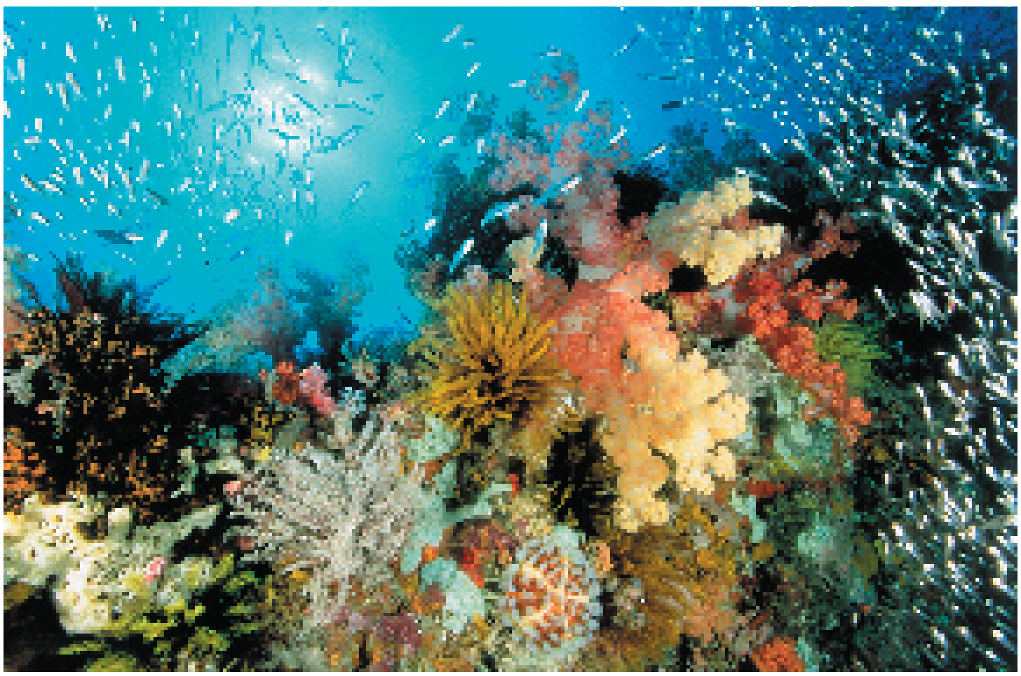
Introduction to Coral Reef Ecosystems, Threats, and Solutions



Burt Jones and Maurine Shimlock photo

The Coral Reef Alliance: Coral Parks Program Education Series

Introduction

Coral reefs are one of the most spectacular and valuable ecosystems on the planet — and one of the most threatened. Climate change, coastal development and tourism, destructive fishing, and other human activities are endangering their very existence. At the current rate of destruction, more than one-third of the world's coral reefs will be destroyed within our lifetime. This will mean devastating losses in biological diversity, shoreline protection, income, food, and scientific discoveries.

However bad the outlook may seem, there is still hope for coral reefs. With increased education comes an increased appreciation and understanding of the immense value of coral reefs. This has led to exciting initiatives and conservation projects in countries throughout the world. Coral reef protected areas are being established worldwide and are considered one of the best tools for reef protection.

This handbook was designed to provide community members, dive instructors, tour operators, park managers, tourists, non-governmental organizations and government officials with a basic overview of coral reef ecology, benefits of coral reefs, global threats, and solutions for keeping coral reefs alive. We hope that this handbook will raise awareness of the beauty and value of coral reefs, and the urgent need to protect them.

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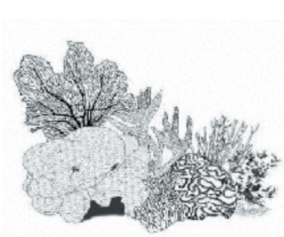

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The staff of the Coral Reef Alliance (CORAL)

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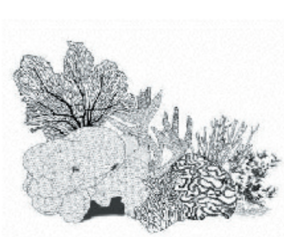

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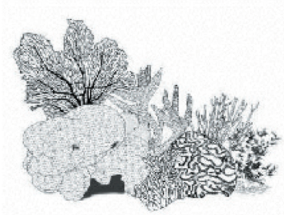
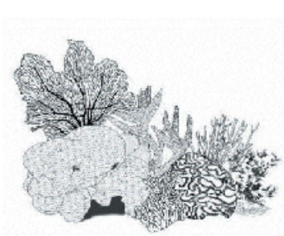


Part I: Understanding Coral Reefs



Understanding Coral Reefs

Clear turquoise water ebbs and flows at the edge of a tropical shore. Beneath the water's surface exists a breathtaking underwater world. Home to a diversity of colorful exotic fish, corals, and countless other marine creatures — this is the coral reef.

Oceans, seas and fresh water cover more than seventy percent of the earth's surface. While coral reefs take up only a very small fraction of the ocean (less than one-tenth of a percent), they are home to an astonishing variety of animals and plants. Coral reefs have very high biological diversity (biodiversity) — approximately 93,000 species of plants and animals have already been identified in coral reefs, and scientists predict that there may be over three million.

Coral reefs are the primary source of food and income for millions of people, produce valuable chemical compounds for medicines, and provide natural wave barriers that protect beaches and coastlines from storms and floods.

Yet coral reefs are in danger. Already, eleven percent of the world's coral reefs have been lost and another sixteen percent were severely damaged during the 1998 El Niño event. Scientists predict that another thirty-two percent may be lost in the next thirty years if human threats are not reduced.

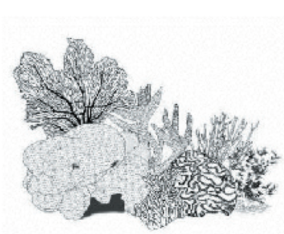
As our awareness of the value of coral reefs increases, so do our efforts to reduce current threats. Coral reef marine protected areas (MPAs), Integrated Coastal Zone Management (ICZM), sustainable tourism, education and outreach programs and coral reef rehabilitation are just a few of the many steps being taken to conserve and protect these valuable and beautiful ecosystems.

Coral reefs support a greater variety of animals and plants than the densest tropical rain forest.

Coral reefs:

- Make up less than 0.1% of the ocean.
- May house over 3 million species of plants and animals.
- 11% of coral reefs have already been lost.
- 32% of coral reefs could die in the next 30 years.

Coral reefs are one of the earth's richest and most beautiful treasures, and one of the most threatened.



The taxonomic hierarchy:

- Kingdom.
- Phylum.
- Class.
- Order.
- Family.
- Genus.
- Species.

Taxonomy and Coral Reefs

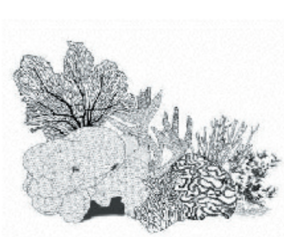
When studying living organisms and ecosystems such as coral reefs, scientists use a structured hierarchy to describe and categorize species based on natural relationships. **Taxonomy** is an ordered classification system that starts with the broadest set of physical similarities between living organisms, and progressively moves towards greater levels of common characteristics.

This system, first established by the Swedish naturalist Carolus Linnaeus in the 18th century, provides a method of universally accepted names for species throughout the living world and across cultural boundaries. The following table is an example of taxonomic classification for humans (*Homo sapiens*) and mushroom coral (*Fungia scutaria*.)

Taxonomic level	Example: Humans	Example: Mushroom Coral
Kingdom	Animalia	Animalia
Phylum	Chordata	Cnidaria
Class	Mammalia	Anthozoa
Order	Primates	Scleractinia
Family	Homonidae	Fungiidae
Genus	*Homo*	*Fungia*
Species	*sapiens*	*scutaria*

Although nearly 100,000 species have been identified in coral reefs, there are likely millions yet to be discovered and named by scientists.

Taxonomy helps prevent confusion surrounding common names of living organisms. For example, in Hawaii there is a popular eating fish named *mahimahi*. However, this same fish is called *dorado* in the Caribbean and *dolphin fish* in many other parts of the world. So, although the common name can change from place to place, the scientific name will always be classified according to it’s genus and species, that being *Coryphaena hippurus*.



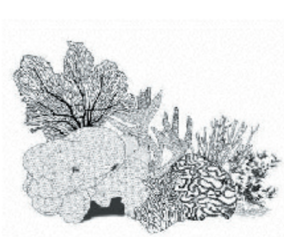
What Are Coral Reefs?

Coral reefs are huge structures built over hundreds, if not thousands, of years.

Reef animals include:

- Sponges.
- Corals.
- Mollusks.
- Worms.
- Crustaceans.
- Echinoderms.
- Marine fish.
- Marine amphibians.

With the invention of SCUBA diving in the 1950's, humans had a whole new way of experiencing, viewing and studying coral reefs.



Coral reefs are massive limestone structures that provide food and shelter for marine life. Hard corals are responsible for much of the solid, limestone (calcium carbonate) framework of the reef. Built over hundreds, if not thousands of years, some coral reefs are so large they can be seen from outer space.

In and around the limestone framework of coral reefs live a complex array of plants and animals. Some of them — like calcareous algae (algae with limestone in its tissues) — help to build the reef up. Others — such as worms, grazing fish, urchins and boring sponges — break it down. Many other animals, including more than 4,000 different species of fish, find shelter on the reef and make it their home. This multitude of life is what we know as the coral reef.

Animals commonly found in and around coral reefs include:

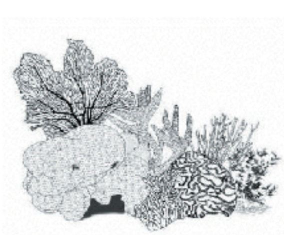
- Soft corals, hard corals, fire corals, anemones.
- Hundreds of different species of sponges.
- Conch, clams, sea slugs, cowries.
- Fireworms, Christmas tree worms, fan worms.
- Crabs, lobster, shrimp.
- Urchins, starfish, basket stars, sea cucumbers.
- Thousands of different species of fish.
- Sea turtles and sea snakes.

These animals co-exist in complex relationships. If one species on a coral reef is removed or dies out from human impacts such as overfishing, its disappearance can have far reaching consequences for the whole coral reef and the balance of the ecosystem can be dramatically changed.

What are corals?

- Cnidarians - corals, anemones, hydroids and jellyfish.
- Cnidocytes - specialized stinging cells.
- Polyp - coral animal.
- Colonies - groups of polyps.

Coral polyps can range in size from 1-3 millimeters in diameter (for colonial corals) to 25 centimeters (in some solitary corals).



What Are Corals?

Although they are often mistaken for plants or rock, corals are simple animals, belonging to a group of invertebrates (spineless animals) called **cnidarians**. Anemones, hydroids and jellyfish are also cnidarians. All cnidarians are characterized by a large stomach cavity and specialized stinging cells called **cnidocytes**, which they use to capture prey.

Polyps are the actual coral animals. Thousands of these animals cover one coral branch or mound. A polyp has a small cylindrical body, with an opening or mouth encircled by numerous stinging tentacles.

Corals often grow into huge coral **colonies** or coral heads. Each coral head can be made up of hundreds or thousands of individual polyps, which are all linked to their neighbors by connective tissue — including their stomach. So when one eats, they all eat!

Cross-section of a coral polyp

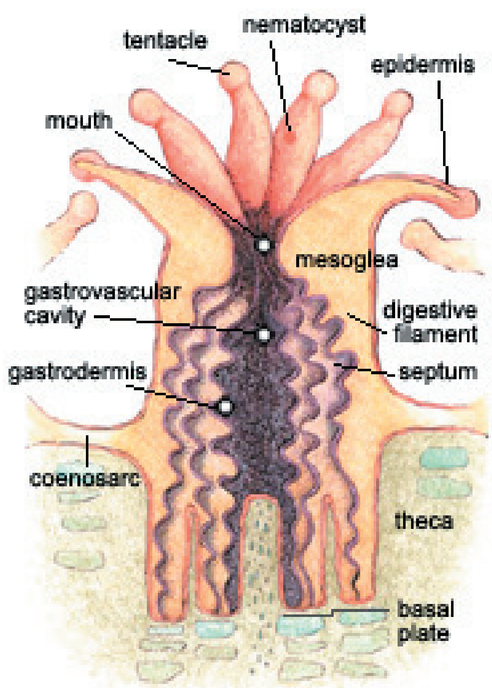


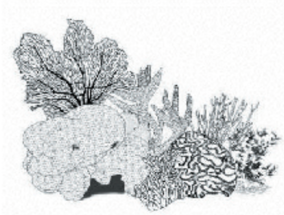
Illustration courtesy of NOAA

Corals are very sensitive and conditions need to be just right for them to flourish.

Corals need:

- Sunlight.
- Warm water.
- Low nutrients.
- Sediment-free water.
- Salty water.
- A hard substrate to grow on.

Corals are very sensitive to changes in temperature. Sometimes an increase of just 1 or 2°C can cause coral bleaching.



Environmental Conditions Necessary for a Healthy Coral Reef

Corals are very sensitive organisms and environmental conditions need to be just right. Corals need:

Abundant Sunlight
Reef-building corals cannot survive without sunlight, since **zooxanthellae**, their symbiotic algae, require sunlight for photosynthesis. The majority of zooxanthellae reef-building corals do not grow below 45m (150ft).

Warm Temperatures
Corals can only live within a narrow temperature range from around 16°C - 29°C (62°F - 85°F). This explains why corals thrive in the warmer waters of the tropics.

Low Nutrient Levels
Corals are adapted to live in ocean water, which contains very low levels of nutrients. Nutrients, which are needed by all living organisms, are found in food and dissolved in water. Too many nutrients can upset the natural balance of life on the reef, creating conditions that favor other fast growing organisms such as marine plants and sponges.

Clear Sediment-Free Water
Corals prefer clear water with low levels of **sediments** (small particles of earth, rock and sand). Sediments can bury corals, blocking out needed sunlight and killing them. Corals tend to live in areas with some wave action as this helps supply them with food and oxygen as well as keeping corals free of sediment.

Salty Water
Corals are marine animals adapted to live in seawater with a salinity of around 35 parts per thousand. In areas that are too salty, or not salty enough, corals cannot survive.

Hard Substrate
Corals need a hard **substrate** or surface to attach to and cannot successfully colonize loose substrates such as rubble or sand. If the substrate is unstable, young coral colonies will be crushed and killed by wave action and storms.

How Old Are Coral Reefs?

Coral reefs have existed for more than 570 million years.

Coral reefs have survived:

- Sea level changes.
- Mass extinctions.
- Land uplifting.
- Glaciations.
- Natural disasters.

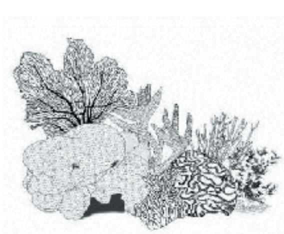
Coral reefs are one of the **oldest ecosystems on earth.**

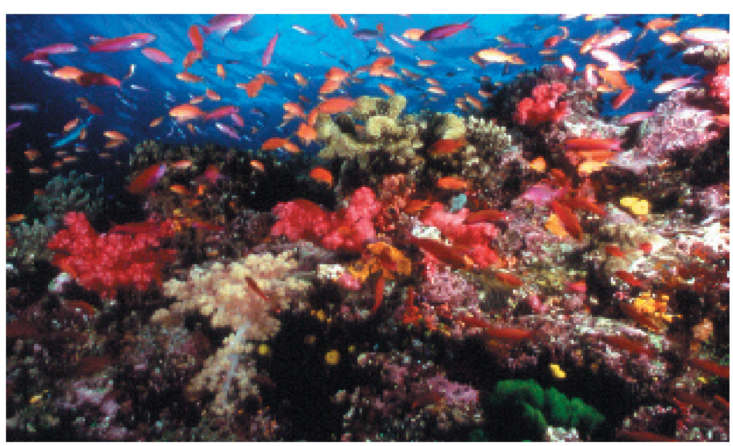
- The ancestors of modern coral reef ecosystems were formed around **570 million years ago**. During this time, blue green algae and later sponges (not corals), were the major reef builders.
- Modern coral reefs as we know today, have existed for a staggering **240 million years**.
- **T**he tropical seas were divided from **24 to 5 million years** ago and coral reefs were distributed into the regions that we know of today.
- Most existing coral reefs are between **5,000 and 10,000 years old**.

Over geological time there have been several mass extinctions associated with coral reefs. Reefs have survived changing sea levels, uplifting of landmasses, periods of widespread warming and repeated ice ages as well as recurrent short-term natural disasters such as cyclones and hurricanes. Over geological time coral reefs have shown a remarkable ability to adapt and survive.

Unfortunately, human activities now represent a much more immediate threat to the short-term survival of coral reefs than do natural disasters. Loss of coral reefs as a result of human activities has been steadily increasing in recent decades and is now a problem in nearly every region of the world. In Southeast Asia alone, eighty-eight percent of coral reefs are “at risk” from human impacts.

The age of coral can be determined by counting annual growth bands similar to tree rings.





Vibrant coral reef Kevin Roland photo

Where Are Coral Reefs Found?

Distribution of coral reefs:

- 284,300 square kilometers of coral reefs worldwide.
- Coral reefs live between 30°N and 30°S of the equator.
- Most coral reefs are found in the Indo-Pacific.

Worldwide, coral reefs cover an estimated 284,300 square kilometers. This area represents less than 0.1 percent of the world's oceans and less than 1.2 percent of the continental shelf area.

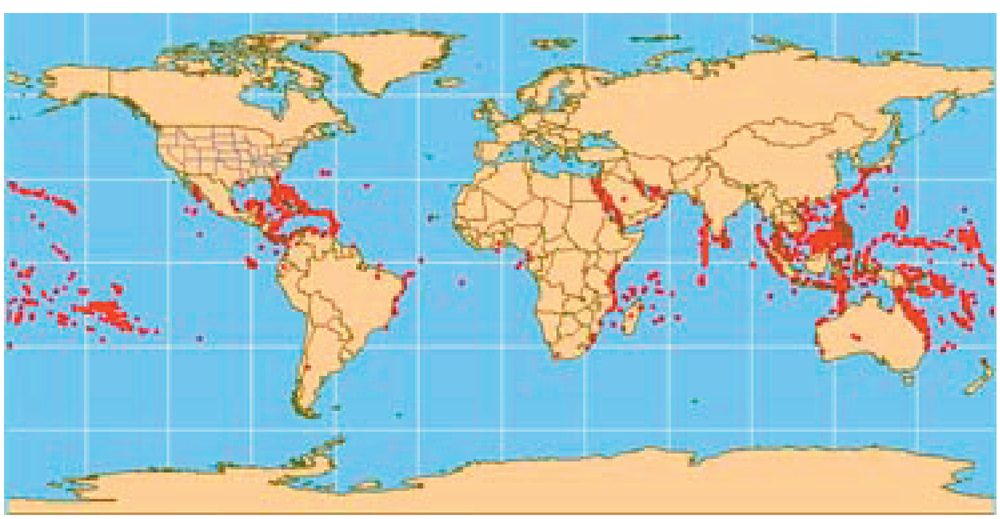
Coral reefs are found all around the world within the tropics (between 30 degrees north and 30 degrees south of the equator). Some are also found farther from the equator in places where warm currents flow out of the tropics, such as Florida and southern Japan.

Coral reefs can be found in 3 broad regions:

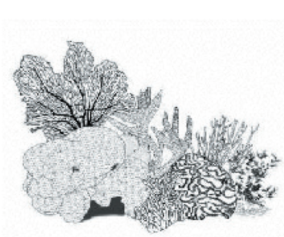
- Caribbean and Atlantic
- Indian Ocean and Red Sea
- Pacific and Southeast Asia

Most coral reefs are found in the **Indo-Pacific**, an area that stretches from the Red Sea to the Central Pacific. This is also the area of highest species diversity among reefs overall. Less than eight percent of the world's coral reefs are found in the Caribbean and Atlantic, and species diversity is much lower in these regions.

Indonesia has more coral reefs and greater species diversity than any other country in the world.



The red dots represent areas with coral reefs. Illustration courtesy of NOAA



Types of Coral Reefs

Scientists generally divide coral reefs into five main classes: fringing, barrier, atolls, bank or platform, and patch reefs.

There are five main types of reef:

- Fringing.
- Barrier.
- Atoll.
- Bank or platform.
- Patch.

Fringing reefs lie around islands and continents, and are separated from the shore by narrow, shallow lagoons. They usually parallel the coastline and at their shallowest point can reach the water's surface.

Barrier reefs also grow parallel to the coastline, but are separated by deep, wide lagoons. At their shallowest point, they can reach the water's surface, forming a "barrier" to navigation. The Great Barrier Reef in Australia is the most famous example, and is the largest barrier reef in the world.

Atolls are rings of coral that create protected lagoons and are often located in the middle of the sea. Atolls usually form when islands surrounded by fringing reefs sink into the sea or the sea level rises around them (they are often the tops of underwater volcanoes). The fringing reefs continue to grow and eventually form circles with lagoons inside.

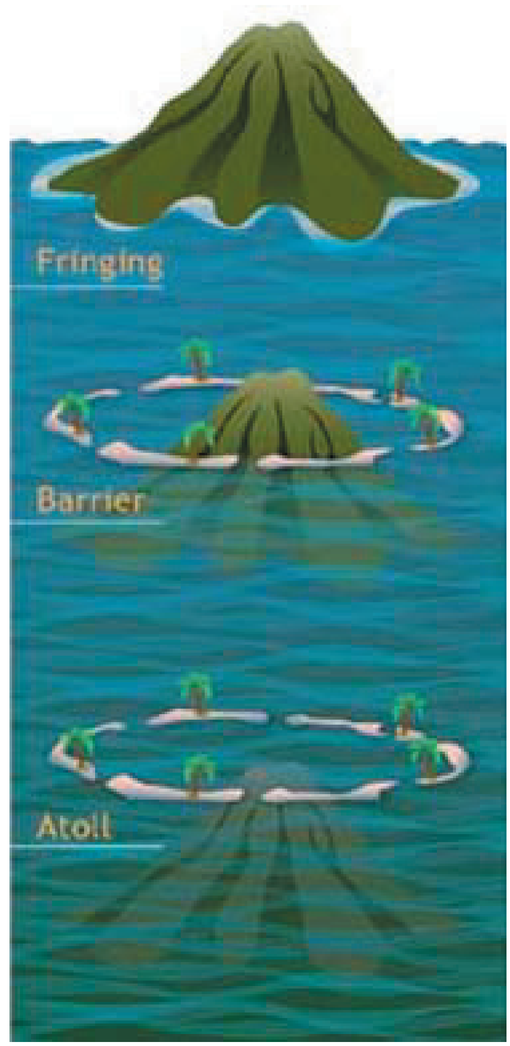


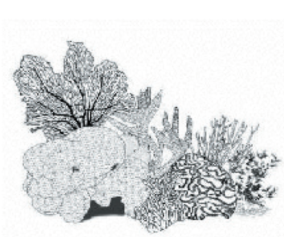
Illustration courtesy of NOAA

Over geological time, the formation and eventual erosion of oceanic islands leads to the creation of several different types of coral reefs.

The word "atoll" comes from the Maldivian word *atolu*. Atolls are mainly found in the Pacific, and along a wide stretch in the Indian Ocean.

Bank or platform reefs are open ocean reefs that are simple structures with many different origins, yet no clear attachment to the coastline. Most of these reefs have an area that is exposed to wind and a sheltered side where lagoons and small reef patches can be found. Larger and slightly submerged reefs of this type are also called **shoals**.

Patch reefs are small areas of reef that occur in shallow waters and lagoons.



Reef patterns and zones:

- Intertidal zone.
- Lagoons.
- Reef flat.
- Back reef.

Reef Patterns, Zones and Related Ecosystems

Coral reefs are very unique, differing from one to the next. Yet, there are similar patterns or **zones** (see illustration page 14) that can be identified on most reefs, based on depth, environmental conditions, reef structure, and species composition. The following zones and related ecosystems are found in many coral reefs around the world:

The **intertidal zone** is where the land meets the ocean, and includes beaches, mangroves, lagoons and areas where fresh water meets salt water. **Beaches** are important for coral reefs, as they filter out runoff and sediments from the land. Much of the sand on beaches is produced from the natural breakdown of coral fragments. **Mangroves** are highly adapted plants that thrive in intertidal waters. They are also extremely important for coral reefs, filtering mud and sediments from the land, and acting as nurseries for juvenile reef species. A recent study documented that up to 26 times more fish can be found on reefs near intact mangroves than reefs far from mangroves.

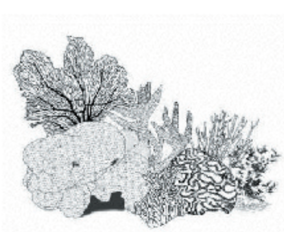

NOAA photo courtesy of Richard Mieremet

Lagoons are areas of deeper water (3-10 meters deep) that separate reefs from the coast. They are generally filled with sand, seagrasses and patch reefs, and are home to a diverse group of plants and animals. **Seagrasses** provide habitat and nursery grounds for many marine animals, and help stabilize the sand and **substrate**.


NOAA photo courtesy of Heather Dine

Mangroves are being destroyed at an alarming rate. At one time, mangroves lined 75% of tropical coastlines. Today less than half remain.

The **reef flat** is the shallow platform that extends outwards from the shore (1 to 2 meters deep and up to hundreds of meters wide). Exposure to harsh physical conditions limits coral growth, giving way to sand, rubble and encrusting algae. Many small invertebrates are found in the reef flat, including mollusks, worms and crustaceans.



The **back reef** is located where the lagoon rises up towards the shallow waters of the reef flat. The back reef gets a lot of sun exposure with generally calm conditions, and is characterized by a mixture of intricate coral gardens and sandy patches.

Reef Patterns and Zones (continued)

Reef patterns and zones:

- Reef crest/algal ridge.
- Forereef/reef front.
- Spur and groove.
- Buttress zone.

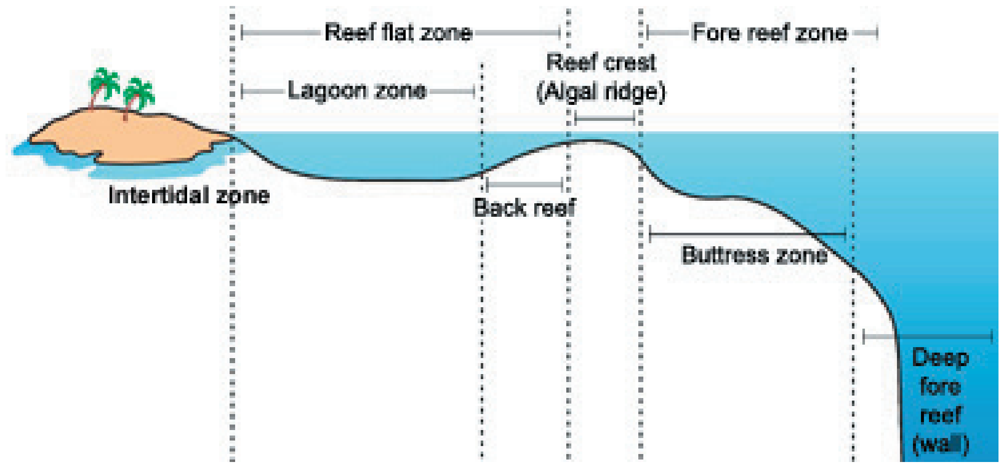


Illustration courtesy of NOAA

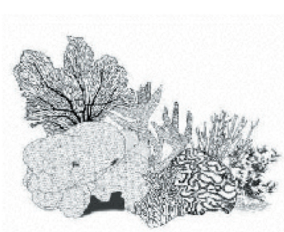
The **reef crest or algal ridge** is the highest point of the reef facing the ocean, and is characterized by a line of waves that break along the edge. Often exposed at high tide, the reef crest ranges from 1-50 meters wide. Constant wave action and exposure limits coral growth, but some branching corals have adapted to this environment. Coralline algae dominates (hence the name "algal ridge"), and small crabs, shrimps and cowries can be found seeking shelter in the nooks and crevices.

The **forereef** or **reef front** is on the seaward side of the reef crest, where the reef slope falls steeply towards the seabed. Conditions change greatly with depth.

The ridges of the buttress zone help coral reefs by dissipating the impact of strong waves, and draining debris and sediment off the reef.

In the shallowest areas there is intense wave action, with limited coral growth (mainly branching corals).

Between 10-20 meters is the greatest diversity and abundance of life on the reef. Massive corals prevail, and extensive **spur and groove** formations — sections of a reef found seaward from the reef flat and made of high ridges of corals (spurs) that are separated by sandy bottom channels (grooves) — often develop in the **buttress zone** (the zone of deep channels separated by high ridges or buttresses). Many animals inhabit the holes and crevices, and large fish, including sharks, jacks, barracudas and tunas patrol the buttress zone in search of food.

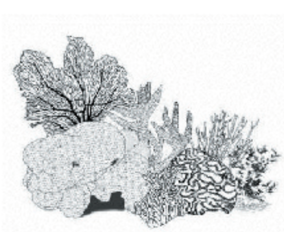


In the deeper, darker waters of the forereef (beyond 20 meters), corals become patchy and are replaced with sponges, sea whips, sea fans and ahermatypic (non-reef building) corals that do not depend on sunlight.

Hard corals:
- Hermatypes (reef-building corals).
- Limestone skeleton.
- 6 tentacles.
- Depend on zooxanthellae.
- Tropical waters

Soft Corals:
- Ahermatypes (non-reef-building corals).
- Soft and bendable.
- 8 tentacles.
- Not all depend on zooxanthellae.
- Live in both tropical and cooler waters.

Hard corals are responsible for building the single largest biological structure in the world – the 2300 kilometers long Great Barrier Reef in Australia.



Hard Versus Soft Corals

Corals are generally classified as either **hard coral** or **soft coral**. Hard corals are the primary reef-building animals, and are responsible for the limestone foundation of tropical coral reefs. Although **soft corals** do not have the reef-building capacity of hard corals, they and their cousins **gorgonians** (sea fans and sea whips), form an important part of the coral reef ecosystem, occurring in most reef habitats and displaying a dazzling array of colors and shapes.

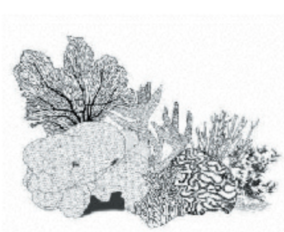
Hard corals	Soft corals
Architects of coral reefs, known as the **reef-building corals** or **hermatypes**.	Known as **ahermatypes** or **non-reef building corals**.
Hard skeletons made of limestone (calcium carbonate).	Soft and bendable skeletons, often resembling plants or trees.
Six tentacles on their polyps.	Eight tentacles on their polyps.
Depend on microscopic plants called **zooxanthellae**, which live within the tissue of the polyps.	Some, but not all soft corals, depend on **zooxanthellae**.
Only found in tropical waters.	Can grow in cool, dark regions like caves, where reef-building corals cannot survive.
Examples include brain coral and elkhorn coral.	Examples include leather coral and tree coral.

How do hard corals build a reef?
Each hard coral polyp grows within its own hard cup or "**calyx**" where it lays down a skeleton of limestone. When the polyp dies, its limestone skeleton is left behind and is used as the foundation for a new polyp. Over time, layer upon layer of limestone builds up to create the framework of the reef. At the surface of the framework is a thin layer of living coral animals.

Hard corals can be divided into a number of different shapes including:

- Branching.
- Elkhorn.
- Digitate.
- Encrusting.
- Table.
- Foliose.
- Massive.
- Submassive.
- Mushroom.
- Flower/cup.

The growth rate of corals varies according to their shape. A massive coral may grow just 4 millimeters per year, whereas a branching coral can grow up to 10 centimeters per year.



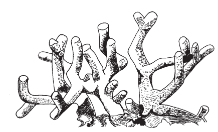
Growth Forms of Coral

Scientists currently estimate that there are 794 species of reef-building corals throughout the world. Identifying coral species can be surprisingly difficult even for experts, and in some cases impossible without taking a sample to a laboratory for testing. A simple way to categorize corals is based on their different shapes. Corals can be classified into ten general growth forms:

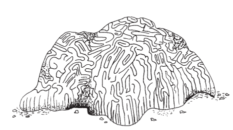
1) **Branching** - numerous branches with secondary branches.
2) **Elkhorn** - large, sturdy, flattened branches.
3) **Digitate** - like fingers or clumps of cigars with no secondary branches.
4) **Encrusting** - grows as a thin layer against the hard rocky surface.
5) **Table** - broad horizontal surfaces with fused branches.
6) **Foliose** - plate-like portions rising above the substrate, similar to the open petals of a rose.
7) **Massive** - ball-shaped or boulder-like and can be as small as an egg or as large as a house.
8) **Submassive** - knobs, columns or wedges protruding from an encrusting base.
9) **Mushroom** - resemble the tops of mushrooms, mostly solitary, living unattached to any underlying substrate.
10) **Flower/Cup** - look like flowers, or like egg cups that have been squashed, elongated or twisted.

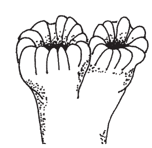

Branching


Elkhorn


Digitate


Foliose


Massive


Cup or Flower

While growth patterns are primarily species-specific, the exact same kind of coral can look very different from one place to the next, changing its shape, color and size to suit its environment. For example, where there are strong waves, corals tend to grow into robust mounds or flattened shapes. In more sheltered areas they grow into more intricate shapes such as delicate branching patterns.

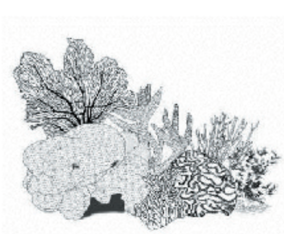
Reef builders include:

- Hard corals.
- Coralline algae.
- Fire coral.
- Sand & sediments.
- Encrusting organisms.

Reef eroders include:

- Sponges.
- Worms.
- Sea urchins.
- Parrotfish.
- Crown-of-thorns starfish.

Coral reefs are constantly in a state of change, being broken down by storms and natural eroders, while they are at work rebuilding themselves.



How Do Reefs Grow?

Coral reefs are in a constant state of change. While reefs naturally grow upward towards the sun, there are also forces at work that constantly erode and break reefs down. Reef growth can be illustrated by comparing the rate of construction with the rate of erosion:

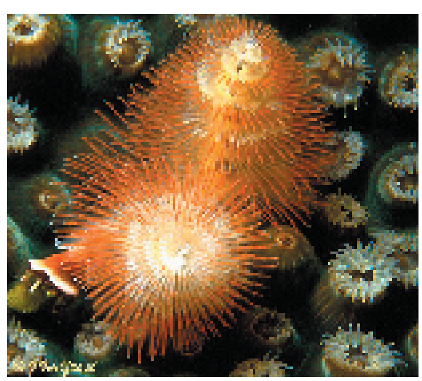
Reef Growth =
Reef Construction - Reef Erosion

Reef Construction

Hard corals build the reef framework by laying down layer upon layer of calcium carbonate (limestone). Reef limestone also comes from sediments and other natural materials that fall into open spaces and are glued together by **cementing organisms** such as **coralline algae**, sponges or encrusting fire coral. Cementing organisms make the reef structure stronger and more wave resistant. Over hundreds, if not thousands of years, this accumulation can result in massive limestone structures, some large enough to be seen from space.

Reef Erosion

The reef framework is also constantly being broken down and eroded from waves and storms, and from bioeroders. **Bioeroders** are species that eat away at corals or burrow into the reef structure. Bioeroders include, for example, sponges, polychaete worms, sea urchins, parrotfish, and crown-of-thorns starfish.



Christmas Tree Worm M.L. Frost photo

How Do Corals Eat?

Corals cannot make it on their own - they need their symbiotic friends.

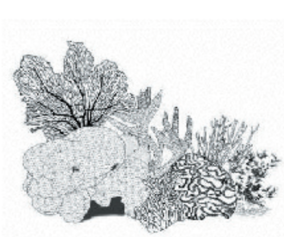
Zooxanthellae:

- Share food with corals.
- Process polyps' wastes.
- Give coral its color.

Corals:

- Provide a safe and sheltered home for zooxanthellae.
- Appear white or "bleached" without zooxanthellae.

A single zooxanthella is about 10 microns in diameter or equivalent to the thickness of a human hair.



Zooxanthellae

Within the tissues of hard coral polyps live microscopic, single-celled algae called **zooxanthellae** (pronounced zo-zan-THEL-ee). Several million of these algae live in just one square inch of coral, and give coral its brownish-green hue.

Zooxanthellae and coral have a **symbiotic** relationship, in which both the coral and the algae benefit. This relationship is complex and not yet fully understood.

Scientists believe that the algae provide coral with:

- **Energy and nutrition** - Zooxanthellae use the energy from sunlight to create sugars through photosynthesis. The algae also process the polyps' wastes, helping to retain important nutrients. Up to ninety-eight percent of a hard coral's nutritional needs can be met by the surplus food produced in this way. This allows hard corals to survive in nutrient-poor waters.

- **Calcium carbonate** - Zooxanthellae help produce calcium carbonate for the polyps' skeleton.

Meanwhile, the coral polyps provide zooxanthellae with:

- **Shelter** - Coral polyps provide the tiny algae with a safe home.

- **Nutrient recycling** - The algae uses the coral's waste matter (such as nitrates and phosphates) to help with photosynthesis.

Can corals survive without zooxanthellae?

Hard corals are extremely reliant on zooxanthellae, and often cannot survive without it, unless they are able to acquire enough nutrition by capturing plankton from the water column. Stress can cause coral polyps to expel their zooxanthellae. They then appear white or **bleached**. While most hard corals seem to be able to live without symbiotic algae for short periods of time, they often die over the long-term during intense or extensive bleaching events.

How Do Corals Eat? (continued)

Filter Feeders

Corals are also known as **filter feeders**, as they filter **zooplankton** (tiny, floating animals) from the water. At night some of the coral polyps come out of their skeletons to feed, stretching out their long, stinging tentacles to capture the zooplankton as it floats by.

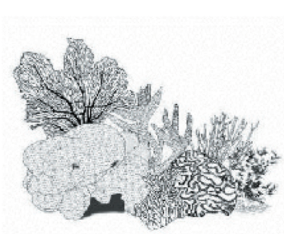
The **cnidocytes** (stinging cells) of the polyp are covered with **nematocysts**, which are small, coiled, harpoon-like structures. As zooplankton pass by, the nematocysts are ejected, delivering a painful sting that stuns the prey and draws it back in to the mouth of the polyp.

While soft corals can feed all day long, in most cases, hard corals only feed after dark. During the daytime, coral polyps retract their tentacles into their cups. All that can be seen of hard corals are their skeletons and a thin layer of tissue. This is why people sometimes mistakenly believe these delicate animals are rocks.

- Corals are filter feeders that capture zooplankton (tiny animals) from the seawater.

Coral polyps — Leslie Richter photo

The word "zooplankton" comes from "zoo," meaning animal, and the Greek word "planktos," meaning wanderer or drifter.



How Do Corals Reproduce?

Coral reproduction is highly varied:

Asexual reproduction:

- Budding.
- Fragmentation.

Sexual reproduction.

- Hermaphrodites.
- Planula Larva.
- Brooding.
- Spawning.

Corals have many strategies for reproducing, which are highly variable and complex. Corals reproduce both asexually and sexually.

Asexual Reproduction

Some corals reproduce asexually in a process called **budding**, in which the parent polyp divides into an exact genetic replica of itself. As new polyps are added, a coral colony develops.

Another type of asexual reproduction is called **fragmentation**, in which pieces or fragments of the coral colony are broken off and distributed by currents and waves. If the fragment settles on solid bottom, it may fuse right there and continue to grow asexually through budding.

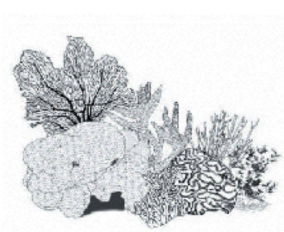
Sexual Reproduction

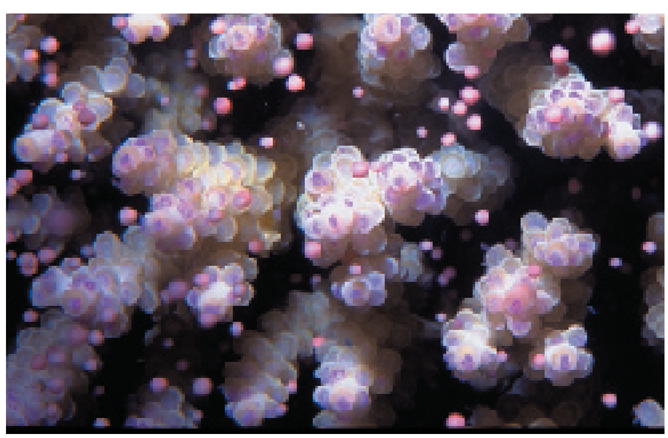
About three-quarters of coral species are **hermaphrodites**, meaning that they are both male and female, and one colony produces both eggs and sperm. The remaining quarter of coral species have separate male and female colonies that produce eggs and sperm separately.

Sexual reproduction can happen in two ways:

- The sperm swims into the mouth of a polyp containing an egg and fertilizes it internally. The young polyp **(planula larva)** then matures within the polyp in a process known as **brooding**.
- Most coral species (seventy-five percent) reproduce by **coral spawning**, in which the polyps eject both eggs and sperm into the sea for external fertilization.

Coral spawning events on the Great Barrier Reef can be so highly synchronized that the massive slick of eggs and sperm can be clearly seen the next day from the air.





Coral spawning Chuck Savall photo

Reproduction:

- Spawning – release of sperm and egg in the sea for fertilization.
- Gametes – eggs and sperm.
- Planula larvae – baby corals.

How Do Corals Reproduce? (continued)

Mass Coral Spawning

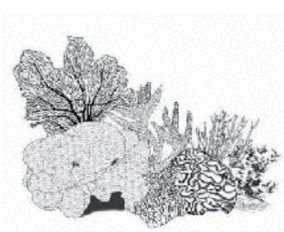
Extraordinarily, in some areas of the world, mass coral spawning events occur on the same night once a year, as millions of **gametes** (eggs and sperm) are released into the water. With such a high concentration of gametes in the water, the threat of predators is reduced for each individual. Scientists believe this synchronicity is influenced by the moon, water temperature, and biological factors involving chemicals in the water column.

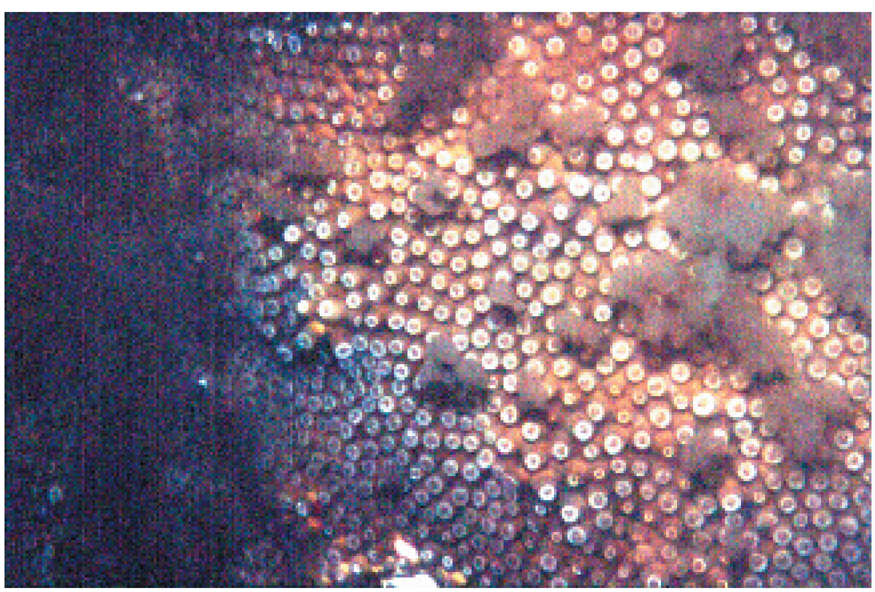
Life of the Planula Larva

Once the egg is fertilized, a new individual is created called a **planula larva**. It is naturally attracted to the light, and swims to the surface of the water where it remains for several days up to several weeks. The planula larva eventually returns to the bottom of the ocean floor, and if conditions are favorable, it attaches to a hard surface or **substrate** and starts a new coral colony.

Planula larvae can travel long distances, driven by winds and currents. This means that a coral in one part of the world can produce a new coral in another part of the world. This greatly affects species distribution, and has important implications for marine protected area (MPA) managers when setting up networks of marine reserves.

Planula larvae travel long distances, and can repopulate coral reefs hundreds to thousands of miles away.





Coral spawning David Colvard photo

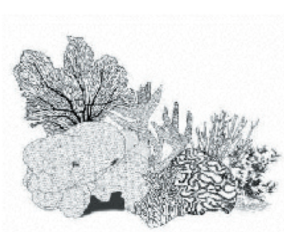
Coral Reef Ecology: Key Concepts

Coral reefs are one of the most diverse and productive ecosystems on the planet.

Key concepts:

- Ecology
- Ecosystem
- Habitat
- Community
- Population
- Organism
- Biodiversity

At least 11% of the world's reefs qualify as biodiversity hot spots: areas of high species uniqueness and diversity that have already been significantly impacted by humans.



Ecology - The study of the interactions among and between organisms and their environment, and the study of the abundance and distribution of those organisms. Ecologists are fascinated by coral reefs, as they are one of the most diverse and productive ecosystems on the planet.

Ecosystem - The combination of living or "biotic" organisms (fish, algae, zooplankton) and non-living or "abiotic" conditions (rain, salinity, sunlight) that make up a particular environment, and make it unique. Coral reefs are one type of ecosystem. Other related coastal ecosystems are seagrasses and mangrove forests.

Habitat - The specific location where a plant or animal lives. For example, the habitat of a particular species of flounder might be sand, coral rubble and seagrass areas near patch reefs.

Community - All the plant and animal species that live together in a particular habitat. For example, all of the cardinal fish, lobster and shrimp that occupy a cave are part of the same community.

Population - All the members of one species in a habitat. Therefore, you might refer to a population of shrimp, or a population of frogfish.

Organism - Any living thing that is composed of one or more cells.

Biodiversity - The total diversity of living things and of the ecosystems of which they are a part. This includes genetic variability among individuals within each species (genetic diversity), the diversity of different species (species diversity), and the variety of ecosystems (ecosystem diversity).

Coral Reef Ecology: Diversity and Symbiosis

Coral reef diversity and symbiosis:

Diversity:

- 93,000 coral reef species identified.

Symbiosis:

- Mutualism.
- Commensalism.
- Parasitism.

Coral reefs have very **high species diversity**. In fact, coral reefs have more species per unit-area than the densest tropical rainforest!

- Scientists have identified 93,000 coral reef species.
- Some scientists predict there could be over 3 million reef species.
- There are approximately 4,000 species of coral reef fish (twenty-five percent of all identified marine fish species).
- Coral reefs contain 32 of the 34 recognized animal **phyla** (see explanation of taxonomy on page 6), compared to 9 phyla in tropical rainforests.

With such a multitude of species competing for space on the reef, many have evolved to become very specialized, living in unique habitats with specific diets and defense mechanisms. For example, the octopus will change shape and color to avoid predation. Parrotfish have a specialized beak-like mouth that enable them to scrape algae off of corals. There are countless such examples of specialization on coral reefs.

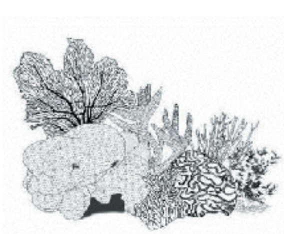
The existance of so many species has also led to a great diversity of interactions, including many complex two-way interactions, known as **symbiosis**. Symbiosis occurs when two species live together and either one or both depend on the other for survival. There are three types of symbiotic relationships:

Some crabs will pick up sponges and seaweed and place them on their backs. The crabs are then camouflaged from predators and the sponges and seaweed can enjoy better food selection.

- **Mutualism** - Both species benefit from the relationship. For example, cleaner fish or “cleaners” have a mutually symbiotic relationship with larger fish such as groupers. The cleaners feed on the parasites and damaged tissues of the skin and mouth of the larger, host fish. The cleaner benefits from the food obtained, and the host rids itself of annoying parasites.

- **Commensalism** - Only one species benefits from the relationship. For example, small fish known as remoras, cling to larger fish such as sharks or rays. Although the shark doesn’t have any known benefit, the remora saves energy from swimming, and is nourished by food scraps from the shark.

- **Parasitism** - One species benefits from the relationship while harming the other. For example, parasitic isopods that look like roaches attach themselves to the heads and faces of certain species of fish and can destroy the flesh.



Coral Reef Ecology: Energy Flow and the Food Web

Key components of energy flow and the food web in coral reefs:

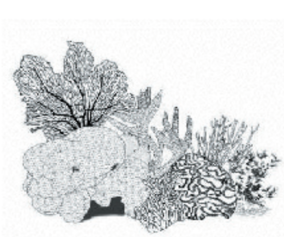
- Organic nutrients.
- Energy flow.
- Photosynthesis.
- Food web.
- Zooxanthellae.

Tropical marine waters are very low in nutrients, so it is difficult for species to survive. Yet, coral reefs are full of life, existing as biologically diverse ecosystems in areas that are low in **organic nutrients** (food derived from living matter). This can be explained by looking at **energy flow** on the coral reef food web and the importance of a tiny algae.

All ecosystems function with energy flowing in one direction from the sun, and through nutrients, which are constantly being transferred through different levels of the ecosystem. Plants are able to use the sun's energy, and convert it to organic matter in a process known as **photosynthesis**. This energy is then passed through the ecosystem in a series of steps of eating and being eaten, otherwise known as the **food web**.

On a coral reef, photosynthesis is carried out primarily by the small algae called **zooxanthellae** (see page 18). These tiny algae live within the tissues of corals in a **symbiotic relationship** and are arguably the most important organisms on coral reefs. Like all green plants, zooxanthellae obtain energy from the sun. The coral benefits from this energy, which can provide up to ninety-eight percent of its nutritional needs. Hard reef-building corals are able to thrive in relatively nutrient free waters, since they can get so much energy

Coral reefs live in shallow, sunny waters because their symbiotic algae needs sunlight for photosynthesis.

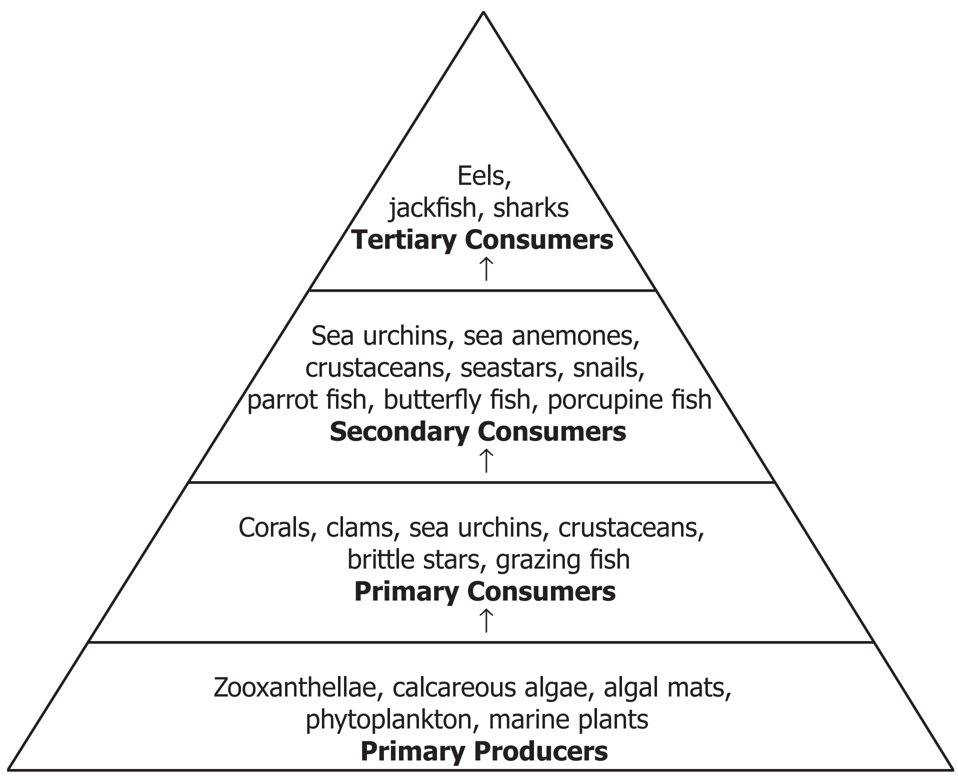


Energy Flow and the Food Web (continued)

The sun is the source of all energy on the coral reef.

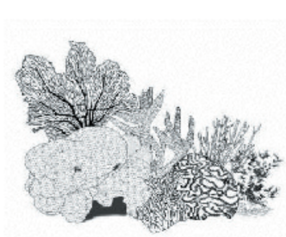
- Producers - produce energy from the sun.
- Consumers - eat plants and animals.
- Detritivores - scavengers that eat waste matter from plants and animals.

Each step in the food web involves a transfer of energy through different feeding or **trophic levels**. Coral reef algae produce energy from the sun, and are therefore called **producers**. Zooxanthellae is a **primary producer**. All other species in the food web are called **consumers**, because they get their energy by eating other organisms. So, for example, a coral is a **primary consumer** as it obtains its energy from zooxanthellae and other tiny animals. A butterflyfish then eats the coral, so is a **secondary consumer.** A barracuda then comes along and eats the butterflyfish, so is a **tertiary consumer**, and so on. Energy is lost in each step of the trophic levels.



Coral reefs are more productive than tropical rainforests.

Also important are the **detritivores** or scavengers, which are animals that feed on dead plants and animals and their wastes. Detritivores help speed up the process of breaking down dead animal and plant material, thus recycling nutrients back into the food web. A sea cucumber is one example of a detritivore.



What does it mean to say a coral reef is "productive"?
This means that the primary producer, being **zooxanthellae**, generates a lot of energy for the ecosystem. Coral reefs have higher productivity than tropical rainforests — one reason that reefs are so fascinating to ecologists.

Competition and Disturbance

Competition and disturbance:

- Corals and reef organisms are constantly competing for space.
- Local disturbance helps maintain biodiversity.

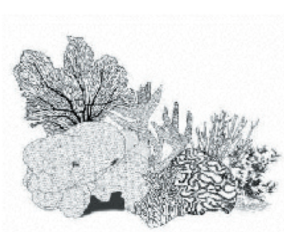
All organisms in nature need both space and habitat in order to survive, and the many species that live among the coral reef are no exception to this general ecological rule. Thus **competition** — striving to survive in a limited space among other organisms — is never-ending in reef environments. As a result, corals and other reef organisms have developed a wide range of both aggressive and defensive mechanisms to help them survive in this competitive environment.

For example:

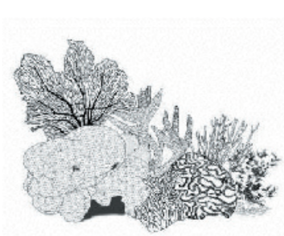
- Branching corals grow more rapidly than encrusting or massive corals, often out-competing them for space.
- Slower growing species survive due to their defensive stinging tentacles, which can prevent faster-growing corals from taking over.
- Soft corals and sponges have toxins that they use for both defense and aggression.
- Some bioeroders, such as segmented worms and some species of urchins, live within holes and tunnels that they have bored into the reef structure.
- Many other creatures make their homes in the natural open spaces of the reef structure.

The saddled butterfly fish, having evolved resistance to their toxins, will rip tentacles from sea anemones if given the chance.

Constant change is another fundamental aspect of any living ecosystem. **Disturbance** to the biological or physical structure of a coral reef — resulting from natural forces such as storms and waves — commonly opens up new places for animals and plants to grow and allows new species to colonize or establish themselves in a particular environment. With such intense competition for space, this type of local disturbance can actually be beneficial. It can prevent individual species from taking over, helping to maintain stability and biological diversity in a coral reef environment.



Part II: Value of Coral Reefs



Why Are Coral Reefs Important?

Coral reefs are valuable in many different ways:

- High biodiversity.
- Coastal protection.
- Seafood.
- Jobs and income.

Biodiversity

Coral reefs have a very high level of **biological diversity**, with 93,000 species already identified by scientists. In fact, coral reefs contain 32 of the 34 recognized animal phyla (see page 6), compared to only 9 phyla found in tropical rainforests. Diversity is critical in maintaining the delicate balance of ecosystems. If one major species or population is removed, the ecosystem can be permanently disrupted.

Coastal Protection

Coral reefs protect coastlines and help prevent erosion. They act as natural **breakwaters**, absorbing the force of storm waves and reducing damage to the shore. With more than half of the world's population living within 60km of the sea, coastal erosion is an issue affecting billions of people.

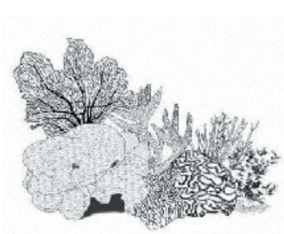
Seafood

Coral reefs have supplied communities with food for millennia. Not only is seafood a major source of animal protein, coral reef fisheries are also important sources of income. If managed properly, reefs can yield, on average, 15 tons of fish and other seafood per kilometer per year.

Economic Value

Coral reefs provide millions of people with jobs and income through fishing and tourism. Studies have shown that on average, countries with coral reef industries derive more than half of their gross national product from them. By one estimate, coral reefs provide economic goods and ecosystem services worth about $375 billion each year.

Approximately 500 million people depend on coral reefs for their livelihoods.



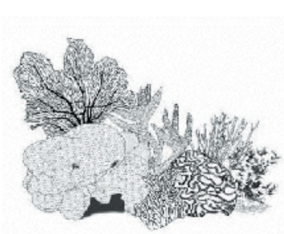
Tegan Hoffmann photo

Coral reef fishes are a primary source of protein for coastal communities throughout tropical regions of the world.

Coral reefs are valuable in many different ways:

- Aesthetic and cultural.
- Medicines.
- Carbon sink.

In dollars per unit area, coral reefs are the most valuable ecosystem on the planet.



Why Are Coral Reefs Important? (continued)

Aesthetic and Cultural Value

Coral reefs are one of the most colorful and unique environments in the natural world. Humans are drawn to the beauty of coral reefs, which we explore by snorkeling, diving, or through photographs. Coral reefs are also culturally significant to many coastal communities, with legends and religious practices tied to reef life.

New Medicines

More and more species that live on coral reefs have been found to contain compounds that can be used in medicine (biomedical compounds), including some applied to the treatment of human immunodeficiency virus (HIV), cancer, ulcers and cardiovascular diseases. In addition, the unique skeletal structure of coral has been used to make our most advanced forms of bone grafting materials.

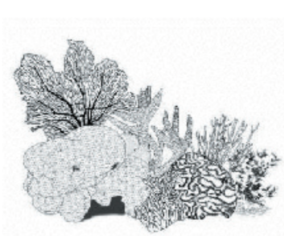
Carbon Sinks

Coral reefs absorb carbon dioxide from the atmosphere. Carbon dioxide is one of the **greenhouse gases** involved in **global warming**, which has been implicated in rising global and sea surface temperatures, rising sea levels and the associated loss of land. For this reason, coral reefs are known as **"carbon sinks"** because they help remove carbon dioxide from the

Mary Lou Frost photo

The beauty of coral reefs inspires many people to experierince these natural wonders.

Part III: Threats to Coral Reefs



Threats to Coral Reefs

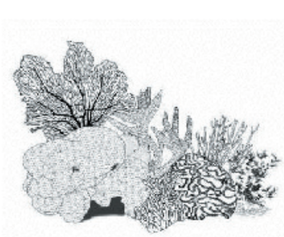
Coral reefs are in peril:

- 11% of the world's coral reefs are already dead.
- 32% of coral reefs could die in the next 30 years.

Scientists identify threats as:

- Natural vs. Anthropogenic (caused by humans).
- Acute vs. chronic.
- Small-scale vs. large-scale.

If human threats are not reduced, coral reefs could be lost forever.



Coral reefs are among the world's most fragile and endangered ecosystems. Eleven percent of the world's coral reefs have already been lost and another sixteen percent were severely damaged during the 1997-1998 global bleaching event. Scientists predict that another thirty-two percent may be lost over the next thirty years if human threats are not reduced.

The loss of healthy coral reefs would mean the extinction of thousands of marine species, as well as the elimination of a primary source of food, income and employment for millions of people around the world.

When scientists identify threats to coral reefs, they generally categorize them as: **natural vs. anthropogenic**; **acute vs. chronic**; and **small-scale vs. large-scale**.

Natural vs. Anthropogenic
Coral reefs have been altered by **natural** events for millions of years, such as storms and hurricanes, volcanic activity, changes in sea level and sea surface temperature, natural predators and disease outbreaks. Natural events are often very slow. For example, changes in sea level can take thousands of years, allowing coral and other organisms to adapt to different environmental conditions.

Natural events, such as hurricanes, can damage and weaken coral reefs. But healthy reefs generally have a strong ability to recover from such natural disturbance. Hurricane events can actually benefit the reef, helping to maintain biodiversity by opening up new space and habitat for coral species to grow.

In the past century, **anthropogenic** or human-induced threats have increased in both frequency and intensity, and what once took hundreds of years to occur now takes hours, days, weeks, and months. This causes severe and sometimes irreversible damage to coral reefs, as the coral has not had time to adapt or recover from these rapid environmental changes. Examples of anthropogenic threats include pollution, sedimentation, destructive fishing and global warming. Scientists believe that human activities actually intensify some natural disturbances (see page 33).

Threats to coral reefs:

- Acute vs. chronic.
- Small-scale vs. large-scale.

Threats to Coral Reefs (continued)

Acute vs. Chronic

Acute disturbances are short-term and often have a significant immediate impact on the environment. Natural events like hurricanes are considered acute, as are human-induced threats such as the one-time dropping of an anchor on a coral head. Given time, corals and reef communities can recover from acute disturbances.

However, chronic disturbances can be more damaging to reefs over time. **Chronic** threats are long-term, low-level, and sometimes undetectable. They include, for example, the day-to-day exposure of reefs to human waste and sewage, or anchor damage from multiple boats that occurs on a regular basis. Scientists have found that it is much more difficult for coral reefs to recover from such chronic threats.

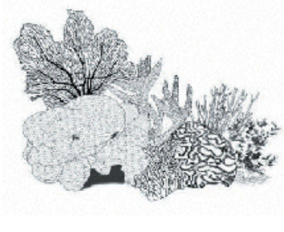
When faced with both acute and chronic threats, coral reefs are at great risk.

Small-scale vs. Large-scale

Scientists also distinguish between small and large-scale disturbances. Small-scale disturbances occur in a localized area for a short period of time. Examples include a small, local bleaching event, the spread of a coral disease, or a Crown of Thorns starfish (COTS) outbreak.

Large-scale disturbances affect a larger area, and often occur more frequently and to a point beyond which the reef can recover. Examples include a mass global bleaching event, a widespread disease outbreak, or a major oil spill.

Coral reefs are at risk from long-term, chronic threats such as pollution, overfishing and global warming.



Natural Threats

Natural threats:

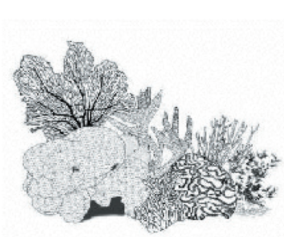
- Low tides and sunlight.
- Hurricanes/typhoons and big storms.
- Volcanic eruptions.
- Sea level change.
- Sea surface temperature change (SST).
- Predators.
- Disease.

Natural disturbances can cause severe changes to coral communities, but coral reefs are resilient, and have managed to survive and adapt to these pressures for millions of years.

- Environmental threats such as **low tides** and **sunlight** can expose shallow corals to air and ultraviolet radiation, which can overheat and dry the coral's tissues.
- Powerful **volcanic eruptions, hurricanes, typhoons or storms** can flatten a reef in minutes. This can lead to compounded problems, such as **phase-shifts**, in which fast growing algae replaces the slower-growing corals.
- **Increased sea surface temperatures** and **changing sea levels** can also have a profound effect on corals, leading to exposure and coral bleaching.
- **Predators** consume the tissue of coral polyps, such as fish, marine worms, snails, barnacles and starfish.
- **Disease** also occurs naturally in coral reefs, causing mass mortality in corals, sea fans and other reef creatures.

Coral reefs generally recover from natural threats. However, if subjected to numerous and sustained threats, such as those influenced by humans, the survival rate is sigificantly decreased.

Corals are more susceptible to disease when they are already stressed by other factors, such as sedimentation and pollution.



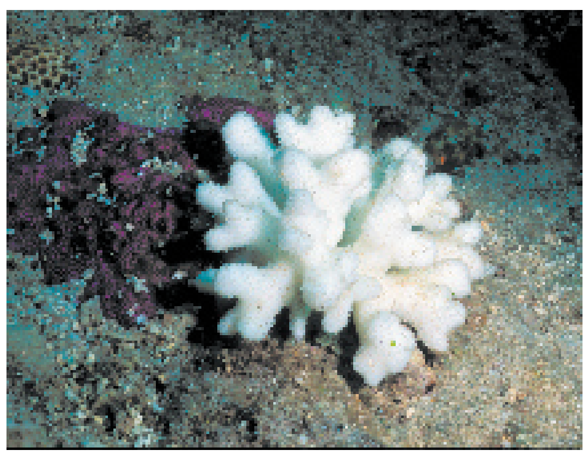
Natural Threats Influenced by Humans

Scientists believe that human activities are increasing the rate and severity of natural threats, such as:

- Mass bleaching events.
- Disease outbreaks.
- Predator outbreaks.

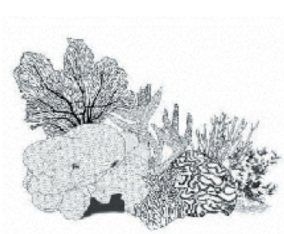
In the past few decades, natural threats to coral reefs have become more frequent and intense. **Coral bleaching** events correlated with **climate change** have become widespread disasters, and disease and predators of the coral reef ecosystem have exploded in **outbreaks**. Scientists have found direct connections between human activities and the increase in natural threats to coral reefs, including:

- **Mass Bleaching Events and Climate Change:** Increases in carbon dioxide emissions is changing the climate, increasing sea surface temperature and ultraviolet light, leading to mass bleaching events around the world.
- **Disease Outbreaks:** Sewage effluent is correlated with the outbreak and spread of disease, such as Black Band Disease in the Caribbean.
- **Predator Outbreaks:** Over-fishing and increased nutrients in the water column from agro-industry and sewage effluents are causing predator outbreaks, such as Crown of Thorns Starfish (COTS).



Bleached coral — Wolcott Henry photo

Between 1979 and 2002 scientists documented over 65 mass bleaching events. Only 9 were documented between 1960 and 1979.



PHASE SHIFT
Often, when a coral dies, other reef life immediately tries to gain access to the valuable space. The first species to colonize the empty spaces are usually algae and soft corals, which grow much faster than hard corals. When this happens, a coral reef changes into a community comprised primarily of algae and soft coral. This is called a phase shift.

Mass Bleaching Events and Climate Change

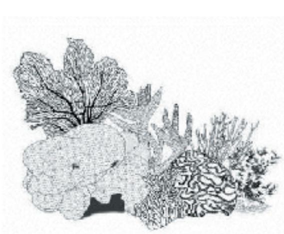
Climate change causes:

- Increased sea surface temperatures.
- Rising sea levels.
- More storms.

Impacts to coral reefs include:

- Coral bleaching.
- Slower coral growth.
- Physical damage.

In 1997, the United States emitted about one-fifth of total global greenhouse gases of the industrialized world.



Over the last twenty years, human-induced climate change has been a growing concern for scientists, policy makers, and environmentalists. Coral reefs are one of the ecosystems most vulnerable to climatic influences.

The **greenhouse effect** is a natural occurrence in which heat-trapping gases — primarily carbon dioxide, methane, and nitrous oxide — act as a blanket, preventing the heat of the sun from escaping. Without the greenhouse effect, the earth would be too cold to live on.

However, in recent years the temperature of the earth has increased significantly in what is known as **global warming**. Most scientists believe that global warming is the result of human activities that have increased greenhouse gases in the atmosphere. This is mainly due to the burning of **fossil fuels** (coal, oil and gas) to run cars, power industries, and heat and cool homes. Increased agriculture, deforestation, landfills, industrial production, and mining also contribute to the problem. The resulting side effects have been:

- Increase in sea surface temperatures (SSTs).
- Rising sea levels.
- More frequent and severe storms.

These climatic changes have had devastating consequences for coral reefs:

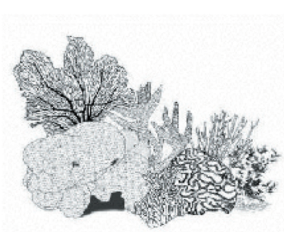
- **Coral Bleaching** – Coral polyps exposed to heat, utraviolet (UV) light and other stressors expel their symbiotic algae (zooxanthellae), and appear white or bleached. Corals can survive some degree of bleaching, but as the length and severity of the stress increase, so does coral mortality.
- **Slower Coral Growth** – Sea level is expected to increase between 15 and 95 centimeters over the next century. The growth rate of coral is likely to be slower than this. As a result, corals will be deeper, receive less sunlight and grow at a slower rate.
- **Physical Damage** – Increased coral mortality is expected as storms and cyclones become more frequent and intense. Coral reef growth may not be able to keep pace with these destructive events.

Disease Outbreaks

Examples of coral reef disease outbreaks include:

- White band disease in hard corals.
- *Fibropapilloma* in sea turtles.
- *Aspergillus* in sea fans.
- Coralline Lethal Orange Disease in coralline algae.

During the 1970s and 1980s, white-band disease spread throughout the western Atlantic, eliminating up to 95 percent of the elkhorn and staghorn corals in some locations.



The incidence of disease on coral reefs has only recently been recognized. The first observations were recorded in the Caribbean as recently as the 1970's and in the past few years the number of recorded diseases has increased dramatically.

Diseases have contributed to the die-off of seagrasses, corals, sea fans, sea urchins, sponges, fish, and other organisms. Diseases can modify the structure and composition of reefs by removing locally abundant species. Examples of disease outbreaks include:

- **White-band Disease**, affecting staghorn and elkhorn corals, devastated Caribbean coral populations by as much as ninety-five percent in the 1980's.
- ***Fibropapilloma**, a* tumor-forming, debilitating and often fatal disease, has affected sea turtles globally.
- ***Aspergillus,*** a fungus of terrestrial origin, has caused tissue destruction, skeletal erosion and death in Caribbean sea fans.
- **Coralline Lethal Orange Disease (CLOD)** has affected coralline algae in the Pacific.

People have observed hundreds of coral reef diseases all over the world, but scientists have only documented approximately 10 official coral reef diseases, including black-band, CLOD, white plague and yellow blotch disease.

Diseased coral Wolcott Henry photo

What causes disease?

- Natural conditions.
- Stress.
- Contact with polyps.
- Nutrients.

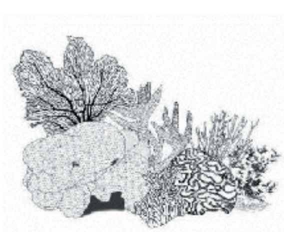
Disease Outbreaks (continued)

What causes disease outbreaks?

- Outbreaks can occur **naturally** on a local level. Oftentimes, disease outbreaks start locally but then expand to affect a wider region.
- Any **stress** to corals can make them more vulnerable to disease. Stresses include: sedimentation, pollution, physical damage, increased nutrients, extreme temperatures, extreme salinities.
- **Contact with coral polyps** (such as diver or anchor damage) removes its protective mucus and causes tissue damage that can make the coral vulnerable to attack from disease.
- There is a correlation between certain disease outbreaks and **increased nutrients** in the water column from sewage.

DIADEMA
During the early 1980's the black spiny urchin, *Diadema*, got sick and died by the thousands all around the Caribbean. Up until then divers had considered Diadema to be nothing more than a nuisance and scientists had not given it much thought at all. However *Diadema* is an herbivore. It spends its life grazing on the marine plants (algae) that live on the reef and compete with corals for space to grow. Without Diadema to keep the plants in check many reefs became quickly overgrown with algae and the corals were killed.

Coral diseases have become a chronic and often catastrophic problem for reefs in the Caribbean.

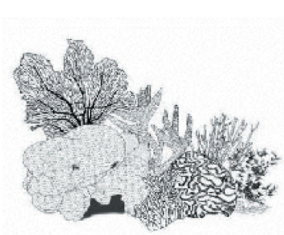


Magnificent Sea Urchin   Jeff Dawson photo

Population explosions:

- Drupella (coral-eating snail).
- Crown of Thorns Starfish - COTS.

In 1978-79 a massive COTS outbreak devastated 90% of the coral reefs of Fagatele Bay in American Samoa.



Crown of Thorns and Other Predator Outbreaks

Predator population explosions occur when a species of animal on a reef increases dramatically, threatening the health and well being of the reef. This is particularly damaging when the animal preys on coral.

- **Drupella** is a small snail that eats away at the tissue of branching corals. It is a common predator in the Indo-Pacific, and has caused significant damage to some coral reefs.

- The **Crown of Thorns Starfish (COTS)** is a predator of corals, able to eat extensive sections of reef in one night's grazing. Recent population outbreaks in the Pacific have devastated whole reefs, with up to ninety percent mortality in some areas. COTS generally prefer branching corals over large massive corals.

What causes COTS outbreaks? Scientists belive there are several possible explanations:

- It could be a natural cycle of the species, with populations reaching these numbers only once every hundred years.

- Nutrient pollution from the land could increase the plankton food for Crown of Thorns larvae.

- Overfishing of predators of juvenile COTS such as snappers.

- Overfishing of predators of adult COTS such as Tritons.

- Rising sea temperatures may favor COTS by increasing its ability to reproduce.

CROWN OF THORNS
Early attempts to contain Crown of Thorns outbreaks failed because people did not take into account the biology of the predator. Divers would remove all the COTs they could find from a reef, chop them up and throw them back into the water. Unfortunately COTS can regenerate arms and other parts quickly, so the divers were literally doubling and tripling the problem.

Anthropogenic (Human-Caused) Threats

Human activities are threatening the world's reefs at an alarming rate. In the last century human pressures have increased dramatically with rapid and unplanned coastal development, pollution, overfishing, coral mining, and other damaging activities. The scale and rate of impacts affecting tropical waters is increasing, and the intensity of disturbances are becoming more **chronic** and **long-term** so that the corals are not able to recover.

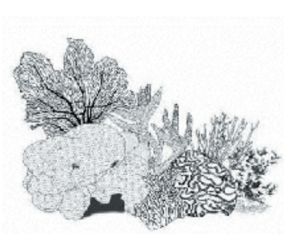
The main anthropogenic threats reviewed in this section include:

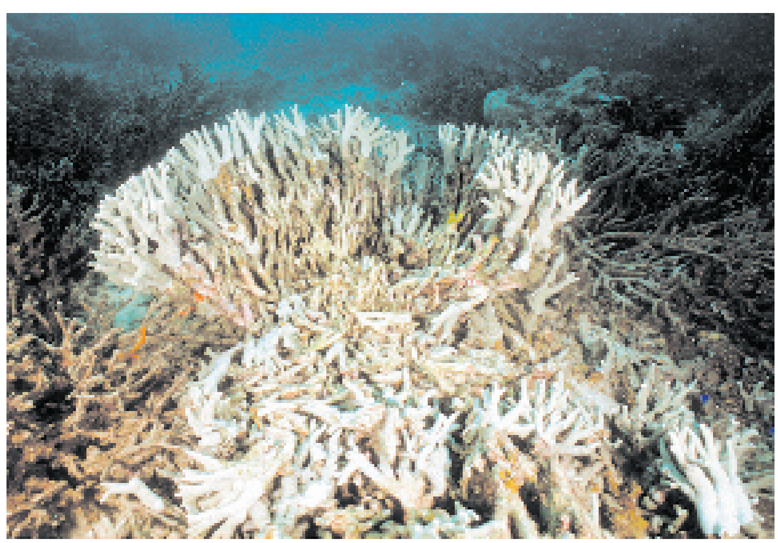
1) Destructive Fishing Practices and Overfishing
2) Marine-based Pollution
3) Marine Debris
4) Mining, Harvesting and Trade
5) Land-based Pollution
6) Coastal Development and Sedimentation
7) Tourism

The four tops threats, according to the World Resource Institute include:

- Over-fishing and destructive fishing.
- Marine-based pollution.
- Land-based pollution.
- Coastal development.

Human threats could destroy 32% of coral reefs within the next 30 years.





Wolcott Henry photo

Coral destroyed by destructive dynamite fishing.

Destructive Fishing Practices and Overfishing

Unsustainable fishing practices include:

- Dynamite or "blast" fishing.
- Cyanide fishing.
- Muro Ami.
- Bottom trawling.
- Overfishing.

In many areas, coral reefs are threatened by destructive fishing practices and overfishing. As fish catches get smaller, there is increased pressure for fishermen to use more extreme methods to catch fish and find an income. Although this may yield short-term economic benefits, it endangers the long-term sustainability of the fishing industry and other related coral-reef industries.

Destructive fishing techniques destroy coral reefs habitats, reduce fish stocks, and prevent coral growth as a result of sedimentation. Types of destructive fishing include:

- **Dynamite or "blast" fishing** - Fish are killed by an explosion and then skimmed off the surface or collected from the bottom. The explosion kills large numbers of fish and other marine organisms, and destroys the physical structure of the reef.

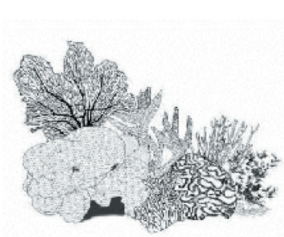
- **Cyanide fishing** - Fishers squirt cyanide, bleaches and other poisons in reef crevices to stun fish, making them easy to catch. This is a popular method for capturing live fish for the aquarium and food trades. The poisons cause bleaching and kill surrounding corals and marine life.

- **Muro Ami** - A line of divers smash the reef with rocks and poles to drive the fish into waiting nets, causing physical damage to the reef structure. Muro ami has recently been replaced by a more sustainable technique know as **paaling** in which the divers hold hoses with compressed air and drive the fish towards the nets with bubbles.

According to the 2002 Reefs at Risk Report, 56% of the coral reefs in Southeast Asia are at risk from destructive fishing practices.

- **Bottom-trawling** - A bottom trawl is dragged along the bottom of the sea floor in order to catch a target species. The trawl net is dragged over everything in its path, indiscriminately capturing virtually all marine life in the habitat being fished.

- **Overfishing** occurs when fish and marine creatures are harvested at rates faster than they can reproduce. In some areas, overfishing has already resulted in the local extinction of highly-valued species such as giant clam and grouper. Changes in fish populations can greatly affect the reef ecosystem. For example, the removal of algal grazers such as parrotfish may lead to algal blooms that smother living corals.



Marine-Based Pollution

Sources of marine pollution:

- Oil discharge from boats and planes.
- Tanker accidents.
- Oil leaks.
- Ballast and bilge discharge.
- Radioactive waste.

Marine-based pollution is harmful to coral reefs, although the degree of its impact is still unknown.

Marine pollution comes from:

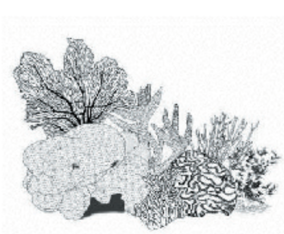
- Deliberate discharge of oil from tanks and vessels.
- Tanker accidents causing oil leaks.
- Oil leaks from tanks and pipelines.
- Dumping of fuel from airplanes.
- Ballast and bilge discharge containing oil, tar and other pollutants as well as non-native species that can become **invasive**.
- Radioactive waste from military activity.

Marine-based oil and toxic chemicals damage coral reefs by:

- Altering coral reproductive tissues, growth, behavior and development.
- Harming zooxanthellae.
- Preventing juvenile coral from settling on the reef and growing.
- Deteriorating the physical reef structure.
- Reducing the resilience of coral reefs to other stresses.

A 1986 oil spill in Panama led to a decrease in live coral coverage of 50-75% in the shallow water reefs.

Although tanker wrecks and oil spills receive a great deal of press coverage, the damage is often **acute** and **short-term**. Coral reefs are far more threatened by the **chronic**, **long-term** leakage of fuel from boats and land.



Marine Debris

Sources of marine debris:

- Land.
- Boats.
- Ship wrecks.

Garbage is harmful to coral inhabitants because it:

- Strangles and chokes marine life.
- Spreads alien species.
- Reduces the beauty of a location.

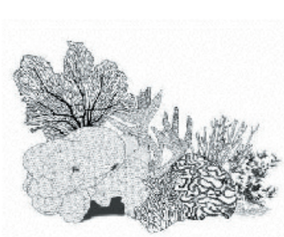
Marine debris or garbage is also harmful to coral reef inhabitants. Marine debris comes from:

- Garbage washed into the sea from land.
- Materials discarded from boats.
- Fishing nets that have been lost or discarded by commercial fishing vessels (otherwise known as **ghost nets**).
- Ship and plane wrecks from battles and bombing raids that often release toxic paints and chemicals into the marine environment.

Free-floating nets and garbage can be deadly to marine life — smothering, suffocating, entangling and destroying corals, fish, sharks, sea turtles and marine mammals. Sea turtles often mistake plastic bags for jellyfish, and as a result, eat them and die. Alien (non-native) species that are attached to marine debris are sometimes transported far from their place of origin and introduced in remote reefs, altering the natural ecosystem.

Garbage can also destroy the beauty of beaches and coral reefs, which lessens the appeal of a location for tourists. This can result in significant economic losses to coastal areas dependent on the tourism industry.

In the Northwestern Hawaiian Islands more that 300 tons of debris - primarily discarded fishing nets - has been removed by government divers.



NOAA photo

Marine debris, particularly discarded fishing nets, can cause extensive damage to coral reefs and other marine species.

Mining, Harvesting and Trade (continued)

Coral reefs are exploited for many different things.

Mining and harvesting may be for:

- Construction.
- Souvenirs/Jewelry.

Coral reef species are harvested and traded in numerous domestic and international markets for:

Construction

Corals are mined for limestone and construction materials. Sometimes coral pieces are removed for use as bricks or road-fill. Sand and limestone from coral reefs are also made into cement for new buildings.

Jamie Oliver photo

Corals are commonly harvested for construction materials on both a local and commercial scale in many places around the world.

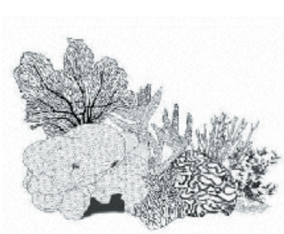
Souvenirs/Jewelry

Coral species are used in the dried ornamental trade business, where they are collected and traded for souvenirs and jewelry.

Wolcott Henry photo

The sale of corals as souvenirs and jewelry poses a serious threat to the helath of coral reefs in many regions of the world.

According to one study, Indonesia supplies 95% of the world's coral trade, while the United States imports 85% of the dead coral and 98% of the live coral.



Mining, Harvesting and Trade

Coral reefs are exploited for many different things.

Mining and harvesting may be for:

- Aquarium trade.
- Medicines.

Aquarium trade

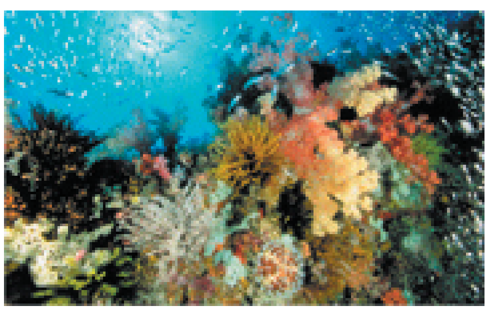
Coral, fishes and **"live rock"** (dead coral rock covered with encrusting organisms such as algae and sponges) are collected for the marine aquarium industry.

Chuck Savall photo

In addition to living coral and "live rock," milions of coral reefs fishes are harvested every year from around the world to support the aquarium industry.

Medicines

Coral reef species are collected for Eastern medicines (such as seahorses) and Western medicine (coral used for bone grafts).

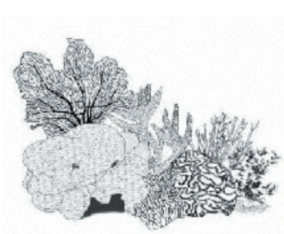


Burt Jones and Maurine Shimlock photo

Medicines can be derived from a variety of coral reef organisms, including hard corals, gorgonians and others.

Experts estimate that 95% of the fish sold in the saltwater aquarium trade are wild-caught.

While these practices provide short-term economic benefits, if not managed in a sustainable way, they result in long-term damage.



CITES
The Convention on International Trade in Endangered Species (CITES) regulates the international trade of certain animals and plants. Under the terms of the convention, species are classified based on their vulnerability to extinction. Species listed under "Appendix II," including many corals, sea turtles and shellfish, cannot be imported without special permits.

Land-Based Pollution

Land-based pollution is a serious threat to coral reefs. Sources of pollution can be:

- Non-point source pollution.
- Point-source pollution.
- Pollution causes eutrophication (excess nutrients) leading to phytoplankton blooms.

As coastal populations increase, so does the discharge of **effluents** (liquid waste products) in coral reef areas. It has been estimated that about forty percent of marine pollution is land-based, and ninety percent of this collects in shallow, coastal waters, where coral reefs thrive.

Seventy-five percent of pollutants entering the sea come from **non-point sources**, meaning that they come from a general area rather than one single source such as a discharge pipe. Examples include:

- Storm-water runoff from urban areas and industry.
- Agricultural runoff (pesticides, herbicides, fertilizers).
- Atmospheric discharge of soot (airborne materials generated from the burning of various fossil fuels) and toxic chemicals.

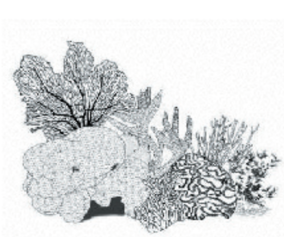
Point-source pollution comes from a specific, easily identifiable source that discharges directly into the water. It often leads to small areas of contamination that impact shallow, near-shore coral reefs. Examples include:

- Pipes that discharge industrial pollutants and toxins directly into the water.
- Sewage overflow.

More than 400 million gallons of oil enter the oceans every year, but only about 37 million gallons of it is from major oil spills – the rest is primarily from industrial waste and automobiles.

The main impact of pollution is the resulting excess in nutrients, primarily caused by human waste and agricultural runoff. **Eutrophication** (high nutrient levels) can produce increased algal cover, and can result in **phytoplankton blooms** (algal plankton) that turn the water green and block out the sunlight needed for hard corals to survive.

Pollution may also increase coral diseases and predators, and help the growth of animal competitors such as filter-feeding sponges, boring mollusks, and polychaete worms, which overtake living corals.



Coastal Development

Poorly managed coastal development can lead to:

- Acute physical damage from construction.
- Chronic, long-term damage from sedimentation and pollution.

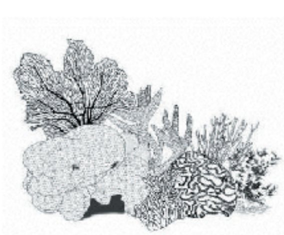
Almost half a billion people live within 100 kilometers of a coral reef. This number is expected to double by 2050, with the greatest increases in population likely to take place in the poorer developing countries in the tropics. Coastal development is necessary to support growing populations. However, unplanned development is one of the major causes of coral reef damage.

Construction to support growing human populations can cause **acute physical damage** to coral reefs. Coastal development damages coral reefs from:

- **Direct physical damage** from the construction of piers, resorts and airports, dredging of marinas or shipping lanes and land reclamation (shoreline filling) to build airports and hotels.
- **Pollution** from agricultural chemicals, sewage and other pollutants draining into the sea.
- **Sedimentation** from construction and inland erosion that reaches reefs from storms and rivers.

Singapore has lost an estimated 60% of its coral reefs through land reclamation.

Coastal development in Cancun, Mexico Wolcott Henry photo



Sedimentation

Sedimentation is caused by:

- Dredging.
- Forestry.
- Agriculture.
- Over-grazing.
- Land-clearance.
- Land reclamation.
- Mangrove deforestation.
- Bottom-trawling.

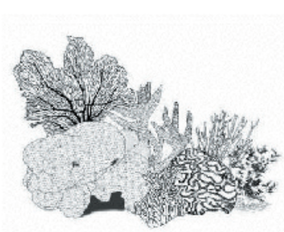
Sedimentation — suspended earth, rock and sand particles in the water — is a **leading cause of coral reef damage**. A main impact of coastal development has been increased sedimentation in near-shore waters. Corals cannot thrive in water containing high levels of sediment which:

- Makes the water cloudy or **turbid**, blocking out sunlight.
- Smothers and buries corals.
- Prevents **planula larvae** (juvenile corals) from finding a suitable **substrate** to colonize.

Sediment is washed into the sea from runoff in rivers and rainwater. It is also stirred up from the ocean floor. Sedimentation comes from:

- **Dredging** of ports and boat marinas.
- **Forestry**, particularly clear-cutting.
- **Agriculture**, especially ploughing between crops.
- **Over-grazing** of cattle and other animals.
- **Land-clearance** for housing, industrial development, agriculture, etc. Land cleared for logging or agriculture is most susceptible to erosion. Heavy rains wash the loose mud and silt directly into the ocean and onto coral reefs.
- **Land reclamation** and shoreline filling for coastal development.
- **Clearing of mangrove forests** for firewood and shrimp farms (mangroves filter sediments from the reef).
- **Bottom trawling** for fish.

Silt from dredging and runoff buries corals and suffocates sensitive reef organisms.



Tourism

The damaging impacts of tourism are primarily caused by:

- Coastal development.
- Hotel, cruiseships, lodging, and restaurant operations.
- Marine recreation.

Coastal Development for Tourism
Tourism related coastal construction includes the development of resorts, stores, restaurants and parking lots; the construction of piers and marinas; and the development of artificial beaches and beach replenishment. These activities lead to:

- **Physical damage** to the coral and reef structure.
- Increased **sedimentation**.
- Increased **industrial and toxic pollution**.

This can greatly affect the health of coral reefs, which can in turn, negatively affect the tourism industry.

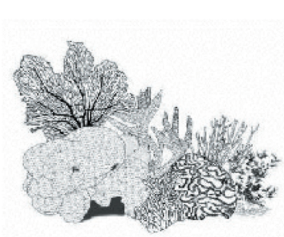
Hotels, Lodging and Restaurants
Hotels, cruiseships, and lodging operations create solid and liquid wastes from landscaping, sewage, laundry, and other guest services. Restaurants that sell local endangered fish and shellfish are depleting the local marine resources. These activities cause:

- Increased **sedimentation**.
- Increased **sewage** and other **land-based pollutants.**
- Increased **destructive or overfishing** of marine resources.

Impacts from tourism are mainly produced from:

- Tourism development.
- Hotels, lodging and restaurants.
- Marine recreation.

It takes only a second to break a small piece of coral off, but it can take up to 25 years for it to grow back.



Marine recreation causes:

- Physical damage.
- Marine pollution.
- Sedimentation.
- Destructive fishing.
- Disturbances to marine life.

Tourism (continued)

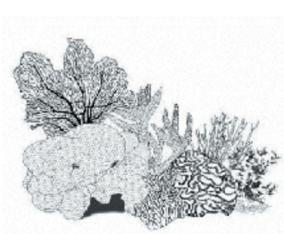
Marine Recreation

Specific activities such as snorkeling and diving can have negative effects on coral reefs, including:

- **Physical damage** caused by anchors and ship groundings. In Guam there were at least 15 ship groundings and 13 sinkings between 1992 and 1996. Divers, snorkelers and swimmers also cause physical damage by kicking and walking on living corals.
- **Marine pollution** from boat maintenance and operation and improper sewage and garbage disposal.
- **Sedimentation** from poor boating practices, divers, and snorkelers.
- **Destructive and overfishing** of marine resources for souvenirs.
- **Disturbing marine wildlife** while viewing, such as turtles, whales, dolphins, and other wildlife.

For more information on tourism and coral reefs see CORAL's Handbook on Sustainable Tourism for Marine Recreation Providers.

According to NOAA, over 23 million Americans spend over 290 million boating days a year in coastal waters, primarily in coral reef areas.

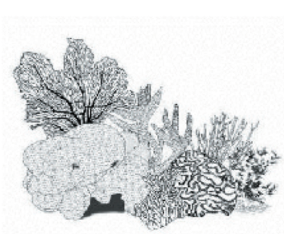


Part IV: Searching for Solutions

Searching for Solutions

Coral reef conservation efforts include:

- International, Regional, and National projects.
- Community-Based Conservation.
- Coral reef protected areas.
- Integrated Coastal Zone Management.
- Awareness/Advocacy.
- Sustainable Tourism.
- Coral Reef Recovery and Rehabilitation.
- Individual actions.



Human activities are a serious threat to the future of coral reefs. If immediate action is not taken to reduce human impacts, many of the world's coral reefs could be lost forever. By promoting and participating in the conservation of these unique marine ecosystems, we protect the lives and homes of millions of sea creatures. We also enhace jobs, food, income and places of incredible natural beauty for local communities and tourists alike.

As public awareness of the value of coral reefs increases, so do efforts to protect them. Conservation programs range from international and regional projects `and laws to the day-to-day actions of individuals.

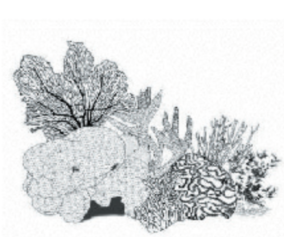
This section highlights the following solutions:

- International, Regional and National Efforts.
- Community-Based Conservation.
- Coral Reef Protected Areas.
- ICZM – Integrated Coastal Zone Management.
- Awareness and Advocacy.
- Sustainable Tourism.
- Coral Reef Recovery and Rehabilitation.
- Individual Actions.

International programs:

- ICRI.
- ICRAN.
- GCMRN.
- ICRIN.
- Reef Base.
- Dive In To Earth Day.
- Reef Check.
- REEF.

Coral reef conservation begins at home, yet there are lessons to be shared by experts and communities around the world.



International Efforts

International
Experts and policymakers from around the world have joined forces on several international initiatives to help understand, monitor, and reverse the decline in coral reef health. International programs address:

- Global trends.
- Shared lessons.
- Funding from international agencies and programs.
- International laws and conventions.

The central international body for coral reef conservation is called the **International Coral Reef Initiative (ICRI)**. ICRI draws on various international experts to develop solutions to coral reef problems, and draws attention to coral reef issues at international forums. ICRI has several operating units including:

- **International Coral Reef Action Network (ICRAN)** – Improves marine protected area management and effectiveness.
- **Global Coral Reef Monitoring Network (GCMRN)** – Central body for coral reef monitoring information.
- **International Coral Reef Initiative (ICRIN)** – Spreads awareness and education of coral reef issues.

There are many other international coral reef initiatives that exist, such as:

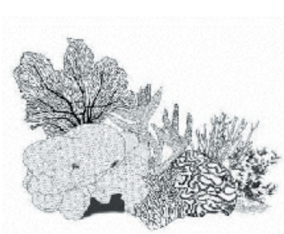
- **Reef Base** - Online information system about coral reef ecosystems around the world (www.reefbase.org).
- **Dive In To Earth Day** - Grassroots coral reef conservation events held in more than 50 countries each year (www.coral.org/divein).
- **Reef Check (**www.reefcheck.org/**)** and **Reef Environmental Education Foundation (REEF)** (www.reef.org/) - Volunteer networks for global coral reef monitoring.

International agencies such as the **United Nations Environment Programme (UNEP)**, and several non-governmental organizations such as the **Coral Reef Alliance**, the **World Wildlife Fund**, and **The Nature Conservancy**, also work at an international level to help reverse coral reef degradation.

Coral reef initiatives include:

- National programs.
- Regional programs.
- International programs.

The South Pacific Regional Environment Program supports coral reef conservation projects throughout Polynesia, Melanesia, and Micronesia.



Regional and National Efforts

Regional

Coral reefs regularly pass through more than one country, such as the Mesoamerican Barrier Reef, or the Red Sea. Even seemingly distant and remote coral reefs are interconnected by larval distribution, or are affected by the same weather patterns or human disturbances. It is therefore important to approach coral reef conservation from a regional perspective to address shared coral reef issues within a geographic region. Examples include the Caribbean Environment Programme (CEP), and the Eastern African Regional Seas Programme.

Regional initiatives help to:

- Identify and understand patterns such as coral bleaching events or disease outbreaks.
- Establish networks of marine protected areas (MPAs).
- Understand larval distribution.
- Monitor species distribution.
- Establish policies and programs that prevent and/or solve threats.

National

Coral reefs exist in more than one hundred countries, and national laws and policies vary greatly from one country to the next. In some, coral reef protection is incorporated within broad environmental policies. In other situations, there are particular agencies and laws that deal specifically with coral reefs. Involvement at the federal level is necessary to:

- Establish national laws and policies.
- Enforce legislation.
- Set up marine protected areas (MPAs).
- Collect user-fees (based on who are the "users" of a MPA) and taxes.
- Prioritize national funding for conservation projects.

Examples of national projects include the United States Coral Reef Task Force and the Indonesian Coral Reef Working Group.

Community-Based Conservation

Community involvement and support is key to the success of a conservation program.

- Key stakeholders: People who rely on coral reef resources for their livelihood.

Although it is important to address coral reef conservation from a global perspective, without the support of the local community, most conservation projects will not succeed. **Community-based conservation** involves the active participation and support of the local communities who depend on the coral reef for food and income.

Conservation planning should involve representatives from **key stakeholder groups** (people who rely on coral reef resources for their livelihood). Examples of key stakeholders include:

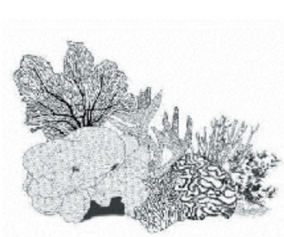
- Boat taxi drivers.
- Community members.
- Developers.
- Dive and tour operators.
- Fishers.
- Investors.
- Local government officials.
- Local merchants.
- Non-governmental organizations (NGO's).

It is also important to incorporate local knowledge and wisdom in coral reef conservation planning. In many parts of the world coral reefs have been successfully managed and protected by indigenous communities for hundreds of years.

In Fiji and other Pacific Island nations, reefs were sustainably harvested for millennia using wisdom passed down through generations.

There are many different ways that communities can be involved in coral reef conservation. For example, dive operators can collect user fees from tourists to support local marine protected areas. Fishermen can help patrol the reefs from illegal poaching. Community groups can organize regular beach cleanups and educational programs. In some cases, non-governmental organizations (NGO's) can be hired to manage the marine protected areas.

Every place is different, with its own reefs and unique problems. Models cannot always be replicated, but sharing lessons and information helps everyone improve their conservation efforts.



Coral Reef Protected Areas

Different types of protected areas:

- MPAs.
- Reserves.
- LMMAs.
- Coral Parks.

A **coral reef protected area** is an area that has been set aside to provide lasting protection for part or all of the coral reef and related ecosystems within its boundaries. Coral reef protected areas have been used as a management tool to protect, maintain, or restore natural and cultural resources in coastal and marine waters that contain coral reefs. They have proven to be one of the most promising solutions for the survival of coral reefs and the many benefits they provide to people.

There are many different types of coral reef protected areas that can vary in name, official designation and management approach.

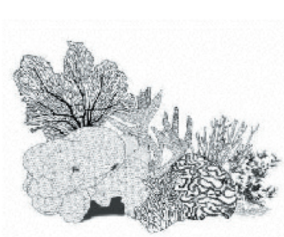
- **Marine Protected Area (MPA)** generally refers to a protected area that is officially recognized by a government body. For example, Arrecifes de Cozumel in Mexico, or the Great Barrier Reef Marine Park in Australia.

- **Marine Reserve** is a protected area that prohibits fishing and harvesting of marine resources in order to protect fish stocks and other reef organisms. An example is the Hol Chan Marine Reserve in Belize.

- **Locally Marine Managed Area (LMMA)** is a community designated and managed protected area, such as the coral reef of Waitabu, Fiji. Each LMMA may have a different conservation strategy. For example, one may be a marine reserve, prohibiting fishing and harvesting of marine organisms, while another might balance different uses of local resources.

- **Coral Park** is a broad term used to describe any protected area that includes a coral reef within its boundaries and allows visitation (such as dive tourism). Just like parks on land, coral parks combine sensible recreation and management to help protect the park's ecosystem. Examples of coral parks are Bunaken National Park in Indonesia and Apo Island in the Philippines, both of which are also recognized MPAs.

The Great Barrier Reef Marine Park is the largest coral reef protected area in the world, covering 344,800 square kilometers.



Coral Reef Protected Areas (continued)

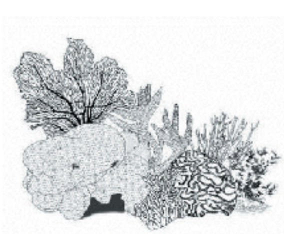
Benefits of MPAs include:

- Renewed fish stocks.
- Social and economic benefits.
- Research.
- Biodiversity.

Benefits of coral reef protected areas
If properly managed, coral reef protected areas can benefit from:

- **Renewed fish stocks.** Areas with **"no-take" zones** (no fishing) have shown to have:
  - Increase in fish **biomass** (weight of fish catch) both inside and outside the protected area.
  - Higher fish density and biodiversity.
  - Larger carnivorous fish and invertebrates.
  - Increase in fish larvae, which also repopulate neighboring areas as larvae is transported by currents.
- **Social and economic benefits**
  - Improved quality of life for local communities, as cultural heritage is preserved, and increased fish stocks lead to more food and income.
  - Reef-based tourism can be a non-extractive industry (an practice that uses the reef without harvesting resources) that attracts millions of divers and snorkelers each year. This income can replace the community's reliance upon destructive activities with short-term benefits such as dynamite fishing.
- **Research**
  - Researchers can learn about the natural functioning of intact coral reef ecosystems.
  - Scientists can conduct biomedical research in healthy coral reef ecosystems in order to find cures for diseases.
- **Biodiversity**
  - Protection of natural biological diversity and food web stability.
  - Protection of reproductive spawning grounds for fish and other reef-based organisms.

In 2000, there were an estimated 660 coral reef marine protected areas worldwide.



Coral Reef Protected Areas (continued)

Ten Ways Effective Parks Protect Coral Reefs

Coral parks and other types of coral reef protected areas have proven to be one of the most effective ways at protecting and conserving coral reef ecosystems. A coral park is a marine protected area (MPA) that includes a coral reef in its boundaries and allows visitors. The coral parks program of the Coral Reef Alliance (CORAL) helps tourism and conservation to work in partnership for the benefit of coral reefs, the tourism industry and local communities.

1. **Address Specific Threats.** Each coral park has its own goals and objectives, depending on what activities and threats are present. In general, parks protect against threats such as overfishing, coral collecting, dynamite fishing, mining, sedimentation, and pollution.

2. **Provide Active Management.** Staff or volunteers patrol the park, enforce rules, anticipate and address new threats, and provide services, facilities, and information to users.

3. **Supply Visitor Education.** Information is available to visitors and community members about the rules of the park and the life found there.

4. **Support Local Education.** Outreach and education programs for local communities help ensure protection of coral reefs. Examples include snorkeling programs for local children, seminars for those who work in or near the park, and resources and materials for teachers.

5. **Promote Dive Briefings.** Dive operators are active partners in frontline protection by briefing divers about ways to reduce recreational damage.

6. **Partner with Local Dive Operators.** They are the eyes and ears of the park and can report violations and encourage visitors to follow regulations.

7. **Collect Admission Fees.** Financial support comes from park visitors, ensuring that the park is self-sustaining and providing an insurance policy for the reef, allowing visitors to return to a protected spot. A self-financed park is not subject to politics or current fads.

8. **Install Mooring Buoys.** Moorings are in place, used and maintained. They protect fragile reefs from anchor damage caused by tour boats and fishermen.

9. **Conduct Research and Monitoring.** Ongoing programs scientifically monitor the state of the reefs.

10. **Provide Protection for Critical Habitat and Endangered Species.** Parks are poised for action when development plans or overfishing threaten particular species. Parks can exert pressure to leave turtle nesting grounds undisturbed or fight the removal of nearby mangrove forests.

Integrated Coastal Zone Management (ICZM)

ICZM

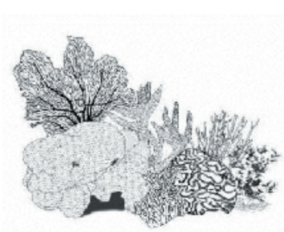
- ICZM manages activities in all parts of the coastal zone.
- Communication and cooperation are keys to success.

ICZM takes a comprehensive approach to coastal zone management, with the goal of coordinating all uses of the coastal zone. This includes ocean-based activities such as fishing and diving; beachside activities such as beach replenishment and hotel development; and inland activities such as agriculture and forestry. ICZM views the coastal zone as a complete system, not as separate parts.

The underlying concept of ICZM is that **no part of the physical environment exists independently** — actions in one impact another. So, for example, if a mangrove forest is cut down, this could lead to coastal erosion and flooding, which could impact coastal settlements and destroy near shore coral reefs.

ICZM depends on **communication and cooperation** between all management bodies and stakeholders. For example, if the parks department of a local, state or federal government establishes a marine reserve — but does not use a comprehensive ICZM approach to coordinate with other coastal zone activities — the reserve may be threatened by impacts resulting from a large private sector development that is planned within the next five years. In an ideal scenario, stakeholders, government officials and community members involved in ICZM planning would be aware of these development proposals, and would communicate with the developers to come up with a compromise or alternative plan of action that minimizes impact to the environment.

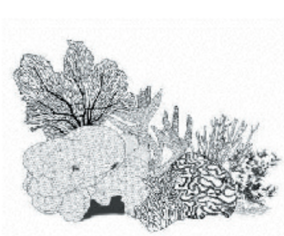
A coast is more than just a beach. The coastal zone is the transitional area between land and sea.



Sustainable Tourism:

- Sustainable tourism allows future generations to use the resource.
- Unsustainable tourism destroys the resource.

Sustainable tourism is estimated to be the largest growth area in tourism in the next decade.



Sustainable Tourism

Tourism is the fourth largest industry in the world and is growing rapidly. Eighty-five percent of all global tourism is in coastal areas. Reef-based tourism is a big draw for tourists and is vital to many tropical countries — especially small islands and developing states.

What is sustainable vs. unsustainable tourism?

- **Sustainable tourism** uses natural resources in such a way as to leave them healthy and undamaged for future generations.
- **Unsustainable tourism** degrades and destroys the natural resources that support the economy of a region.

What are the benefits of sustainable tourism?

- It is a non-extractive industry (uses the reef without harvesting resources) that can provide income to local communities while sustaining healthy reefs over the long-term.
- It can help generate income and much needed revenue to keep a Marine Protected Area functioning. There is a demand for sustainable tourism from divers in particular, who are willing to pay more for the best dive spots, and are willing to do so through MPA user fees.
- It can educate tourists about the coral reef through environmental literature and briefings aboard boats and other tour operations and a general sense of businesses engaging in good environmental practices.
- It is estimated to be the largest growth area in tourism over the next decade. This growth can simultaneously benefit the environment and businesses and communities that adopt good environmental practices.

For more information, see CORAL's Handbook on Sustainable Tourism for Marine Recreation Providers.

Through education, people gain:

• Appreciation

• Respect

• Pride

• Foresight

• Empowerment

• Motivation

Awareness/Advocacy

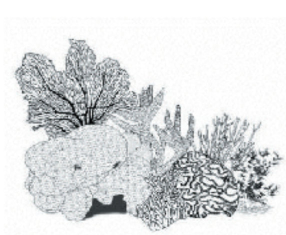
Outreach and education — to local communities, key stakeholders, policy makers, tourists, and other target audiences — is critical to any successful conservation program. We are all responsible for educating others about the value of coral reefs. Help coral reefs by sharing your knowledge.

Through education, people gain:

- **Appreciation** of the beauty and complexity of coral reef ecosystems.
- **Respect** for the value of coral reefs as sources of protein, income, medicine and recreation.
- **Pride** in local coral reef resources.
- **Foresight** and understanding of the long-term consequences of our actions, which might ultimately change our behavior.
- **Empowerment** with the knowledge necessary to make informed decisions and participate in management discussions.
- **Motivation** to participate in or support coral reef conservation projects through donations or time.

Fijian dive operators celebrate the completion of a CORAL workshop in Taveuni, Fiji, 2003.

The United Nations declared 1997 the International Year of the Reef to spread global awareness of the plight of coral reefs.



CORAL has educational and outreach materials such as good environmental practice guidelines for the marine recreation sector, issue briefs for policy makers and influential community leaders, and handbooks on other coral reef-related topics (See appendix, page 74.) For more information, visit our website at www.coral.org/ or email us at info@coral.org/.

Coral Reef Recovery and Restoration

Coral reef recovery and restoration:

- Restocking marine life.
- Transplanting coral fragments.
- "Planting out" articficially reared corals.
- Enhancing coral growth rates.
- Artificial reefs.

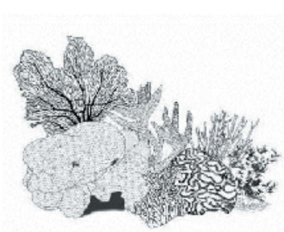
Reef recovery occurs when a coral reef returns to the condition it was in before being damaged by threats such as hurricanes, oil spills, bleaching events, or other impacts.

Scientists are studying various ways to help restore reefs and restock marine life in damaged or depleted areas:

- **Transplanting coral fragments.** In areas that have been damaged by storms or development projects, biologists can take coral fragments and reattach them to the substrate to establish coral colonies in new areas.
- **"Planting out" artificially reared corals**. This process involves taking corals grown in farms — both in the ocean and in artificial tanks — and placing them out in living coral reef areas.
- **Enhancing coral growth rates**. Scientists are looking at various ways to enhance the growth rates of living corals. One method, called mineral accretion, uses low voltage electrical current to speed up the growth rates of marine organisms with limestone skeletons.
- **Artificial reefs**. Often constructed of such items as old tires, rocks and "reef balls," artificial reefs can contribute to the recovery of marine life in previously damaged or depleted areas.

Low-tech and low-cost restoration projects have been implemented in Komodo National Park using rock piles to help create places for corals to settle and grow.

Some scientists question the value of such approaches in comparison to natural recovery processes. Furthermore, the high cost of such activities makes them unrealistic options for most coral reef communities. At a minimum, efforts should be made to reduce human threats, educate people,

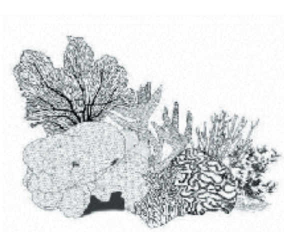


Divers survey a reef in Indonesia.

We can all make a difference:

• In our communities.

• In the water.



What We Can Do As Individuals

Everyone Can Help Keep Coral Reefs Alive and Healthy

As a community member:

- Learn about and obey local laws designed to protect coral reefs.
- Support local MPAs and other coral reef protected areas by paying user-fees, even if they are voluntary.
- Participate in community stakeholder discussions.
- Volunteer your time or money to help with a conservation project (organize a Dive In To Earth Day event www.coral.org/divein).
- Share your knowledge with others.

In the water:

- Do not step on or touch coral.
- Do not disturb or harass marine life. *(Download CORAL's Diving, Snorkeling, Whale & Dolphin Watching, and Turtle Watching Guidelines at www.coral.org.)*
- Be a responsible boater: avoid dropping anchors on coral reefs, dispose of waste in a proper receptacle, navigate carefully, use clean-burning 4-stroke outboard engines, perform regular maintenance on engines and fuel tanks, safely dispose of waste, etc. *(See CORAL's Handbook on Sustainable Tourism for Marine Recreation Providers).*

Dive in to Earth Day 2003 in Apo Island, Philippines.

We can all make a difference:

- At home.
- If you live on a small island.

What We Can Do As Individuals (continued)

At home:

- **Reduce, reuse, recycle**. Try to keep trash to a minimum and dispose of batteries in a safe way. Try to avoid excess packaging and plastic bottles, which often end up on in the ocean.

- **Save energy**. Turn out lights you are not using. Run dishwashers and washing machines with full loads. Buy energy efficient appliances. Wrap your water heater to save heat. Use compact florescent bulbs.

- **Drive less**. Take public transportation to help reduce fossil fuel emissions. Join a car pool. Walk or bike to work.

- **Avoid fertilizers or other pesticides** in your garden.

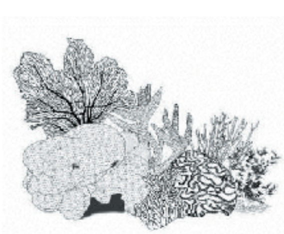
If you live on a small island:

- Avoid non-biodegradable items such as styrofoams and plastics, which can threaten marine life if they get into the ocean.

- Buy non-threatened fish species that are harvested in a sustainable manner and do not deplete local fisheries.

- Avoid dumping toxic chemicals and household cleaners down drains and sewers that flow directly into the ocean.

- Promote and support community programs aimed at protecting local coral reefs and other natural areas.



Dive in to Earth Day 2003, cleaning trash from the beach in Barbados.

We can all make a difference:

• As a consumer.

• As a business owner.

What We Can Do As Individuals (continued)

As a consumer:

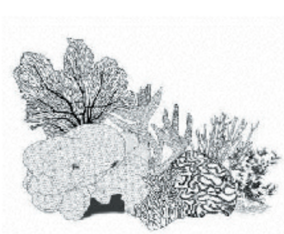
- Avoid purchasing souvenirs made from coral or other marine organisms.
- Buy the least toxic household products, such as biodegradable cleaners or water-based, low biocide/volatile organic compound (VOC) paints.
- Avoid ordering seafood that is harvested in an unsustainable way. For more information, check out www.seafoodchoices.com/.
- Support businesses that make an effort to protect the environment.

As a marine recreation business owner or operator:

- Avoid selling items that threaten local natural areas, such as coral jewelry, shells or threatened fish species.
- Support environmentally responsible boating practices such as the use of moorings as an alternative to anchoring (See CORAL's handbook, *Sustainable Tourism for Marine Recreation Providers*.
- Support and promote sustainable fishing practices.
- Educate tourists about how to minimize their impact on the environment during marine recreation activities.
- Support work being done by local non-governmental organizations (NGOs) to protect the environment.

Wolcott Henry photo

Avoiding the purchase of ornamental items such as coral jewelry can go a long way towards protecting coral reefs.



Activities to help reduce threats to your reefs

Here are some creative ideas to help reduce threats to your reefs:

Overfishing and Destructive Fishing

- **Conduct fish or reef surveys.** Monitoring species diversity and abundance on the reef helps track changes and improves our understanding of the threats impacting those changes, such as overfishing. You can take part in reef monitoring programs such as Reef Check or REEF.

- **Make friends with local fishers**. Teach a fisher how to dive, or hire local fishers to give them an alternative source of income. Talk to fishermen about the benefits of marine reserves and coral reef protected areas.

- **Involve children.** Children are our future fishers - and our future ambassadors for coral reefs. Teach them about the beauty and importance of coral reefs. Plan a lesson or event with the local school that teaches about over-fishing and destructive fishing. Have a conservation poster contest and display the entries in local business windows.

- **Bring the underwater world to the non-diving community.** Show slide shows and videos of beautiful coral reefs to your community. Set up a touch tank for local kids and adults to experience some of the amazing creatures that inhabit the reef. This can help educate them about species that are affected by destructive fishing practices.

- **Hold a fair or festival.** You can use a variety of activities at a festival to involve and educate, including art displays, environmental displays, music and speakers. You can also raise funds with sales of food or merchandise and donate those funds to your local coral reef protected area. Involve the community in planning and execution by soliciting participation by businesses, clubs, or other community groups.

Anchor Damage

- **Install mooring buoys**. Even a carefully placed anchor can drag and destroy reefs. Installation and use of mooring buoys dramatically reduces anchor damage on reefs. *Borrow ideas from CORAL's Handbook on Mooring Buoy Installation and Maintenance.*

- **Throw a fundraiser** to raise money for new buoys and for mooring buoy maintenance.

- **Plan a community meeting.** Build community support and awareness by holding a slideshow that contrasts healthy and anchor-damaged coral.

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Coastal Development

- **Invite local government** and policymakers on a glass bottom boat tour. The opportunity to experience the reef first-hand can leave a lasting impression and stimulate interest in coral reefs.

- **Mangrove restoration**. Support mangrove restoration in your local community and talk to your local government about the importance of mangroves to coral reef health.

- **Have children conduct a natural history of your area**. Talk to the elders and find out where vibrant reefs and mangroves used to be. This helps preserve cultural traditions and illustrate the impacts of development.

- **Help your community adopt a reef, coral park or beach.** You can personalize efforts by focusing on one area to protect and preserve.

- **Have a coastal/underwater clean up.** Keep track of the types and total quantities of garbage to help determine what is impacting the reefs.

- **Start an indigenous plant nursery**. Removal of vegetation for development increases erosion and increases sedimentation in coastal waters. Planting native plants helps protect the reefs.

Diver / Snorkeler Damage

- **Distribute Coral Friendly Guidelines.** These guidelines help raise awareness of ways that divers and snorkelers can reduce damage to the reef. You can download copies at www.coral.org**.**

- **Participate in community events such as *Dive In To Earth Day*.** This helps build a community network of concerned citizens. Visit www.coral.org/divein.

- **Offer buoyancy clinics.** This can be a fun way to strengthen bonds within the dive and snorkel community and refresh basic skills in a casual setting.

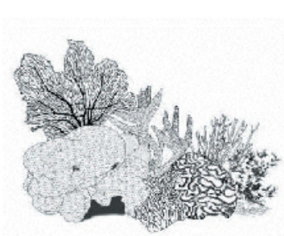
- **Give environmental dive briefs** to your clients on every dive. Studies have shown that divers who have been given an environmental brief cause far less damage to reefs.

- **Are your dive sites too crowded?** If the same dive groups tend to visit the same dive sites, consider rotating through several different sites. This helps to reduce stress on the reef and makes sites more attractive places to dive.

- **Form a Dive Operator Association.** Work with others in the dive industry to develop local codes of conduct and environmental standards. A unified voice can make a big difference.

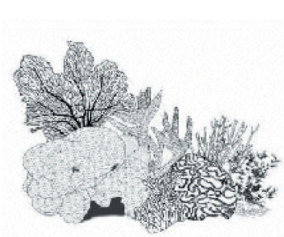
We can all help to keep coral reefs alive for future generations.
Thank you for doing your part - The Coral Reef Alliance (CORAL)

Part V: Appendix



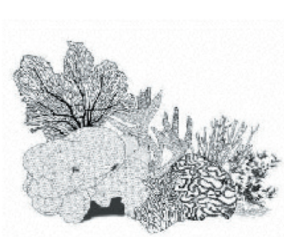
Glossary

Acute threat: A threat that is short-term and dramatic.
Ahermatypic (non-reef building) corals: Corals with a soft, bendable skeleton and eight tentacles; also known as soft corals.
Annelids: Worms that have a segmented body form. Marine worms are called polychaete worms.
Anthozoans: Marine organisms with radial segments that grow individually or in colonies (corals, anemones, gorgonians).
Anthropogenic threat: A human-induced threat to the natural environment.
Asexual reproduction: A form of reproduction that takes place without the formation or union of gametes (eggs and sperm).
Atoll: A type of coral reef that develops as a ring around a central lagoon; commonly the result of sinking islands or volcanoes.
Back reef: The inner section of a barrier reef or atoll that rises up towards the shallow waters of the reef flat.
Bank or platform reef: Open ocean reefs that are simple structures with many different origins, yet no clear attachment to the coastline.
Barrier reef: A type of coral reef that generally is found at some distance from the coast. At their shallowest point they can reach the water's surface and form a "barrier" to navigation.
Biodiversity: The total diversity of living things and of the ecosystems of which they are a part (including species, genetic and ecosystem diversity).
Bioeroders: Any living organisms that naturally breaks down coral by burrowing, scraping away, or eating the coral. Examples include urchins, parrotfish and some polychaete worms.
Biomass: The total weight of living organic material in an environment.
Bleaching: Symbiotic algae (zooxanthellae) are expelled by reef corals causing the coral to look white or "bleached"; generally a response to stress.
Bottom trawling: A method of fishing where large nets are weighted and dragged behind a vessel, often catching many target and non-target species and well as causing significant physical disturbance to bottom habitats.
Branching: A type of coral growth form where colonies branch out to maximize surface area; commonly found in calm, shallow waters.
Breakwater: A barrier that protects a shore from waves and coastal erosion.
Brooding: A form of fertilization where planula larvae develop within the stomach-like structure of corals before they are released into the water.
Budding: A form of asexual reproduction in which a new individual is produced as an exact gentic replica of the parent polyp.
Buttress zone: Deep channels outside of a reef crest where spur and groove formations commonly occur.



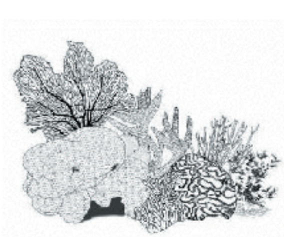
Glossary

Calcareous algae: Algae that secretes calcium carbonate from seawater and deposits it in its tissues. When the algae dies, it leaves a fossil "skeleton" behind.
Calcium carbonate: A mineral that hard corals secrete from sea water to create their limestone skeletons.
Calyx: A small, cup-like skeletal depression which is home to the coral polyp.
Carbon sink: Ecosystems, such as oceans and forests, that absorb carbon from the atmosphere.
Chronic threat: A threat that is persistent over time.
Cnidarians: Invertebrates with stinging cells and a large stomach cavity (corals, anemones, jellyfish).
Cnidocyte: A type of cell which releases a harpoon like structure (called a nematocyst) for capturing prey and defense; found in Cnidarians.
Colonies: The collection or family of polyps that make up a coral head.
Commensalism: A symbiotic relationship in which one species benefits without harming the other.
Community: All the plant and animal species that live together in a particular habitat.
Coral park: A broad term that is used to describe any protected area that includes a coral reef within its boundaries and allows visitation.
Coral reef protected area: An area that has been set aside to provide lasting protection for part or all of the coral reef and related ecosystems within its boundaries.
Coral spawning: The release of coral gametes (eggs or sperm) into the water for external fertilization.
Crown of Thorns starfish: A starfish that eats living reef corals.
Crustaceans: Animals with a segmented body and an external skeleton or shell made of calcium carbonate (crab, lobster, shrimp, barnacles).
Cup/flower coral: A form of soft, ahermatypic coral that is commonly found in caves or overhangs where hard, hermatypic corals are rare.
Cyanide fishing: The process of using cyanide to poison and stun fish for capture on a coral reef; commonly used to catch live fish for restaurants or the aquarium trade.
Detritivores: Organisms that feed on dead plants and animals and their wastes (sea cucumbers, bristle worms, certain starfish).
Digitate: A type of coral growth form also known as finger or columnar; commonly found in calm or deep waters, below the reach of normal wave action.
Disturbance: An event that brings about biological or physical change to an ecosystem.



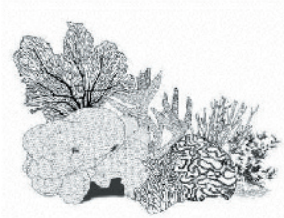
Glossary

Dynamite or "blast" fishing: The process of using dynamite or other explosions to capture fish from a coral reef or other marine environment.
Echinoderms: Sea animals with a radially symmetric body, a water-vascular system, and tube feet (sea stars, urchins, sand dollars).
Ecology: The study of the interactions among and between organisms and their environment, and of the abundance and distribution of those organisms.
Ecosystem: The combination of biotic (living) organisms - fish, algae, zooplankton - and abiotic (non-living) conditions - rain, salinity, sunlight - that make up a particular environment, and make it unique.
Effluent: Something that flows into waterways or into the ocean, including outflow from sewers or discharge of liquid waste.
Elkhorn: A type of coral growth form that has large, sturdy, and flattened branches; often found in calm waters.
Encrusting: A type of coral growth form that is generally flat, spread out and grows in a thin layer on a hard surface; commonly found in areas of very high-wave energy or very poor sunlight.
Erosion: The process of wearing away or gradually destroying.
Eutrophication: Pollution caused by an increase in plant nutrients in coastal marine environments.
Filter feeder: Feeders that filter food particles from the water column (corals, sponges).
Foliose: A type of coral growth form with wide flattened plates.
Fragmentation: A form of sexual reproduction. Coral broken off into pieces as a result of wave action or storm surges may still have living tissue and can re-attach and eventually begin to grow again as living coral colonies.
Fringing reef: A type of coral reef that develops as a narrow structure close to the shoreline. They usually parallel the coastline and at their narrowest point can reach the water's surface.
Gamete: A type of reproductive cell (eggs, sperm) that develops into a new individual after its union with another gamete.
Ghost nets: Nets that have inadvertently or purposefully been discarded from fishing or other vessels. Theses nets are known to drift around the ocean for several years and in many cases lead to the death of marine animals that become entangled or coral reefs that they wash up onto.
Global warming: An increase in the natural phenomenon known as the "greenhouse effect" as a result of an increase of carbon dioxide and other gases in the atmosphere.
Gorgonians: Anthozoans with a skeleton made of protein (sea fans, sea whips).



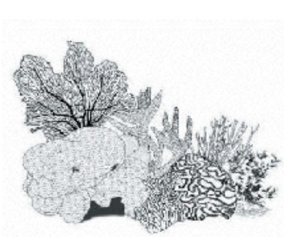
Glossary

Greenhouse gases: Various types of gases in the earth's atmosphere that contribute to a natural warming of the planet through the greenhouse effect.
Habitat: The specific location where a plant or animal lives.
Hermaphrodite: An organism that has both male and female sexual organs.
Hermatypic (reef-building) coral: A coral that builds reefs through the deposition of calcium carbonate, usually contains zooxanthellae.
Intertidal communities: The community of organisms found in the zone between the high and low tide.
Invasive/Exotic or "non-indigenous" species: A foreign species introduced into a new environment by humans.
Invertebrates: Animals lacking a backbone.
Lagoon: A shallow and generally sheltered body of water separated from the open sea by coral reefs, and/or barrier islands.
Land reclamation: Modification of land in order to make it suitable for cultivation or development.
"Live rock": Dead coral and other calcium carbonate deposits on a reef that provide habitat for numerous reef dwelling organisms.
Locally marine managed area (LMMA): A community designated and managed area that protects coral reefs and other marine resources.
Mangroves: Shrubs and trees that live along the seashore in tropical and sub-tropical regions and have a high tolerance for the chemical composition of saltwater.
Marine protected areas (MPAs): An area of coastal land and water that is specifically designated to protect natural resources and ecosystems.
Marine reserve: A type of marine protected area that prohibits fishing and other extractive resource use.
Massive: A type of coral growth form that is ball-shaped or boulder-like. Massive corals tend to be found in areas of high wave action; can be as small as an egg or large as a house.
Mollusks: Invertebrates with a soft, unsegmented body, a muscular foot, and sometimes a shell (bivalves, squids, octopuses, snails).
Muro Ami: A method of fishing where free divers collectively bang a reef with rocks, sticks and other objects in order to lure fish into nets.
Mushroom: A type of coral growth form that is not attached to the reef, and resembles the tops of mushrooms.
Mutualism: A symbiotic relationship in which both species benefit.
Natural threat: A natural occurrence that can threaten living ecosystems, such as storms, El Nino cycles, or geological events such as earthquakes and volcanic eruptions.



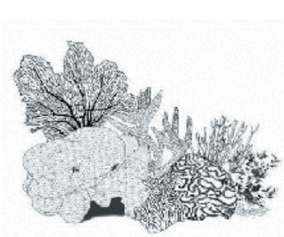
Glossary

Nematocysts: Small, harpoon-like structures possessed by cnidarians which contain stinging cells and are used to capture prey.
Non-point source pollution: Pollution whose origin is not easily identifiable (e.g. runoff from a parking lot or pollution in a river generated from a variety of sources.)
"No-take zones": A general description for areas where fishing and commercial extraction is prohibited.
Organism: Any living thing which is composed of one or more cells.
Overfishing: Fishing an area beyond the capacity for fish stocks to remain sustainable over time.
Parasitism: A symbiotic relationship in which one species benefits while the other is harmed.
Patch reefs: Small areas of reef that occur in shallow waters and lagoons.
Phase shift: When a main component of a reef, such as hard corals, die off, this process takes place in which new organisms, such as algae or soft corals, fill in the open ecological niches.
Photosynthesis: The chemical process of taking energy from the sun and producing organic matter.
Phylum: A major division of a biological kingdom, consisting of closely-related classes (e.g. Cnidaria, Porifera).
Phytoplankton bloom: An excess growth of algal plankton in the marine environment, often caused by eutrophication.
Planula larva: The young larva of corals.
Point-source pollution: Pollution that enters the environment from an identifiable source, such as a sewer or pipeline.
Polychaete worms: Invertebrate worms that have a segmented body form. There are nearly 8,000 species, many of which are found in coral reef ecosystems.
Polyp: An individual cnidarian or member of a cnidarian colony.
Population: All the members of one species in a habitat.
Porifera: Invertebrates that are commonly known as sponges.
Primary consumer: Organism that feeds on primary producers.
Primary producer: Organism that produces energy from the sun (e.g. plants).
Reef crest: The shallow and sloping outer edge of a coral reef; often forming the highest portion of the reef.
Reef flat: The wide and typically shallow upper surface of a coral reef that extends outwards from the shore.



Glossary

Reef front (fore reef): The outer part of a barrier reef or atoll where the reef slope falls steeply towards the seabed; typically where the greatest diversity on the reef is found.
Reef recovery: The process in which a reef recovers to its previous condition prior to damage incurred from such things as hurricanes, oil spills or bleaching events.
Secondary consumer: An organism that feeds on primary consumers.
Sedimentation: The build-up of natural material such as earth, rock and sand that settles to the bottom or stays suspended in the water column.
Sexual reproduction: Reproduction that involves the union of gametes.
Submassive: A type of coral growth form that develops as knobs, columns or wedges protruding from an encrusting plate.
Substrate: The bottom-type or material on or in which an organism lives.
Shoals: Shallow sand banks or sand bars in the marine environment.
Spur and groove: The section of a reef found seaward from the reef flat and is made of high ridges of corals (spurs) that are separated by sandy bottom channels (grooves). Wave and wind dominated regions often lead to the development of spur and groove formations.
Sustainable tourism: Tourism that uses natural resources in such a way as to leave them healthy and undamaged for future generations.
Symbiosis: A close relationship between two species that generally benefits at least one of the organisms; different types include commensalism, mutualism, and parasitism.
Taxonomy: An ordered scientific classification system that starts with the broadest set of similarities between living organisms, and progressively moves towards greater levels of common characteristics.
Tertiary consumer: An organism that feeds on secondary consumers.
Trophic levels: Levels of feeding within an ecosystem.
Table: A type of coral shape that is flat or "table-like" and is often found in calm, well-lit water and has broad horizontal surfaces with fused branches.
Turbidity: Suspension or stirring up of sediment and foreign particles in water.
Unsustainable tourism: Tourism that degrades and destroys the natural resources that support the economy of a region.
Zooplankton: Animal plankton that live within the aquatic realm.
Zooxanthellae: Small algae (or dinoflagellates) that live within the tissues of reef corals and other marine animals. Zooxanthellae, as photoynthesizers, provide some corals with the majority of their nutrition.



About the Coral Parks Program

What is a coral park?

A coral park is a protected area that includes a coral reef in its boundaries and allows visitors. The coral parks program helps tourism and conservation to work in partnership for the benefit of coral reefs and the tourism industry.

The goal of the Coral Reef Alliance's (CORAL) Parks Program is to help coral park managers leverage sustainable tourism to build local investment in the conservation of coral reef parks. We work to achieve this goal by providing training, tools and resources to partners in local coral reef communities, including dive operators, conservation groups, and community leaders, and through our global partnership with the International Coral Reef Action Network (ICRAN). Our current geographic focus is on the Western Pacific, the Caribbean and the Mesoamerican Barrier Reef.

Training and technical assistance for coral parks: CORAL provides on-site training and technical assistance to communities and businesses that depend on coral reefs, helping to ensure the success of local coral parks. Topics include sustainable financing, preventing anchor damage, sustainable marine tourism, and coral reef ecology. CORAL works with marine recreation providers, bulk purchasers (such as cruise lines and tour operators), park managers, and other community members involved in the coral reef tourism industry. Through the development of partnerships between tourism and coral parks, CORAL builds cooperation that enhances both environmental and economic sustainability.

Financial support of park conservation programs: CORAL's microgrant program has provided much needed financial support to local conservation programs around the world. Since 1995, CORAL has provided over $350,000 in microgrants to support grass-roots conservation. Currently, CORAL provides seed money to local partners participating in CORAL's training program. Through microgrants we help coral parks pay for mooring buoys to stop anchor damage, purchase functioning boats to patrol and enforce fishing rules, and publish brochures to educate visitors of park rules. Read more about past microgrant recipients on the CORAL website.

Information and Resources: The parks program provides tools and resources, as well as education and outreach materials (see page 74), to help park managers and communities to more effectively protect their coral reefs. Visit our website at www.coral.org/ to find information on:

- Coral Reef Fact Sheets for the general public
- International Directory of Coral Reef Organizations
- Online Coral Reef Education Materials Library
- Coral Reef Photobank

For more information:

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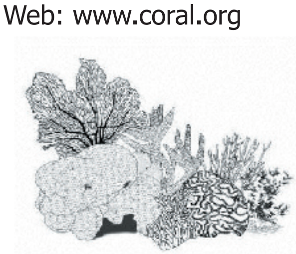

CORAL's Educational and Outreach Materials

The Coral Reef Alliance (CORAL) has developed a broad selection of outreach and educational materials to promote the conservation and protection of coral reefs. Some of our materials include the following:

Guidelines for Good Environmental Practices - CORAL's guidelines reflect the most commonly accepted "good practices" around the world for marine recreation activities and give essential advice on how to protect coral reefs while enjoying activities in and around them. Guidelines are available in English, Spanish, Indonesian and Japanese, and address the following topics:

- Diving
- Snorkeling
- Whale and Dolphin Watching
- Turtle Watching
- Underwater Cleanup


Environmental Issue Briefs - CORAL's issue briefs discuss some of the most important issues being addressed by CORAL and the partners of the International Coral Reef Action Network (ICRAN), and are designed to assist policymakers, business leaders and other influential community members to make informed decisions on issues that affect the health of coral reefs. Issue briefs are available in English and Spanish, with topics including:

- Coral Reefs and Global Climate Change
- Coral Reefs and Sustainable Coastal Development
- Watersheds and Healthy Reefs
- Exploitive Fishing
- Effective Coral Reef Marine Protected Areas (MPAs)
- Coral Reef Mining, Harvesting and Trade

Handbooks - CORAL's handbooks provide a comprehensive look at the nature of coral reefs, threats to these marine ecosystems, and practical solutions to promote and implement conservation. Our handbook series includes the following publications:

- *Introduction to Coral Reef Ecology, Threats and Solutions*
- *Mooring Buoy Installation and Maintenance.*
- *Sustainable Tourism for Marine Recreation Providers*

For more information on available materials and resources, visit our website at www.coral.org/ or email us at info@coral.org/.

CORAL's educational and outreach materials:

- Guidelines for good environmental practices.
- Issue briefs for policy makers and community leaders.
- Handbooks on:

Coral Reef Ecology, Threats and Solutions.

Sustainable Tourism for Marine Recreation Providers.

Mooring Buoy Installation and Maintenance.

"Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has."

-Maragaret Mead