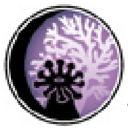

Welcome to Corals

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.

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.

To go directly to the *SciLinks* log-on page, click here: http://www.scilinks.org/.

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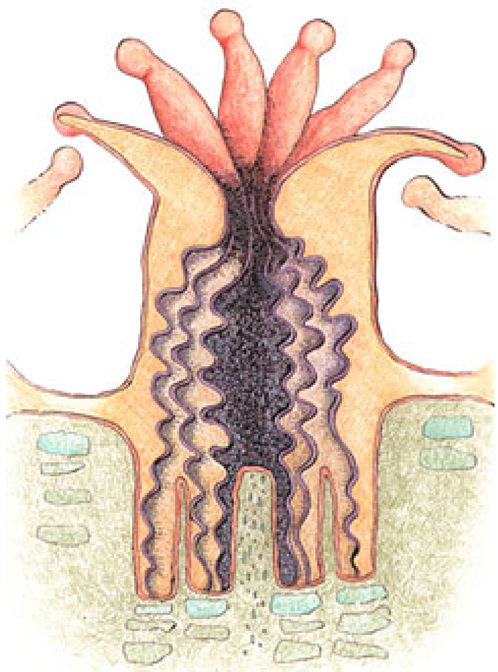
Corals

What are Corals?

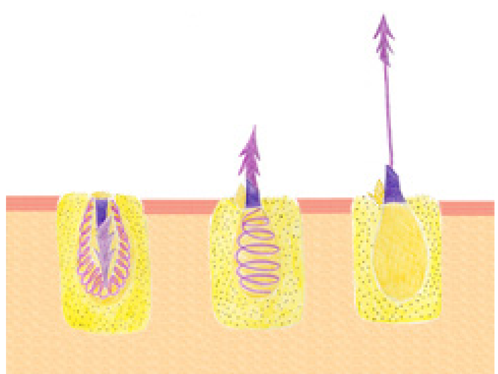
When corals are mentioned, most people immediately think about clear, warm tropical seas and fish-filled reefs. In fact, the stony, shallow-water corals—the kind that build reefs—are only one type of coral. There are also soft corals and deep water corals that live in dark cold waters.



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.*

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 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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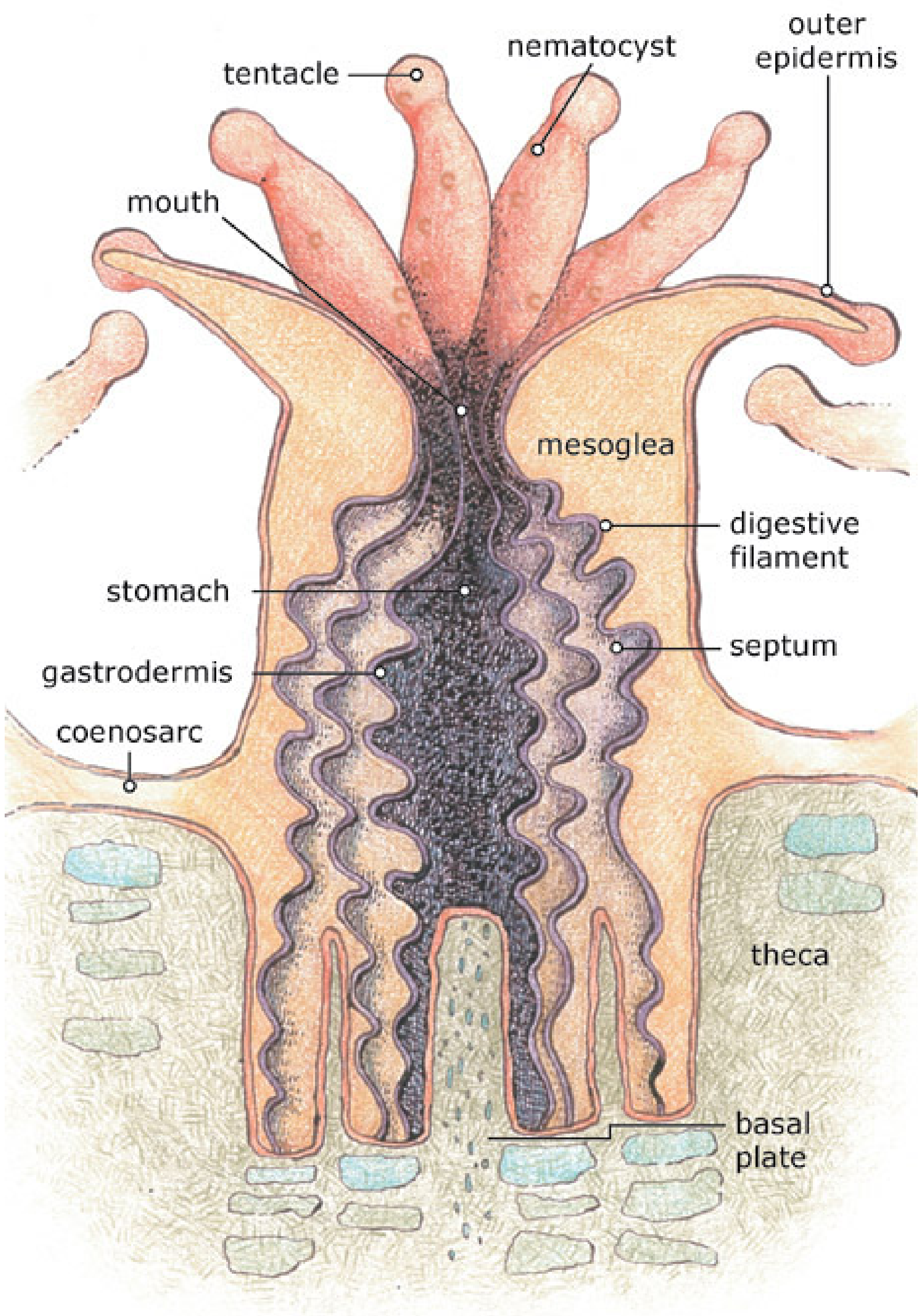
coral reef conservation


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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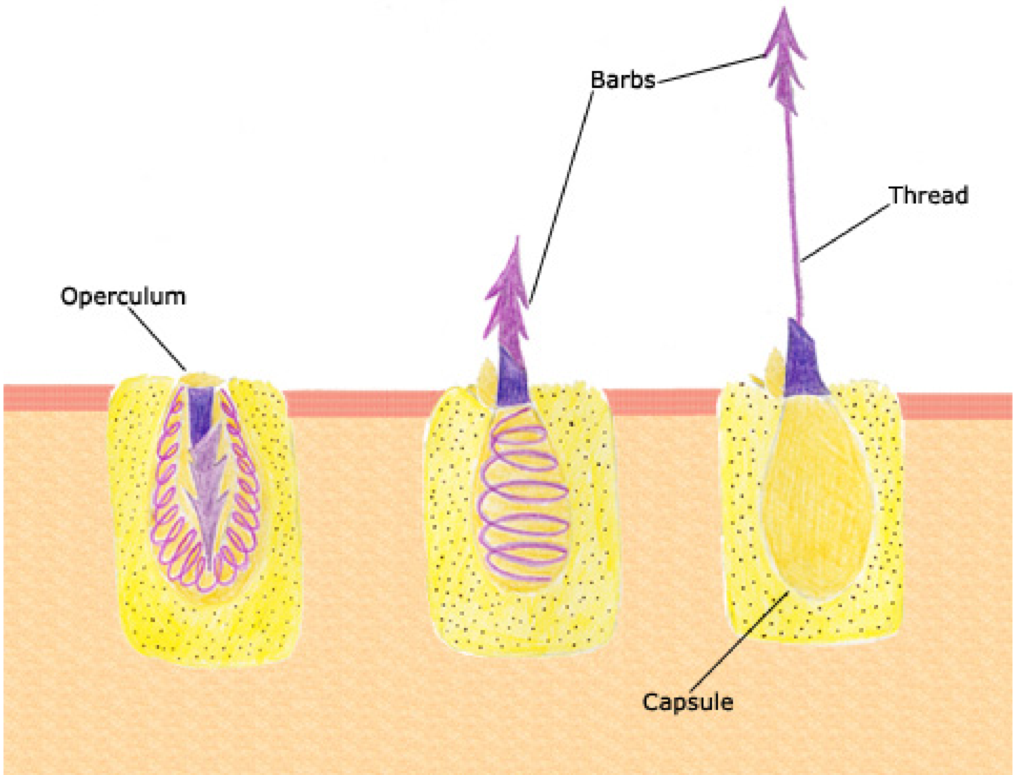


The diagram above shows the anatomy of a nematocyst cell and its “firing” sequence, from left to right. On the far left is a nematocyst inside its cellular capsule. The cell’s thread is coiled under pressure and wrapped around a stinging barb. When potential prey makes contact with the tentacles of a 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.

(top)

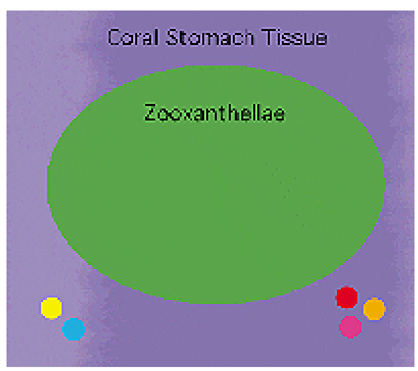
Corals

Zooxanthellae... What's That?

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).

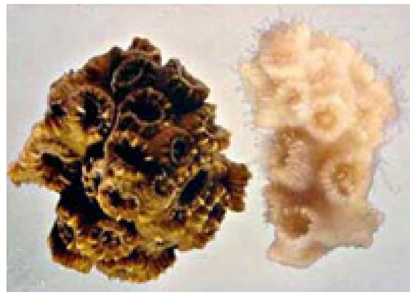
Tiny plant cells called zooxanthellae live within most types of coral polyps. They provide the coral with foods resulting from photosynthesis. *Click the image for a larger view of these cells.*

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).



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.*

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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.

(top)

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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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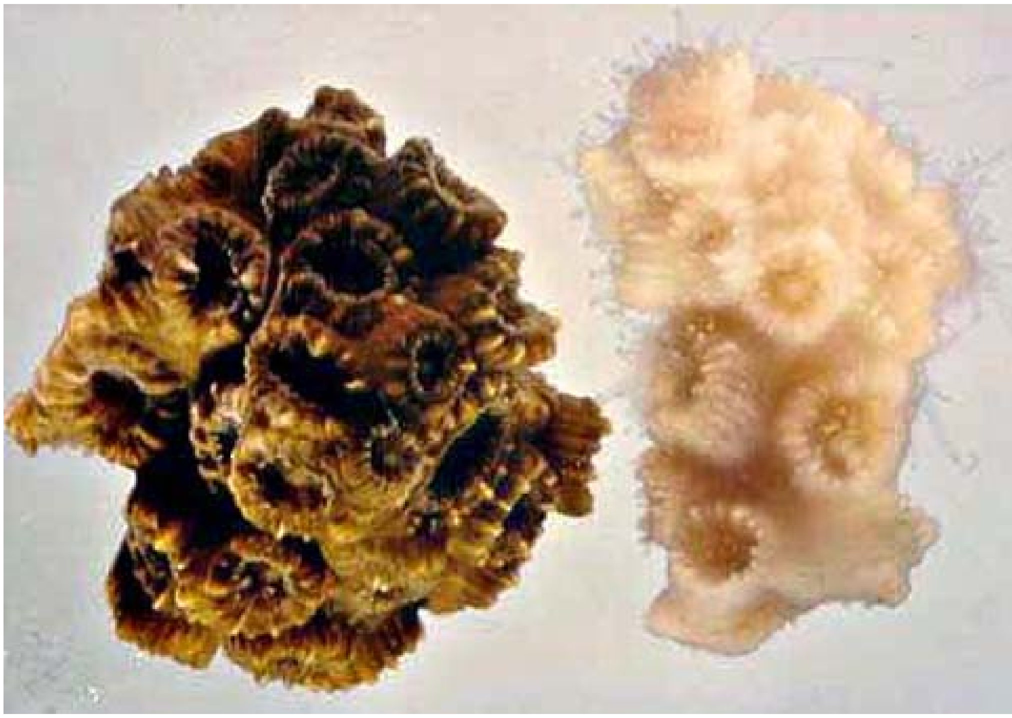
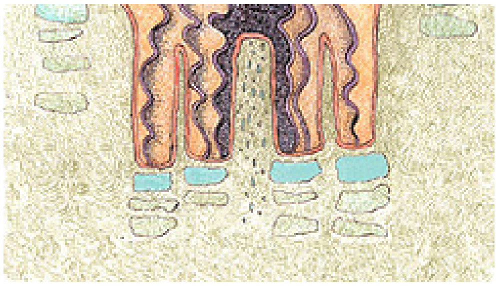


Zooxanthellae cells provide corals with pigmentation. On the left is a healthy stony coral. On the right is a stony coral that has lost its zooxanthellae cells and has taken on a bleached appearance. If a coral polyp is without zooxanthellae cells for a long period of time, it will most likely die.

(top)

Corals

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



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.*

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.

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.

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.*

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.

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.

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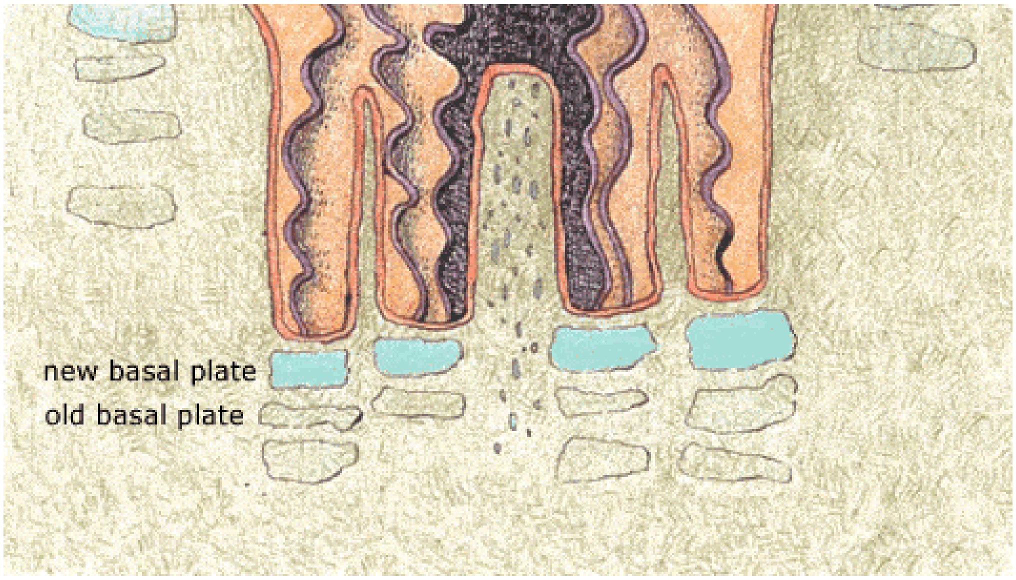

This animation demonstrates how stony corals grow vertically. In the first frame we see a coral polyp resting on its base, which is called the basal plate. In the next frame we see the polyp's tissues begin to lift up off the basal plate, leaving an empty space beneath it (shown by dashed lines). In 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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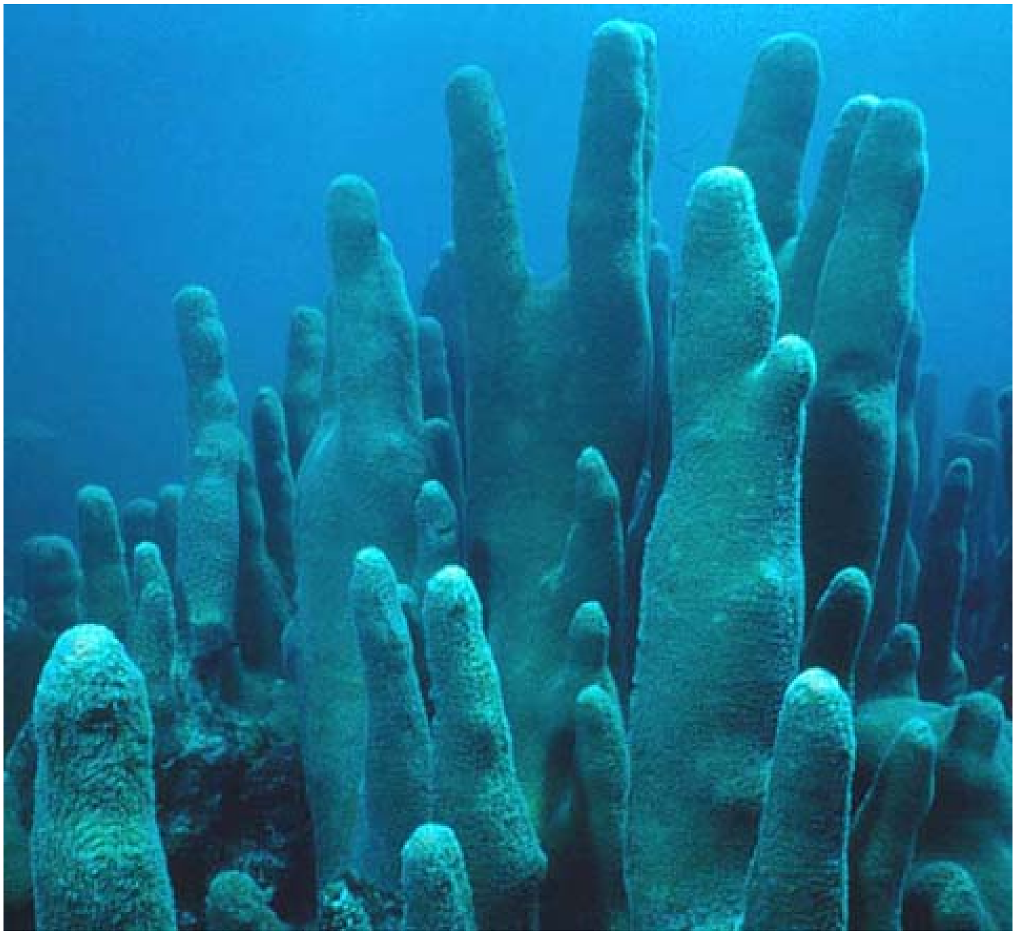

These pillar corals were seen in the Florida Keys. Pillar corals are a type of digitate coral, growing upward in cylindrical forms that have been compared to fingers or clumps of cigars. Digitate corals are distinguished from branching corals in that they have no secondary branches. (Photo: Harold Hudson)

Next coral type: Table Corals

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NOAA's National Ocean Service | National Oceanic and Atmospheric Administration | U.S. Department of Commerce
http://oceanservice.noaa.gov/education/kits/corals/media/supp_coral03c.html
Best viewed in Internet Explorer 5+ or Netscape 6+.

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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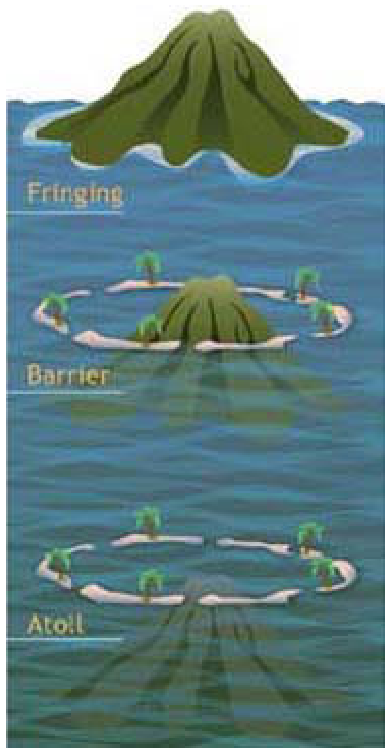
Corals

How Do Coral Reefs Form?

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 algal ridge, buttress zone, and seaward slope.

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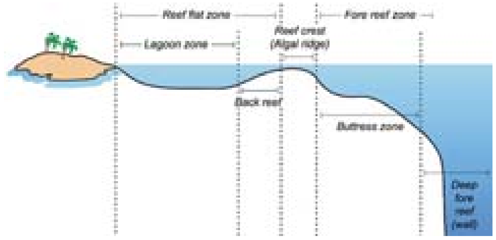
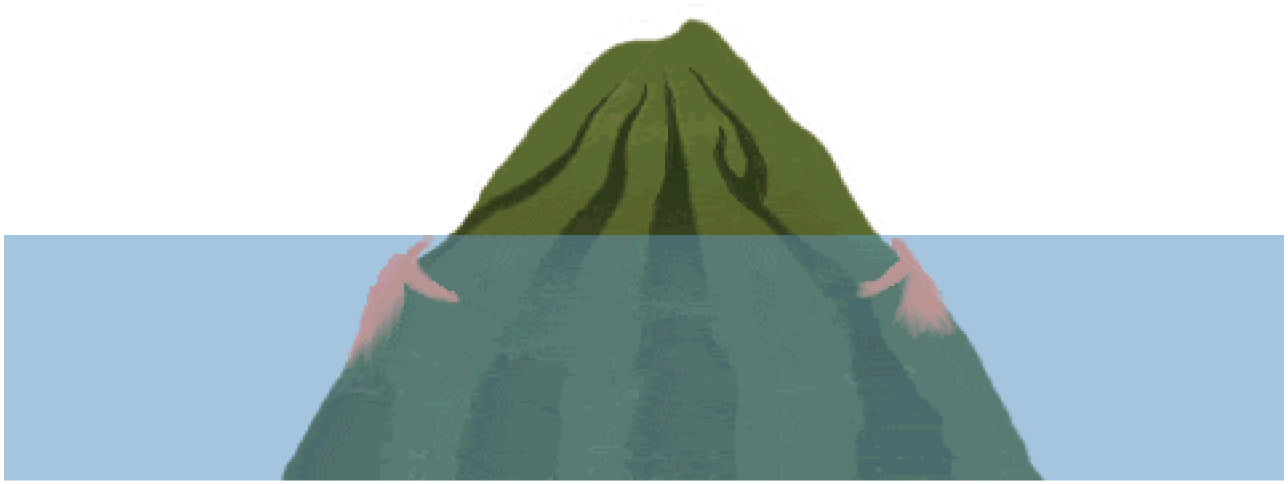


As coral reefs grow, they establish characteristic biogeographic patterns. *Click the image for a larger view.*

coral reef conservation



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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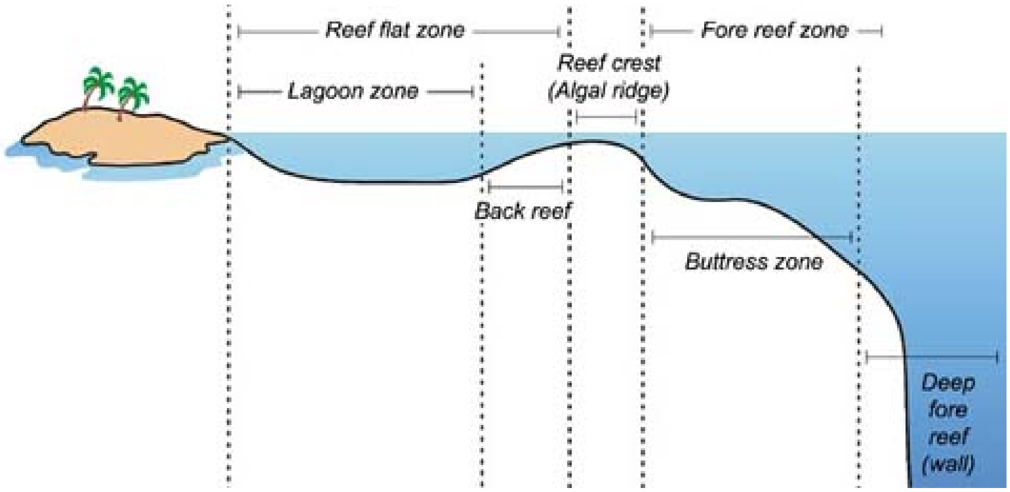

Over time, many coral reefs develop similar biogeographic profiles. Moving seaward from the shore, the reef flat, reef crest, buttress zone and seaward slope form the major divisions common to most reefs. The reef flat is on the sheltered side of the reef. The substrate is formed of coral rock and loose 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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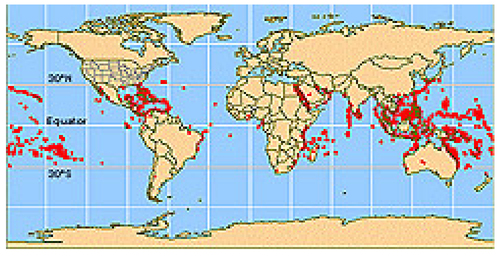
Corals

Where Are Reef Building Corals Found?



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 29^0C, but some can tolerate temperatures as high as 40^0C 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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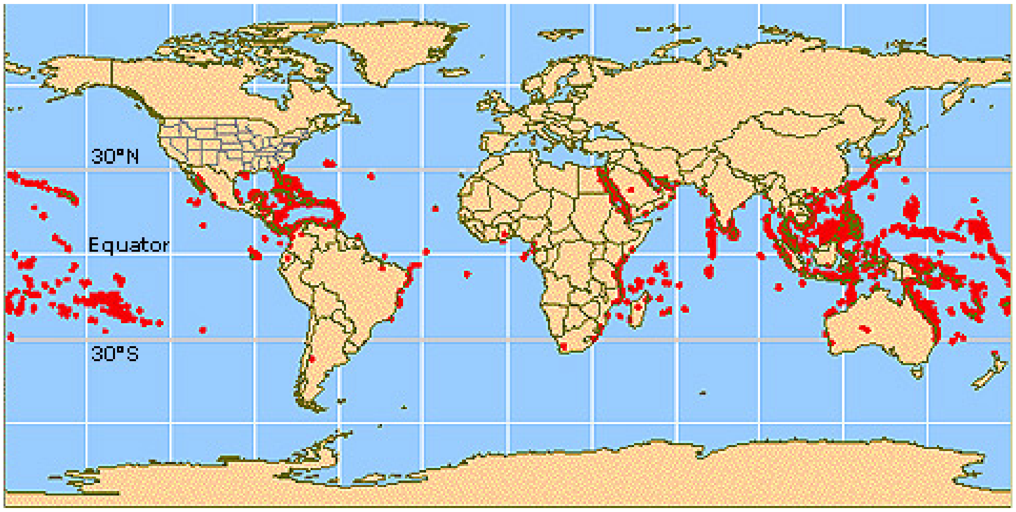

The majority of reef building corals are found within tropical and subtropical waters. These typically occur between 30^0 north and 30^0 south latitudes. The red dots on this map show the location of major stony coral reefs of the world.

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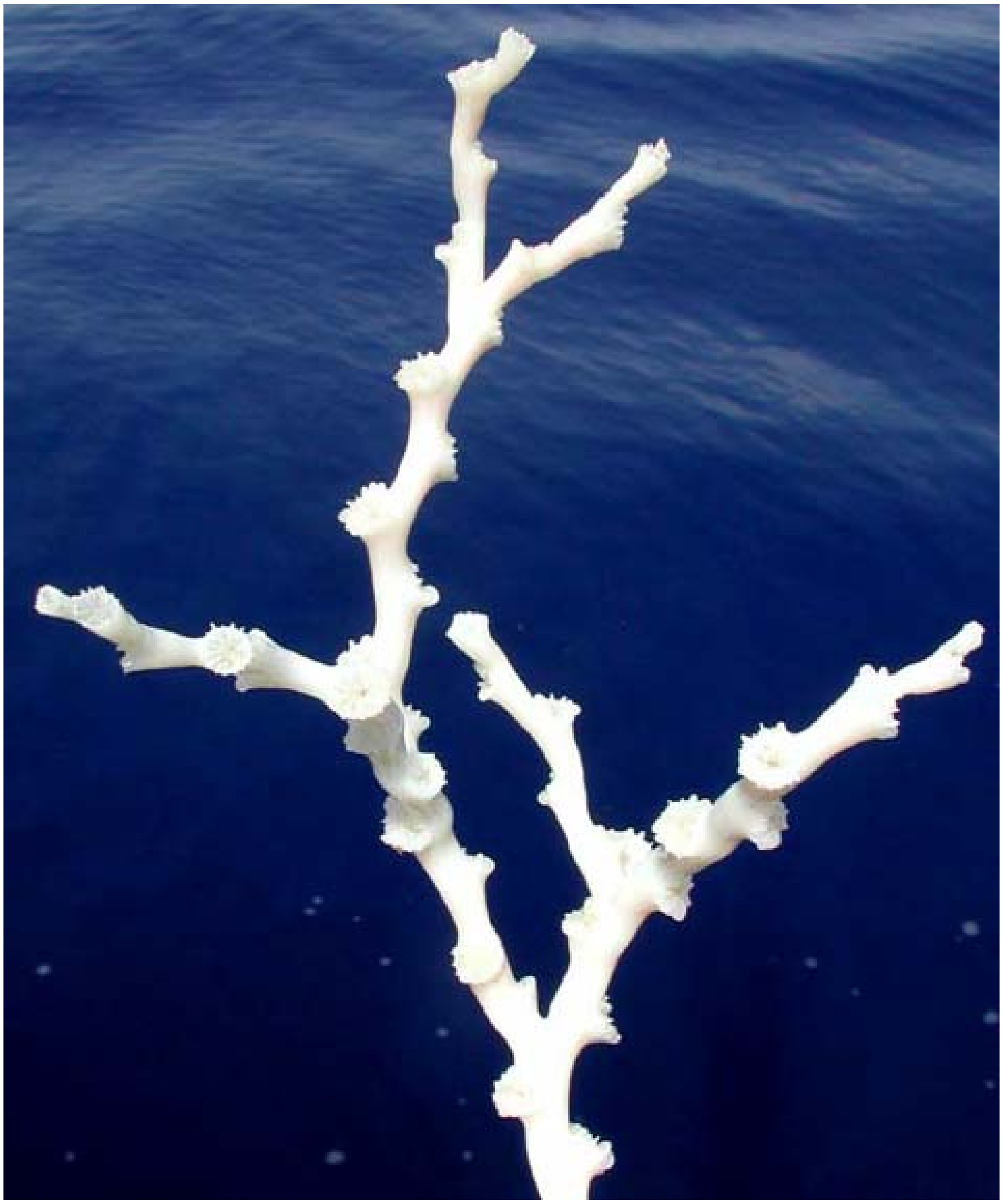

This branch of *Lophelia* coral was brought up from over 1,250 feet of water from a reef off the coast of North Carolina. The reef that this branch of coral was taken from is believed to be over 10,000 years old. Deep sea corals are challenging our knowledge of coral growth and worldwide distribution 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.

(top)

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Corals

How Do Corals Reproduce?

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).

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)

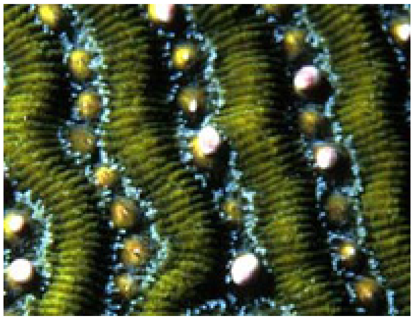
About three-quarters of all stony corals produce male and/or female gametes. Most of these species are broadcast spawners, releasing massive numbers of eggs and sperm into the water to distribute their offspring over a broad geographic area (Veron, 2000). The eggs and sperm join to form free-floating, 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.

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).

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

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).



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

(top)

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)

(top)

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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.

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)

(top)

Corals

Importance of Coral Reefs

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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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

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

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.

(top)

Corals

Anthropogenic Threats to Corals

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).

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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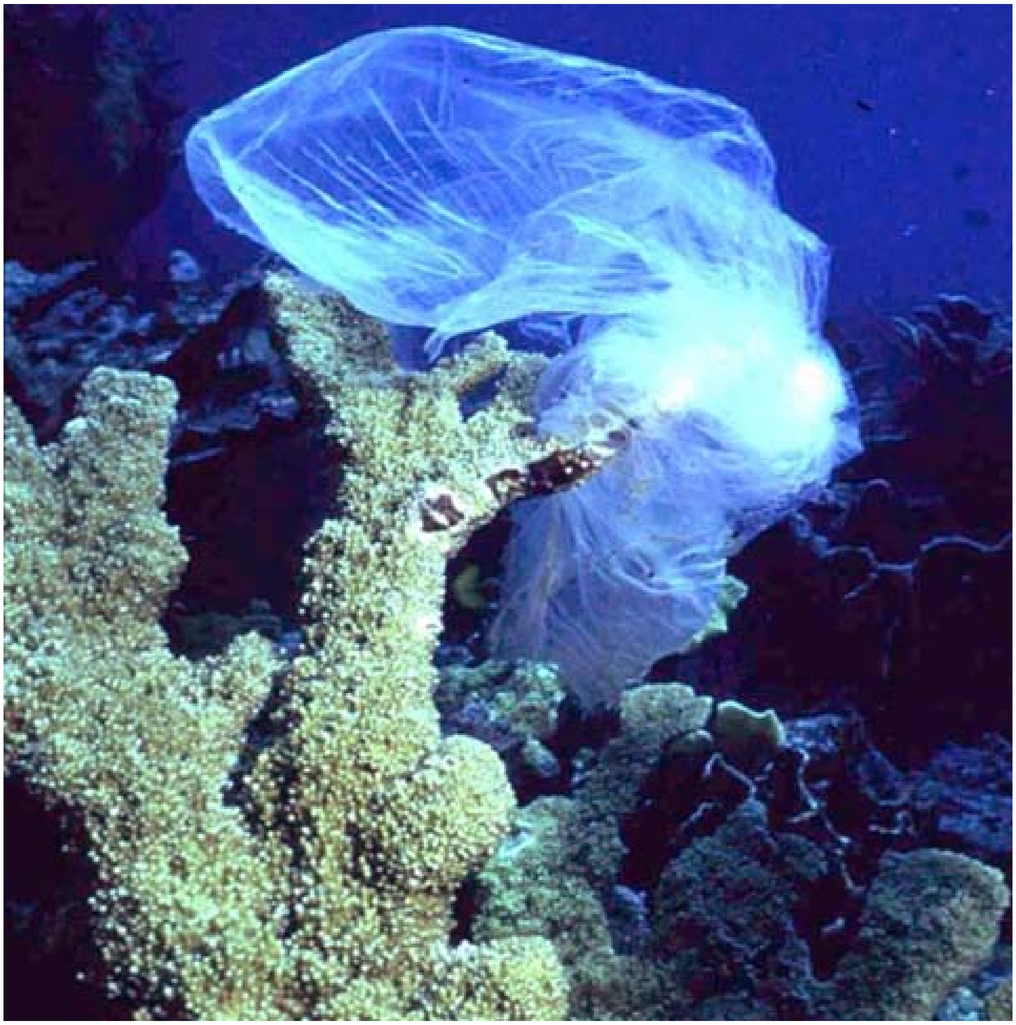


There are many ways that pollution can damage reefs. Debris like this plastic bag can quickly become entangled on a coral and smother it.

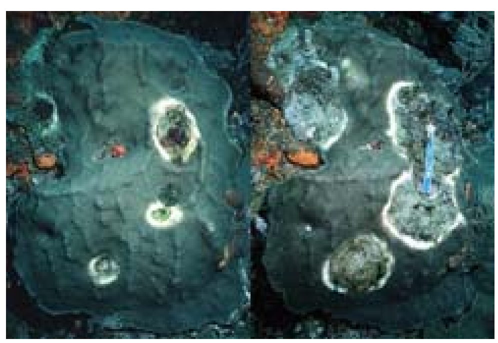
Corals

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.

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)

(top)

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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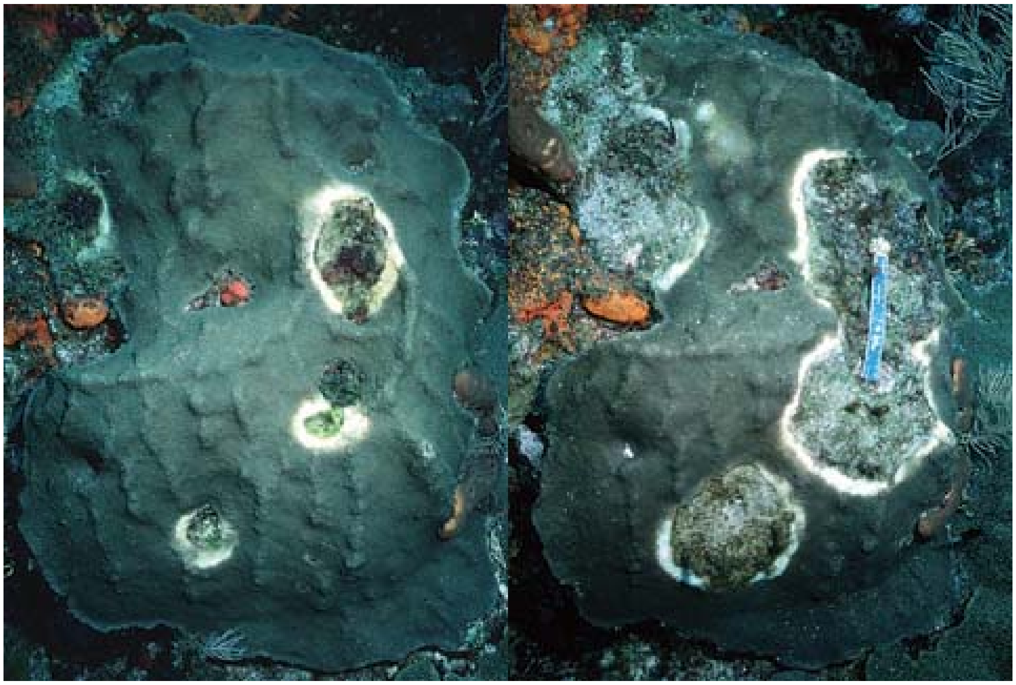

Yellow-band disease can rapidly spread over a coral destroying the delicate underlying tissues. On the left is a massive coral in the early stages of attack by yellow-band disease. On the right is the same coral several weeks later. Note how rapidly the area of destroyed tissue has expanded. (Photo: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

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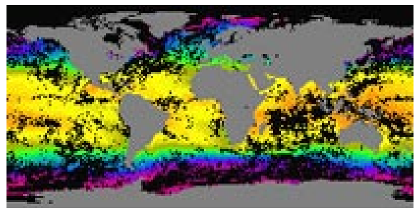
Corals

Protecting Coral Reefs

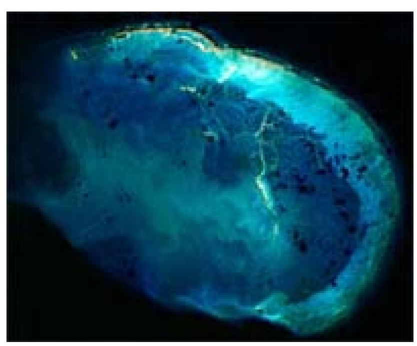
Coral reefs are truly miracles of nature. These beautiful ecosystems are biologically and economically valuable. Beset by natural threats and human activities, coral reefs and the magnificent creatures that call them home are in danger of disappearing if actions are not taken to protect them.



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.*

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.

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.



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.*

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.

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.

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.*

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.

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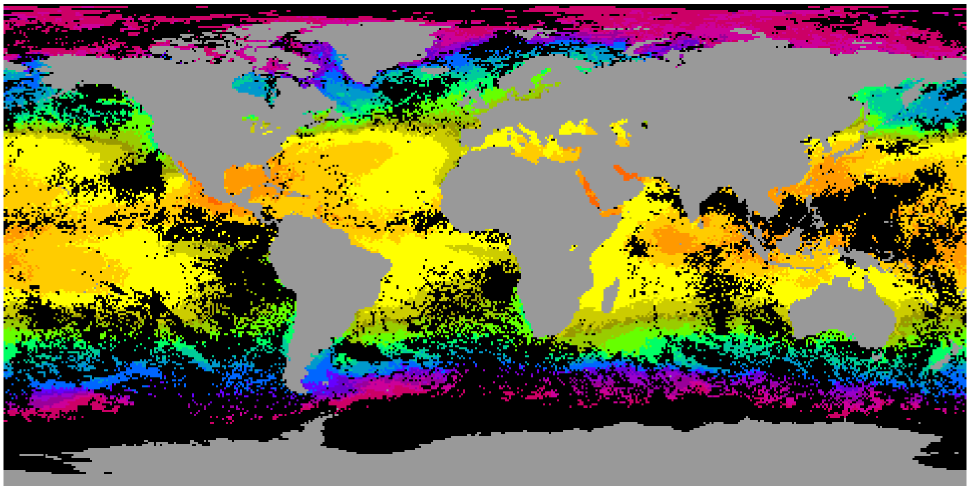

This animation is a composite of average weekly sea surface temperatures over the course of a year. Yellow and orange represent hotter waters and green, blue and purple represent progressively cooler waters. Broad scale, environmental processes can have long ranging effects on coral reefs, which are 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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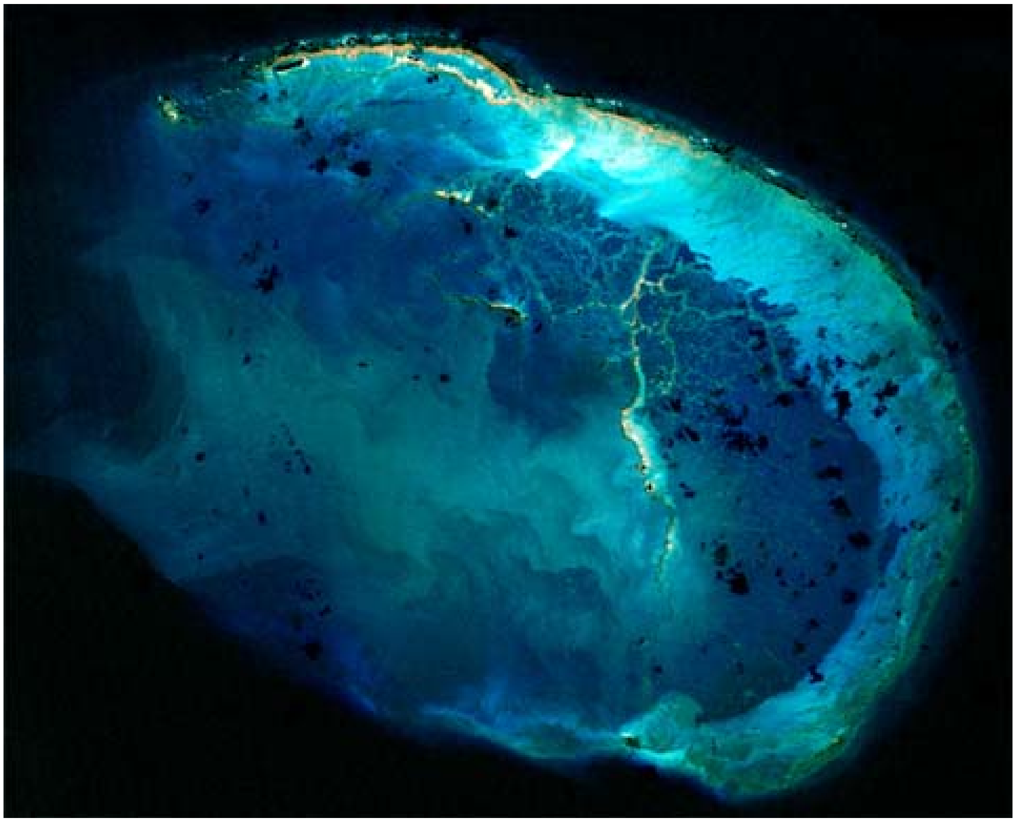

This high-resolution image of the French Frigate Shoals in the Northwestern Hawaiian Islands group was taken by the Landsat 7 satellite. Launched in 1998, Landsat 7 circles the earth at an altitude of 705 kilometers. The detailed imagery from Landsat 7 helps scientists conduct preliminary mapping and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

(top)

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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Corals Roadmap to Resources

NOAA has many coral reef resources available online. These Web pages and resources are meant to guide educators and students to specific data related to the information presented in the online coral tutorial. Many of the Web pages listed reside within larger Web sites. You may wish to browse each Web site to examine other available resources.

Coral Reef Information System (CoRIS)

CORIS
http://www.coris.noaa.gov

This web site is designed to be a single point of access to NOAA's coral reef information and data products. The following sections of the Web site may be of most use to educators and students:

About Coral Reefs
http://www.coris.noaa.gov/about/welcome.html

This section of the CORIS Web site includes detailed essays on coral reef ecology, including the physical and biological characteristics of corals, coral reef pathologies, and human and natural hazards.

CORIS Glossary
http://www.coris.noaa.gov/glossary/welcome.html

This section of the CORIS Web site provides definitions for hundreds of terms associated with coral reef science and conservation.

Oil Spills in Coral Reefs

Reports on Planning and Response to Oil Spills in Coral Reefs http://www.response.restoration.noaa.gov/oilaids/coral/reports.html

This Web site provides access to a report published by NOAA's Office of Response and Restoration http://response.restoration.noaa.gov/ It includes information on coral ecosystems; human-caused and naturally-occurring environmental impacts on coral; a current review of oil toxicity to coral; guidance for responding to spills in coral reefs and considerations for open-water cleanup measures; restoration of damaged reefs; case studies that illustrate new technologies being used to restore coral reefs; and a glossary and listing of Web sites with useful data on reefs. The report is available for download in PDF format (*80 pages, 9.8Mb).* Because it is a very large document, it may be downloaded in sections ranging in size from 88k to 3.3 Mb.

Coral Reef Restoration Projects

The Wellwood Coral Reef Restoration Project http://www.sanctuaries.noaa.gov/special/wellwood/

Columbus Iselin Coral Reef Restoration Project http://www.sanctuaries.noaa.gov/special/columbus/columbus.html

These two Web sites provide detailed information and images of two coral reef restoration projects implemented in the Florida Keys National Marine Sanctuary after vessel groundings caused major damage. These Web pages detail the areas impacted, the design of the restoration effort, laws governing habitat destruction and restoration, a timeline, and images of the project. These pages are part of the *National Marine Sanctuary Web site* http://www.sanctuaries.noaa.gov/ which provides additional information on coral reefs in the Florida Keys, off the coast of Texas at Gray's Reef and in American Samoa in Fagatele Bay.

Images of Corals and Coral Reefs

NOAA Library Photo Collection: Coral Section http://www.photolib.noaa.gov/reef/index.html

This section of the NOAA Library on-line photo collection includes high-resolution images of fish, invertebrates and scuba divers from Caribbean, Pacific and Red Sea coral reefs. Also available are historical drawings created during the first study of coral reefs in Florida during the 1880s.

Maps of Coral Habitats

Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve Maps http://www.hawaiireef.noaa.gov/imagery/welcome.html

This section of the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve Web site http://www.hawaiireef.noaa.gov/ provides a set of maps and imagery of the areas complex and beautiful coral ecosystem. Selected maps are supplemented with high-resolution images taken by the LandSat 7 Satellite. This Web site It also contains information about the area's geology and ecology, and the legal process involved in designating it as a reserve.

Map Tiles of Florida Keys Benthic Habitats

http://spo.nos.noaa.gov/projects/benthic_habitats/tile_htmls/map_tiles.html

This Web page provides color-coded maps of specific benthic habitats (sea bottom types) for the entire Florida Keys. To view a map, click on one of the 32 numbered boxes. A map of the area will appear. It includes information on the nine different types of habitats found in the area, including patch reefs and seagrasses, and any legally protected areas. Each map also identifies the percentage of each habitat type found in that particular area.

Data and Information on Coral Reefs

NOAA's Coral Reef Watch Coral Bleaching Index Web Site
http://coralreefwatch.noaa.gov/satellite/index.html

This Web site provides static and animated presentations of worldwide sea surface temperatures (SSTs), SST anomalies, HotSpots and coral bleaching indices. Scientists track SSTs to identify areas of the ocean that may be susceptible to coral bleaching. NOAA's National Environmental Satellite Data and Information Service (NESDIS) continuously monitors SSTs worldwide using buoys and polar orbiting satellites (POES).

NOAA's National Ocean Service Remote Sensing Team Web Site
http://ccmaserver.nos.noaa.gov/rsd/products.html

This Web site provides high-resolution habitat images of the Northwest Hawaiian Islands taken by IKONOS and LandSat 7 Satellites. All of the data on this page may be downloaded as an atlas in three parts in pdf format. In addition to the high resolution imagery, the atlas provides information on the geology, ecology and management of the Northwest Hawaiian Islands.

Essays on the State of Coral Reef Ecosystems

State of the Coast: The Extent and Condition of U.S. Coral Reefs
http://oceanservice.noaa.gov/websites/retiredsites/sotc_pdf/CRF.PDF (pdf, 3Mb)

This collection of essays covers the extent and condition of coral reefs found in U.S. waters (circa 1996-97). The essays present national, regional and local perspectives. The authors are scientists or environmental managers with expertise in the subject area and active engagement in the field.

In most of the essays, case studies illustrate several examples that highlight improved or deteriorating conditions, and successful and unsuccessful responses to problems. The essays also include reference lists, an annotated list of Web sites that can provide additional information, and a glossary. (NOTE: Some listed Web sites may be outdated)

The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States
http://coastalscience.noaa.gov/documents/status_coralreef.pdf (pdf, 16.3Mb)

Coral Reef Ecosystems of the Northwestern Hawaiian Islands
http://coastalscience.noaa.gov/documents/nowramp.pdf (pdf, 2.5Mb)

The National Centers for Coastal Ocean Science (NCCOS) Notable Additions
http://coastalscience.noaa.gov/publications/notables.html provides documents that can be downloaded in PDF format. The two publications listed above provide detailed ecological information on more than 11 major coral reef ecosystems. As these documents are very large, you may wish to download them in sections from the NCCOS Notable Additions Web page (link above) This section of the NCCOS Web site also provides information on other NCCOS research areas including marine pollution, invasive species and climate change.

(top)

Corals Lesson Plans

A set of lesson plans on corals have been developed for students in grades 9–12, but are easily adaptable for students at the middle school or undergraduate level. Each lesson integrates information presented in the corals tutorial with data offerings from the corals roadmap to resources. These lesson plans focus on the biology of coral reefs and the roles they play in aquatic ecosystems, 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.

In addition to being tied to specific National Science Education Standards, each hands-on, inquiry-based activity includes: Focus Questions, Learning Objectives, Teaching Time, Seating Arrangement, Background Information, Learning Procedures, a “Me” Connection, Evaluations, Extensions, Resources and Student Handouts.

Read a description of each lesson plan and/or download them to your computer. All of the lesson plans are available in PDF format, and may be viewed and printed with the free Adobe Acrobat Reader. To download a lesson plan, click on its title from the listing below.

Caution: Do Not Bleach ! (24 pages, pdf, 488Kb)
Focus: Coral Reef Bleaching (Life Science)

- Students will be able to identify and explain five ways that coral reefs benefit human beings.
- Students will be able to identify and explain three major threats to coral reefs.
- Students will be able to describe major components of the Coral Reef Early Warning System.
- Students will be able to identify and discuss actions that can be undertaken to reduce or eliminate threats to coral reefs.
- Students will be able to discuss at least one hypothesis that explains why corals under stress may expel their zooxanthellae.

Keeping Watch on Coral Reefs (22 pages, pdf, 444Kb)
Focus: Management of Coral Reefs (Earth Science)

- Students will be able to identify and explain five ways that coral reefs benefit human beings.
- Students will be able to identify and explain three major threats to coral reefs.
- Students will be able to describe major components of the Coral Reef Early Warning System.
- Students will be able to identify and discuss actions that can be undertaken to reduce or eliminate threats to coral reefs.
- Students will be able to obtain and analyze several types of oceanographic data from remote-sensing satellites.

search

This site NOAA

Corals Tutorial

Corals Roadmap

Corals Lesson Plans

Who Has the Data? (11 pages, 352kb)
Focus: Coral Reef Monitoring (Life Science/Earth Science)

- Students will be able to describe and explain the importance of asexual and sexual reproductive strategies to reef-building corals.
- Students will be able to explain the need for baseline data in coral reef monitoring programs.
- Students will be able to identify and explain five ways that coral reefs benefit human beings.
- Students will be able to identify and explain three major threats to coral reefs.

A Reef of Your Own (10 pages, 272kb)
Focus: Coral Reef Biology (Life Science)

- Students will be able to describe and explain the importance of asexual and sexual reproductive strategies to reef-building corals.
- Students will be able to explain why is it important that reef-building corals have a nutritional strategy that includes both photosynthesis and carnivory.
- Students will be able to describe two behaviors that reef-building corals use to compete for living space with other species.
- Students will be able to explain how coral reefs can produce high levels of biological material when the waters surrounding these reefs contain relatively small amounts of the nutrients normally needed to support biological production.

(top)

CORAL REEF LESSON PLAN

Caution: Do Not Bleach!

Focus

Coral reef bleaching

Grade Level

9-12 (Life Science)

Focus Question

Why are coral reefs important, and what are possible explanations for the phenomenon known as "coral bleaching?"

Learning Objectives

- Students will be able to identify and explain five ways that coral reefs benefit human beings.

- Students will be able to identify and explain three major threats to coral reefs.

- Students will be able to describe major components of the Coral Reef Early Warning System.

- Students will be able to identify and discuss actions that can be undertaken to reduce or eliminate threats to coral reefs.

- Students will be able to discuss at least one hypothesis that explains why corals under stress may expel their zooxanthellae

Materials

- Copies of either "Coral Reef Subject Review" *(fill-in-the-blank version, with or without word bank)* or "Coral Reef Subject Review Crossword Puzzle," one copy for each student or student group
- Computers with internet access

Audio/Visual Materials

None, unless students require A-V equipment for their public education programs

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Classroom style or groups of 4-6 students

Maximum Number of Students

30

Key Words

Coral reefs
Zooxanthellae
Symbiosis
Bleaching

Background

Coral reefs are one of the most biologically productive ecosystems on Earth. Most people have seen images of brightly colored fishes and other reef-dwelling organisms, yet many do not understand why these systems are personally important. Programs and articles about coral reefs typically point out benefits that include protecting shorelines from erosion and storm damage, supplying foods that are important to many coastal communities, and providing recreational and economic opportunities. These benefits are obviously important to people who live near reefs, but there is another aspect of coral reefs that can benefit everyone: the highly diverse biological communities are new sources of powerful antibiotic, anti-cancer and anti-inflammatory drugs.

The idea of coral reefs as a source of important new drugs is new to many people; but in fact, most drugs in use today come from nature. Aspirin, for example, was first isolated from the willow tree. Morphine is extracted from the opium poppy. Penicillin was discovered from common bread mold. Although almost all of the drugs derived from natural sources come from terrestrial organisms, recent systematic searches for new drugs have shown that marine invertebrates produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. Particularly promising invertebrate groups include sponges, tunicates, ascidians, bryozoans, octocorals, and some molluscs, annelids, and echinoderms.

Some of the drugs derived from marine invertebrates are:

Ecteinascidin – Extracted from tunicates; being tested in humans for treatment of breast and ovarian cancers and other solid tumors

Topsentin – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; anti-inflammatory agent

Lasonolide – Extracted from the sponge *Forcepia* sp.; anti-tumor agent

Discodermalide – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent

Bryostatin – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia and melanoma

Pseudopterosins – Extracted from the octocoral (sea whip) *Pseudopterogorgia elisabethae*; anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing

ω**-conotoxin MVIIA** – Extracted from the cone snail *Conus magnus*; potent pain-killer

Think a moment about the invertebrates in this list. Notice that most of these species are sessile, and live all or most of their lives attached to some sort of surface. Several reasons have been suggested to explain why these animals are particularly productive of potent chemicals. One possibility is that they use these chemicals to repel predators, since they are basically "sitting ducks." Since many of these species are filter feeders, and consequently are exposed to all sorts of parasites and pathogens in the water, they may use powerful chemicals to repel parasites or as antibiotics against disease-causing organisms. Competition for space may explain why some of these invertebrates produce anti-cancer agents: If two species are competing for the same piece of bottom space, it would be helpful to produce a substance that would attack rapidly dividing cells of the competing organism. Since cancer cells often divide more rapidly than normal cells, the same substance might have anti-cancer properties.

For more information on drugs from the sea, visit *http://www.reefcheck.org/articles/june_03/drugs_sea.pdf* and *http://www.reefcheck.org/articles/june_03/marine_pharmacology.pdf*

Despite their numerous benefits to humans, many coral reefs are threatened by human activities. Sewage and chemical pollution can cause overgrowth of algae, oxygen depletion, and poisoning. Fishing with heavy trawls and explosives damages the physical structure of reefs as well as the coral animals that build them. Careless tourists and boat anchors also cause mechanical damage. Thermal pollution from power plants and global warming cause physiological stress that kills coral animals and leaves the reef structure vulnerable to erosion. Many of these impacts are the result of ignorance; people simply aren't aware of the importance of coral reefs or the consequences of their actions, but the damage and threats to reefs continues to increase on a global scale.

Some of the most severe damage appears to be caused by thermal stress. Shallow-water reef-building corals live primarily in tropical latitudes (less than 30° north or south of the equator). These corals live near the upper limit of their thermal tolerance. Abnormally high temperatures result in thermal stress, and many corals respond by expelling the symbiotic algae (zooxanthellae) that live in the corals' tissues. Since the zooxanthellae are responsible for most of the corals' color, corals that have expelled their algal symbionts appear to be bleached. Because zooxanthellae provide a significant portion of the corals' food and are involved with growth processes, expelling these symbionts can have significant impacts on the corals' health. In some cases, corals are able to survive a "bleaching" event and eventually recover. When the level of environmental stress is high and sustained, however, the corals may die.

Prior to the 1980s, coral bleaching events were isolated and appeared to be the result of short-term events such as major storms, severe tidal exposures, sedimentation, pollution, or thermal shock. Over the past twenty years, though, these events have become more widespread, and many laboratory studies have shown a direct relationship between bleaching and water temperature stress. In general, coral bleaching events often occur in areas where the sea surface temperature 1°C or more above the normal maximum temperature.

In 1998, the President of the United States established the Coral Reef Task Force (CRTF) to protect and conserve coral reefs. Activities of the CRTF include mapping and monitoring coral reefs in U.S. waters, funding research on coral reef degradation, and working with governments, scientific and environmental organizations, and business to reduce coral reef destruction and restore damaged coral reefs. Using high-resolution satellite imagery and Global Positioning System (GPS) technology, the National Oceanic and Atmospheric Administration (NOAA) has made comprehensive maps of reefs in Puerto Rico, the U.S. Virgin Islands, the eight main Hawaiian Islands and the Northwestern Hawaiian Islands. Maps of all shallow U.S. coral reefs are expected to be completed by 2009. NOAA monitors reefs using a system of specially designed buoys that measure air temperature, wind speed and direction, barometric pressure, sea temperature, salinity and tidal level, and transmit these data every hour to scientists. Satellites are also used to monitor changes in sea surface temperatures and algal blooms that can damage reefs. Research and restoration projects on selected coral reefs are conducted by NOAA's National Undersea Research Program.

The first part of this lesson is intended to:

- introduce students to coral reefs and improve their understanding of why these systems are important, how they are threatened, and what can be done to protect and restore these unique and valuable ecosystems; and to
- introduce students to hypotheses that explain why corals under stress may expel their zooxanthellae.

In the second part of this lesson, students design and prepare educational programs to improve public awareness of the importance of coral reefs and what needs to be done to reduce or eliminate harmful impacts from human activities. This activity offers many opportunities for cross-curricular activities, and may be extended over several weeks or months. If time is limited, you may choose to use the first part alone.

Learning Procedure

Part 1

1.

Direct students to the coral reef tutorials at *http://www.oceanservice.noaa.gov/education/kits/corals*. You may want to assign different tutorial sections to each student group. Have each student or student group complete one version of the Coral Reef Subject Review and lead a discussion to review the answers. Be sure that students understand the relationship between coral animals and their symbiotic algae (zooxanthellae), and that under thermal stress many corals will expel their zooxanthellae.

Briefly explain the purpose and activities of the U. S. Coral Reef Task Force (CRTF), and highlight the monitoring functions that are intended to identify reef areas threatened by thermal stress or algal blooms.

2.

Tell students that their assignment is to investigate possible explanations for zooxanthellae expulsion by corals under stress, and prepare a written report outlining at least one hypothesis that explains this behavior. The report should explain:

- the symbiotic relationship between corals and their zooxanthellae;
- how corals obtain their zooxanthellae; and
- how environmental stress may alter the symbiosis.

If you want to provide a starting point for this research, the following resources will be useful:

http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html (Roadmap to Resources: Corals)

http://www.gbrmpa.gov.au/corp_site/info_services/publications/reef_research/issue2_98/2rmn1.html (article: Bleaching The Great Unknown)

http://www.oneocean.org/overseas/200009/coral_bleaching_the_hows_and_whys_and_whats_next.html (article: Coral Bleaching: the Whys, the Hows and What Next?)

http://ioc.unesco.org/coralbleaching/Hughes et al.pdf (article: Climate Change, Human Impacts, and the Resilience of Coral Reefs)

http://www.crc.uri.edu/download/COR_0011.PDF (article: Coral Bleaching: Causes, Consequences and Response)

3.

Lead a discussion of students' research results. Written reports should include most of the following points:

- Zooxanthellae are single-celled motile algae (dinoflagellates).
- Many marine invertebrates in addition to corals have symbiotic algae.
- Photosynthesis by zooxanthellae provides a significant source of nutrition for many host symbionts; as much as 90% of the total energy requirement in some coral and giant clam species.
- Zooxanthellae are also involved in calcium carbonate deposition (skeletal growth) in some corals.
- Some zooxanthellae produce an ultraviolet-absorbing pigment that may act as a sort of "sunscreen" for host corals.
- The mechanism by which corals obtain zooxanthellae (or, from a slightly different perspective, become infected with zooxanthellae) is not known, but sea anemone larvae have been reported to indiscriminantly ingest zooxanthellae along with other particulate materials. The algal cells become incorporated into the larvae's endodermal cells, while other particulate materials are either digested or expelled.
- "Bleaching" has been observed in most marine organisms that host zooxanthellae.
- It is not known whether bleaching happens because the algae leave their host animal or because the host expels the algae.

- Bleaching can also occur when algae expel their pigments.
- Bleaching appears to be the result of various types of environmental stress, including high temperature, exposure to excessive irradiance, lowered salinity, and pollution.
- Combinations of different stresses may result in bleaching, even though corals might be tolerant of the individual conditions (for example, if corals are near their upper thermal limit, even small increase in irradiance can result in bleaching).
- Elevated temperatures reduce the photosynthetic ability of zooxanthellae.
- Increased atmospheric carbon dioxide may lead to an increased in dissolved carbon dioxide in seawater, which will increase the solubility of calcium and reduce calcification.
- While there is no absolute proof that bleaching events are the result of global warming, many scientists consider the link to be incontrovertible.
- Different species of corals have different tolerance levels for various environmental factors. Similarly, different strains of zooxanthellae have different tolerance levels.
- Different strains of zooxanthellae are found within and among coral species.
- Coral genera with fast growth rates and high metabolic rates are most susceptible to bleaching.
- The "adaptive bleaching hypothesis" proposes that corals expel their zooxanthellae under stress so that they can be replaced with other strains that are better suited to the stress conditions. There is no evidence, however, that corals can simply take up more tolerant strains of algae. In addition, high mortality, reduced growth rates, and decreased fecundity in bleached corals do not suggest an effective adaptation to stress conditions.
- If the stress conditions that cause bleaching do not persist for more than about six weeks, most bleached corals recover.
- Some scientists have predicted that persistent temperature increases coupled with other stresses will lead to widespread loss of coral reefs, which may require 500 years or more to recover.
- Marine protected areas are currently the most effective management tool for protecting coral reefs and other marine resources, but they cannot stop temperature increases or other adverse climate changes.

Ask students to discuss why coral reefs are at risk, and what they think can or should be done to reduce or eliminate the negative impacts of human activity on coral reefs. There is a strong possibility that a significant part of the current risk to coral reef systems is the result of human activity, particularly as it relates to global warming. Meaningful actions to address this type of issue depend upon widespread understanding of the problem and commitment to workable solutions. Public education is an important step toward building this sort of understanding and commitment. Have students brainstorm what "key messages" might form part of a public education program about coral reefs, what audiences should be targeted to receive these messages, and how these messages might be most effectively delivered to these audiences.

Part 2

Have students or student groups prepare one or more public education programs about coral reefs, based on the results of their brainstorming sessions in Step 3. Encourage students to consider various media, including publications, visual presentations, drama, music, etc. You may want to have an entire class work on a single program, or have smaller groups work on multiple programs using the medium (or media) or their choice. There are many possibilities, depending upon the target audiences. These presentations also offer cross-curricular opportunities, particularly with social studies, English language arts, and fine arts. Whatever media students choose to work with, their final presentation should be accompanied by a list of sources for the information they present. A good starting point for this activity is the Roadmap to Resources: Corals *(http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html)*, which provides links to many other sources of coral reef data and information.

The Bridge Connection

http://www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the navigation menu to the left, then "Habitats", "Coastal", "Coral Reef."

The "Me" Connection

Have students write a short essay on why coral reefs are personally important, what personal actions may contribute to human-caused threats to coral reefs, and what they could do to reduce these threats.

Extensions

1. The symbiotic relationship between zooxanthellae and coral polyps can be a springboard for discussing other types of cellular symbionts. Many biology students tend to overlook microbial associations in natural communities, but there is mounting evidence that eukaryotic organisms were (and are) the result of symbiotic associations between prokaryotic organisms. At some point in these associations, one (or more) species (called endosymbionts) entered the cells of another species, and performed useful functions. Each species had its own DNA, and when these organisms reproduced, both were replicated. Eventually, the individual identities of the species disappeared, resulting in a new type of organism. This sort of transformation has actually been seen in the laboratory, and is described in Margulis and Sagan (1986). For more information and a lesson plan devoted to this topic, visit *http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_CellMates.pdf*.

2. Have students or student groups prepare a report on a specific aspect of coral biology, ecology, or management. Some possible topics include:
   - coral diseases
   - natural and anthropogenic hazards
   - oil spills on coral reefs
   - coral reef restoration
   - species diversity on coral reefs
   - benthic habitats associated with coral reefs
   - relationships between coral reefs and seagrass or mangrove ecosystems

See Roadmap to Resources: Corals *(http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html)* for links to information on these and other relevant topics.

Resources

http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html – National Ocean Service website's Roadmap to Resources about corals, with links to many other sources of coral reef data, background information, and reports

Anonymous, 1998. Bleaching The Great Unknown. Reef Research volume 8. *http://www.gbrmpa.gov.au/corp_site/info_services/publications/reef_research/issue2_98/2rmn1.html*

Ariadne, D. and D. Diamante-Fabunan. 2000. Coral Bleaching: the Whys, the Hows and What Next? OverSeas, The Online Magazine for Sustainable Seas. *http://oneocean.org/overseas/200009/coral_bleaching_the_hows_and_whys_and_whats_next.html*

http://coral.aoml.noaa.gov – website with a bulletin board on coral bleaching

Hughes, T.P., et al. 2003. Climate Change, Human Impacts, and the Resilience of Coral Reefs. Science 301:929-933. Available online at *http://ioc.unesco.org/coralbleaching/Hughes et al.pdf*

http://www.crc.uri.edu/download/COR_011.PDF-"Coral Bleaching: Causes, Consequences and Response;" a collection of papers presented at the Ninth International Coral Reef Symposium, October 2002.

Margulis, L. and D. Sagan. 1986. Microcosmos. University of California Press. Berkeley.

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- The cell
- Interdependence of organisms
- Behavior of organisms

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

CORAL REEF LESSON PLAN

Coral Reef Subject Review

1. ____________ organisms are composed of hundreds to hundreds of thousands of individual animals.

2. Individual coral animals are called __________.

3. The mouth of individual coral animals is surrounded by a circle of _____________.

4. After food is consumed by corals, waste products are expelled through the ______________.

5. Time of day when most corals feed: _____________

6. To capture their food, corals use stinging cells called ____________________.

7. Nematocysts are capable of delivering powerful, often lethal, _____________.

WORD BANK

plants	digitate	erosion	pollution
clear	table	weather	algae
productive	elkhorn	algae	fishing
calcium carbonate	colonial	tidal emersions	fringing
habitats	zooplankton	El Niño	barrier
encrusting	planulae	zooxanthellae	cm
calyx	broadcast	mutualistic	flat
theca	mortality	photosynthesis	crest
basal plate	synchronized	poor	buttress
feed	lunar	atoll	seaward
branching	tentacles	stresses	slope
foliase	mouth	temperatures	below
metamorphose	night	CREWS	euphotic
massive	nematocysts	mucous	sessile
polyps	toxins	recycling	asexual
mushroom	species	zooxanthellae	millions
larvae	medicines	physical stress	
sunset	tourism	predation	
phototaxis	food	anthropogenic	

8. A coral's prey ranges in size from nearly microscopic animals called ________________ to small fish.

9. Many corals collect fine organic particles in films and strands of _____________.

10. Most reef-building corals contain photosynthetic algae called __________________ which live in their tissues.

11. Corals and algae have a ___________ relationship.

12. Symbiotic algae supply corals with glucose, glycerol, and amino acids, which are the products of ____________.

13. Tropical ocean waters are generally [rich or poor] ___________ in nutrients.

14. The relationship between the algae and coral polyp facilitates a tight __________ of nutrients, which is the driving force behind the growth and productivity of coral reefs.

15. The unique and beautiful colors of many stony corals are caused by ________________.

16. ___________ can cause coral polyps to expel their algal cells.

17. Coral _____________ occurs when coral polyps expel their algal cells, causing the colony to take on a stark white appearance.

18. Because of their intimate relationship with symbiotic algae, reef-building corals respond to the environment like _________.

19. Because their algal cells need light for photosynthesis, reef corals require ___________ water.

20. Although coral reefs require nutrient-poor water, they are among the most ___________ and diverse marine environments.

21. Reefs form when polyps secrete skeletons of __________.

22. As they grow, coral reefs provide structural __________ for hundreds to thousands of different vertebrate and invertebrate species.

23. The skeletons of stony corals are secreted by the lower portion of the polyp. This process produces a cup, or ________, in which the polyp sits.

24. The walls surrounding the corals' skeletal cup are called the ____________.

25. The floor of the corals' skeletal cup is called the ____________.

26. __________ is a system of specially designed buoys that measure conditions that may cause bleaching on coral reefs.

27. When polyps are physically stressed, they contract into their calyx so that virtually no part is exposed above their skeleton. At other times, polyps extend out of the calyx. Most polyps extend the farthest when they __________.

28. __________ corals have primary and secondary branches.

29. __________ corals look like fingers or clumps of cigars and have no secondary branches.

30. __________ corals form table-like structures and often have fused branches.

31. __________ coral has large, flattened branches.

32. __________ corals have broad plate-like portions rising in whorl-like patterns.

33. __________ corals grow as a thin layer against a substrate.

34. __________ corals are ball-shaped or boulder-like and may be small as an egg or as large as a house.

35. __________ corals resemble the attached or unattached tops of mushrooms.

36. Coral reefs begin to form when free-swimming __________ attach to submerged rocks or other hard surfaces along the edges of islands or continents.

37. __________ reefs project seaward directly from the shore, forming borders along the shoreline and surrounding islands.

38. __________ reefs border shorelines, but are separated from their adjacent land mass by a lagoon of open, often deep water.

39. An ____________ is formed when a reef has developed around a volcanic island that subsides completely below sea level while the coral continues to grow upward.

40. Massive corals have growth rates of 0.3 to 2 __________ per year

41. Bottom topography, depth, wave and current strength, light, temperature, and suspended sediments act on coral reefs to create horizontal and vertical zones of living species. The reef __________ is usually the zone closest to shore, followed by the reef __________ or algal ridge, then the __________ zone, and finally the __________.

42. Reef-building corals cannot tolerate water temperatures [above or below] __________ 18° Celsius (C).

43. Most reef-building corals require very saline water.

44. Reef-building corals' requirement for high light explains why most reef-building species are restricted to the ______ ____ zone, the region in the ocean where light penetrates to a depth of approximately 70 meters.

45. As adults, almost all corals are __________, which means that they remain on the same spot on the sea floor for their entire lives.

46. In __________ reproduction, new polyps bud off from parent polyps to expand or begin new colonies.

47. In sexual reproduction, coral eggs and sperm join to form free-floating, or planktonic, larvae called __________.

48. Species that release massive numbers of eggs and sperm into the water to distribute their offspring over a broad geographic area are called __________ spawners.

49. The time between planulae formation and settlement is a period of exceptionally high __________ among corals.

50. Along many reefs, spawning occurs as a __________ event, when all the coral species in an area release their eggs and sperm at about the same time.

51. 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 __________ cues.

52. The final release of gametes during spawning is usually based on the time of __________.

53. Planulae exhibit positive ___________.

54. Once planulae settle on the bottom, they __________ into polyps and form colonies that increase in size.

55. Coral reefs support more __________ per unit area than any other marine environment.

56. Scientists estimate that there may be ____________ of undiscovered species of organisms living in and around reefs.

57. Coral reef biodiversity is considered key to finding new __________ for the 21st century.

58. Healthy reefs contribute to local economies through __________.

59. In developing countries, coral reefs provide critical __________ resources for tens of millions of people.

60. Coral reefs buffer adjacent shorelines from wave action and prevent __________, property damage and loss of life.

61. Natural damage to coral reefs frequently occurs because of __________.

62. Slow-growing corals that are damaged by storms may be overgrown by __________ before they can recover.

63. Reefs also are threatened by __________ that can cause shallow water coral heads to overheat and dry out.

64. Increased sea surface temperatures, decreased sea level and increased salinity from altered rainfall can all result from weather patterns such as __________.

65. Corals are vulnerable to __________ by fishes, marine worms, barnacles, crabs, snails and sea stars.

66. Human-caused, or __________ activities are major threats to coral reefs.

67. One of the most significant human-caused threats to reefs is __________.

68. When some contaminants enter the water, nutrient levels can increase, promoting the rapid growth of __________ and other organisms that can smother corals.

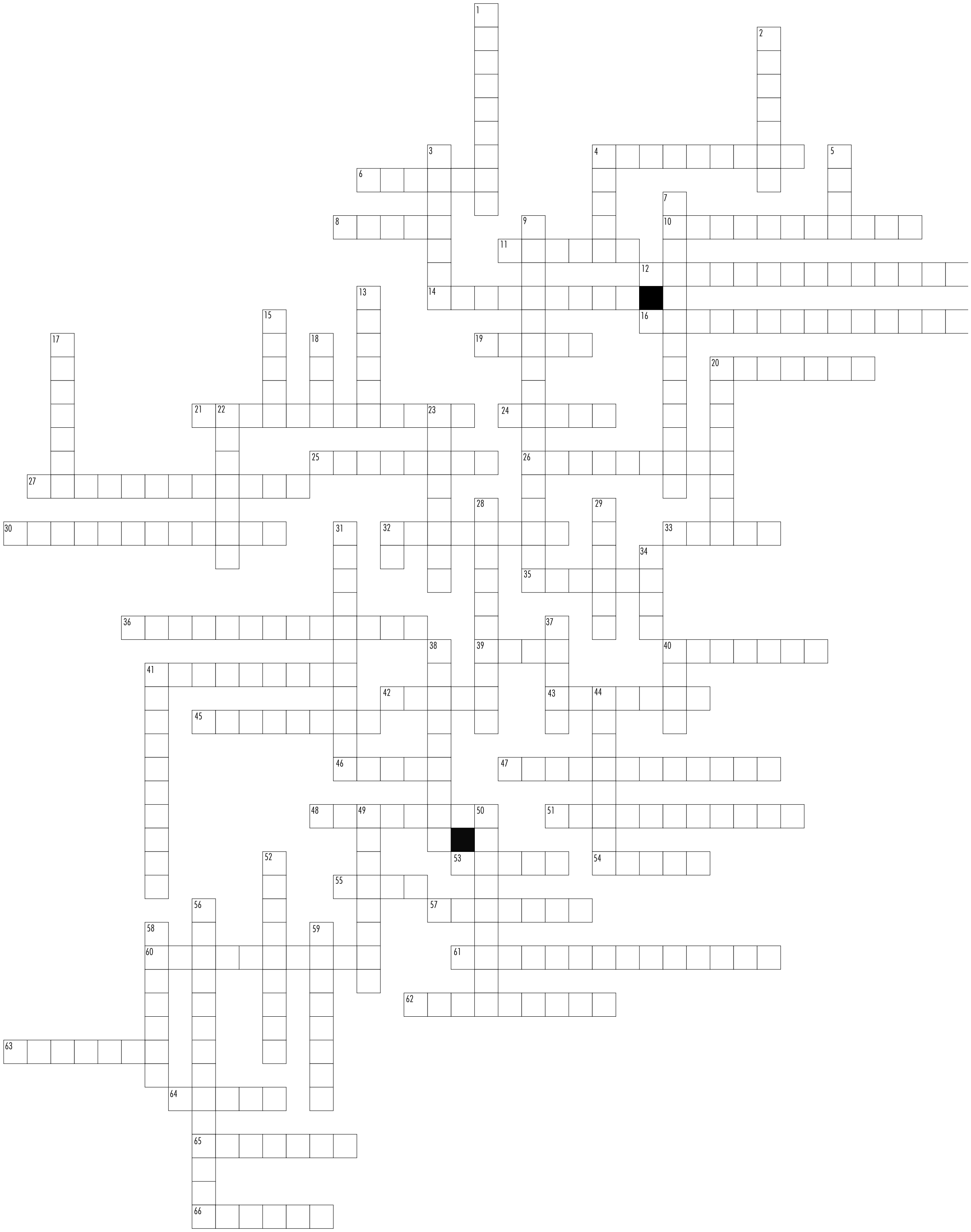
69. In many areas, coral reefs are destroyed when cyanide or dynamite are used for __________ activities.

70. Coral diseases generally occur in response to biological __________, such as bacteria, fungi and viruses, and non-biological stresses, such as increased sea surface temperatures, ultraviolet radiation and pollutants.

71. Many scientists believe that the increased frequency of coral diseases over the last 10 years is related to deteriorating water quality and increased __________ that may allow for the proliferation and colonization of microbes.

CORAL REEF LESSON PLAN

Coral Reef Subject Review: Crossword Puzzle



Across

4. The mouth of individual coral animals is surrounded by a circle of ____.
6. Many corals collect fine organic particles in films and strands of ______.
8. 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 __________ cues.
10. To capture their food, corals use stinging cells called _____ _____.
11. Coral reefs begin to form when free-swimming __________ attach to submerged rocks or other hard surfaces along the edges of islands or continents.
12. __________ can cause coral polyps to expel their algal cells.
14. Coral reef biodiversity is considered key to finding new __________ for the 21st century.
16. Most reef-building corals contain photosynthetic algae called _________which live in their tissues.
19. After the food is consumed by corals, waste products are expelled through the __________.
20. __________ corals have broad plate-like portions rising in whorl-like patterns.
21. The __________ is usually the zone farthest from shore.
24. plate The floor of the corals' skeletal cup is called the __________.
25. As they grow, coral reefs provide structural __________ for hundreds to thousands of different vertebrate and invertebrate species.
26. Coral __________ occurs when coral polyps to expel their algal cells, causing the colony to take on a stark white appearance.
27. Once planulae settle on the bottom, they __________ into polyps and form colonies that increase in size.
30. Many scientists believe that the increased frequency of coral diseases over the last 10 years is related to deteriorating water quality and increased __________ that may allow for the proliferation and colonization of microbes.
32. __________ organisms are composed of hundreds to hundreds of thousands of individual animals.
33. Slow-growing corals that are damaged by storms may be

overgrown by __________ before they can recover.
35. Increased sea surface temperatures, decreased sea level and increased salinity from altered rainfall can all result from weather patterns such as __________.
36. The unique and beautiful colors of many stony corals are caused by __________.
39. __________ corals form table-like structures and often have fused branches.
40. In many areas, coral reefs are destroyed when cyanide or dynamite are used for __________ activities.
41. Corals are vulnerable to __________ by fishes, marine worms, barnacles, crabs, snails and sea stars.
42. Most reef-building corals require very __________ water.
43. In __________ reproduction, new polyps bud off from parent polyps to expand or begin new colonies.
45. __________ corals look like fingers or clumps of cigars and have no secondary branches.
46. Time of day when most corals feed [__________]
47. Along many reefs, spawning occurs as a __________ event, when all the coral species in an area release their eggs and sperm at about the same time.
48. __________ corals resemble the attached or unattached tops of mushrooms.
51. Corals and algae have a __________ relationship.
53. __________ is a system of specially designed buoys that measure conditions that may cause bleaching on coral reefs.
54. The skeletons of stony corals are secreted by the lower portion of the polyp. This process produces a cup, or ________, in which the polyp sits.
55. When polyps are physically stressed, they contract into their calyx so that virtually no part is exposed above their skeleton. At other times, polyps extend out of the calyx. Most polyps extend the farthest when they __________.
57. Natural damage to coral reefs frequently occurs because of __________.
60. Although coral reefs require nutrient-poor water, they are among the most __________ and diverse marine environments.
61. Reefs also are threatened by __________ that can cause shallow water coral heads to overheat and dry out.
62. The relationship between the algae and coral polyp facilitates a tight __________ of nutrients, which is the driving

force behind the growth and productivity of coral reefs.

63. As adults, almost all corals are __________, which means that they remain on the same spot on the sea floor for their entire lives.
64. An __________ is formed when a reef has developed around a volcanic island that subsides completely below sea level while the coral continues to grow upward.
65. Coral reefs buffer adjacent shorelines from wave action and prevent __________, property damage and loss of life.
66. The final release of gametes during spawning is usually based on the time of __________.

Down

1. Species that release massive numbers of eggs and sperm into the water to distribute their offspring over a broad geographic area are called __________ spawners.
2. __________ reefs border shorelines, but are separated from their adjacent land mass by a lagoon of open, often deep water.
3. Healthy reefs contribute to local economies through __________.
4. The walls surrounding the corals' skeletal cup are called the __________
5. Individual coral animals are called __________
7. Human-caused, or __________ activities are major threats to coral reefs.
9. Reefs form when polyps secrete skeletons of __________
13. Because of their intimate relationship with symbiotic algae, reef-building corals respond to the environment like __________.
15. Reef-building corals cannot tolerate water temperatures [above or below] 18° Celsius (C).
17. __________ corals are ball-shaped or boulder-like and may be small as an egg or as large as a house.
18. Tropical ocean waters are generally [rich or poor] in nutrients.
20. __________ reefs project seaward directly from the shore, forming borders along the shoreline and surrounding islands.
22. __________ coral has large, flattened branches.
23. In sexual reproduction, coral eggs and sperm join to form free-floating, or planktonic, larvae called __________.

28. __________ corals grow as a thin layer against a substrate.
29. Nematocysts are capable of delivering powerful, often lethal, __________
31. A coral's prey ranges in size from nearly microscopic animals called __________ to small fish.
32. Massive corals have growth rates of 0.3 to 2 __________ per year
34. In developing countries, coral reefs provide critical _______ __ resources for tens of millions of people.
37. Because their algal cells need light for photosynthesis, reef corals require __________ water.
38. One of the most significant human-caused threats to reefs is __________.
40. The reef __________ is usually the zone closest to shore.
41. Planulae exhibit positive __________
44. Reef-building corals' requirement for high light explains why most reef-building species are restricted to the ______ ____ zone, the region in the ocean where light penetrates to a depth of approximately 70 meters.
49. Coral diseases generally occur in response to biological __ ________, such as bacteria, fungi and viruses, and nonbiological stresses, such as increased sea surface temperatures, ultraviolet radiation and pollutants.
50. The time between planulae formation and settlement is a period of exceptionally high __________ among corals.
52. __________ corals have primary and secondary branches.

56. Symbiotic algae supply corals with glucose, glycerol, and amino acids, which are the products of __________.
58. Coral reefs support more __________ per unit area than any other marine environment.
59. Scientists estimate that there may be __________ of undiscovered species of organisms living in and around reefs.

CORAL REEF LESSON PLAN

Keeping Watch on Coral Reefs

Focus
Management of coral reefs

Grade Level
9-12 (Earth Science)

Focus Question
Why are coral reefs important, and what can be done to protect them from major threats?

Learning Objectives
- Students will be able to identify and explain five ways that coral reefs benefit human beings.

- Students will be able to identify and explain three major threats to coral reefs.

- Students will be able to describe major components of the Coral Reef Early Warning System.

- Students will be able to identify and discuss actions that can be undertaken to reduce or eliminate threats to coral reefs.

- Students will be able to obtain and analyze several types of oceanographic data from remote-sensing satellites.

Materials
- Copies of "Satellite Imagery Worksheet," one copy for each student or student group
- Copies of either "Coral Reef Subject Review" (*fill-in-the-blank version, with or without word bank*) or "Coral Reef Subject Review Crossword Puzzle," one copy for each student or student group
- Computers with internet access

Audio/Visual Materials

None, unless students require A/V equipment for their public education programs

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Classroom style or groups of 4-6 students

Maximum Number of Students

30

Key Words

Coral
Zooxanthellae
Symbionts
Remote Sensing

Background

Coral reefs are one of the most biologically productive ecosystems on Earth. Most people have seen images of brightly colored fishes and other reef-dwelling organisms, yet many do not understand why these systems are personally important. Programs and articles about coral reefs typically point out benefits that include protecting shorelines from erosion and storm damage, supplying foods that are important to many coastal communities, and providing recreational and economic opportunities. These benefits are obviously important to people who live near reefs, but there is another aspect of coral reefs that can benefit everyone: the highly diverse biological communities are new sources of powerful antibiotic, anti-cancer and anti-inflammatory drugs.

Despite their numerous benefits to humans, many coral reefs are threatened by human activities. Sewage and chemical pollution can cause overgrowth of algae, oxygen depletion, and poisoning. Fishing with heavy trawls and explosives damages the physical structure of reefs, as well as the coral animals that build them. Careless tourists and boat anchors also cause mechanical damage. Thermal pollution from power plants and global warming cause physiological stress that kills coral animals and leaves the reef structure vulnerable to erosion. Many of these impacts are the result of ignorance; people simply aren't aware of the importance of coral reefs or the consequences of their actions, but the damage and threats to reefs continues to increase on a global scale.

Some of the most severe damage appears to be caused by thermal stress. Shallow-water reef-building corals live primarily in tropical latitudes (less than 30° north or south of the equator). These corals live near the upper limit of their thermal tolerance. Abnormally high temperatures result in thermal stress, and many corals respond by expelling the symbiotic algae (zooxanthellae) that live in the corals' tissues. Since the zooxanthellae are responsible for most of the corals' color, corals that have expelled their algal symbionts appear to be bleached. Because zooxanthellae provide a significant portion of the corals' food and are involved with growth processes, expelling these symbionts can have significant impacts on the corals' health. In some cases, corals are able to survive a "bleaching" event and eventually recover. When the level of environmental stress is high and sustained, however, the corals may die.

Prior to the 1980s, coral bleaching events were isolated and appeared to be the result of short-term events such as major storms, severe tidal exposures, sedimentation, pollution, or thermal shock. Over the past twenty years, though, these events have become more widespread, and many laboratory studies have shown a direct relationship between bleaching and water temperature stress. In general, coral bleaching events often occur in areas where the sea surface temperature is 1°C or more above the normal maximum temperature.

In 1998, the President of the United States established the Coral Reef Task Force (CRTF) to protect and conserve coral reefs. Activities of the CRTF include mapping and monitoring coral reefs in U.S. waters, funding research on coral reef degradation, and working with governments, scientific and environmental organizations, and business to reduce coral reef destruction and restore damaged coral reefs. Using high-resolution satellite imagery and Global Positioning System (GPS) technology, the National Oceanic and Atmospheric Administration

(NOAA) has made comprehensive maps of reefs in Puerto Rico, the U.S. Virgin Islands, the eight main Hawaiian Islands and the Northwestern Hawaiian Islands. Maps of all shallow U.S. coral reefs are expected to be completed by 2009. NOAA monitors reefs using a system of specially designed buoys that measure air temperature, wind speed and direction, barometric pressure, sea temperature, salinity and tidal level, and transmit these data every hour to scientists. Satellites are also used to monitor changes in sea surface temperatures and algal blooms that can damage reefs. Research and restoration projects on selected coral reefs are conducted by NOAA's National Undersea Research Program.

The first part of this lesson is intended to:
- introduce students to coral reefs and improve their understanding of why these systems are important, how they are threatened, and what can be done to protect and restore these unique and valuable ecosystems; and to
- introduce students to some of the data available from remote-sensing tools that can be used by anyone who wants to study the Earth's oceans.

In the second part of this lesson, students design and prepare educational programs to improve public awareness of the importance of coral reefs and what needs to be done to reduce or eliminate harmful impacts from human activities. This activity offers many opportunities for cross-curricular activities, and may be extended over several weeks or months. If time is limited, you may choose to use the first part alone.

Learning Procedure

Part 1

1.

Direct students to the coral reef tutorials at *http://oceanservice.noaa.gov/education/kits/corals/welcome.html*. You may want to assign different tutorial sections to each student group. Have each student or student group complete one version of the Coral Reef Subject Review, and lead a discussion to review the answers. Be sure that students understand the relationship between coral animals and their symbiotic algae (zooxanthellae), and that many corals under various types of stress will expel their zooxanthellae.

Briefly explain the purpose and activities of the U. S. Coral Reef Task Force (CRTF), and highlight the monitoring functions that are intended to identify reef areas threatened by thermal stress or algal blooms.

2.

Briefly describe some of the satellites and sensors that currently provide various types of oceanographic data:

A great deal of information on oceanographic conditions is available from various satellites. NOAA's Polar Operational Environmental Satellite (POES) carries the Advanced Very High Resolution Radiometer (AVHRR), which provides information on sea surface temperature (SST) for the entire Earth on a daily basis. NASA's Terra and Aqua satellites cross the equator in the morning and afternoon, providing coverage of the entire Earth surface every 1 – 2 days. These satellites carry Moderate Resolution Imaging Spectrometers (MODIS) that provide information on chlorophyll-a as well as SST. NASA's QuikSCAT satellite carries the SeaWinds sensor that provides global information on wind speed and direction near the ocean surface. Data from these (and other) satellites are available free via the internet.

Distribute copies of "Satellite Imagery Worksheet" to each student or student group. Tell students that their assignment is to use satellite data to answer the questions on the worksheet. When students have completed the worksheet, point out that the CRTF's monitoring program keeps track of selected oceanographic conditions on an hourly or daily basis at twenty-four coral reef sites. You may want to have students visit *http://www.osdpd.noaa.gov/PSB/EPS/CB_indices/coral_bleaching_indices.html* to check out current conditions at these reefs.

Have students investigate the history of temperature conditions at each of the three reefs listed on the "Satellite Imagery Worksheet" over the period 1997 to present, using data at *http://coralreefwatch.noaa.gov/satellite/current/sst_series_24reefs.html* and *http://coralreefwatch.noaa.gov/satellite/archive/sst_series_24reefspath.html* (use Grand Bahama Island (GBI) instead of Lee Stocking Island for this exercise). Ask whether temperatures have reached the coral bleaching threshold at any of these reefs during this time period. Students should recognize that the threshold has been exceeded at:

- Glover's Reef in September 1997; August and September, 1998; October, 1999; October, 2003;
- Grand Bahama Island in July, August, and September, 1998; August, 1999; and
- Sombrero Reef in July, August, and September, 1997; August and September, 1998; July, August, and September, 1999

3.

Lead a discussion of how data from the CRTF monitoring program help protect coral reefs. Student will probably realize that these data cannot directly improve the condition of reefs, since the root problem appears to be climate conditions that are beyond human control (at least in the short term). These data are very useful, however, in identifying sites that are at risk of environmental stress so that scientists and resource managers can learn more about the response of corals and coral reef systems to these conditions.

Ask students to discuss why coral reefs are at risk, and what they think can or should be done to reduce or eliminate the negative impacts of human activity on coral reefs. There is a strong possibility that a significant part of the current risk to coral reef systems is the result of human activity, particularly as it relates to global warming. Meaningful actions to address this type of issue depend upon widespread understanding of the problem and commitment to workable solutions. Public education is an important step toward building this sort of understanding and commitment. Have students brainstorm what "key messages" might form part of a public education program about coral reefs, what audiences should be targeted to receive these messages, and how these messages might be most effectively delivered to these audiences.

Part 2

Have students or student groups prepare one or more public education programs about coral reefs, based on the results of their brainstorming sessions in Step 3. Encourage students to consider various media, including publications, visual presentations, drama, music, etc. You may want to have an entire class work on a single program, or have smaller groups work on multiple programs using the medium (or media) of their choice. There are many possibilities, depending upon the target audiences. These presentations also offer cross-curricular opportunities, particularly with social studies, English language arts, and fine arts. Whatever media students choose to work with, their final presentation should be accompanied by a list of sources for the information they present. A good starting point for this activity is the Roadmap to Resources: Corals (*http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html*), which provides links to many other sources of coral reef data and information.

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the navigation menu to the left, then "Habitats", "Coastal", "Coral Reef."

The "Me" Connection

Have students write a short essay on why coral reefs are personally important, what personal actions may contribute to human-caused threats to coral reefs, and what they could personally do to reduce these threats.

Extensions

Have students or student groups prepare a report on a specific aspect of coral biology, ecology, or management. Some possible topics include:

- coral diseases
- natural and anthropogenic hazards
- oil spills on coral reefs
- coral reef restoration
- species diversity on coral reefs
- benthic habitats associated with coral reefs
- relationships between coral reefs and seagrass or mangrove ecosystems

See Roadmap to Resources: Corals (*http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html*) for links to information on relevant topics.

Resources

http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html – NOAA's National Ocean Service Web site's Roadmap to Resources about corals, with links to many other sources of coral reef data, background information, and reports

http://coastwatch.noaa.gov/cw_dataprod.html – description and links to satellite remote sensing ocean data provided by NOAA CoastWatch

http://coastwatch.noaa.gov/interface/interface.html – search page for satellite remote sensing ocean data provided by NOAA CoastWatch; use navigation bar at left to select geographic region, type of data, and date range

http://www.coral.noaa.gov/index.shtml – NOAA's Coral Health and Monitoring Program home page, with links to coral reef data, maps, and other resources

http://www.osdpd.noaa.gov/PSB/EPS/SST/climohot.html – coral bleaching hotspot chart

http://www.osdpd.noaa.gov/PSB/EPS/CB_indices/coral_bleaching_indices.html - Tropical Ocean Coral Bleaching Indices for 24 coral reef sites

Ariadne, D. and D. Diamante-Fabunan. 2000. Coral Bleaching: the Whys, the Hows and What Next? OverSeas, The Online Magazine for Sustainable Seas. *http://oneocean.org/overseas/200009/coral_bleaching_the_hows_and_whys_and_whats_next.html*

Hughes, T.P., et al. 2003. Climate Change, Human Impacts, and the Resilience of Coral Reefs. Science 301:929-933. Available online at *http://ioc.unesco.org/coralbleaching/Hughes%et%20al.pdf*

http://www.crc.uri.edu/download/COR_0011.PDF – "Coral Bleaching: Causes, Consequences and Response;" a collection of papers presented at the Ninth International Coral Reef Symposium October 2002.

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

Content Standard D: Earth and Space Science

- Energy in the earth system
- Geochemical cycles

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

CORAL REEF LESSON PLAN

Satellite Imagery Worksheet

Two conditions that have been linked to coral bleaching are water temperatures that exceed 30°C and little or no surface wind. Your assignment is to use satellite data to investigate whether these conditions have occurred during the past week at three coral reef areas. These reefs are:

- Sombrero Reef in the Florida Keys, located at 25.0°N, 81.5°W;
- Lee Stocking Island in the Bahamas, located at 23.5°N 76.5°W;
- Glover's Reef, in Belize, located near 16.5°N, 88.0°W.

I. Follow these steps to obtain the necessary information about sea surface temperatures (SST):

1. Go to *http://cwcaribbean.aoml.noaa.gov*

2. Click on the Access Coastwatch icon.

3. Click on the Database Query icon.

4. Build your query.

   a. Check all dates

   b. Uncheck "WC" and "EC" under "Regions," and check the boxes for Florida Keys (FK), Bahamas (BH), and Belize (BZ).

   c. Under "Types", check the boxes for daytime SST (D7), and uncheck the box for nighttime SST (S7).

   d. At the bottom of the page, click "Submit"

5. Select the most recent imagery for each of the three reefs, and determine the sea surface temperature (SST).

II. Follow these steps to obtain the necessary information about surface winds data

1. Go to *http://coastwatch.noaa.gov*

2. Click on "Link: Product Search"

3. Build Query:

   a. In the "View Results as" window, select "As Images"

   b. In the "Select a Region" window, select "Caribbean" or "Gulf of Mexico"

   c. In the "Select Product" window, select "Surface Winds"

   d. In the Sensor Select window, select "Seawinds"

   e. In the Satellite window, select "QUIKSCAT"

   f. In the From and To date windows, enter the dates from the most recent images of sea surface temperatures in exercise I above.

4. Click on "Search"

CORAL REEF LESSON PLAN

Coral Reef Subject Review

1. ___________ organisms are composed of hundreds to hundreds of thousands of individual animals.

2. Individual coral animals are called __________.

3. The mouth of individual coral animals is surrounded by a circle of ____________.

4. After food is consumed by corals, waste products are expelled through the _____________.

5. Time of day when most corals feed: ____________

6. To capture their food, corals use stinging cells called ___________________.

7. Nematocysts are capable of delivering powerful, often lethal, ____________.

WORD BANK

plants	digitate	erosion	pollution
clear	table	weather	algae
productive	elkhorn	algae	fishing
calcium carbonate	colonial	tidal emersions	fringing
habitats	zooplankton	El Niño	barrier
encrusting	planulae	zooxanthellae	cm
calyx	broadcast	mutualistic	flat
theca	mortality	photosynthesis	crest
basal plate	synchronized	poor	buttress
feed	lunar	atoll	seaward
branching	tentacles	stresses	slope
foliase	mouth	temperatures	below
metamorphose	night	CREWS	euphotic
massive	nematocysts	mucous	sessile
polyps	toxins	recycling	asexual
mushroom	species	zooxanthellae	millions
larvae	medicines	physical stress	
sunset	tourism	predation	
phototaxis	food	anthropogenic	

8. A coral's prey ranges in size from nearly microscopic animals called ________________ to small fish.

9. Many corals collect fine organic particles in films and strands of _____________.

10. Most reef-building corals contain photosynthetic algae called ___________ , which live in their tissues.

11. Corals and algae have a ___________ relationship.

12. Symbiotic algae supply corals with glucose, glycerol, and amino acids, which are the products of ____________.

13. Tropical ocean waters are generally [rich or poor] ___________ in nutrients.

14. The relationship between the algae and coral polyp facilitates a tight __________ of nutrients, which is the driving force behind the growth and productivity of coral reefs.

15. The unique and beautiful colors of many stony corals are caused by ________________.

16. ___________ can cause coral polyps to expel their algal cells.

17. Coral _____________ occurs when coral polyps expel their algal cells, causing the colony to take on a stark white appearance.

18. Because of their intimate relationship with symbiotic algae, reef-building corals respond to the environment like _________.

19. Because their algal cells need light for photosynthesis, reef corals require ___________ water.

20. Although coral reefs require nutrient-poor water, they are among the most ___________ and diverse marine environments.

21. Reefs form when polyps secrete skeletons of __________.

22. As they grow, coral reefs provide structural __________ for hundreds to thousands of different vertebrate and invertebrate species.

23. The skeletons of stony corals are secreted by the lower portion of the polyp. This process produces a cup, or ________, in which the polyp sits.

24. The walls surrounding the corals' skeletal cup are called the ____________.

25. The floor of the corals' skeletal cup is called the ____________.

26. __________ is a system of specially designed buoys that measure conditions that may cause bleaching on coral reefs.

27. When polyps are physically stressed, they contract into their calyx so that virtually no part is exposed above their skeleton. At other times, polyps extend out of the calyx. Most polyps extend the farthest when they __________.

28. __________ corals have primary and secondary branches.

29. __________ corals look like fingers or clumps of cigars and have no secondary branches.

30. __________ corals form table-like structures and often have fused branches.

31. __________ coral has large, flattened branches.

32. __________ corals have broad plate-like portions rising in whorl-like patterns.

33. __________ corals grow as a thin layer against a substrate.

34. __________ corals are ball-shaped or boulder-like and may be small as an egg or as large as a house.

35. __________ corals resemble the attached or unattached tops of mushrooms.

36. Coral reefs begin to form when free-swimming __________ attach to submerged rocks or other hard surfaces along the edges of islands or continents.

37. __________ reefs project seaward directly from the shore, forming borders along the shoreline and surrounding islands.

38. __________ reefs border shorelines, but are separated from their adjacent land mass by a lagoon of open, often deep water.

39. An ____________ is formed when a reef has developed around a volcanic island that subsides completely below sea level while the coral continues to grow upward.

40. Massive corals have growth rates of 0.3 to 2 __________ per year

41. Bottom topography, depth, wave and current strength, light, temperature, and suspended sediments act on coral reefs to create horizontal and vertical zones of living species. The reef __________ is usually the zone closest to shore, followed by the reef __________ or algal ridge, then the __________ zone, and finally the __________.

42. Reef-building corals cannot tolerate water temperatures [above or below] __________ 18° Celsius (C).

43. Most reef-building corals require very saline water.

44. Reef-building corals' requirement for high light explains why most reef-building species are restricted to the ______ ____ zone, the region in the ocean where light penetrates to a depth of approximately 70 meters.

45. As adults, almost all corals are __________, which means that they remain on the same spot on the sea floor for their entire lives.

46. In __________ reproduction, new polyps bud off from parent polyps to expand or begin new colonies.

47. In sexual reproduction, coral eggs and sperm join to form free-floating, or planktonic, larvae called __________.

48. Species that release massive numbers of eggs and sperm into the water to distribute their offspring over a broad geographic area are called __________ spawners.

49. The time between planulae formation and settlement is a period of exceptionally high __________ among corals.

50. Along many reefs, spawning occurs as a __________ event, when all the coral species in an area release their eggs and sperm at about the same time.

51. 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 __________ cues.

52. The final release of gametes during spawning is usually based on the time of __________.

53. Planulae exhibit positive ___________.

54. Once planulae settle on the bottom, they __________ into polyps and form colonies that increase in size.

55. Coral reefs support more __________ per unit area than any other marine environment.

56. Scientists estimate that there may be ____________ of undiscovered species of organisms living in and around reefs.

57. Coral reef biodiversity is considered key to finding new __________ for the 21st century.

58. Healthy reefs contribute to local economies through __________.

59. In developing countries, coral reefs provide critical __________ resources for tens of millions of people.

60. Coral reefs buffer adjacent shorelines from wave action and prevent __________, property damage and loss of life.

61. Natural damage to coral reefs frequently occurs because of __________.

62. Slow-growing corals that are damaged by storms may be overgrown by __________ before they can recover.

63. Reefs also are threatened by __________ that can cause shallow water coral heads to overheat and dry out.

64. Increased sea surface temperatures, decreased sea level and increased salinity from altered rainfall can all result from weather patterns such as __________.

65. Corals are vulnerable to __________ by fishes, marine worms, barnacles, crabs, snails and sea stars.

66. Human-caused, or __________ activities are major threats to coral reefs.

67. One of the most significant human-caused threats to reefs is __________.

68. When some contaminants enter the water, nutrient levels can increase, promoting the rapid growth of __________ and other organisms that can smother corals.

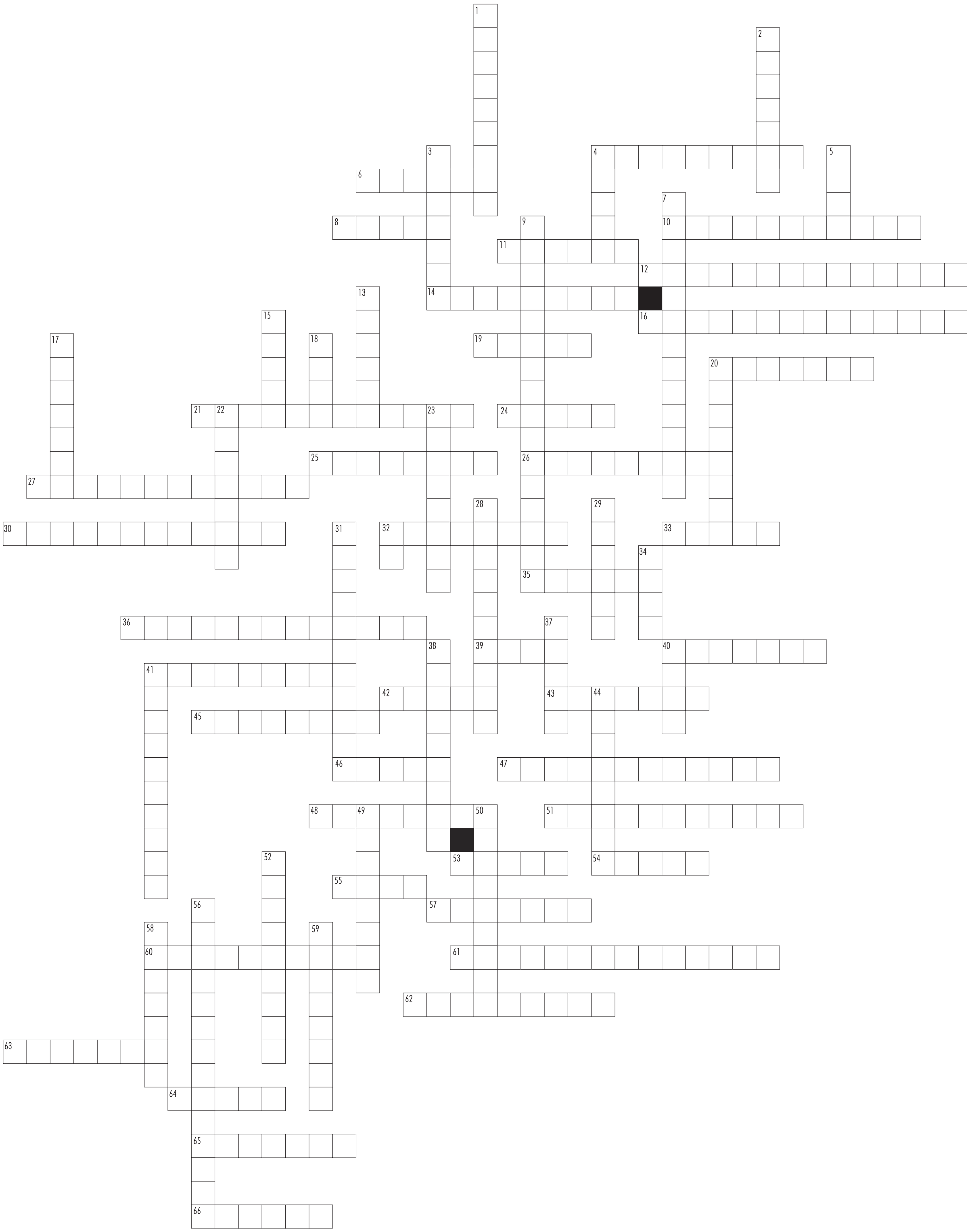
69. In many areas, coral reefs are destroyed when cyanide or dynamite are used for __________ activities.

70. Coral diseases generally occur in response to biological __________, such as bacteria, fungi and viruses, and non-biological stresses, such as increased sea surface temperatures, ultraviolet radiation and pollutants.

71. Many scientists believe that the increased frequency of coral diseases over the last 10 years is related to deteriorating water quality and increased __________ that may allow for the proliferation and colonization of microbes.

CORAL REEF LESSON PLAN

Coral Reef Subject Review: Crossword Puzzle



Across

4. The mouth of individual coral animals is surrounded by a circle of ____.
6. Many corals collect fine organic particles in films and strands of ______.
8. 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 __________ cues.
10. To capture their food, corals use stinging cells called _____ _____.
11. Coral reefs begin to form when free-swimming __________ attach to submerged rocks or other hard surfaces along the edges of islands or continents.
12. __________ can cause coral polyps to expel their algal cells.
14. Coral reef biodiversity is considered key to finding new __________ for the 21st century.
16. Most reef-building corals contain photosynthetic algae called _________which live in their tissues.
19. After the food is consumed by corals, waste products are expelled through the __________.
20. __________ corals have broad plate-like portions rising in whorl-like patterns.
21. The __________ is usually the zone farthest from shore.
24. plate The floor of the corals' skeletal cup is called the __________.
25. As they grow, coral reefs provide structural __________ for hundreds to thousands of different vertebrate and invertebrate species.
26. Coral __________ occurs when coral polyps to expel their algal cells, causing the colony to take on a stark white appearance.
27. Once planulae settle on the bottom, they __________ into polyps and form colonies that increase in size.
30. Many scientists believe that the increased frequency of coral diseases over the last 10 years is related to deteriorating water quality and increased __________ that may allow for the proliferation and colonization of microbes.
32. __________ organisms are composed of hundreds to hundreds of thousands of individual animals.
33. Slow-growing corals that are damaged by storms may be

overgrown by __________ before they can recover.
35. Increased sea surface temperatures, decreased sea level and increased salinity from altered rainfall can all result from weather patterns such as __________.
36. The unique and beautiful colors of many stony corals are caused by __________.
39. __________ corals form table-like structures and often have fused branches.
40. In many areas, coral reefs are destroyed when cyanide or dynamite are used for __________ activities.
41. Corals are vulnerable to __________ by fishes, marine worms, barnacles, crabs, snails and sea stars.
42. Most reef-building corals require very __________ water.
43. In __________ reproduction, new polyps bud off from parent polyps to expand or begin new colonies.
45. __________ corals look like fingers or clumps of cigars and have no secondary branches.
46. Time of day when most corals feed [__________]
47. Along many reefs, spawning occurs as a __________ event, when all the coral species in an area release their eggs and sperm at about the same time.
48. __________ corals resemble the attached or unattached tops of mushrooms.
51. Corals and algae have a __________ relationship.
53. __________ is a system of specially designed buoys that measure conditions that may cause bleaching on coral reefs.
54. The skeletons of stony corals are secreted by the lower portion of the polyp. This process produces a cup, or ________, in which the polyp sits.
55. When polyps are physically stressed, they contract into their calyx so that virtually no part is exposed above their skeleton. At other times, polyps extend out of the calyx. Most polyps extend the farthest when they __________.
57. Natural damage to coral reefs frequently occurs because of __________.
60. Although coral reefs require nutrient-poor water, they are among the most __________ and diverse marine environments.
61. Reefs also are threatened by __________ that can cause shallow water coral heads to overheat and dry out.
62. The relationship between the algae and coral polyp facilitates a tight __________ of nutrients, which is the driving

force behind the growth and productivity of coral reefs.

63. As adults, almost all corals are __________, which means that they remain on the same spot on the sea floor for their entire lives.
64. An __________ is formed when a reef has developed around a volcanic island that subsides completely below sea level while the coral continues to grow upward.
65. Coral reefs buffer adjacent shorelines from wave action and prevent __________, property damage and loss of life.
66. The final release of gametes during spawning is usually based on the time of __________.

Down

1. Species that release massive numbers of eggs and sperm into the water to distribute their offspring over a broad geographic area are called __________ spawners.
2. __________ reefs border shorelines, but are separated from their adjacent land mass by a lagoon of open, often deep water.
3. Healthy reefs contribute to local economies through __________.
4. The walls surrounding the corals' skeletal cup are called the __________
5. Individual coral animals are called __________
7. Human-caused, or __________ activities are major threats to coral reefs.
9. Reefs form when polyps secrete skeletons of __________
13. Because of their intimate relationship with symbiotic algae, reef-building corals respond to the environment like __________.
15. Reef-building corals cannot tolerate water temperatures [above or below] 18° Celsius (C).
17. __________ corals are ball-shaped or boulder-like and may be small as an egg or as large as a house.
18. Tropical ocean waters are generally [rich or poor] in nutrients.
20. __________ reefs project seaward directly from the shore, forming borders along the shoreline and surrounding islands.
22. __________ coral has large, flattened branches.
23. In sexual reproduction, coral eggs and sperm join to form free-floating, or planktonic, larvae called __________.

28. __________ corals grow as a thin layer against a substrate.
29. Nematocysts are capable of delivering powerful, often lethal, __________
31. A coral's prey ranges in size from nearly microscopic animals called __________ to small fish.
32. Massive corals have growth rates of 0.3 to 2 __________ per year
34. In developing countries, coral reefs provide critical _______ __ resources for tens of millions of people.
37. Because their algal cells need light for photosynthesis, reef corals require __________ water.
38. One of the most significant human-caused threats to reefs is __________.
40. The reef __________ is usually the zone closest to shore.
41. Planulae exhibit positive __________
44. Reef-building corals' requirement for high light explains why most reef-building species are restricted to the ______ ____ zone, the region in the ocean where light penetrates to a depth of approximately 70 meters.
49. Coral diseases generally occur in response to biological __ ________, such as bacteria, fungi and viruses, and nonbiological stresses, such as increased sea surface temperatures, ultraviolet radiation and pollutants.
50. The time between planulae formation and settlement is a period of exceptionally high __________ among corals.
52. __________ corals have primary and secondary branches.

56. Symbiotic algae supply corals with glucose, glycerol, and amino acids, which are the products of __________.
58. Coral reefs support more __________ per unit area than any other marine environment.
59. Scientists estimate that there may be __________ of undiscovered species of organisms living in and around reefs.

CORAL REEF CONSERVATION LESSON PLAN

Who Has the Data?

Theme

Coral Reef Monitoring

Links to Overview Essays and Resources Needed for Student Research

http://oceanservice.noaa.gov/topics/oceans/coralreefs
http://www.sanctuaries.noaa.gov/about/ecosystems/coralwelcome.html
http://www.coris.noaa.gov/activities/assessment.html#monitor

See specific citations on “Coral Monitoring Data Worksheet” on Page 9 of this Lesson Plan.

Subject Area

Life Science/Earth Science

Grade Level

9-12

Focus Question

What types of data do scientists collect to monitor coral reefs, and how are these data used?

Learning Objectives

- Students will be able to access data on selected coral reefs and manipulate these data to characterize these reefs.
- Students will be able to explain the need for baseline data in coral reef monitoring programs.
- Students will be able to identify and explain five ways that coral reefs benefit human beings.
- Students will be able to identify and explain three major threats to coral reefs.

Materials Needed

- “Coral Monitoring Data Worksheet,” one copy per student group

- (optional) Computers with internet access; if students do not have access to the internet, you can download copies of the reef habitat images cited under "Learning Procedure" and prepare transparent grids for use in determining area of habitat types on each reef; you can also download copies of other materials cited under "Learning Procedure" and on the worksheet, and provide copies of these materials to each student or student group
- (optional; see Learning Procedure) Grid (approximately 2 mm square) photocopied onto transparencies; one for each student group

Audio/Visual Materials Needed

None

Teaching Time

One 45-minute class period, plus time for student research

Seating Arrangement

Groups of 3-4 students

Maximum Number of Students

32

Key Words

Coral reefs
Zooxanthellae
Monitoring
Benthic habitat
Fish census
Bleaching

Background Information

Coral reefs are some of the most biologically productive and economically valuable ecosystems on Earth. Benefits provided by coral reefs include protecting shorelines from erosion and storm damage, supplying foods that are important to many coastal communities, and providing recreational and economic opportunities. In addition, the highly diverse biological communities associated with coral reefs are new sources of powerful antibiotic, anti-cancer and anti-inflammatory drugs that have the potential to benefit the entire human race.

Despite these benefits, many coral reefs are threatened by human activities as well as natural processes. Sewage and chemical pollution can cause overgrowth of algae, oxygen depletion, and poisoning. Poor land management and deforestation can lead to excessive runoff and sedimentation that can smother living reefs and reduce light needed by many shallow-water corals. Fishing with heavy trawls, poisons, and explosives damages the physical structure of reefs as well as the coral animals that build them. Careless tourists, boat anchors, and collection for the aquarium trade also cause mechanical damage. Thermal pollution from power plants and unusually hot weather cause physiological stress that kills coral animals and leaves the reef structure vulnerable to erosion. Oil spills, fuel discharges, and anti-fouling chemicals from boats add additional stress. Many of these impacts are the result of ignorance; people simply aren't aware of the importance of coral reefs or the consequences of their actions. But the damage and threats to reefs continue to increase on a global scale.

In addition to stress from human activities, coral reefs are also subject to natural threats. Hurricanes and cyclones can break corals loose and scatter them into areas where they cannot survive. Severe storms also cause impacts on coastal areas that increase sedimentation and runoff. Unusually low tides can leave corals exposed to high temperatures, solar radiation, and the risk of drying out. Heavy rains can lower salinity to dangerous levels.

High temperatures associated with phenomena such as El Nino cause severe damage through thermal stress. Shallow-water reef-building corals are found primarily in tropical latitudes (less than 30° north or south of the equator) and live near the upper limit of their thermal tolerance, so temperatures one or two degress above normal can result in thermal stress. One of the most striking responses to thermal stress is known as "bleaching." Most reef-building corals have single-cell algae (zooxanthellae) living within their tissues. These algae play an important role in the corals' nutrition and growth. Pigments in the algae are also responsible for most of the corals' color. Under thermal stress, some corals may expel these algae, causing the corals to appear bleached. Some corals may recover and acquire replacement algae, but others may die. Corals are also subject to predation and disease. Rates of disease outbreaks in corals appear to be increasing, and many researchers believe that at least part of the reason is that the corals have been weakened by other stress factors.

In response to growing concern for the future of coral reefs, the President of the United States established the Coral Reef Task Force (CRTF) in 1998 to protect and conserve coral reefs. The CRTF has prepared a plan to reduce human threats to coral reefs and to improve our understanding of coral reef ecosystems. Strategies for reducing human threats include:

- Expanding and strengthening coral reef marine protected areas (MPAs);
- Reducing damage caused by extractive uses such as overfishing;
- Reducing habitat destruction and pollution;
- Restoring damaged reefs; and
- Creating an informed public.

Strategies to improve our understanding of coral reef ecosystems include:

- Comprehensive mapping, inventory and monitoring of U.S. reefs; and
- Research on coral reef ecology, bleaching, diseases, and best management practices for successful coral reef conservation.

Mapping and monitoring are an essential part of coral reef conservation. The purpose of this activity is to acquaint students with sources of information and data on coral reef monitoring, and to provide hands-on experience with manipulating and interpreting some of these data.

Learning Procedure

1.

If you plan to have your students use NIH Image to analyze benthic habitat maps, download the program and manual from *http://rsb.info.nih.gov/nih-image/*. Be sure that the RAM allocation for the Image program is at least 8,000K, and that the Clipboard and Undo Buffer is set to 1,000K. An alternative to this approach is to photocopy a grid (approximately

2mm squares) onto transparencies, and have students use the transparencies to count the number of grid squares contained in each of the habitat regions shown on the habitat maps. The total number of squares for each habitat type can be used to quantify the relative area occupied by each habitat.

2.

Direct students to the Corals Discovery Kit at *http://oceanservice.noaa.gov/education/kits/corals*. You may want to assign different tutorial sections to each student group. Have each student or student group complete one version of the Self-Test in the Lesson Plan section of the Discovery Kit (downloadable), and lead a discussion to review the answers.

Briefly review the purpose and activities of the U. S. Coral Reef Task Force (CRTF), and highlight the monitoring functions that are intended to identify threatened reef areas and to improve understanding of reef ecosystems (visit *http://coralreef.noaa.gov* for more information on the CRTF).

3.

Tell students that their assignment is to use online data tools to investigate selected coral reefs. Assign one of the following marine protected areas in the Florida Keys to each student group:

- Carysfort/South Carysfort Reef
- French Reef
- Molasses Reef
- Conch Reef
- Hen and Chickens
- Davis Reef
- Alligator Reef
- Sombrero Key
- Looe Key
- Western Sambos/Eastern Sambos
- Sand Key

Provide each student group with a “Coral Monitoring Data Worksheet.” Have each student group complete the tasks described, and prepare a written report containing answers to the questions on the worksheet.

4.
Lead a discussion of students' results. Students should realize that a primary purpose of habitat and fish census data is to establish baselines that can be compared with subsequent surveys to detect changes in coral reef systems. Discuss the variability of habitats in marine protected areas of the Florida Keys. Students should recognize that there is often considerable variability among habitats, even though the habitats are in the same geographic area. An important part of developing a comprehensive understanding of coral reef ecosystems is knowing how reefs change over time in response to various types of environmental change. Students' examination of sea surface temperature data should reveal that Sombrero Key (the monitoring station located in the Florida Keys) was exposed to water temperatures exceeding the coral bleaching threshold on three occasions during the period January 1, 2000 – December 31, 2003; during August and September 2001, August 2002, and August 2003.

Students should recognize that fish census data from St. Croix, USVI, are typical of many healthy coral reef systems in that while there are a large number of different species present, only a few of these are present in large numbers, and there are many more small fishes than large ones. The two most abundant species (*Halichoeres bivittatus* and *Thalassoma bifasciatum*) are strongly associated with reef/hard bottom substrates. In contrast, the two species with the greatest number of large (> 30 cm) individuals were much more strongly associated with vegetated areas.

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the navigation menu to the left, then "Ecology," then "Coral."

The Me Connection

Have students write a short essay on why coral reefs are personally important and what specific actions individuals might take to reduce threats to coral reefs.

Extensions

Online data and tools introduced in this activity can be used for a wide variety of additional activities related to coral reefs and coral reef management. Many of these data and tools can be accessed through "Discover NOAA's Data" at the CoRIS home page (*http://coris.noaa.gov/*) and the "Corals Roadmap to Resources" (*http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html*)

Resources

http://www.nodc.noaa.gov/col/projects/coral/Coralhome.html – The National Oceanographic Data Center (NODC) coral reefs Web page

http://response.restoration.noaa.gov/oilaids/coral/tour/tour.html – Guided tour of coral reefs presented by the National Ocean Service, Office of Response and Restoration; includes a basic overview of coral ecology, types of things which can harm coral, and shows how resource managers go about response and restoration efforts

Anonymous, 1998. Bleaching The Great Unknown. Reef Research Volume 8. *http://www.gbrmpa.gov.au/corp_site/info_services/publications/reef_research/issue2_98/2rmn1.html*

Ariadne, D. and D. Diamante-Fabunan. 2000. Coral Bleaching: the Whys, the Hows and What Next? OverSeas, The Online Magazine for Sustainable Seas. *http://www.oneocean.org/overseas/200009/coral_bleaching_the_hows_and_whys_and_whats_next.html*

http://www.coral@coral.aoml.noaa.gov – Web site with a bulletin board on coral bleaching

http://www.crc.uri.edu/download/COR_011.PDF – "Coral Bleaching: Causes, consequences and response;" a collection of papers from the ninth international coral reef symposium.

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science
- Interdependence of organisms

Content Standard D: Earth and Space Science
- Geochemical cycles

Content Standard E: Science and Technology
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Links to AAAS "Oceans Map" (aka benchmarks)

5D/H2
"Like many complex systems, ecosystems tend to have cyclic fluctuations around a state of rough equilibrium. In the long run, however, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution."

5D/H3
"Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems."

CORAL REEF MONITORING LESSON PLAN

Coral Monitoring Data Worksheet

1. Obtain a map of benthic habitats for your assigned area:
   a. Point your web browser to *http://coris.noaa.gov/*. This is the home page for NOAA's Coral Reef Information System (CoRIS), which is designed to be a single point of access to NOAA coral reef information and data products.

   b. Click on "Discover NOAA's Data," then "Browse," then "Browse Data Descriptions."

   c. Select "Place Keywords - Multiple Pages." Click on the letter "F," then scroll down to "Florida" and find the entry for "florida_keys_benthic_habitat_1992." Click on "FAQ" then "3. What does it look like?."

   d. Select the link to "*http://spo.nos.noaa.gov:16080/projects/benthic_habitats/pro_areas_htmls/pro_areas_map.html*" which opens a page showing protected areas in the Florida Keys for which benthic habitat maps have been constructed.

   e. Click on the name of the reef area that has been assigned to your group. A window will open with a benthic habitat map for the selected area.

   f. Click on "Legend" and print a copy of the map legend.

2. Return to the previous page (with the benthic habitat map) and copy the map image into an image processing program such as Adobe Photoshop. Save the image as a TIFF file. Do not compress the file in any way, or it will not open in NIH Image.

3. Open the saved TIFF file in NIH Image. Use the heart-shaped freehand selection tool to trace the outline of each habitat on the map that is inside the protected area (the boundaries of the protected area are drawn in magenta). When you have completed tracing one of the habitats, choose "Measure"

under the "Analyze" pull-down menu. The area of the traced area will appear in the "Info" window. The units of measurement are squares, which is adequate for the purpose of this analysis since we are only interested in the relative abundance of each habitat type. Keep a list of the area measurements for each habitat.

4. When all habitats have been traced, add the area measurements for each habitat type and prepare a table showing these areas.

5. Add all the measurements together, then divide this number into the total area for each habitat type to calculate the relative area (percent of total) for each habitat.

6. Construct a pie chart showing the relative areas for each type of habitat.

7. Coral bleaching events often occur in areas where the sea surface temperature is1°C or more above the normal maximum temperature. Find out whether coral reefs in the Florida Keys have been exposed to water temperatures that could cause "bleaching." From the entries under "Florida" in step 1c, find the entry for "avhrr_cur_timeseries." Click on "FAQ," then "1.How should this data set be cited?" and select the link to *http://coralreefwatch.noaa.gov/satellite/current/sst_series_24reefs.html*, to open the "Most Current SST Time Series" page.

   This page contains links to sea surface temperature (SST) data for 24 selected coral reef locations beginning in the year 2000. These data are obtained from the Advanced Very High Resolution Radiometer (AVHRR), which provides information on sea surface temperature (SST) for the entire Earth on a daily basis. The AVHRR is carried on NOAA's Polar Orbiting Environmental Satellite (POES).

   Click on the location that is in or near the Florida Keys.

   During the period January 1, 2000 – December 31, 2003, did the water temperature at this location ever exceed the coral bleaching threshold? How often?

8. Point your web browser to *http://biogeo.nos.noaa.gov/*. This is the home page for NOAA's Biogeography Program that is responsible for developing knowledge and products on living marine resource distributions and ecology throughout the Nation's estuarine, coastal and marine environments, and to provide managers and scientists with an improved ecosystem basis for making decisions.

    a. Click on "Projects," then on "Reef Fish Ecology" in the menu on the left side of the page.

    b. Click on "Reef Fish Database," then "Custom Summary Statistics."

    c. Click on St. Croix in the map image. This opens a summary page for reef fish censuses in St. Croix, USVI.

    d. Click on "Species List," which opens a page that summarizes information for all fish species included in the St. Croix fish censuses. Identify:

    - Which two species had the largest number of individuals?
    - In what type of habitat would you most likely find these species?
    - Which two species had the largest number of individuals whose length was greater than 30 cm?
    - In what type of habitat would you most likely find these species?

CORAL REEF CONSERVATION LESSON PLAN

A Reef of Your Own

Theme
Coral Reef Biology

Links to Overview Essays and Resources Needed for Student Research
http://oceanservice.noaa.gov/topics/ocean/coralreefs
http://www.coris.noaa.gov/about/biology
http://oceanservice.noaa.gov/education/kits/corals/coral01_intro.html

Subject Area
Life Science

Grade Level
9-12

Focus Question
What physiological, ecological, and behavioral strategies contribute to the success of reef-building corals?

Learning Objectives
- Students will be able to describe and explain the importance of asexual and sexual reproductive strategies to reef-building corals.

- Students will be able to explain why is it important that reef-building corals have a nutritional strategy that includes both photosynthesis and carnivory.

- Students will be able to describe two behaviors that reef-building corals use to compete for living space with other species.

- Students will be able to explain how coral reefs can produce high levels of biological material when the waters surrounding these reefs contain relatively small amounts of the nutrients normally needed to support biological production.

Materials Needed

- Copies of either "Coral Reef Self-Test" (fill-in-the-blank version, with or without word bank) or "Coral Reef Self-Test Crossword Puzzle," one copy for each student or student group, available at: *http://oceanservice.noaa.gov/education/kits/corals/lessons/coral_bleach.pdf*
- (optional) Computers with internet access; if students do not have access to the internet, direct them to local library resources, and/or download copies of materials cited under "Learning Procedure" and provide copies of these materials to each student or student group

Audio/Visual Materials Needed

None

Teaching Time

Two or three 45-minute class periods, plus time for student research; additional time will be needed if you decide to set up a model coral reef ecosystem

Seating Arrangement

Groups of 3-4 students

Maximum Number of Students

30

Key Words

Coral reefs
Aquarium
Symbiosis
Zooxanthellae
Broadcast spawning

Background Information

Coral reefs are among the most biologically diverse and productive ecosystems on Earth. Coral reefs protect shorelines from erosion and storm damage, supply foods that are important to many coastal communities, and provide recreational and economic opportunities. In addition, the highly diverse biological communities associated with coral reefs are new sources of powerful antibiotic, anti-cancer and anti-inflammatory drugs that have the potential to benefit the entire human race (for more information on drugs from coral reefs, visit *http://oceanservice.noaa.gov/education/corals/lessons/coral_bleach.pdf* and *http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/edu.html*).

Unfortunately, coral reefs are regularly damaged by a variety of natural stresses. Hurricanes and cyclones can break corals loose and scatter them into areas where they cannot survive. Storm damage to coastal areas can increase the inflow of sediments that can smother living reefs and reduce light needed by many shallow-water corals. Freshwater runoff may cause additional stress by lowering the salinity of water surrounding reefs. Unusually low tides can leave corals exposed to high temperatures, solar radiation, and the risk of drying out. High temperatures associated with phenomena such as El Nino and prolonged periods of unusual warmth cause severe damage through thermal stress and may be lethal. Corals are also subject to predation and disease. Coral reefs have survived these types of threats for millions of years. Some reefs have become extinct, but others have flourished.

Corals are also threatened by human activities. These stresses may have a much greater impact than natural stresses. Sewage and chemical pollution can cause overgrowths of algae, oxygen depletion, and poisoning. Poor land management and deforestation can lead to excessive runoff and sedimentation. Fishing with heavy trawls, poisons, and explosives damages the physical structure of reefs as well as the coral animals that build them. Careless tourists, boat anchors, and collection for the aquarium trade also cause mechanical damage. Thermal pollution from power plants and other human activities that raise water temperatures cause physiological stress that kills coral animals and leaves the reef structure vulnerable to erosion. Oil spills, fuel discharges, and anti-fouling chemicals from boats add additional stress. Many of these impacts are the result of ignorance; people simply aren't aware of the importance of coral reefs or the consequences of their actions. But the damage and threats to reefs continues to increase on a global scale. There is also evidence that impacts caused by humans may be increasing the severity of natural threats. Many researchers have noticed an increase in coral diseases and believe that at least part of the reason is that the corals have been weakened by other stress factors.

One of the most striking responses to thermal stress is known as "bleaching." Most reef-building corals have single-cell algae called zooxanthellae living within their tissues. These algae play an important role in the corals' nutrition and growth. Pigments in the algae are also responsible for most of the corals' color. Under thermal stress, some corals may expel these algae, causing the corals to appear bleached. Some corals may recover and acquire replacement algae, but many others die.

In 1998, the President of the United States established the Coral Reef Task Force (CRTF) to protect and conserve coral reefs. The CRTF has identified six problem areas for priority action:

- Land-based sources of pollution;
- Overfishing;
- Lack of public awareness;
- Recreational overuse and misuse;
- Climate change and coral bleaching; and
- Disease.

All of these areas can benefit from broad public involvement, even from people who live thousands of miles from a living reef. The first step toward effective action to protect and manage coral reefs is to understand the biology of the organisms that create the reef structure.

In this activity, students will explore biology of reef-building corals, and use this knowledge to design a miniature coral reef system. If time permits, students may implement their design with live corals and other reef organisms.

Learning Procedure

1.

Direct students to the coral reef tutorials at *http://oceanservice.noaa.gov/education/kits/corals/coral01_intro.html*. You may want to assign different tutorial sections to each student group. Have each student or student group complete one version of the Self-Test, and lead a discussion to review the answers. Be sure students grasp the following points.
Almost all reef building corals are sessile (they remain in one place and do not move), and are adapted to their environment through specific physiological and behavioral characteristics.

Particularly important are:
- Reproductive strategies (both sexual and asexual modes, including mass spawning events);
- A combination of photosynthetic and carnivorous nutrition; and
- Behavioral interactions with other species that allow corals to successfully compete for living space.

2.
Tell students that they are going to design a functioning model of a coral reef ecosystem that could be put together in your classroom. To prepare for this task, their assignment is to research relevant aspects of
- Nutritional strategies used by corals;
- How corals compete with other species for space;
- How corals reproduce;
- How coral reefs can support large numbers of plants and animals when the waters surrounding these reefs contain so little of the nutrients needed to support biological production that these waters are often called "biological deserts"; and
- Key physical factors (temperature, water movement, etc.) required by corals.

You may want to brainstorm some of these functions to get things started. Students may recognize the need for a source of energy (which implies one or more food chains), some means for disposing of wastes, a source of oxygen, etc. In addition to the coral reef tutorials, you may want to direct students to the Roadmap to NOAA Resources: Corals at *http://www.oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html*.

3.
Lead a discussion of students' research results in the context of designing a model coral reef ecosystem. Students should recognize photosynthesis as the primary source of energy in coral reef systems and the role of the algae living within the coral tissues (zooxanthellae). Ask students to identify organisms that could provide an energy source for their miniature coral reef ecosystem. Corals with their associated zooxanthellae are one possibility. Algae (both microscopic and macroscopic) are another possibility, and on natural reefs compete directly with

corals for space. Since the algae can grow more quickly than corals, they could overrun a reef ecosystem unless there was a way to keep the algae in check. On natural reefs, grazing fishes and invertebrates fill this niche. You may want to point out that coralline algae have hard surfaces similar to the surfaces of corals. Coralline algae are very important to reef growth, since the larvae of many corals can only settle on surfaces that have been previously colonized by coralline algae.

Be sure to discuss the food chains (or webs) that will exist in the model system, and how many steps in the chain (trophic levels) might reasonably be included in the system. You may need to remind students that it takes at least 10 grams of primary producers to support 1 gram of herbivores, and 1 gram of herbivores can support less than 0.1 gram of primary carnivores, and so forth (i.e., energy transfer efficiency between trophic levels is less than 10%). This means that the number of trophic levels in your model ecosystem will be quite limited unless an external source of energy (i.e., supplemental feeding) is provided. Similarly, large or highly active organisms (including many fishes) will probably require supplemental feeding, and leftover artificial food is a major cause of pollution in small aquaria.

Students should understand that while zooxanthellae supply a major part of corals' energy needs through photosynthesis, most corals must feed on other animals as well. When feeding, the individual coral animals (polyps) extend their tentacles, sting living prey with toxic microscopic darts produced by cells called nematocysts, then draw the victims into their mouths. Most corals also produce strands of mucous that extend from the mouth. Floating particles of dead plants and animals stick to the mucous strands, which are periodically drawn back into the mouth. Some species feed entirely on these particles. Carnivory is essential to most corals, because food from animal sources provides nitrogen to corals and their zooxanthellae. This element is essential to both organisms, and is cycled back and forth between them.

This cycling process is a key to why coral reefs are often called "oases of productivity in biological deserts." The tropical ocean waters that surround coral reefs are generally nutrient-poor, and consequently support much less biological production than most temperate waters. The relationship between corals and zooxanthellae is a classic example of a mutualistic symbiosis (a symbiosis is a relationship between two organisms; a mutualistic symbiosis benefits both). This relationship overcomes the problem of limited nutrients by cycling key nutrients between the symbionts, and provides the basis for a highly productive and biologically diverse ecosystem. Similar cycling is involved with various metabolic by-products. In human societies we often call these by-products "waste," but in nature they are raw materials for other organisms. The resulting linkages are the basis for many material cycles. Since much of this work is done by microorganisms, these also need to be present in the model system.

Another consideration is the reproductive strategy used by coral species that are candidates for the model system. Students should recognize that most (about 75%) stony coral species form hermaphroditic colonies that produce both male and female gametes, while the remainder are gonochoristic (the colonies produce either male or female gametes, but not both). In many coral species (and other sessile organisms such as sponges), neighboring individuals of the same species release their gametes almost simultaneously, a process known as "broadcast spawning." Discuss the advantages of broadcast spawning, which is found in about 75% of reef-building coral species. In nature, spawning time is correlated with lunar cycles. The exact moment at which gametes are simultaneously released by hundreds of individual corals appears to be triggered by the time of sunset. The gametes fuse in the water column to form floating larvae (planulae). Planulae usually swim toward the surface, then settle within two days, although the larval stage of some species may last several weeks or even months. The time between planulae formation and settlement is typically a period of very high mortality (mortality is lower in some coral species that brood the planulae within their bodies after internal fertilization).

This is also a good context in which to discuss competition. Remind students that corals require hard substrates (often coralline algae) for settlement and growth. Fast-growing corals compete for space using a strategy known as "overtopping," in which the faster-growing species shades its competition from light and currents bearing food particles, so the slower-growing species eventually starves. But the slow-growers have their own strategies. Nematocysts can be used for defense as well as feeding, and some corals are able to directly attack and kill nearby polyps of other species by extending tentacles and parts of their digestive system onto the polyps. Obviously, it would not be a good idea to locate an aggressive species near another species in the model system, unless one wants to see what happens.

Students should identify at least four key physical factors. Because most shallow-water corals are tropical, they need water temperatures between 18°C and 32°C. Salinity should be that of normal seawater (about 35 parts per thousand). Zooxanthellae obviously require light for photosynthesis, and students should recognize that the wavelengths present should resemble those of natural sunlight filtered through one to two meters of water. Water movement is essential to the transport of food particles to sessile organisms, as well as for the removal of byproducts of metabolism that will be toxic if allowed to accumulate.

4.
Have each student group prepare a written report describing how they would set up a miniature coral reef ecosystem, including a description of the key system functions, and how these functions will be provided. Students should compare and contrast the processes for providing these functions in their model system with the processes that provide these functions in natural coral reef systems. A typical model system would probably include a thermostat-controlled heater, a full-spectrum light with a time switch, and a circulating water pump capable of providing good flow rates (usually 5 to 10 times the volume of the aquarium per hour). Supplemental aeration may also be needed, depending upon the configuration of the water pump (a water circulating system that includes a fountain-like device will provide aeration as well as flow). Have each group present their designs, and lead a discussion to select the best features for an “optimum” model coral reef.

If you want to actually set up a model coral system, turnkey kits are commercially available (e.g., from Carolina Biological

Supply Company *http://www.carolina.com*). It is important to remember that a significant amount of damage is done to reefs by collectors who supply (often illegally) unscrupulous aquarium dealers. So be certain to verify the sources of any corals and other reef species brought into the classroom.

The Bridge Connection

http://www.vims.edu/bridge/reef.html

The Me Connection

Have students write a brief essay describing what an individual could do to protect and/or restore coral reefs, and why this sort of action is important. If they don't think this is important, have them justify their opinion.

Extensions

Review and discuss "Things You Can Do to Protect Coral Reefs" at *http://coralreef.noaa.gov/outreach/thingsyoucando.html*. Even if you don't live near a reef, you can help protect coral reefs in the U.S.A. and around the world.

Resources

http://coralreef.noaa.gov/ – Home page for NOAA's Coral Reef Conservation Program

http://www.oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html – Roadmap to NOAA Resources: Corals; a guide for educators and students to specific online coral data offerings within the NOS and NOAA family of products

http://www.coris.noaa.gov/activities/actionstrategy – National Coral Reef Action Strategy

http://coralreef.noaa.gov/outreach/thingsyoucando.html – Things you can do to help protect coral reefs

http://www.coris.noaa.gov – NOAA's Coral Reef Information System (CoRIS) designed to be a single point of access to NOAA coral reef information and data products

http://www.coralreef.gov/taskforce/las.html – Coral Reef Local Action Strategies

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Science and technology in local, national, and global challenges

Links to AAAS "Oceans Map" (aka benchmarks)

5D/H1

Ecosystems can be reasonably stable over hundreds or thousands of years. As any population of organisms grows, it is held in check by one or more environmental factors: depletion of food or nesting sites, increased loss to increased numbers of predators, or parasites. If a disaster such as flood or fire occurs, the damaged ecosystem is likely to recover in stages that eventually results in a system similar to the original one.

5D/H2

Like many complex systems, ecosystems tend to have cyclic fluctuations around a state of rough equilibrium. In the long run, however, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution.

5D/H3

Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems.