Welcome to Corals

Coral reefs are some of the most diverse ecosystems in the world. Thousands of species rely on reefs for survival. Thousands of communities all over the world also depend on coral reefs for food, protection and jobs. NOAA's National Ocean Service is involved in research and efforts to conserve these important ecosystems.

Most corals are made up of hundreds to hundreds of thousands of individual coral polyps like this one.

In this subject, you will find three sections devoted to learning about coral reefs: an online tutorial, an educational roadmap to resources, and formal lesson plans.

The Coral Tutorial is an overview of the biology of and threats to coral reefs. The tutorial is content rich and presented in easy-to-understand language. It is made up of 11 "chapters" or pages (plus a reference page) that can be read in sequence by clicking on the arrows at the top or bottom of each chapter page. The tutorial includes many illustrative and interactive graphics to enhance the text.

The Roadmap to Resources complements the information in the tutorial. The roadmap directs you to specific coral data offerings within the NOS and NOAA family of products.

The Lesson Plans integrate information from the tutorial with data offerings from the roadmap. These lesson plans have been developed for students in grades 9–12 and focus on the benefits of coral reefs to humans, the major threats to coral reefs today, and how satellites are used to monitor and maintain the health of these fragile ecosystems.

SciLINKS Selected by Science Educators from NSTA

The National Science Teachers Association (NSTA) has included this online resource in its *SciLinks* database. *SciLinks* provide students and teachers access to Web-based, educationally appropriate science content that has been formally evaluated by master teachers.

For more information about the *SciLinks* evaluation criteria, click here: http://www.scilinks.org/certificate.asp.

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Corals

What are Corals?

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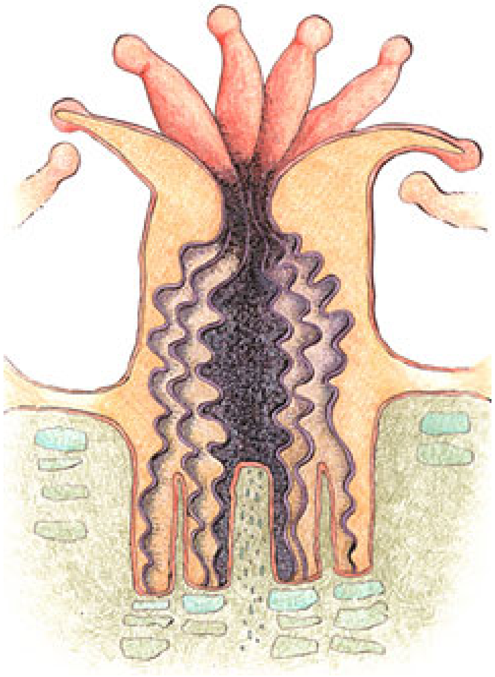
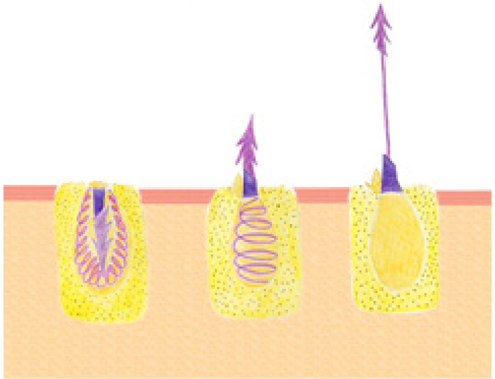
When corals are mentioned, most people immediately think about clear, warm tropical seas and fish-filled reefs. In fact, the stony, shallow-water corals—the kind that build reefs—are only one type of coral. There are also soft corals and deep water corals that live in dark cold waters.

Almost all corals are colonial organisms. This means that they are composed of hundreds to hundreds of thousands of individual animals, called polyps (Barnes, R.D., 1987; Lalli and Parsons, 1995). Each polyp has a stomach that opens at only one end. This opening, called the mouth, is surrounded by a circle of tentacles. The polyp uses these tentacles for defense, to capture small animals for food, and to clear away debris. Food enters the stomach through the mouth. After the food is consumed, waste products are expelled through the same opening (Barnes, R.D., 1987; Levinton, 1995).



Most corals are made up of hundreds to hundreds of thousands of individual coral polyps like this one. *Click the image for a detailed diagram and a description of a polyp's anatomy.*

Most corals feed at night (Barnes, 1987). To capture their food, corals use stinging cells called nematocysts. These cells are located in the coral polyp's tentacles and outer tissues. If you've ever been “stung” by a jellyfish, you've encountered nematocysts.



Nematocysts are special stinging cells used by coral polyps to capture food. *Click the image for a diagram of a nematocyst cell's anatomy and how it works.*

Nematocysts are capable of delivering powerful, often lethal, toxins, and are essential in capturing prey (Barnes, R. D., 1987). A coral's prey ranges in size from nearly microscopic animals called zooplankton to small fish, depending on the size of the coral polyps. In addition to capturing zooplankton and larger animals with their tentacles, many corals also collect fine organic particles in mucous film and strands, which they

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then draw into their mouths (Barnes and Hughes, 1999).

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http://oceanservice.noaa.gov/education/kits/corals/coral01_intro.html
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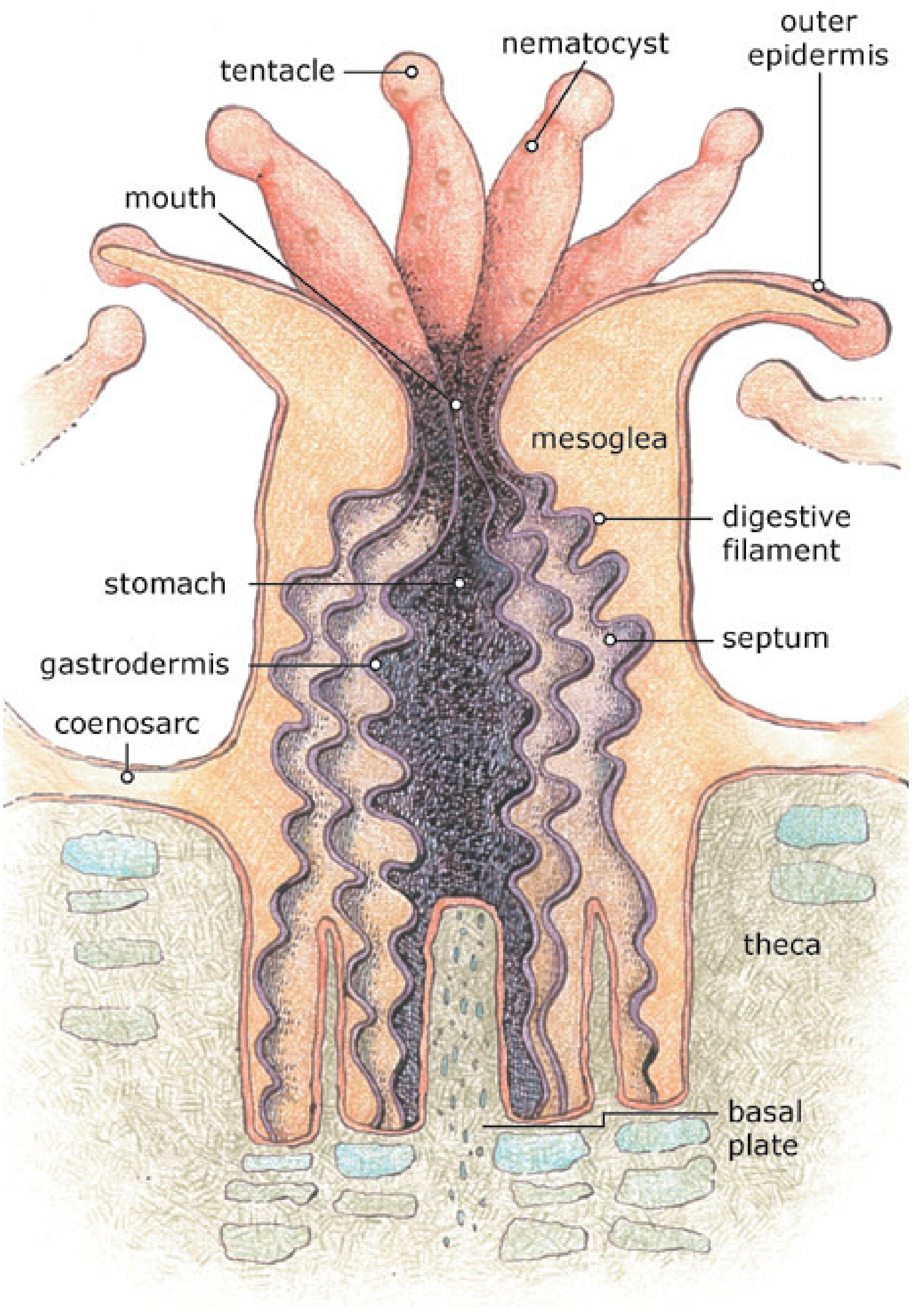
tentacle
nematocyst
outer epidermis
mouth
mesoglea
digestive filament
stomach
septum
gastrodermis
coenosarc
theca
basal plate

Most corals are made up of hundreds of thousands individual polyps like this one. Many stony coral polyps range in size from one to three millimeters in diameter. Anatomically simple organisms, much of the polyp’s body is taken up by a stomach filled with digestive filaments. Open at only one end, the polyp takes in food and expels waste through its mouth. A ring of tentacles surrounding the mouth aids in capturing food, expelling waste and clearing away debris. Most food is captured with the help of special stinging cells called nematocysts which are inside the polyp' outer tissues, which is called the epidermis. Calcium carbonate is secreted by reef-building polyps and forms a protective cup called a calyx within which the polyps sits. The base of the calyx upon which the polyp sits is called the basal plate. The walls surrounding the calyx are called the theca. The coenosarc is a thin band of living tissue that connect individual polyps to one another and help make it a colonial organism.

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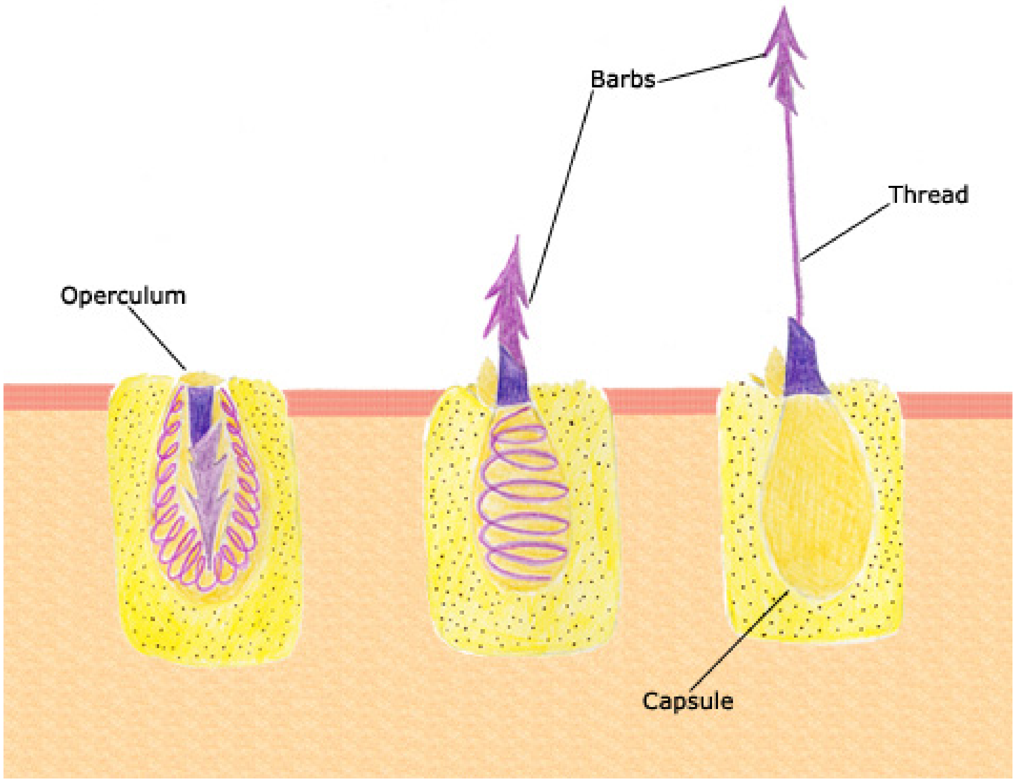

The diagram above shows the anatomy of a nematocyst cell and its “firing” sequence, from left to right. On the far left is a nematocyst inside its cellular capsule. The cell’s thread is coiled under pressure and wrapped around a stinging barb. When potential prey makes contact with the tentacles of a polyp, the nematocyst cell is stimulated. This causes a flap of tissue covering the nematocyst —the operculum—to fly open. The middle image shows the open operculum, the rapidly uncoiling thread and the emerging barb. On the far right is the fully extended cell. The barbs at the end of the nematocyst are designed to stick into the polyp’s victim and inject a poisonous liquid. When subdued, the polyp’s tentacles move the prey toward its mouth and the nematocysts recoil back into their capsules.

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Corals

Zooxanthellae... What's That?

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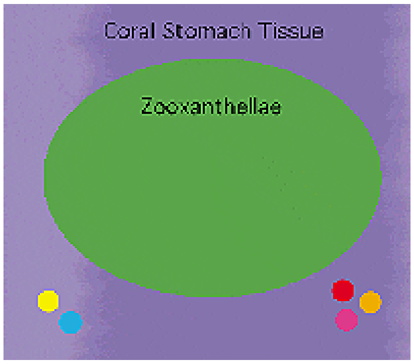
Most reef-building corals contain photosynthetic algae, called zooxanthellae, that live in their tissues. The corals and algae have a mutualistic relationship. The coral provides the algae with a protected environment and compounds they need for photosynthesis. In return, the algae produce oxygen and help the coral to remove wastes. Most importantly, zooxanthellae supply the coral with glucose, glycerol, and amino acids, which are the products of photosynthesis. The coral uses these products to make proteins, fats, and carbohydrates, and produce calcium carbonate (Barnes, R.D., 1987; Barnes, R.S. K. and Hughes, 1999; Lalli and Parsons, 1995; Levinton, 1995; Sumich, 1996). The relationship between the algae and coral polyp facilitates a tight recycling of nutrients in nutrient-poor tropical waters. In fact, as much as 90 percent of the organic material photosynthetically produced by the zooxanthellae is transferred to the host coral tissue (Sumich, 1996). This is the driving force behind the growth and productivity of coral reefs (Barnes, 1987; Levinton, 1995).

Tiny plant cells called zooxanthellae live within most types of coral polyps. They provide the coral with foods resulting from photosynthesis. *Click the image for a larger view of these cells.*

In addition to providing corals with essential nutrients, zooxanthellae are responsible for the unique and beautiful colors of many stony corals. Sometimes when corals become physically stressed, the polyps expel their algal cells and the colony takes on a stark white appearance. This is commonly described as "coral bleaching" (Barnes, R.S.K. and Hughes, 1999; Lalli and Parsons, 1995). If the polyps go for too long without zooxanthellae, coral bleaching can result in the coral's death.



Coral polyps, which are animals, and zooxanthellae, the plant cells that live within them, have a mutualistic relationship. *Click the image to see an animation.*

Because of their intimate relationship with zooxanthellae, reef-building corals respond to the environment like plants. Because their algal cells need light for photosynthesis, reef corals require clear water. For this reason they are generally found only in waters with small amounts of suspended material, i.e., in water of low turbidity and low productivity. This leads to an interesting paradox—coral reefs require clear, nutrient-poor water, but they are among the most productive and diverse marine environments (Barnes, 1987).

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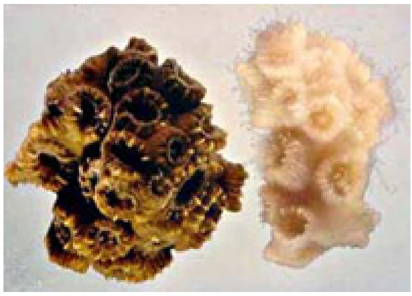

Zooxanthellae cells provide corals with pigmentation. On the left is a healthy stony coral. On the right is a stony coral that has lost its zooxanthellae cells and bleached. *Click the image for a larger view.*

coral reef conservation

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Photo: Scott Santos, State University of New York at Buffalo

Tiny plant cells called zooxanthellae live within most types of coral polyps. They help the coral survive by providing it with food resulting from photosynthesis. In turn, the coral polyps provide the cells with a protected environment and the nutrients they need to carry out photosynthesis.

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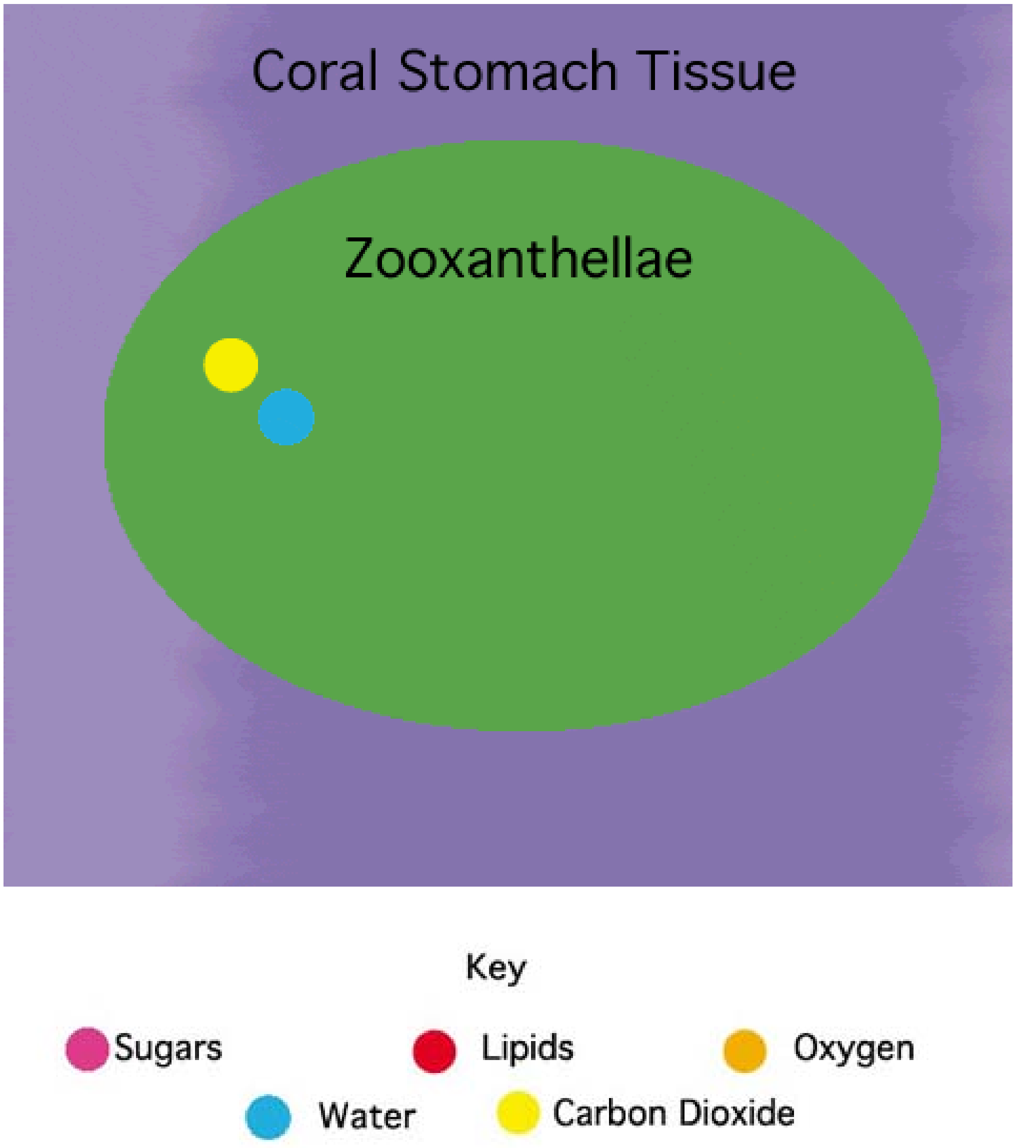

Coral polyps, which are animals, and zooxanthellae, the plant cells that live within them, have a mutualistic relationship. Coral polyps produce carbon dioxide and water as byproducts of cellular respiration. The zooxanthellae cells use the carbon dioxide and water to carry out photosynthesis. Sugars, lipids (fats) and oxygen are some of the products of photosynthesis which the zooxanthellae cells produce. The coral polyp then uses these products to grow and carry out cellular respiration. The tight recycling of products between the polyp cells and the zooxanthellae is the driving force behind the growth and productivity of coral reefs. This animation shows how the products created by the algal polyp and zooxanthellae cells are provided to each other for their mutual benefit.

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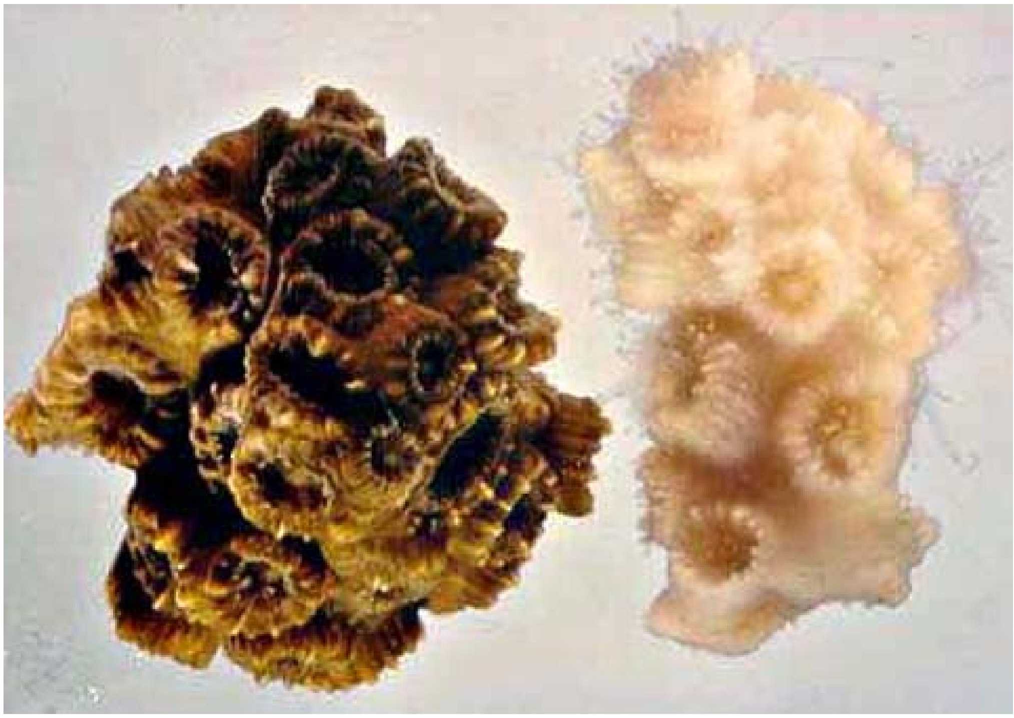

Zooxanthellae cells provide corals with pigmentation. On the left is a healthy stony coral. On the right is a stony coral that has lost its zooxanthellae cells and has taken on a bleached appearance. If a coral polyp is without zooxanthellae cells for a long period of time, it will most likely die.

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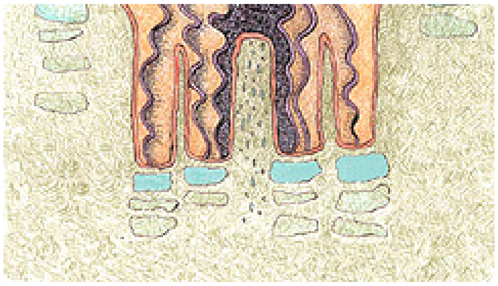
Corals

How Do Stony Corals Grow? What Forms Do They Take?

Over the course of many years, stony coral polyps can create massive reef structures. Reefs form when polyps secrete skeletons of calcium carbonate ($CaCO_3$). Most stony corals have very small polyps, averaging 1 to 3 millimeters in diameter, but entire colonies can grow very large and weigh several tons. As they grow, these reefs provide structural habitats for hundreds to thousands of different vertebrate and invertebrate species.



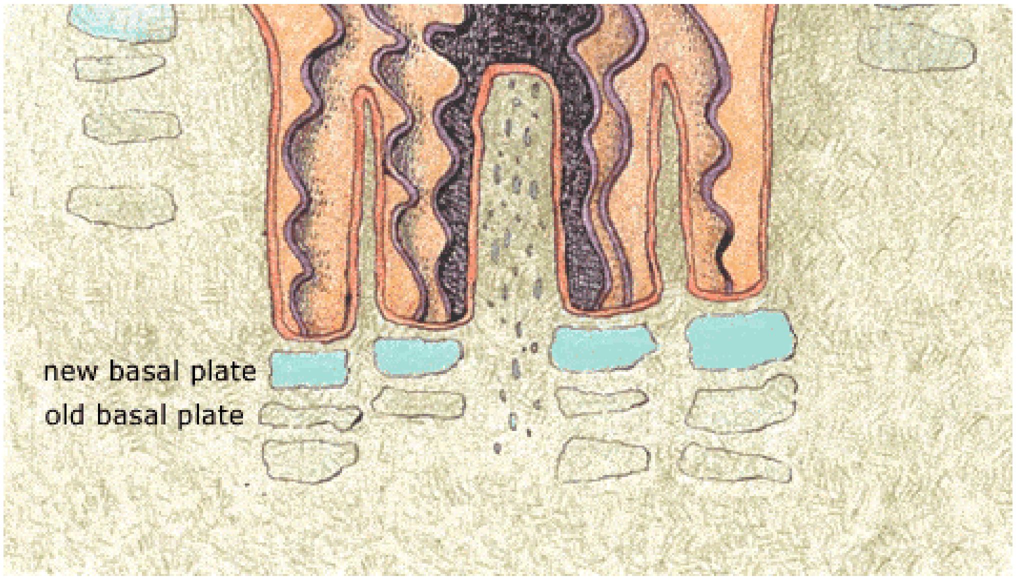
Stony corals grow when individual polyps lift themselves up from the base of the stony cups in which they reside, and create a new base above it. *Click the image for an animation of polyps growing.*

The skeletons of stony corals are secreted by the lower portion of the polyp. This process produces a cup, or calyx, in which the polyp sits. The walls surrounding the cup are called the theca, and the floor is called the basal plate. Periodically, a polyp will lift off its base and secrete a new basal plate above the old one, creating a small chamber in the skeleton. While the colony is alive, $CaCO_3$ is deposited, adding partitions and elevating the coral.

When polyps are physically stressed, they contract into their calyx so that virtually no part is exposed above their skeleton. This protects the polyp from predators and the elements (Barnes, R.D., 1987; Sumich, 1996). At other times, polyps extend out of the calyx. Most polyps extend the farthest when they feed.

Coral species number in the thousands, and stony corals take on several characteristic forms. *Click the image to see a series of eight major coral growth patterns.*

Reef-building corals exhibit a wide range of shapes. For instance, branching corals have primary and secondary branches. Digitate corals look like fingers or clumps of cigars and have no secondary branches. Table corals form table-like structures and often have fused branches. Elkhorn coral has large, flattened branches. Foliase corals have broad plate-like portions rising in whorl-like patterns. Encrusting corals grow as a thin layer against a substrate. Massive corals are ball-shaped or boulder-like and may be small as an egg or as large as a house. Mushroom corals resemble the attached or unattached tops of mushrooms.



This animation demonstrates how stony corals grow vertically. In the first frame we see a coral polyp resting on its base, which is called the basal plate. In the next frame we see the polyp's tissues begin to lift up off the basal plate, leaving an empty space beneath it (shown by dashed lines). In the next frame, the polyp rises even higher, expanding the space between it and the basal plate. In the final frame the polyp has created a new basal plate to rest on, leaving an empty space between it and the old basal plate. Using this method, a coral polyp can grow anywhere from 1 to 10 millimeters per year, depending on the species and surrounding environmental conditions.

(top)

Branching corals are characterized by having numerous branches, usually with secondary branches. This large field of branching corals belonging to the family *Acroporidae* was observed in the French Frigate Shoals, one of the many reefs that make up the Northwestern Hawaiian Islands chain.

Next coral type: Pillar Coral

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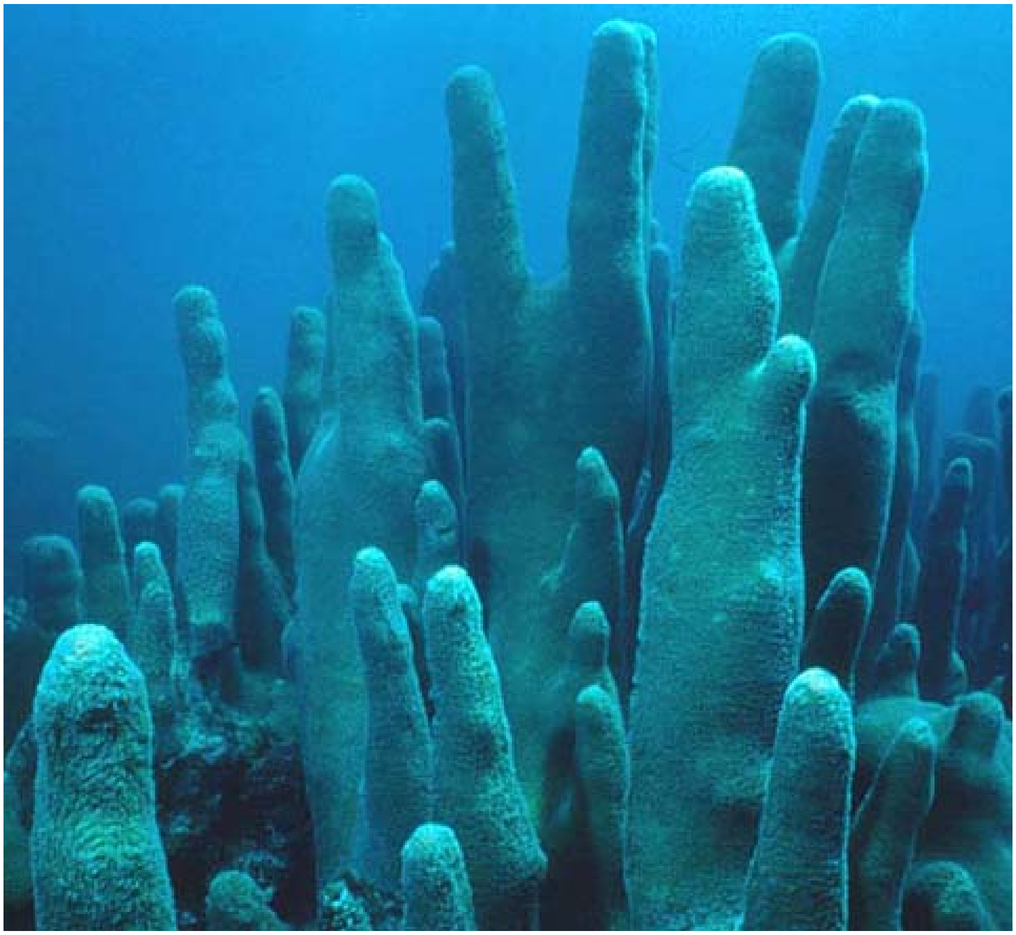

These pillar corals were seen in the Florida Keys. Pillar corals are a type of digitate coral, growing upward in cylindrical forms that have been compared to fingers or clumps of cigars. Digitate corals are distinguished from branching corals in that they have no secondary branches. (Photo: Harold Hudson)

Next coral type: Table Corals

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Corals that form broad horizontal surfaces are commonly called table corals. This pattern of growth increases the exposed surface area of the coral to the water column. Polyps are provided greater access to light for their zooxanthellae and it is easier for them to feed on zooplankton with their tentacles.

Next coral type: Elkhorn Coral

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Elkhorn corals are members of the family *Acroporidae.* They have a unique growth pattern with exceptionally thick and sturdy antler-like branches. Elkhorn corals are usually fast growing with branches increasing by 5-10 cm per year. This coral also typically lives in areas of high wave action.

Next coral type: Foliase Coral

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Corals with foliase or whorl-like growth patterns form beautiful structures that have been compared to the open petals of a flower. The coral's folds and convolutions greatly increases its surface area, and the spaces in between the whorls may provide shelter for fish and invertebrates. (Photo: Linda Wade)

Next coral type: Encrusting Coral

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Encrusting corals are characterized by low spreading growth forms that usually adhere to hard rocky surfaces. Growing larger in diameter verses upward like many other forms of coral, encrusting species have a major advantage over their branched relatives. Branching corals are much more susceptible to breakage due to violent storm conditions.

Next coral type: Massive Coral

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Massive corals are characteristically ball- or boulder-shaped and relatively slow-growing. Because they have very stable profiles, massive corals are seldom damaged by strong wave action unless they are dislodged from their holdfasts.

Next coral type: Mushroom Coral

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Mushroom corals are often flat or dome-shaped, and circular or slightly oval in shape, resembling the cap of a mushroom. Most mushroom shaped corals are solitary forms living unattached to any underlying substrate. They are found in Indo-Pacific waters.

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How Do Coral Reefs Form?

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Coral reefs begin to form when free-swimming coral larvae attach to submerged rocks or other hard surfaces along the edges of islands or continents. As the corals grow and expand, reefs take on one of three major characteristic structures — fringing, barrier or atoll. Fringing reefs, which are the most common, project seaward directly from the shore, forming borders along the shoreline and surrounding islands. Barrier reefs also border shorelines, but at a greater distance. They are separated from their adjacent land mass by a lagoon of open, often deep water. If a fringing reef forms around a volcanic island that subsides completely below sea level while the coral continues to grow upward, an atoll forms. Atolls are usually circular or oval, with a central lagoon. Parts of the reef platform may emerge as one or more islands, and gaps in the reef provide access to the central lagoon (Lalli and Parsons, 1995; Levinton, 1995; Sumich, 1996).

Corals usually develop into one of three characteristic structures: fringing reefs, barrier reefs or atolls. *Click the image to see an animation.*

In addition to being some of the most beautiful and biologically diverse habitats in the ocean, barrier reefs and atolls also are some of the oldest. With growth rates of 0.3 to 2 centimeters per year for massive corals, and up to 10 centimeters per year for branching corals, it can take up to 10,000 years for a coral reef to form from a group of larvae (Barnes, 1987). Depending on their size, barrier reefs and atolls can take from 100,000 to 30,000,000 years to fully form.

All three reef types—fringing, barrier and atoll—share similarities in their biogeographic profiles. Bottom topography, depth, wave and current strength, light, temperature, and suspended sediments all act to create characteristic horizontal and vertical zones of corals, algae and other species. These zones vary according to the location and type of reef. The major divisions common to most reefs, as they move seaward from the shore, are the reef flat, reef crest or

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algal ridge, buttress zone, and seaward slope.

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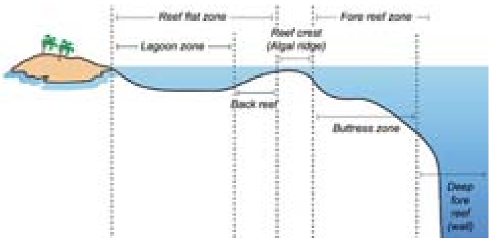

As coral reefs grow, they establish characteristic biogeographic patterns. *Click the image for a larger view.*

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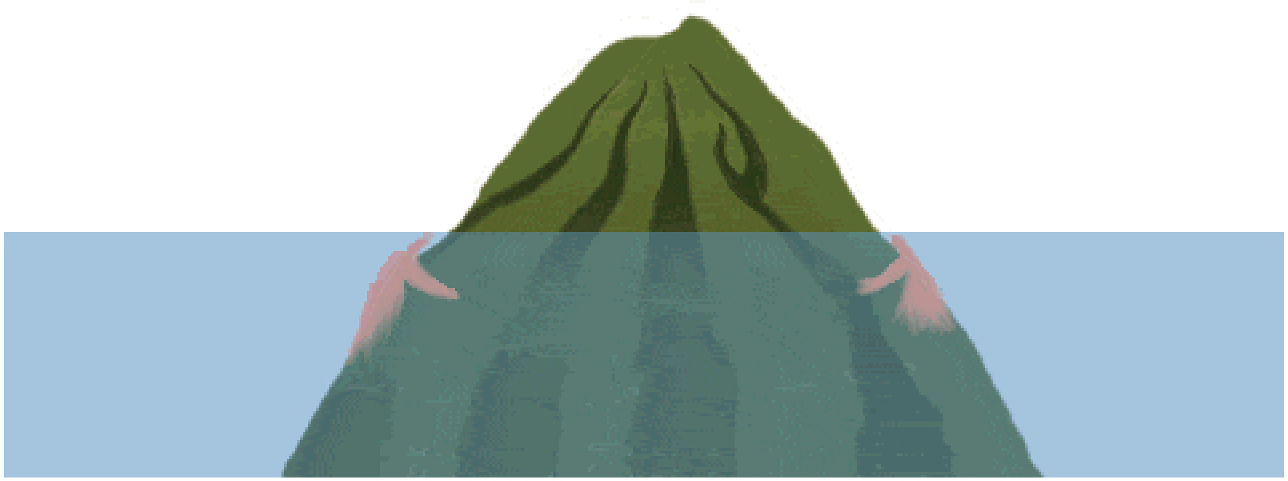

This animation shows the dynamic process of how a coral atoll forms. Corals (represented in tan and purple) begin to settle and grow around an oceanic island forming a fringing reef. It can take as long as 10,000 years for a fringing reef to form. Over the next 100,000 years, if conditions are favorable, the reef will continue to expand. As the reef expands, the interior island usually begins to subside and the fringing reef turns into a barrier reef. When the island completely subsides beneath the water leaving a ring of growing coral with an open lagoon in its center, it is called an atoll. The process of atoll formation may take as long as 30,000,000 years to occur.

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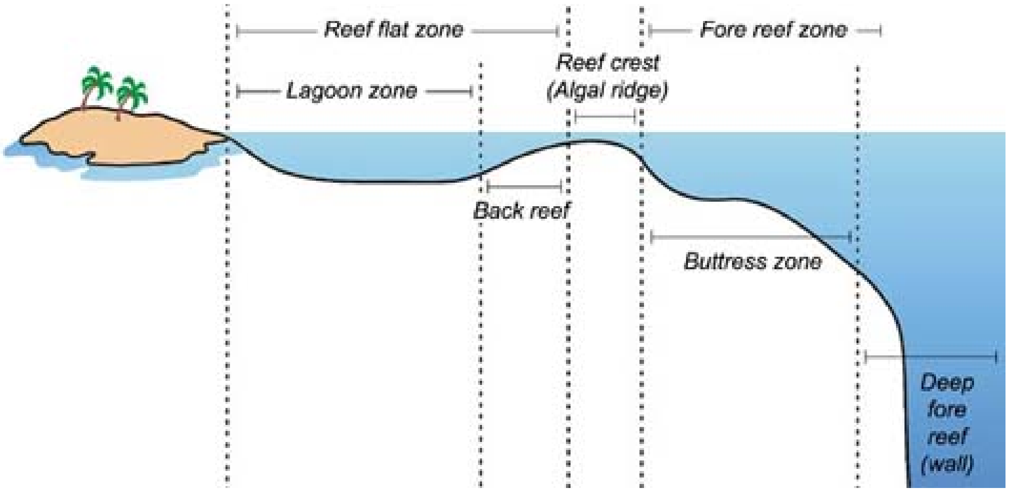

Over time, many coral reefs develop similar biogeographic profiles. Moving seaward from the shore, the reef flat, reef crest, buttress zone and seaward slope form the major divisions common to most reefs. The reef flat is on the sheltered side of the reef. The substrate is formed of coral rock and loose sand, and large parts may be exposed during low tides. The reef crest, or algal ridge, is the highest point of the reef, and is almost always exposed at low tide. The reef crest is exposed to the full fury of incoming waves, and living corals are practically nonexistent here. Small crabs, shrimps, and other animals often live in the cavities under the reef crest, protected from waves and predators. The buttress zone is a rugged area of spurs, or buttresses, radiating out from the reef. Deep channels that slope down the reef face are interspersed between the buttresses. The buttress zone acts to dissipate the tremendous force of unabating waves and stabilizes the reef structure. The buttress zone also drains debris and sediment off the reef and into deeper water. The dropoff of a reef slope can extend hundreds of feet downward. While light intensity decreases, reduced wave action allows greater numbers of coral species to develop. Sponges, sea whips, sea fans, and non-reef-building corals become abundant and gradually replace stony corals in deeper, darker water.

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Where Are Reef Building Corals Found?

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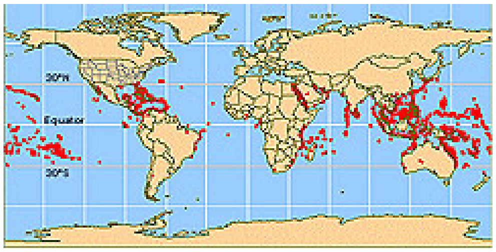

The majority of reef-building corals are found in tropical and subtropical waters. *Click the image for a larger view.*

Reef-building corals are restricted in their geographic distribution by their physiology. For instance, reef-building corals cannot tolerate water temperatures below 18^0 Celsius (C). Many grow optimally in water temperatures between 23^0 and 29^{0}C, but some can tolerate temperatures as high as 40^{0}C for short periods. Most also require very saline (salty) water ranging from 32 to 42 parts per thousand, which must also be clear so that a maximum amount of light penetrates it. The corals' requirement for high light also explains why most reef-building species are restricted to the euphotic zone, the region in the ocean where light penetrates to a depth of approximately 70 meters (Lalli and Parsons, 1995).

Corals have recently been investigated at previously unimagined depths. These *Lophelia* corals were discovered in 1,250 feet of water off the coast of North Carolina. *Click the image for an image of a single branch of this coral.*

The number of species of corals on a reef declines rapidly in deeper water. Corals are also generally absent in turbid, or murky waters, because high levels of suspended sediments smother them, clogging their mouths, impairing feeding and decreasing the depth to which light can penetrate. In colder regions, murkier waters, or at depths below 70 m, certain species of corals still exist on hard substrates, but their capacity to secrete calcium carbonate is greatly reduced (Barnes, R.D., 1987).

With such stringent environmental requirements, reefs generally are confined to tropical and semitropical waters. The number of species of stony corals decreases in higher latitudes up to about 30^0 north and south. Beyond these latitudinal boundaries, reef corals are usually not found. Bermuda, at 32^0 north latitude, is an exception to this rule because it lies directly in the path of the Gulf Stream's warming waters (Barnes, R.D., 1987).

Not only are reef-building corals confined by a specific range of environmental conditions, but as adults, almost all of them are sessile. This means that for their entire lives, they remain on the same spot on the sea floor. Reef-building corals have developed reproductive, feeding and social behaviors that allow them to deal favorably with this situation.

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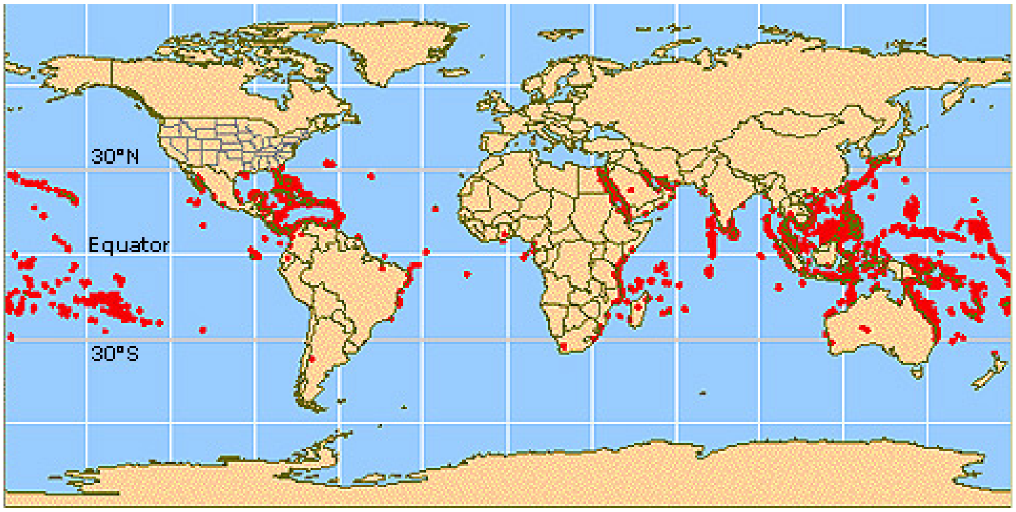

The majority of reef building corals are found within tropical and subtropical waters. These typically occur between 30^0 north and 30^0 south latitudes. The red dots on this map show the location of major stony coral reefs of the world.

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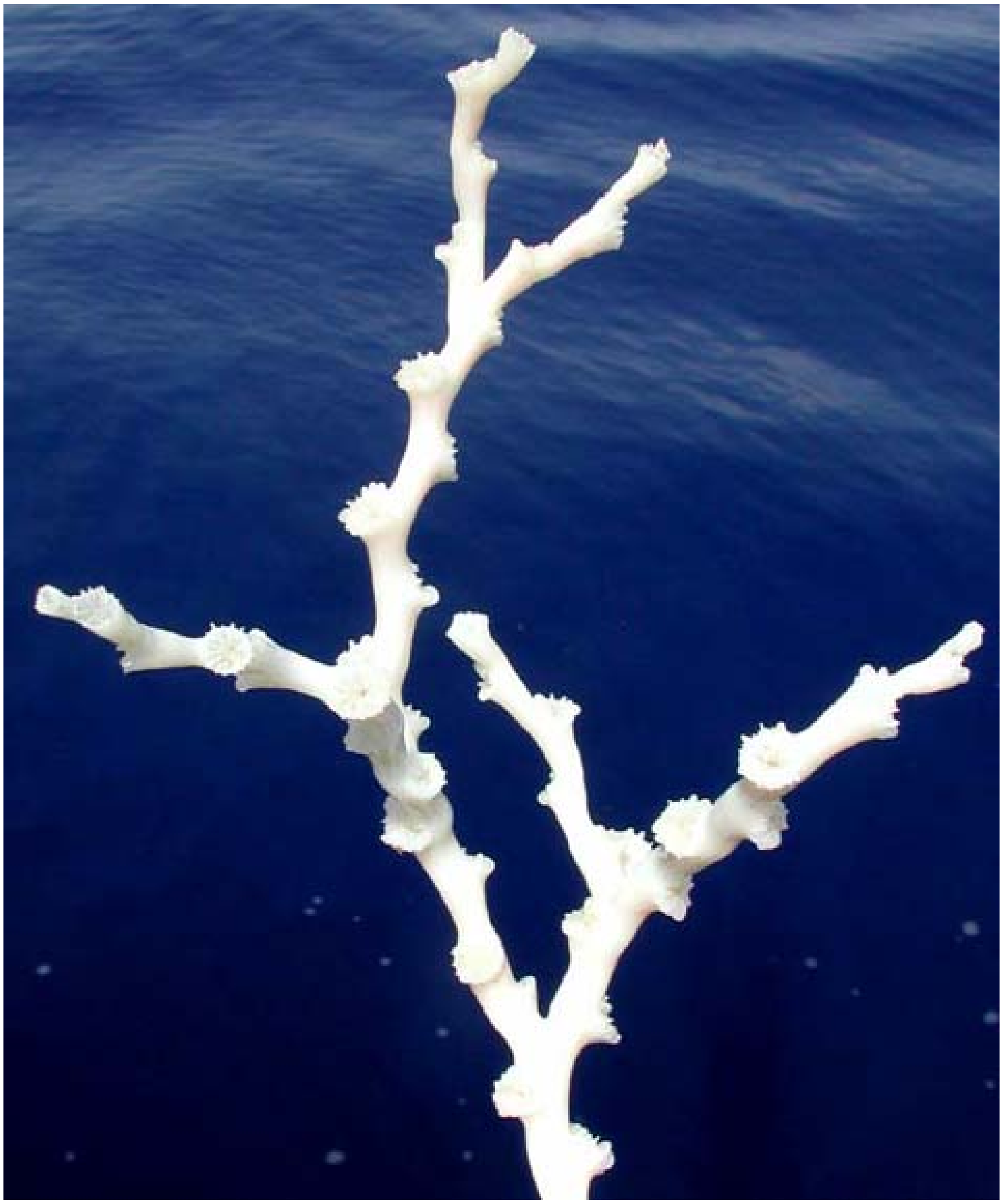

This branch of *Lophelia* coral was brought up from over 1,250 feet of water from a reef off the coast of North Carolina. The reef that this branch of coral was taken from is believed to be over 10,000 years old. Deep sea corals are challenging our knowledge of coral growth and worldwide distribution patterns. Unlike shallow water corals that take on a stark white appearance from expelling their symbiotic algae, *Lophelia* corals are naturally white because they have no zooxanthellae cells.

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Many species of stony coral spawn in mass synchronized events, releasing millions of eggs and sperm into the water at the same time. *Click the image for a larger view.* (Photo: Emma Hickerson)

Corals can reproduce asexually and sexually. In asexual reproduction, new clonal polyps bud off from parent polyps to expand or begin new colonies (Sumich, 1996). This occurs when the parent polyp reaches a certain size and divides. This process continues throughout the animal's life (Barnes and Hughes, 1999).

About three-quarters of all stony corals produce male and/or female gametes. Most of these species are broadcast spawners, releasing massive numbers of eggs and sperm into the water to distribute their offspring over a broad geographic area (Veron, 2000). The eggs and sperm join to form free-floating, or planktonic, larvae called planulae. Large numbers of planulae are produced to compensate for the many hazards, such as predators, that they encounter as they are carried by water currents. The time between planulae formation and settlement is a period of exceptionally high mortality among corals (Barnes and Hughes, 1999). View video of coral spawning.

Here, a coral releases sperm into the water. *Click the image for a larger view.* (Photo: Brendan Holland)

Along many reefs, spawning occurs as a mass synchronized event, when all the coral species in an area release their eggs and sperm at about the same time. The timing of a broadcast spawning event is very important because males and female corals cannot move into reproductive contact with each other. Because colonies may be separated by wide distances, this release must be both precisely and broadly timed, and usually occurs in response to multiple environmental cues (Veron, 2000).

The long-term control of spawning may be related to temperature, day length and/or rate of temperature change (either increasing or decreasing). The short-term (getting ready to spawn) control is usually based on lunar cues. The final release, or spawn, is usually based on the time of sunset (Veron, 2000).

Planulae swim upward toward the light (exhibiting positive phototaxis), entering the surface waters and being transported by the current. After floating at the surface, the planulae swim back down to the bottom, where, if conditions are favorable, they will settle (Barnes and Hughes, 1999). Once the planulae settle, they metamorphose into polyps and form colonies that increase in size. In most species, the larvae settle within two days, although some will swim for up to three weeks, and in one known instance, two months (Jones and Endean, 1973).

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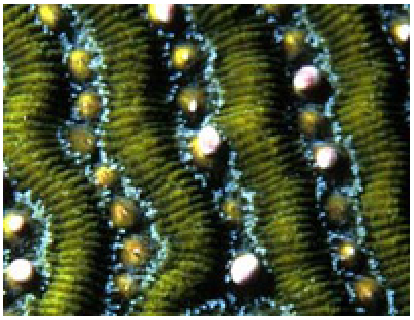

This close-up photo shows rows of individual brain coral polyps in different stages of releasing their eggs. *Click the image for a larger view.* (Photo: Burek)

coral reef conservation

Many species of stony coral spawn in mass synchronized events, releasing millions of eggs and countless numbers of sperm into the water at the same time. Here a brittle star sits on top of a large coral head is it releases its eggs into the water column. (Photo: Emma Hickerson)

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Here a coral with its large polyps exposed releases sperm into the water. (Photo: Brendan Holland)

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n o a a o c e a n s a n d c o a s t s

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In the first segment of this video, a coral head releases male gametophytes (sperm) into the water column, creating a whitish cloud. Look carefully at the early stages of this video clip to see individual polyps simultaneously releasing distinct streams of sperm. In the second half of the video, another coral head releases female gametophytes into the water column. Unlike the male gametophytes, the female gametophytes are released progressively across the coral head. This video was taken during a 2002 coral reef mass spawning event in the Flower Garden Banks National Marine Sancuary, which is located approximately 100 miles south of the Texas Louisiana border in the Gulf of Mexico. Video Credit - Emma Hickerson.

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This close-up photo shows rows of individual brain coral polyps in different stages of releasing their eggs. Images like these are very hard to obtain because mass synchronized spawnings only occur on a few nights each year. (Photo: Burek)

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Corals

Importance of Coral Reefs

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Healthy coral reefs contain thousands of fish and invertebrate species found nowhere else on Earth. *Click the image for a larger view.*

Coral reefs are some of the most diverse and valuable ecosystems on Earth. Coral reefs support more species per unit area than any other marine environment, including about 4,000 species of fish, 800 species of hard corals and hundreds of other species. Scientists estimate that there may be another 1 to 8 million undiscovered species of organisms living in and around reefs (Reaka-Kudla, 1997). This biodiversity is considered key to finding new medicines for the 21st century. Many drugs are now being developed from coral reef animals and plants as possible cures for cancer, arthritis, human bacterial infections, viruses, and other diseases.

Storehouses of immense biological wealth, reefs also provide economic and environmental services to millions of people. Coral reefs may provide goods and services worth $375 billion each year. This is an amazing figure for an environment that covers less than 1 percent of the Earth’s surface (Costanza et al., 1997).

In the 1890s, harvesting sponges was second only to cigar-making in economic importance in the Florida Keys. Nets of recently harvested marine sponges are drying on the top of the boat's wheelhouse. *Click the image for a larger vew.* (photo: Scott Larosa)

Healthy reefs contribute to local economies through tourism. Diving tours, fishing trips, hotels, restaurants, and other businesses based near reef systems provide millions of jobs and contribute billions of dollars all over the world. Recent studies show that millions of people visit coral reefs in the Florida Keys every year. These reefs alone are estimated to have an asset value of $7.6 billion (Johns et al., 2001).

The commercial value of U.S. fisheries from coral reefs is over $100 million (NMFS/NOAA, 2001). In addition, the annual value of reef-dependent recreational fisheries probably exceeds $100 million per year. In developing countries, coral reefs contribute about one-quarter of the total fish catch, providing critical food resources for tens of millions of people (Jameson et al., 1995).

Coral reefs buffer adjacent shorelines from wave action and prevent erosion,

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property damage and loss of life. Reefs also protect the highly productive wetlands along the coast, as well as ports and harbors and the economies they support. Globally, half a billion people are estimated to live within 100 kilometers of a coral reef and benefit from its production and protection.

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coral reef conservation

Healthy coral reefs contain thousands of fish and invertebrate species found nowhere else on Earth. They provide millions of dollars to local economies through tourism and fishing. Many scientists believe that drugs to treat cancer, arthritis, and other diseases may be found by examining the unique species that live only in and around reef systems.

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In the 1890s, harvesting sponges was second only to cigar-making in economic importance in the Florida Keys. Today, commercial sponging still takes place in these coral reefs areas, but on a much smaller scale. Large nets of recently harvested marine sponges can be seen drying on the top of this boat's wheelhouse. (photo: Scott Larosa)

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Corals

Natural Threats to Coral Reefs

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Coral reefs face numerous threats. Weather-related damage to reefs occurs frequently. Large and powerful waves from hurricanes and cyclones can break apart or flatten large coral heads, scattering their fragments (Barnes & Hughes, 1999; Jones & Endean, 1976). A single storm seldom kills off an entire colony, but slow-growing corals may be overgrown by algae before they can recover (UVI, 2001).

Corals growing in very shallow water are the most vulnerable to environmental hazards. Shallow tides can expose them to the air, drying the polyps out and killing them. Branching corals growing in shallow water can be smashed by storms.

Reefs also are threatened by tidal emersions. Long periods of exceptionally low tides leave shallow water coral heads exposed, damaging reefs. The amount of damage depends on the time of day and the weather conditions. Corals exposed during daylight hours are subjected to the most ultraviolet radiation, which can overheat and dry out the coral's tissues. Corals may become so physiologically stressed that they begin to expel their symbiotic zooxanthellae, which leads to bleaching, and in many cases, death (Barnes & Huges, 1999).

Increased sea surface temperatures, decreased sea level and increased salinity from altered rainfall can all result from weather patterns such as El Niño. Together these conditions can have devastating effects on a coral's physiology (Forrester, 1997.) During the 1997-1998 El Niño season, extensive and severe coral reef bleaching occurred in the Indo-Pacific and Caribbean. Approximately 70 to 80 percent of all shallow-water corals on many Indo-Pacific reefs were killed. (NMFS Office of Protected Resources, 2001).

In addition to severe weather, corals are vulnerable to attacks by predators. Large sea stars like this crown-of-thorns (*Acanthaster planci)* slowly crawl over coral reefs consuming all of the living coral tissue they come into contact with. *Click the image for a larger view.*

In addition to weather, corals are vulnerable to predation. Fish, marine worms, barnacles, crabs, snails and sea stars all prey on the soft inner tissues of coral polyps (Jones & Endean, 1976). In extreme cases, entire reefs can be devastated by this kind of predation. In 1978 and 1979, a massive outbreak of crown-of-thorns starfish (*Acanthaster planci)* attacked the reef at the Fagatele Bay

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National Marine Sanctuary in American Samoa. Approximately 90 percent of the corals were destroyed.

Coral reefs may recover from periodic traumas caused by weather or other natural occurrences. If, however, corals are subjected to numerous and sustained stresses including those imposed by people, the strain may be too much for them to endure, and they will perish.

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In addition to severe weather, corals are vulnerable to attacks by predators. As sessile adults, corals spend their entire lives fixed to the same spot on the ocean floor. Certain predators have evolved to take advantage of this. Large sea stars like this Crown-of-thorns (*Acanthaster planci*) slowly crawl over coral reefs, consuming all of the living coral tissue that they come into contact with.

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Corals

Anthropogenic Threats to Corals

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Human-caused, or anthropogenic activities are major threats to coral reefs. Pollution, overfishing, destructive fishing practices using dynamite or cyanide, collecting live corals for the aquarium market and mining coral for building materials are some of the many ways that people damage reefs all around the world every day. (Bryant et al., 1998)

Ships that become grounded on coral reefs may cause immediate and long-term damage to reefs. *Click the image for a larger view.*

One of the most significant threats to reefs is pollution. Land-based runoff and pollutant discharges can result from dredging, coastal development, agricultural and deforestation activities, and sewage treatment plant operations. This runoff may contain sediments, nutrients, chemicals, insecticides, oil, and debris (UVI, 2001).

When some pollutants enter the water, nutrient levels can increase, promoting the rapid growth of algae and other organisms that can smother corals (Jones & Endean, 1976).

Coral reefs also are affected by leaking fuels, anti-fouling paints and coatings, and other chemicals that enter the water (UVI, 2001). Petroleum spills do not always appear to affect corals directly because the oil usually stays near the surface of the water, and much of it evaporates into the atmosphere within days. However, if an oil spill occurs while corals are spawning, the eggs and sperm can be damaged as they float near the surface before they fertilize and settle. So, in addition to compromising water quality, oil pollution can disrupt the reproductive success of corals, making them vulnerable to other types of disturbances. (Bryant, et al, 1998).

There are many ways that pollution can damage reefs. Debris like this plastic bag can quickly become entangled on a coral and smother it. *Click the image for a larger view.*

In many areas, coral reefs are destroyed when coral heads and brightly-colored reef fishes are collected for the aquarium and jewelry trade. Careless or untrained divers can trample fragile corals, and many fishing techniques can be destructive. In blast fishing, dynamite or other heavy explosives are detonated to startle fish out of hiding places. This practice indiscriminately kills other species and can crack and stress corals so much so that they expel their zooxanthellae. As a result, large sections of reefs can be destroyed. Cyanide fishing, which involves spraying or dumping cyanide onto reefs to stun and capture live fish, also kills coral polyps and degrades the reef habitat (NMFS Office of Protected

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Resources, 2001). More than 40 countries are affected by blast fishing, and more than 15 countries have reported cyanide fishing activities (ICRI, 1995).

coral reef conservation

Other damaging fishing techniques include deep water trawling, which involves dragging a fishing net along the sea bottom, and muro-ami netting, in which reefs are pounded with weighted bags to startle fish out of crevices. (Bryant, et al, 1998). Often, fishing nets left as debris can be problematic in areas of wave disturbance. In shallow water, live corals become entangled in these nets and are torn away from their bases (Coles, 1996). In addition anchors dropped from fishing vessels onto reefs can break and destroy coral colonies (Bryant, et al, 1998).

Certain types of fishing can severely damage reefs. Trawlers catch fish by dragging nets along the ocean bottom. Reefs in the net's path get mowed down. Long wide patches of rubble and sand are all that is left in their wake.

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Ships that become grounded on coral reefs may cause immediate and long-term damage to reefs. A grounded ship may smash hundreds of years worth of coral growth in an instant. Over time, fuel, oil, paints and other chemicals may leak from the ship, continuing to damage the fragile corals as the ship's hull rusts in the harsh marine environment.

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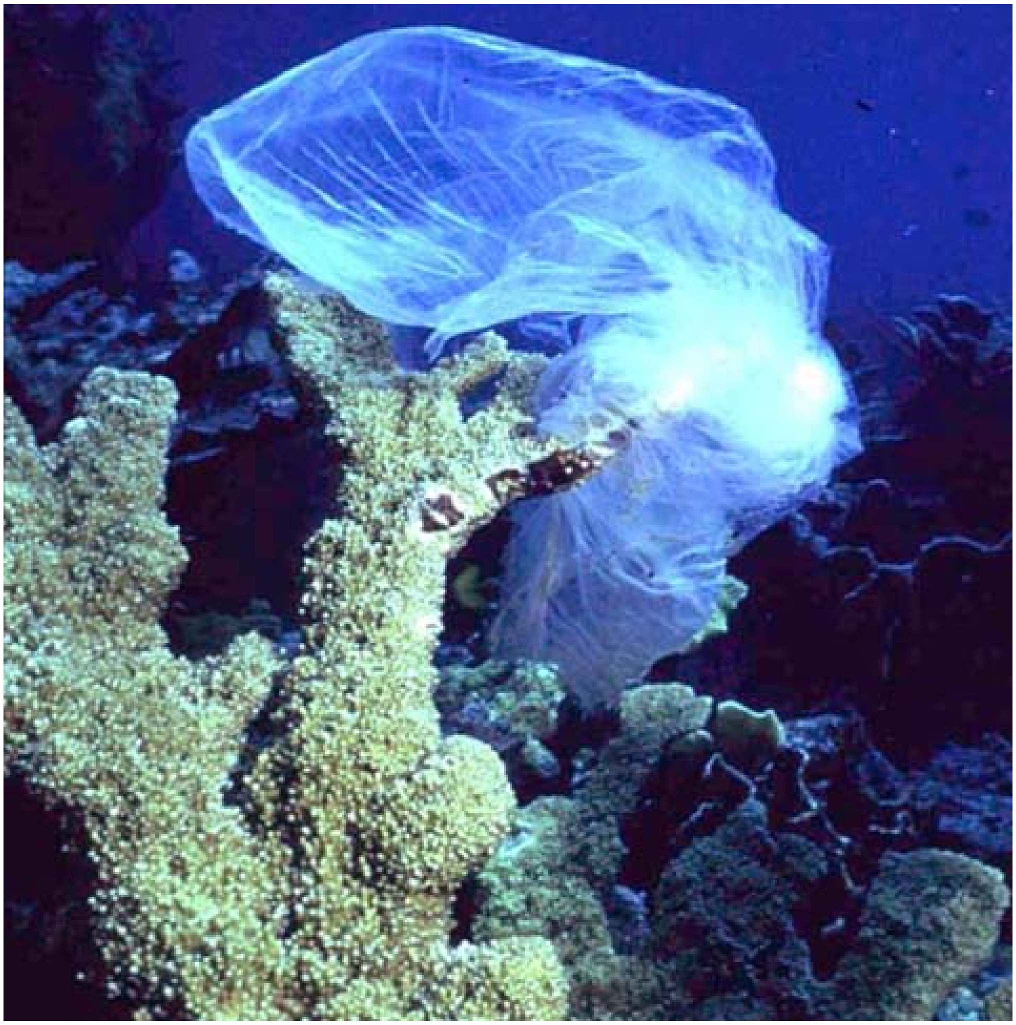

There are many ways that pollution can damage reefs. Debris like this plastic bag can quickly become entangled on a coral and smother it.

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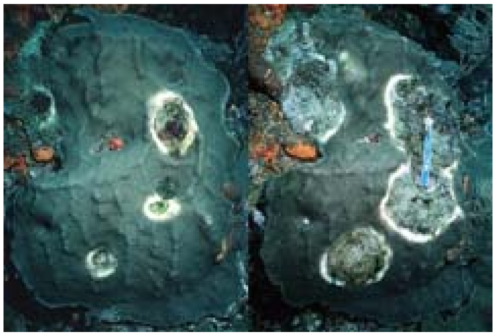
Corals

Coral Diseases

Coral diseases generally occur in response to biological stresses, such as bacteria, fungi and viruses, and nonbiological stresses, such as increased sea surface temperatures, ultraviolet radiation and pollutants. One type of stress may exacerbate the other (NMFS, 2001).

This large brain coral is being attacked by black-band disease. This is the only coral disease that can be successfully treated. *Click the image for a larger view.* (Photo: Andy Bruckner, NOAA)

The frequency of coral diseases has increased significantly over the last 10 years, causing widespread mortality among reef-building corals. Many scientists believe the increase is related to deteriorating water quality associated with human-made pollutants and increased sea surface temperatures. These factors may allow for the proliferation and colonization of microbes. However, exact causes for coral diseases remain elusive. The onset of most diseases likely is a response to multiple factors (NMFS, 2001).



Yellow-band disease can rapidly spread over a coral, destroying the delicate underlying tissues. On the left is a massive coral in the early stages of attack by yellow band disease. On the right is the same coral several weeks later. Note how rapidly the area of destroyed tissue has expanded. *Click the image for a larger view.* (Photo: Andy Bruckner, NOAA)

While the pathologies, or mechanisms by which many diseases act upon the coral polyp are not well known, the effects that these diseases have on corals has been well documented. Black-band disease, discolored spots, red-band disease, and yellow-blotch/band disease appear as discolored bands, spots or lesions on the surface of the coral. Over time, these progress across or expand over the coral's surface consuming the living tissue and leaving the stark white coral skeleton in their wake. Other diseases, such as rapid wasting, white-band, white-plague and white-pox, often cause large patches of living coral tissue to slough off, exposing the skeleton beneath. Once exposed, the coral's limestone skeleton can be a fertile breeding ground for algae and encrusting invertebrates. The colonization and overgrowth of the exposed coral skeleton by foreign organisms often results in the health of the entire colony taking a downward spiral from which it seldom recovers.

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This large brain coral is being attacked by black-band disease. This disease is caused by a cyanobacteria, or blue-green algae, and manifests itself as an expanding black band over the surface of the coral. This is the only coral disease that can be successfully treated. (Photo: Andy Bruckner, NOAA)

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Most corals are made up of hundreds of thousands individual polyps like this one. Many stony coral polyps range in size from one to three millimeters in diameter. Anatomically simple organisms, much of the polyp’s body is taken up by a stomach filled with digestive filaments. Open at only one end, the polyp takes in food and expels waste through its mouth. A ring of tentacles surrounding the mouth aids in capturing food, expelling waste and clearing away debris. Most food is captured with the help of special stinging cells called nematocysts which are inside the polyp' outer tissues, which is called the epidermis. Calcium carbonate is secreted by reef-building polyps and forms a protective cup called a calyx within which the polyps sits. The base of the calyx upon which the polyp sits is called the basal plate. The walls surrounding the calyx are called the theca. The coenosarc is a thin band of living tissue that connect individual polyps to one another and help make it a colonial organism.

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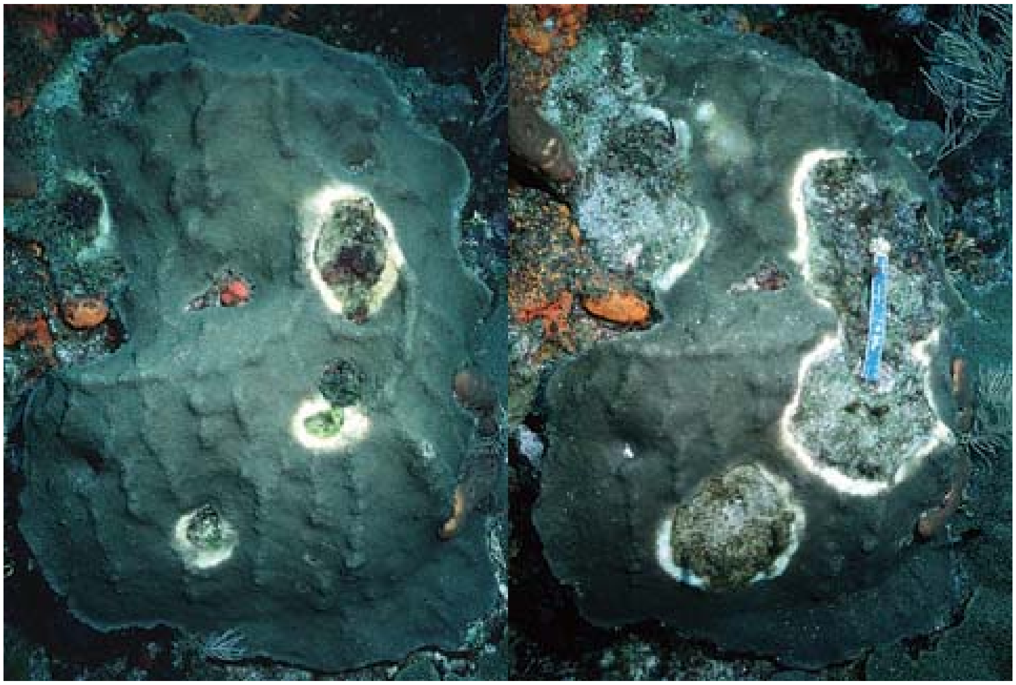

Yellow-band disease can rapidly spread over a coral destroying the delicate underlying tissues. On the left is a massive coral in the early stages of attack by yellow-band disease. On the right is the same coral several weeks later. Note how rapidly the area of destroyed tissue has expanded. (Photo: Andy Bruckner, NOAA)

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Corals

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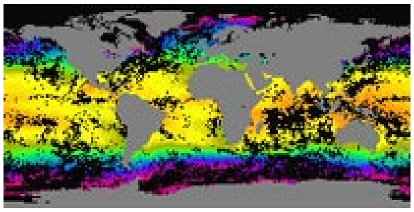
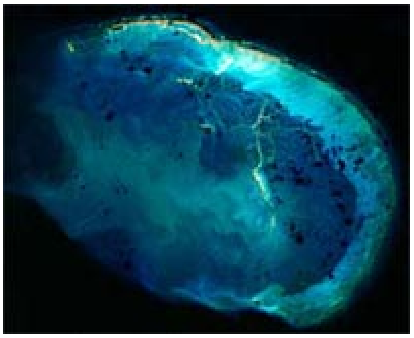


Using color enhanced images of sea surface temperature scientists can observe how environmental changes on a global scale can affect coral reefs in specific regions. *Click the image for an animation of sea surface temperature change over time.*

Coral reefs are truly miracles of nature. These beautiful ecosystems are biologically and economically valuable. Beset by natural threats and human activities, coral reefs and the magnificent creatures that call them home are in danger of disappearing if actions are not taken to protect them.

In 1998, the President of the United States established the Coral Reef Task Force (CRTF) to protect and conserve coral reefs. The goals of this group are to lead U.S. efforts to protect, restore and provide for the sustainable use of coral reef ecosystems. The CRTF is charged to map and monitor all U.S.-held coral reefs; funding research to identify the major causes and consequences of coral reef degradation; working to conserve and restore coral reefs worldwide; and working with governments, scientific and environmental organizations, and the commercial sector to reduce coral reef destruction and restore damaged coral reefs. In cooperation with many partners, the National Oceanic and Atmospheric Administration (NOAA) has been working to achieve the goals of the CRTF.



This high resolution image of the French Frigate Shoals in the Northwestern Hawaiian Islands group was taken by the Landsat 7 satellite. *Click the image for a larger view.*

Using high-resolution satellite imagery and Global Positioning Satellite (GPS) technology, comprehensive digital maps have been made of reefs in Puerto Rico, the U.S. Virgin Islands, the eight main Hawaiian Islands and the Northwestern Hawaiian Islands. By 2009, NOAA and its partners intend to map all shallow U.S. coral reefs. Satellite technology is also used to monitor elevated sea surface temperatures, which can cause coral bleaching and to detect harmful algal blooms that can smother reefs.

NOAA also monitors reefs using the Coral Reef Early Warning System (CREWS). This system consists of specially designed buoys deployed at reef sites that measure air temperature, wind speed and direction, barometric pressure, sea temperature, salinity and tidal level. Every hour, these data are transmitted to scientists about conditions that may cause bleaching on coral reefs. By 2006, a network of 18 CREWS stations is planned for deployment in the Bahamas, U.S. Virgin Islands and American Samoa.

In addition to the remote monitoring work conducted by satellites and buoys, NOAA's National Undersea Research Program

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(NURP) conducts reasearch, assessment and restoration projects of coral reefs in marine reserves and among deep sea coral banks.

Remote sensing and satellite imagery play important roles in mapping, monitoring and protecting coral reefs, but there is no substitute for on-site evaluation. *Click the image for a larger view.*

Restoration programs are being actively implemented by NOAA’s National Marine Fisheries Service (NMFS) and NOAA's National Ocean Servive (NOS). Together these groups are working to remove more than 1,000 metric tons of marine debris from the Northwestern Hawaiian Islands.

Monitoring, research and restoration all are essential in the effort to safeguard coral reefs. However, to ultimately protect coral reefs, legal mechanisms may be necessary. One legal mechanism involves the establishment of marine protected areas (MPAs). Because MPAs have the added force of law behind them, a protected marine enclosure—such as a coral reef system—may stand a better chance for survival.

coral reef conservation

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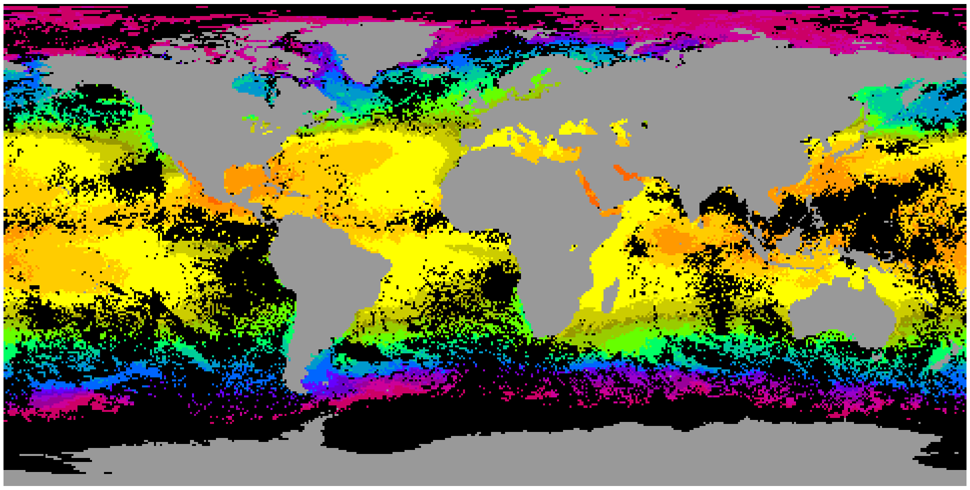

This animation is a composite of average weekly sea surface temperatures over the course of a year. Yellow and orange represent hotter waters and green, blue and purple represent progressively cooler waters. Broad scale, environmental processes can have long ranging effects on coral reefs, which are particularly sensitive to changes in temperature. Studying trends on a global scale can help scientists understand why reefs in certain areas are flourishing and others are suffering.

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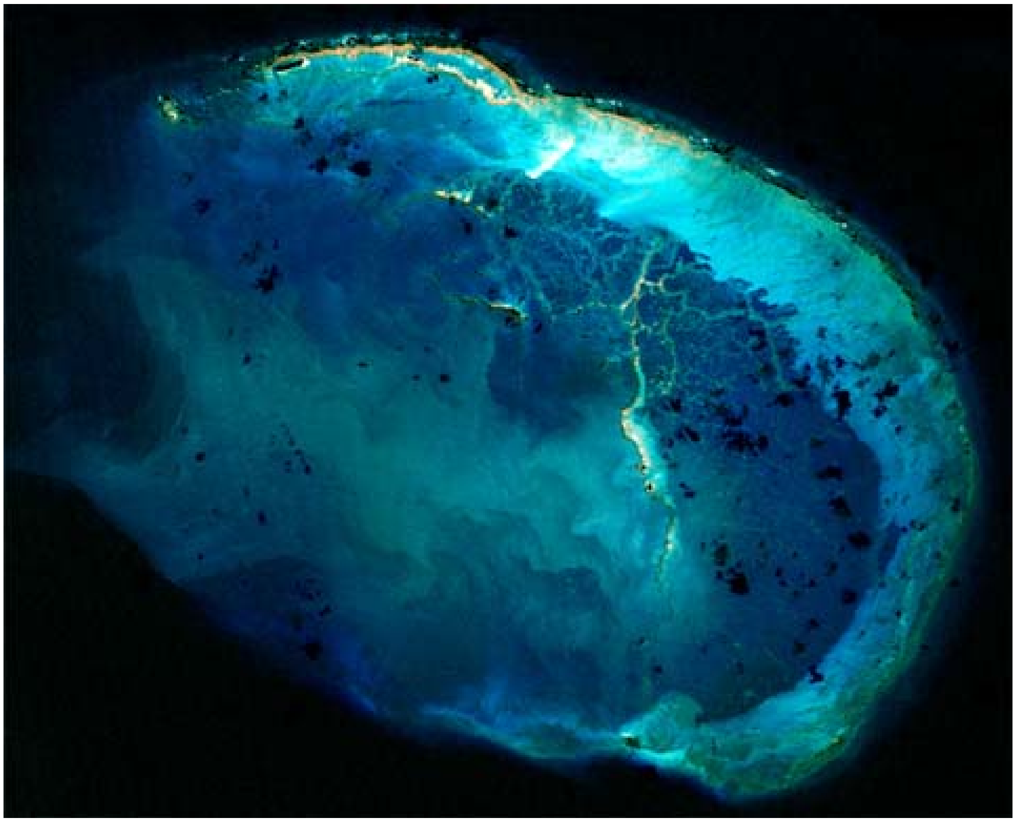

This high-resolution image of the French Frigate Shoals in the Northwestern Hawaiian Islands group was taken by the Landsat 7 satellite. Launched in 1998, Landsat 7 circles the earth at an altitude of 705 kilometers. The detailed imagery from Landsat 7 helps scientists conduct preliminary mapping and evaluation of remote coral reefs. Without this valuable tool, examining these remote reef sites would require a significant investment of time and money.

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Remote sensing and satellite imagery play important roles in mapping, monitoring and protecting coral reefs, but there is no substitute for on-site evaluation. Here, scientists return to the same corals every year and take high-resolution pictures of them. This helps them determine coral health over long periods of time.

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