The Biology of Coral Reefs

Living Treasures of the Sea
Tropical waters once harbored pirate treasure, looted from unlucky merchant ships on the high seas. Today, thousands of visitors armed with a snorkel or scuba gear can find underwater treasures as beautiful and dangerous as any found in the pirates' stronghold. Brilliant gem-colored fishes dart past amethyst and ruby-colored sponges, emerald algae, and sapphire sea fans. Crustaceans, annelids, and arthropods creep through ivory limestone tunnels seeking shelter and food. Armed with razor-sharp teeth, sharks, eels, and fish, the finned assassins of these fortified seas, lurk among the shadows like pirates of old - to attack their unsuspecting prey. This is the coral reef.

These jewels of the sea - corals - are actually skeletons of millions of sea animals. Colonies of coral are visible throughout a range of water depth. Depth and coral type determine the shape of these organisms. Hard, reef-building coral and soft coral, swaying in the ocean current, both provide food and shelter for the reefs many inhabitants. Such a diverse and colorful ecosystem provides everyone with a treasure worth knowing.

Biology of Coral

Anatomy and Physiology:
A coral polyp is a tubular sac-like animal with a central mouth surrounded by one or more rings of gelatinous tentacles. Depending on the species, coral polyps measure anywhere from a few millimeters to several centimeters in diameter. Those small animals are extremely simple affairs, composed of just two layers of cells. Corals often live in colonies, which also vary in size. Small colonies of only 25 cm exist along side larger coral colonies reaching a height of 3-4 meters. The end opposite the tentacles, called the base, is attached to a substrate. Corals may have either internal or external skeletons. Some internal skeletons contain calcareous or protein spicules, which stiffen and protect the polyps. In hard coral species, specialized cells on the lower sides and bottom have the ability to take in calcium carbonate from seawater and produce circular limestone "houses", called corallite, for the polyp. These limestone skeletons are responsible for the creation of island sands and reefs. During the day, the coral polyp curls up inside its limestone shelter. By night, it stretches out up of the corallite and spreads its tentacles to shoot paralyzing darts into their prey, mostly zooplankton and small fish.

The tentacles contain microscopic stinging capsules called nematocysts. A nematocyst is a globular structure containing a venom-filled thread with a minute barb at its tip. A tiny sensor projects outside the nemocyst. When the sensor is stimulated physically or chemically, the capsule explodes and injects the thread with considerable force and speed. The barb penetrates the victim's skin and injects the venom. The external stimulus causes the mouth to open and the food particles are swept into the stomach cavity by the nematocyst filament, tentacles, or cilia (10).

Longitudinal membranes known as mesenteries partition the stomach cavity. The mesenteries increase the stomach's surface area, which allows more protease to digest the food. Once broken down, the particles are moved into vacuoles by endodermal phagocytosis for later use in cellular respiration. Once waste products from cellular respiration form, it must be removed from the polyp. Gaseous waste passes through the two layers of cells and directly into the environment. Solid waste is excreted through its mouth. In addition to feeding by tentacles, the polyps may also secrete films or strands of mucus to collect fine organic particles like protozoa and nanoplankton. By secreting mucus over its entire structure, corals (such as Siderastrea radians) create an enormous surface area for feeding. The coral are then able to use cilia to "clear" the surface in approximately 30 seconds of all food particles dropped on the colony's surface (10).

Even though the coral polyps hide during the daytime and open up to feed at night, the sunlight is critical to the health of coral. The polyps house millions of microscopic algae called zooxanthellae. The zooxanthellae speed up the process by which the coral polyps build coral and provide over 98% of the polyp's nutritional requirements. The zooxanthellae also use the coral's nitrogenous waste and carbon dioxide to grow and multiply. This symbiotic relationship is mutually beneficial to both zooxanthellae and coral.

Like all photosynthetic plants, zooxanthellae use the energy from the sun to change water and carbon dioxide into oxygen, sugars, and starches. Sunlight is also essential for the survival of reef-building (zooxanthellae-containing) types. Colonies shaded under opaque domes on the Great Barrier Reef died within two to six months (a process called bleaching); while unshaded colonies lived for six years or more (17). This explains why the most luxuriant coral growths are found in well-lit, relatively shallow waters (less than 30 meters) and why there is a maximum depth at which coral can actively build reefs (46 meters). Reef-builders will not live at all where the light intensity is too low (below 90 meters). Non-reef-building corals' tissues, on the other hand, do not contain zooxanthellae, are not affected by light, and can be found thriving in waters thousands of meters deep.

The zooxanthellae as well as other algae living within the tissues of coral make the coral appear brown, green, or orange. Natural pigments in coral tissue produce a range of jewel-like colors including ruby, emerald, sapphire, ivory, topaz, and amethyst.

Corals can reproduce both sexually and asexually. An individual polyp may use both reproductive modes within its lifetime. Corals reproduce sexually by either internal or external fertilization. The reproductive cells are found on the mesentery membranes that radiate inward from the layer of tissue that lines the stomach cavity. Some mature adult corals are hermaphroditic; others are exclusively male.
Internally fertilized eggs are brooded in the polyp for a period ranging from days to weeks. Subsequent development produces a tiny larva, known as a planula. Externally fertilized eggs develop during a synchronized spawning. Polyps release eggs and sperm into the water simultaneously. This spawning method disperses eggs over a larger area. Synchronous spawning depends on four factors: time of year, water temperature, and tidal and lunar cycles. Spawning is most successful when there is little variation between high and low tides. The less water movement there is over the reef, the better the chance that an egg will be fertilized. Ideal timing occurs in the spring, release of eggs or planula larva usually occurs at night and is sometimes in phase with the lunar cycle (3-6 days after a full moon). The period from release to settlement lasts only a few days, but some planulae can survive afloat for several weeks (7, 14). They are vulnerable at this time to heavy predation and adverse environmental conditions. For the lucky few which survive to attach to substrate, the challenge comes from competition for food and space.

Due to the mutualistic symbiosis of the coral and zooxanthellae, the zooxanthellae have evolved together with the coral when the time comes to reproduce. Some baby coral larvae carry zooxanthellae within them as they leave the colony, sort of a "housewarming" gift from the parent coral. Corals grow by budding. A coral polyp can branch off an exact duplicate of itself - asexual reproduction. These polyps do not break loose, but remain attached to the parent polyp and build limestone corallites of their own. Some polyps, after budding, separate from the colony and deposit itself in another part of the reef. Gradually, they all add to the coral, branching outward and outward bit by bit, slowly enlarging the reef.

Coral colonies growing in shallow water are often heavily branched. In contrast, deeper water corals often grow in sheets or plates. Upward growth of coral colonies is generally between 1-10 cm per year. In either place, the rate of growth depends on factors such as water temperature, salinity, light intensity, turbidity, food availability, competition for space, and predation.

Competition includes both direct and indirect assaults. An indirect method is to become the fastest growing coral, thereby overshadowing the competition. Direct attacks include a variety of weapons at the corals' disposal. Coral polyps eject digestive filaments through their mouths, tossing them onto its neighbor where enzymes dissolve the enemy polyp. In a similar manner, the use of stinging tentacles involves lobbing the barbs until the more venomous coral forces the retreat of the weaker intruder. Certain species are able to augment their tentacles to form a "sweeper tentacle" (5). The sweeper's duty is the same as that of regular tentacles; however, it is longer and contains more nematocysts (and therefore more venom). Chemical warfare is also part of the coral's arsenal. Usually conducted by soft coral, toxic compounds are released into the water, killing or injuring the competition. Finally, the polyps have been known to cover its neighbor's tissues with mucus; literally sliming the opposition into suffocation.

Habitat and Distribution:
Reef-building corals are scattered throughout the tropical and subtropical Western Atlantic and Indo-Pacific oceans, generally within 30°N and 30°S latitudes, which roughly coincide with the 20°C isotherms. Western Atlantic reefs include the areas of Bermuda, the Bahamas, the Caribbean Islands, Belize, Florida, and the Gulf of Mexico. The Indo-Pacific ocean region extends from the Red Sea and the Persian Gulf through the Indian and Pacific oceans to the western coast of Panama.

The distribution and growth of reefs within this zone are influenced by a variety of factors. The flow of ocean currents is extremely important because not only do currents distribute coral larvae, nutrients, oxygen and food, but they also bring warm or cold streams of water to certain areas. Warm waters needed by the coral are found on eastern shores of major landmasses while relatively cool water flows along the western shores. The Caribbean and Indo-Pacific warm water temperatures of 20-28°C are therefore able to support large quantities of coral life.

In addition to warm water, reef development is more abundant in areas that are subjected to strong wave action. Waves carry food, nutrients, and oxygen to the reef, and distribute planula. Precipitation of calcium from the water is necessary to form a coral polyp's skeleton. This precipitation occurs when water temperature and salinity are high and carbon dioxide concentrations are low (14). These conditions are all typical in shallow, warm tropical waters. Growth is sped up by the zooxanthellae, at a rate of 2-3 times that of the coral alone. Water current erosion would overtake construction rates without the aid of the zooxanthellae. Many reefs would simply have been pounded into sand and have disappeared millions of years ago.

Although various types of corals can be found from water's surface to depths of 6,000 meters, reef-forming corals are found in light-penetrating waters of 46 meters or less. Reefs tend to grow faster in clear water as clear water allows light to reach the symbiotic zooxanthellae within the polyp tissue. Because sedimentation comes from rivers emptying into the sea, thriving coral reefs are generally found farther from the river deltas. In addition to sediment, the rivers carry high levels of nutrients that make the waters eutrophic near the river input. However, corals thrive in oligotrophic (nutrient-poor) waters.

Beyond absorption of soluble organic materials from seawater, the zooxanthellae also absorb inorganic nutrients. In aquatic systems, phosphorus is often the limiting factor (compared to nitrogen and calcium). Zooxanthellae help the coral retain phosphorus by recycling it back to the coral. Nitrogen, on the other hand, is available from many sources and creates serious problems when in too great a quantity. High nitrogen levels (seen in eutrophic water) cause algal blooms. The algal bloom spread out over a wide area, virtually blocking all the light to the zooxanthellae (5).

Geological History and Formation
The earliest reefs developed 2 billion years ago, during the Pre-Cambrian era. These reefs were built by colonies of calcareous algae, not coral (14, 16). Corals have been present in the warm seawaters of the world for over 500 million years, contributing to the formation of reefs all around the world. Early in the Earth's evolutionary history, corals lived in the Tethys Sea. This body of water was vast, circling the globe with a body consisting of the Pacific, central Atlantic, Mediterranean Sea, and Indian Oceans. The water fauna was continuous with no distinct bio-geological zones such as they exist today (10, 17).

Coral reefs have been separated geographically and evolved into new species. Other events during the previous one million years aided in the adaptation of corals to those changes. Ocean currents, ice ages, and fluctuation in sea levels have been linked to the phenomenon of the species we currently see in our coral reefs. It is currently under study that the corals of today bare little to no resemblance to those of the Paleozoic era and time previous to that. As recent as the early Triassic period, the oceans were anoxic, increased levels of carbon
food, shelter, or nesting sites. Seahorses eat continuously, as they have no stomach to store food, forcing them to eat constantly. A
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coral's exoskeleton to get to the algae and then defecate sand. A single parrotfish can produce about five tons of sand per year.
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Sea anemones are close relatives of corals, without the stony skeleton. Anemones secrete a slimy, sticky substance that enables them to
secure a footing. When a new site is desired, it peels itself off and moves to its new location. Indo-Pacific reef anemones are known for their symbiotic relationships with clownfish and anemonefishes. Clownfish are protected from the anemone's stinging tentacles. In fact, the clownfish rarely strays more than a few feet from its host. An anemone's tentacles provide refuge for these fishes and their eggs. In return, anemonefishes may protect the anemone from predators such as butterflyfishes. Anemonefishes may even remove parasites from their host anemones.
Bryozoans encrust the reef. These microscopic invertebrates form branching colonies over coral skeletons and reef debris, cementing the reef structure. The reef is also home to a variety of worms, including both flatworms and polychaetes. Flatworms live in crevices in the reef. Some polychaetes such as Christmas tree worms and feather duster worms bore into coral skeletons.
Sea stars, sea cucumbers, and sea urchins live on the reef. The crown-of-thorns sea star is a well-known predator of coral polyps. Large numbers of these sea stars can devastate reefs, leaving behind only the calcium carbonate skeletons. In dead reefs, recently killed by the crown-of-thorns sea star, larger food and game fish are almost totally absent. Even deep-sea fish populations may be affected by this breakdown in the food chain.
Octopuses, squids, clams, scallops, nudibranches (sea slugs), and marine snails are all mollusks that live on or near the reef. These shell-less mollusks appear defenseless, but they have evolved creative ways to repel attackers. Some nudibranches swallow the stinging cells of sea anemones whole. They store them, undigested and "unfired", in the gills on their backs. Later, they can use them for their protection. Other nudibranches ooze toxic chemicals (sulfuric acid or poisonous slime) from their skin. An octopus uses a squirt of ink to cloud the water while it quickly jets away from its attacker. Carnivorous snails are capable of drilling holes into clams or other shelled animals and then eating them. One of the largest mollusks on the reef is the giant clam - capable of reaching a length of 1.2 meters.
Both schooling and solitary fishes are essential residents of the reef ecosystem. Fishes play a vital role in the reef's food web, acting as both predators and prey. Their leftover food scraps and wastes provide food and nutrients for other reef inhabitants. Some species of sharks, skates, and rays live on or near the reef. Others swim in to eat. Shark species include lemon, nurse, Pacific blacktip, white-tipped reef, and zebra sharks. These sharks, as well as rays, generally eat crabs, shrimps, squids, clams, and small fishes. Parrotfish use chisel-like teeth to nibble on hard corals. These fish are herbivores and eat the algae within the coral. After they grind the coral's exoskeleton to get to the algae and then defecate sand. A single parrotfish can produce about five tons of sand per year. Wrasses comprise a large group of colorful cigar-shaped fishes. Some species are known as cleaners, and set up cleaning stations along the reef. When a larger fish aligns itself at one of these cleaning stations, a cleaner wrasse removes parasites from the fish. If the same two fish met anywhere else, the larger fish would eat the smaller one. But it appears that different rules apply at the cleaning stations.
Other fishes found on the reefs include an incredibly diverse group: angelfishes, butterflyfishes, damselfishes, triggerfishes, seahorses, snappers, groupers, barracudas, and pufferfishes. Angelfish have developed a taste for only a certain kind of sponge or seaweed. An individual angelfish hovers close to its food source and uses its bright warning colors to defend it from all others interested in similar food, shelter, or nesting sites. Seahorses eat continuously, as they have no stomach to store food, forcing them to eat constantly. A
young seahorse may eat as many as 3,500 shrimp in a day. Groupers mature first as females and produce eggs. They change sex later in life to become functioning males.

Eels are one of the reefs' top predators. These fishes live in crevices in the reef and venture out at night to hunt and feed. They have sharp teeth set in a powerful jaw. Eels eat small fishes, octopuses, shrimps, and crabs. Sea snakes are rarely found on reefs but do inhabit the waters around reefs in the Indo-Pacific. They possess small fangs but inject potent venom.

Some sea turtles frequent reef areas. Green, loggerhead, and hawksbill sea turtles live in the warm waters of the Great Barrier Reef. These turtles will migrate thousands of miles in order to return to the same beach of her birth. She digs a hole in the moist sand to cradle hundreds of slippery, Ping-Pong ball-sized eggs. After carefully covering and packing the hole, she shovels dirt loosely all around with her front flippers to hide the nest from predators. Once the eggs hatch, they baby turtles face a gauntlet of seabirds, crabs, and lizards as they scramble across the sand to the sea.

**Longevity and Causes of Death:**

While little is known about the lifespan of corals, it is generally acknowledged that colonies may live for several decades to centuries. But just as the crown-of-thorns sea star and parrotfish can destroy coral with their voracious eating habits, human interaction and natural disasters can permanently damage hundreds of square miles of coral reef.

Human interactions include polluting the oceans in forms such as oil slicks, pesticides and other chemicals in runoff, and using the ocean as our garbage dump. Fertilizer and untreated sewage adds nutrients of coastal waters, which in turn promote algal blooms. Under normal conditions, herbivore fish and some invertebrates keep the algae population in check. On a similar vein, run off may contain vast quantities of sedimentation as a result of poor agricultural practices.

Coastal development and dredging ravage reefs. This development includes building seaside homes, hotels, and harbors; all of which bring more garbage to the water as well as careless water recreation. Divers and snorklers stand, sit or handle coral, which can injure the delicate polyps. Dropped boat anchors can gouge the reef and crush coral.

Fishing with dynamite, cyanide, or bleach has killed coral reefs in the Indo-Pacific region. Between 1986 and 1991, half of the coral reefs in the Philippines have been destroyed by these and other destructive fishing methods. The creation of "superponds" for the large-scale cultivation of shrimp across Southeast Asia has quickly ruined coastal waters. In order to keep the shrimp healthy, huge quantities of chemicals and antibiotics have been added to the water. Unfortunately, the ponds last only a few years and are then abandoned. The water is unsuitable for growing crops, drinking, or any other purposes; and will remain that way for decades (5).

Most of the problem created by humans can be directly traced to man's desire to increase income and economy. The souvenir trade has created an international market for coral, shells, sponges and other reef animals - at an estimated 2,200 tons per year. The tropical fish trade has created a demand for reef fish. Their removal changes the balance of the ecosystem as to the number of predators and prey. While something can be done about human interaction with the coral reefs, we have no control over nature. Changes in sea level may expose coral if the level decreases or "drown" them. If the water level increases dramatically, the coral will not have sufficient sunlight. The zooxanthellae will leave the coral and bleaching will result.

Disease can wipe out entire strands of coral reef. Disease may be connected to the level rise and nutrient level increase (14). Major tropical storms can strip corals from miles of reef-potentially as damaging as disease as disease.

**Conservation: The Delicate World**

Maintaining the health of the coral means maintaining the health of the world. Corals remove and recycle carbon dioxide. Excessive amounts of this gas contribute to global warming. The reefs shelter land from harsh ocean storms and floods as well as providing resources for fisheries. Some evidence suggests that the coral reef could potentially provide important medicines, including anti-cancer drugs and compounds that block UV light.

Coral skeletons are being used as bone substitutes in reconstructive bone surgery. The pores and channels in certain corals resemble those found in human bone. As the bone tissue and blood vessels gradually spread into the coral graft, bone eventually replaces most of the coral implant.

In order to conserve the coral reefs, regulations have been implemented. Corals should not be collected, either alive or dead. The dead still provides shelter to other animals and may be a substrate for future coral polyps. Such banning of coral collection was adopted by several international groups including the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). This group regulates the international trade of certain plants and animals.

Other groups have taken on the task of building coral nurseries in order to counter the rapid disappearance of reefs. Biscayne Bay National Park in Florida has used its budget on start up cost for the nursery. With the ships grounding on the reefs, destructive fishing practices, tropical storms, and pollution, it has become the goal of the National Park Service to grow 2000 colonies in the Bay for the health of the current reef (4).

A balance for this delicate world is necessary for it to continue. It is not possible to save every coral, but we must be vigilant to see that no more is destroyed. Every organism in the reef ecosystem is dependent on a balance of the others. Reefs and islands allow for sea grass beds and coastal mangrove forests to grow. These trap sediment, store nutrients, and serve as nurseries for a number of reef residents. If any one of these is removed, the others are severely affected. By removing one of the main components, such as the mangroves, to create shrimp ponds, we lose the variety of mollusks that naturally reside there. Because the ponds soon become toxic pools, nothing grows there, reducing the catch for local fisherman. The mangrove also acts as a pollution filter for the waters heading toward the corals. The waters around the corals become overfished, allowing predators to destroy the coral. Without the coral to provide food, shelter, and protection other biota die.

Unlike pirates of old, we cannot stake a claim to the tropical seas and destroy anyone who invades our turf or destroys our waters and aquatic wildlife. The coral reefs are our living treasures of the sea. If we wish to keep these jewels, we must be sure to preserve what we have. The corals have been around for millions of years. We need to be sure that this treasure remains with us for a few million more.

**References:**

11. Mastny, L. 2001. On a global scale, add climate change, coral mining, toxic dumping, and overfishing to the phalanx of forces destroyi