What are corals?

Douglas Fenner, Ph.D.

2018

Corals are a critical component in coral reefs, building the structure (along with coralline algae) and providing the habitat for a myriad of other species. But what are corals?

To explain what corals are, I like to begin with sea anemones, which are very closely related to corals and illustrate much of what corals are. Corals have a few additional things which we will consider after studying sea anemones.

A sea anemone is a large polyp. A polyp is a thin-walled bag of sea water with an opening at the top that we call a mouth. The wall is made of 3 layers of cells, an outer ectoderm layer of cells, a middle mesoderm layer that is mostly made of connective tissue that holds it together, and an inner gastroderm layer of cells. The sea water inside the sea anemone is continuous, by way of the mouth, with sea water outside of the anemone. The mouth is surrounded by tentacles on the upper surface. Tentacles are finger-shaped extensions of the body wall which are hollow and filled with sea water that is continuous with that inside the anemone. The ectoderm layer on the lower surface of the anemone has cells that secrete a powerful glue that they use to glue themselves tightly onto a hard surface. They glue themselves on so tightly that if you tried to remove it you would rip it to pieces before you could get it off.

Sea anemones are predators. They are sit and wait predators, they don’t chase their prey. Other sit and wait predators include spiders, lizardfish, frogfish, scorpionfish, and stonefish. Sea anemones sting their prey to paralyze them and kill them, then use the tentacles to pull the prey into the mouth and swallow them. They eat fish and other small animals. The water-filled space inside an anemone is called a “gastrovascular cavity.” It is where digestion occurs, and the water inside serves to carry digested food to the different parts of the anemone. So that seawater serves as a circulatory system. The digestive system of the sea anemone only has one opening, the mouth. So it is a more primitive system than in animals who have a complete digestive system tube where food goes in one opening, moves through the tube, and then the waste products emerge out of an opening at the other end.

Sea anemones are simpler than most animals, they are one of the simplest animals on earth. They do not have organs like a heart, gills, brain, and so on. They are said to have tissues, not organs. The don’t have a brain, but they do have nerve cells that are spread out in the body wall in a pattern that resembles a net, and which is called a “nerve net.” They do have muscle cells in their body wall and tentacles that can contract, so they can move, and the nerves connect to them and stimulate them to move. Sponges are one of the very few organisms that are even simpler, they have no nerves or muscle cells and can’t move.

Sea anemones, coral, jellyfish, and their relatives have one special structure that they use to get food which is powerful and no other animals have. These are stingers called “nematocysts.” Nematocysts are tiny, they are microscopic, and they are inside ectoderm cells, mainly on the tentacles. They are tiny oval structures, with one end touching the outer cell surface. They are used to sting, paralyze, and kill prey animals. As you know, some jellyfish can sting, and some have a dangerous sting. The worst is the Box Jellyfish, which is common along the shore of tropical eastern Australia in the summer. It lives other places as well. It's sting is so bad that it can kill a human baby in as little as 10 seconds, faster than any other animal can kill a human! If you are alive 2 minutes after a sting, you will probably survive. Although all anemones and corals have nematocysts and can sting, humans can't feel their stings, except for a kind of coral called a "fire coral."

Nematocysts have a tiny projection out into the water that is a trigger. It can only be triggered by an animal, if a plant touches it, nothing happens. It is triggered off by a specific short chain of amino acids (called a "polypeptide) that is typically found only in animals. But a mechanical stimulus is also needed. Both are required to trigger the nematocyst, and that only happens with a live animal.

The nematocyst is a tiny oval capsule that cannot stretch. Inside, there is a long, coiled tube, that also has sections telescoped together. This allows a very long tube to be compacted into a very tiny space. The larger open end of the tube is attached to the end of the oval capsule that is attached to the surface of the cell and has the trigger projecting from it. There are spines inside the tube that are attached to the tube and point towards where the tube is attached to the cell surface. Three large spines have their tips against the surface of the cell. When the trigger is activated, water flows through the capsule wall into the capsule. Because the wall of the capsule does not stretch, the pressure inside the cell immediately increases enormously. The pressure rises to about 2000 pounds per square inch, equal to that in a scuba tank. That pressure pushes the three spines against the cell surface and breaks it. Then the pressure causes the tube, which is attached to the cell surface, to start turning inside out like a sock that you turn inside out starting with the opening of the sock. As the tube turns inside out starting at the cell surface, it pushes outside the cell, and the spines inside the tube are pushed forward with the tube until they project from the tube, and as the tube where they are attached turns inside out, they whip around to be on the outside of the tube where it is now turned inside out and become pointed back towards the tentacle. The process continues and when it reaches the surface of the animal (which must be very close to touch the trigger), the spines puncture into the animal and stick into the flesh and then point backwards holding the tube in the flesh. In effect, all this drills the tube into the animal, where it ends up extended into the animal just like a hypodermic needle (even though the tube is thin and not rigid or hard like a needle). The tip of the tube has a tiny pore. The tube is filled with a soup of nasty venoms, including chemicals that attack the blood, chemicals that attack the nervous system, chemicals that attack cells, etc.

The entire process, from the triggering until the tube is fully extended into the prey and pressure is pushing the venoms into the prey, takes about one millionth of a second! It is the fastest movement in the animal kingdom. So now you know why the sting can be so bad, and is so effective at killing prey.

There are curtains of tissue inside an anemone, called "mesenteries." They have just 2 cell layers (the middle and inner), and they project partway into the center of the anemone, but do not meet in the center. When a prey item is brought into through the mouth into the gastrovascular cavity, it goes between the edges of the mesenteries, and the edges of the mesenteries stick onto it and cover it. The edges of the mesenteries have cells that secrete enzymes that digest the prey. The digested prey is juice that then leaks out into the water inside the anemone and eventually diffuses to the body walls and into the tentacles and provides food for all the cells. Periodic contraction and extension of parts of the body wall and tentacles moves the water around and disperses water to the body wall and tentacles. So the gastrovascular cavity serves functions of both digestion and circulation. Anything that is undigestible will then be expelled out the mouth. The mouth stays closed most the time, so that contraction of the body wall doesn't expel the water and deflate the anemone. The mouth has a tiny groove full of beating cilia which push water into the anemone to inflate it.

Anemones have two ways of reproducing. They reproduce two ways: sexually and asexually. In sexual reproduction, cells along the mesenteries change into eggs or sperm, which are released out the mouth. When sperm fertilize eggs, they divide repeatedly and form a little larva smaller than a grain of rice, called a "planula." It settles to the bottom, sniffs around, and glues itself to the bottom and then changes into a tiny polyp (anemone) and starts to catch food and grow.

Anemones also reproduce when different parts of them start to move in opposite directions and slowly pull themselves into two. This is called "fission." The two new polyps are genetically identical like identical twins, and we call them "clone mates" or "clones."

Corals are very closely related to anemones and very similar, but differ in at least three important ways. The first way they differ is that when a coral polyp divides in two, it usually doesn't finish the job. The two polyps remain connected by two thin layers of tissue on the substrate, with a tiny space in between, which is the gastrovascular cavity. They are like conjoint twins connected by their stomachs. When one eats something, the other may get a bit of the food. When a coral larva settles and turns into a polyp, that polyp first grows into the typical size polyp for that species. Then it divides into two polyps that are still connected together. Then four, eight, 16, 32, etc, etc. Some huge colonies can have millions of tiny polyps. The polyps differ in size and shape in different species of corals. The largest coral polyps are about 1 foot in diameter, but most are smaller, ranging from several inches in diameter down to about a half millimeter in diameter. The largest coral polyps are the "mushroom corals" that look like the overturned caps of mushrooms. Each coral has just one polyp. One has tentacles that are so big it looks like a sea anemone. Others have small tentacles, and on most the tentacles are tiny and contracted during the day and not visible. The slit in the center is the mouth. Most corals retract their tentacles during the day and extend them at night. At night, tiny zooplankton (animals) come out of holes in the reef and swim around, because at night most fish can't see them in the dark to catch them. The zooplankton which are out at night make the night a good time to take tentacles out to catch them, and also the fish that like to eat coral tentacles (butterflyfish) are asleep at night.

A second major way in which corals differ from anemones is that anemones must stick to whatever surface they can find, but corals build themselves a place to attach that serves like a chair or a fort. The structure they build is called a "skeleton" and is made of a form of calcium carbonate ($CaCO_3$) in a form called "aragonite." Calcium carbonate has two crystalline forms, one called "calcite" forms small solid crystals and is used to form mollusk shells. Aragonite forms long thin fibers. Corals use the aragonite fibers to form a structure outside and below them that we call a "skeleton." Our skeleton is internal, is composed of many pieces, which we attach our muscles to and use to move around. Also, our skeleton is alive, there are cells in it and there are little holes in it for blood vessels to go into it. The marrow in the center is almost all soft tissue cells which form the white blood cells. The bones are also made of a different material, which has phosphate in it as well. But in corals the skeleton is secreted by the ectoderm cells and is completely external to the tissue and not alive. What happens to the skeleton has no effect on the living coral unless something breaks through into the living tissue. Sponges often bore out parts of the skeleton with no effect on the coral. Coral skeletons also consist of a single piece instead of many pieces, and the skeleton is almost always cemented to the substrate and not mobile.

The skeleton is secreted by the living coral polyp ectoderm cells in the shape of a cup for each polyp. The cup is officially called a "corallite." The corallite includes all the hard skeleton cup that the polyp sits in, so both the inside and the outside of the cup. The inside surfaces of the corallites include many details of the polyp. Coral polyps have soft tissue curtains called mesenteries just like anemones. Corallites also have walls that project in toward the center of the corallite but which are hard. These are called "septa." The body wall of the polyp, including all 3 cell layers, has to go inward around each skeletal septum. So a coral polyp has both soft mesenteries composed of 2 cell layers and hard skeletal septa which are covered by the 3 cell layers of the body wall projecting into it.

Coral skeletons are not actually solid, typically they have many holes in them. The amount of hole space differs between species between skeletons that are almost all holes and the hard skeleton is thus delicate, and skeletons that are almost completely solid with only a few holes and thus very hard. Coral skeletons are hard but brittle. Corals come in a wide variety of shapes and sizes, from round masses we call "massive" to flat thin encrusting colonies, to thin or thick plates with two sides, and thick or thin branches, all in many different shapes. Thin branches and plates are delicate, but thick branches and especially masses are very strong. If you try to break any but the thinnest of branches or plates, you may hurt your fingers in the process, coral skeletons are surprisingly hard. Generally, wave surge doesn't break corals unless it is particularly strong. However, if a piece of coral is broken off and carried by wave surge, it then becomes a battering ram, and because corals are brittle, when it hits a delicate coral the instantaneous impact is too much and it breaks. During storms like hurricanes, broken corals can start a process like dominoes that can break many more corals. On branching corals, the tips often are delicate with lots of holes in the skeleton. Then, as the branch grows, at any one spot in the skeleton the tissue fills in many of the holes as well as thickens the branch, until the base of the branch is both thick and very solid and so very strong. Leverage is greatest at the base of the branch, so the branch is then strengthened right where the strength is needed.

Corals reproduce much like anemones. Some coral species have separate sexes with separate males and females. But most are hermaphrodites, with both males and female gonads in the same polyp. All polyps in a colony are the same sex. Also, the colony becomes sexually mature and reproductive when the colony reaches a minimum size, not when the first polyp reaches a minimum size. So all polyps become sexually mature at the same time (except a small zone at the end of a branch or the edge of a table, where it is rapidly growing and the energy is used in growth not reproduction). Some people think that polyps are individuals, so polyps reproduce to produce more polyps (and colonies certainly do produce more polyps). However, a colony as a whole behaves like a single individual made up of many modules or subunits, instead of individual polyps that just live next to each other. For instance, the nerve net extends from one polyp to the next across the whole colony. Touch one part of the colony and the polyps there contract and a wave of contraction then spreads from polyp to polyp. All polyps are the same sex, and all polyps mature at the same time based on colony size not polyp size. So a colony is best viewed as an individual made up of repeating units, much as an earthworm or a crustacean tail is made up of repeating segments. Even humans have repeating units in their backbone, ribs, and rib muscles. The polyps of corals, however, are completely self-sufficient and can survive by themselves, while the segments of worms and crustaceans can't do that.

Corals also frequently reproduce asexually. Asexual reproduction in corals happens when the skeleton is broken and the pieces re-attach to the bottom, survive, and grow into new colonies. This is called fragmentation. Corals differ in how much fragmentation happens. It is rare in corals with hard massive skeletons, but very common in corals with delicate branches. Some corals reproduce much more by asexual fragmentation than sexual reproduction. Those that do, like staghorns, commonly make extensive thickets of clone mates. Not all fragments survive. Those that land in sand will be smothered unless they are large. The corals actually don't try to make themselves so delicate they break, with just a couple exceptions. There are a couple of small mushroom corals which when they reach full size, dissolve a crack in their skeleton and then break in two. Each half then regrows the other half, and the whole process starts over again. Sometimes these species can be found in aggregations of millions of individuals. Also, all mushroom corals start as a single tiny polyp like other corals. The polyp grows into a tiny short column, then the top of the polyp starts to grow a little disc. Next, a crack dissolves just under the disc, and the disc breaks off. The disc grows into a mushroom coral that can be as big as a foot in diameter, but is not attached to the substrate. The tiny column regrows another tiny disc on the top, then a crack forms and it falls off two and the process repeats over and over, sometimes producing a cluster of genetically identical mushroom corals.

A third difference between corals and some anemones is that corals have tiny single algae cells inside their own cells. They are inside the gastrodermal cells that line the digestive cavity (and inside of the tentacles). These algal cells are called "zooxanthellae." They are brown because in addition to having green chlorophyll that can make food using sunlight, they also have some yellow and orange pigments. They are actually in a group called "dinoflagellates." Inside the coral cells they are just little round sacks, but if they are outside of the coral cells for several generations, they may turn into cells that have typical dinoflagellate features, including a thin cellulose shell, one long flagellum at one pole, and a groove around the middle with a second flagellum in it. When the polar flagellum beats they can swim, and when the equatorial flagellum beats they spin. Other kinds of dinoflagellates are famous for other reasons. One kind produces a toxin that can paralyze a person and commonly accumulates in clams in temperate areas. They are called "red tides" and often make clams lethal. Another kind in the tropics produces a toxin called "ciguotoxin." Fish often eat this one as it sticks to the surfaces of algae. The toxin doesn't hurt the fish, and it can't be tasted or smelled, and cooking doesn't affect it. If you eat the fish, you get very sick and may even die. It has all kinds of strange and nasty effects on the digestive system, nervous system, etc. One strange one is that hot things can feel cold and vice versa. A third famous one can produce a flash of light at night when disturbed. All these, including those in corals, are dinoflagellates.

The zooxanthellae inside a coral do photosynthesis in the presence of light and so make sugar and oxygen. Much of the sugar leaks out of them into the coral animal cell. So they supply a high-energy source for the corals. Corals have two alternative food sources, catching zooplankton and getting food from the photosynthesis that the zooxanthellae do. The zooxanthellae often provide a large proportion of the coral's energy needs, including the energy to make their skeleton. But they supply little in the way of nutrients. At night, the coral may catch zooplankton, which being animals, are high-protein snacks. Corals supplement their daytime high-energy diet with a nighttime high-protein diet for a balanced diet. Pretty slick trick.

The relationship between the coral and the zooxanthellae is a symbiosis, a mutulism. We know how the coral benefits, how do the zooxanthellae benefit? First, they get protection. They live inside cells inside an animal defended with powerful nematocysts. Second, they have a home in the sun. If they were floating free in the water, currents might take them down deep in the sea into the dark, where they can't make food, and could starve. But inside the coral cell, they are always in the light. And finally, they are surrounded by an animal cells, bathed in nutrients. The waste products of animal cells are nutrients for plant cells. The zooxanthellae benefit so much that they are far more abundant inside corals than they are out in the water outside corals, even though they pay a high rent for their living quarters, up to maybe 80% of the food they produce.

The large tropical anemones that have anemonefish or clown fish in them all have zooxanthellae also. This is probably why they can grow so large. Giant clams also have zooxanthellae, but they are in water inside a system of tubes, instead of being inside cells.

The fact that zooxanthellae need sunlight to make food is why reef-building corals are only in shallow sunny water. Zooxanthellae don't do well in cold water and that's why coral reefs are only in tropical waters. Although almost all reef-building corals have zooxanthellae, nearly half of all Scleractinia corals do not have zooxanthellae, and most of those live in dark holes in the reef or in deep water. Then can live down to very deep water, and a few even live in polar zones. Almost all corals that lack zooxanthellae are small to tiny. But a few have thin branches and can make thickets that can be up to hundreds of feet thick and miles long. These are often called deep-water or cold-water reefs, and are most famous in the fjords of Norway. They are very low-diversity structures (usually only one coral species), are formed of a thicket of thin branches not a solid structure, live only in deep dark water, and feed on zooplankton instead of using sunlight. Thus they are very different from tropical coral reefs, even though they are formed by Scleractinian corals.

There are several different groups of corals. The corals I have been talking about are all "hard corals" which are "Scleractinia." They along with the closely related anemones are in a larger group called "Hexacorals." Hexacorals all have six tentacles, six mesenteries, and six septa, or multiples of six, such as 12, 24, etc. Almost all reef hard corals are Scleractinia. Soft corals and gorgonia such as sea whips and sea fans belong to another group called "Octocorals." Octocorals always have exactly eight tentacles, and the tentacles have tiny side branches called "pinnae." Also, they don't have mesenteries. Often the polyps are embedded in a large gelatinous tissue matrix, that can be in a variety of shapes such as trees or fingery colonies or whips or fans. Gorgonia have a flexible stiffening rod in the center of branches which soft corals don't have. They don't build the kind of skeleton that Scleractinia build. Soft corals have little spines in their tissues, called "sclerites." They are made of $CaCO3$ aragonite just like Scleractinian skeletons. Most sclerites are tiny and bumpy, but a few can be larger and pointed. One genus of soft coral, *Dendronephtya*, typically forms bright red, orange, or purple colonies that are lumpy and spiky looking. The spikes are large, sharp sclerites that can easily be seen and felt. Typically the soft corals slowly move sclerites down in their tissues and eventually cement them together underneath themselves. Most species form a smooth, undulating platform of them that they attach to. In at least one species of fingery soft coral called "*Sinularia*," the colony is a bit bigger than a human hand and it forms a fused accumulation of sclerites under it that form branches as thick as a thick upper arm and which can grow as tall as at least 6 feet tall. The fused sclerites are as strong as a scleractinian skeleton. This material can even form sections of reefs. These things are all uncommon to rare, though most soft corals seem to form some kind of platform of sclerites. Some soft corals have zooxanthellae, and others do not. Usually those that have zooxanthellae are dull, brownish colors and are found in direct sunlight, while those that do not are usually bright colors such as reds, oranges and purples, and are found in low light. There are also two species of octocorals that form skeletons that look much like Scleractinia, at least at first glance. One is "blue coral" and the other is "organ pipe coral." Blue coral is *Heliopora coerulea* and has a dark blue skeleton due to iron salts. It forms smooth vertical paddles and columns. The polyps are tiny but visible if extended. Organ pipe coral is *Tubipora musica* and forms a bright red skeleton sometimes found on beaches, which is made of tubes, each of which houses a polyp. It makes cushion-shaped colonies covered with little flower-shaped polyps about 5 mm diameter, often light green.

There are several other related groups of organisms. Black corals, ceranthid anemones, zoanthids ("colonial anemones"), and corallimorphs are hexacorals. Black corals don't have zooxanthellae. Sea pens are octocorals.   All of these plus scleractinia and soft corals and gorgonia are in the very large group ("class") called "Anthozoa." Anthozoa only have polyps. Two other classes are Scyphozoa which are large jellyfish (medusa), and Hydrozoa which have both small jellyfish and small polyps. Jellyfish are basically like polyps except they swim instead of being attached and their mouth and tentacles often (but certainly not always) face down, and their body is more bell-shaped. The bell shape is because the middle layer of cells forms a large thick gelatinous mass in a bell shape. Scyphozoa and Hydrozoa alternate generations between medusa and polyp. In Scyphozoa the polyp is tiny, short lived, and hard to find. In the hydrozoa the polyps are small but longer lived and the medusae are small and short-lived. One group of hydroids (*Millepora*) form large $CaCO_3$ skeletons, have zooxanthellae, live on reefs and add to the reef, and have zooxanthellae. They can also sting and so are often called "fire corals." Their sting is not bad. Their polyps are minute and thread-like, and the polyp cups they live in are pinholes. The polyps can only be seen underwater with strong back lighting, and the skeletons appear smooth without polyp cups since they are too tiny to see. There are a couple related genera that form brightly colored smaller colonies, live in shady areas, and don't have zooxanthellae (*Stylaster* and *Distichopora*). *Millepora*, *Stylaster* and *Distichopora* can be called "hydrocorals." All the corals and their relatives that we have been talking about are in a large phylum named "Cnidaria."