students research the role of reefs in the making of beaches and islands. By exploring and observing the reefs in their communities, students may come to the conclusion that

- the entire beach and all the land of their islands (on low islands), or
- most of the sand on the beach that surrounds their island (on high islands)

is made of broken pieces of coral reef. Depending on the island type, either all or most of beach material, from tiny grains of sand to large rocks, derives from broken fragments of reef and hard parts of coral reef organisms.

1. After completing the activities "Exploring Biodiversity of Coral Reefs" (page 89) and "Classifying Living Things" (pages 90–91) students should be asked to bring a bit of sand, pebbles, small pieces of rocks, shells, any other rock-like material, and the remains of different kinds of living things they find on the beach. Some examples are shown below.

Encourage students to bring things from the beach over several days and collect them all together in a single basket or box. Sand samples are placed apart.

2. On the day of the activity, the teacher pulls one item after another from the basket or box and asks the students what each one is and how it was made. Students try to identify the object as being a piece of coral, coralline algae, mollusk shell, sea urchin spine, etc.

3. In pairs, students create different groups of items following a classification system of their own or the traditional system used locally. They must be able to explain why any one item was placed in a group. Students then review the identification system scientists use (pages 94–95) and then classify their findings in that way (example shown below). Students reflect on the various methods used to group or classify organisms.

4. The teacher poses the question, “What is the role of reefs in the making of our beaches and islands?” Students discuss in pairs and then share ideas that are recorded on the board or paper. Students examine different groups of organisms together and discuss which of them are the main reef builders.

5. Students examine grains of sand and offer ideas as to where they come from. They observe their sand samples under magnification, using a magnifying glass or other instruments that may be available. Students use visual representation or graphic illustration (e.g., drawings, concept maps, flow charts) to demonstrate and explain the processes that led to the existence of the grains of sand.

6. The collection of organisms and sand should be preserved for future reference. These objects may be valuable when teaching about different aspects of coral reefs. For example, a piece of coral is a great help when discussing coral polyps, coral colonies, and their hard skeletons.
OUR REEFS, OUR KNOWLEDGE

We are better able to understand and protect our reefs if we can draw from the multiple forms of knowledge available in our communities. The goal of this activity is to use local ecological knowledge, as well as science—through observations, traditional legends, and contemporary stories—to learn about local reefs, identify challenges, and find community-based solutions.

This activity unfolds in three phases. Students keep records of their findings, observations, and stories gathered using a graphic organizer, such as the one shown on the next page.

1. Students visit a local reef with a teacher and/or elder to observe plants, animals, corals, weather, and people. Teachers and students encourage elders to share stories, legends, sayings, and memories during the visit. Students keep a record of their observations through notes and drawings, either during the visit or after returning to class.

Students open a conversation with their community at two community meetings.

2. At the first meeting, students invite family, clan, and community members to school to co-create questions that student can use to gather information about human activities on their reefs through interviews and observation. During this meeting, students first ask the community to share stories and memories about the role of the reef in their culture, how humans used it in the past versus now, the current health of the reef, and how it is cared for. Students then share that they will gather information about human activities on the reef through observation and interviews with local users of the reef over the following two weeks. Finally, students and community members co-create questions that will guide the students’ interviews. The students should return to the same reef for further observations and reflection.

3. In two weeks, students invite community members back to school for a second meeting to report on their findings. At that time, students and community members identify solutions that will restore and/or protect reefs, and the roles for students are specified in terms of actions within agreed-upon solutions. Students record information gathered in the community meetings in their graphic organizer, either during the meetings or after returning to class.

Students are encouraged to share the results of the community meetings in local media (e.g., newspaper, television, radio, social media), along with stories and photos of activities to protect our reefs. And when appropriate, students are also encouraged to share traditional stories, chants, songs, and proverbs that reference reefs.

Teachers who lead this activity should actively seek collaboration at different levels. For example, this activity would be relevant in subject areas such as Social Studies, Language Arts, Cultural Studies, and Music, in addition to Science and Math. Teachers can connect with local non-governmental organizations to support this activity, perhaps in donating equipment (e.g., snorkels and reef shoes) or identifying local experts to work with the students.

The authors of this book would also welcome stories from students and teachers! If you would like to share, please send us a message at pccp@prel.org.
REFERENCES AND FURTHER READING


Schomp, V. 2014. 24 Hours on a Coral Reef, Cavendish Square Publishing, New York, USA.


INFORMATIVE WEBSITES

www.livingoceansfoundation.org
www.reefbase.org
www.reef.edu.au
www.coralreef.org
www.coralreef.noaa.gov
www.coralreef alliance.org
www.coris.noaa.gov
www.teachoceanscience.net

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OTHER BOOKS IN THIS SERIES

This book is a part of the series, Pacific islands Climate Education Partnership (PCEP), Place-based resources for Pacific Island schools. The series also includes the following titles published thus far.

**Our High Island Home** is a book about natural island environments that Pacific children and their families will enjoy reading together. Highly visual images make familiar high island land- and seascapes come to life. Children living on high islands will recognize their everyday world and yet be amazed at the hidden treasures found within.

**Our Low Island Home** is a book about natural island environments that Pacific children and their families will enjoy reading together. Highly visual images make familiar low island land- and seascapes come to life. Children living on low islands will recognize their everyday world and yet be amazed at the hidden treasures found within.

**Pacific High Island Environments** is a book for those wanting to learn more about the places, plants, and animals on tropical high islands in the Pacific. The reader learns how high islands are formed and the various environments that create habitats for many species of plants and animals. From agroforests to mangrove swamps and lagoons, the reader is connected to island life and how important these environments are for the communities that live there.

**Pacific Low Island Environments** is a book for those wanting to learn more about the places, plants, and animals on tropical low islands in the Pacific. The reader learns how low islands are formed and the various environments that create habitats for many species of plants and animals. From atoll forests to patch reefs and the open ocean, the reader is connected to island life and how important these environments are for the communities that live there.

**Mangroves—Living on the Edge in a Changing Climate** offers readers of all ages a fascinating journey through the inner worlds of the mangroves. Intricate adaptations and unexpected habitats emerge from the pages of the swamp, unsettling the reader into realizing the incredible value of this island ecosystem. Mangroves provide many resources for local communities, and help reduce global warming by storing more carbon in the soil and its trees than other comparable ecosystems. This book also explains climate change, and how communities can help protect mangroves from climate change impacts such as rising sea levels.

**Agroforests—Growing Resilient Communities** takes readers of all ages on an exploration among the trees and other plants that shape the life and cultures of our Pacific islands. Through these pages, readers will meet the living organisms that make up traditional agricultural areas on Pacific islands, find out who cares for and works in these places, and come to understand that maintaining healthy agroforests can help us adapt to climate change.

**Adaptations—Finding a Fit in the Changing World** is a book that children and their families will love. It is full of colorful pictures about how living things are adapted to meet their basic needs in the places they live. Children will be fascinated to learn that some plants have developed chemicals so that animals that share their environment will not eat them. Children will also learn that there are many different types of birds’ beaks, all adapted to meet their need for getting food in different places. As children turn these pages, they quickly realize that all living things adapt to get what they need. It is this unique ability to adapt that help all living things survive.