Issue 24

CORAL ROCKS! THE VALUE OF THE WORLD'S CORAL REEFS

KEY QUESTIONS

- What are coral reefs, where are they located, and what organisms contribute to reef construction and function?
- What is the importance of coral reefs as reservoirs of biodiversity?
- How important are coral reefs to marine fisheries?
- What is their significance in the carbon cycle?
- What are the global threats to the health of coral reefs?

Coral reefs are tropical, shallow-water, limestone mounds formed mainly by coral animals and plants that remove calcium carbonate ($CaCO_3$) from seawater and deposit it as skeletal material, a process known as "carbonate-fixing."

Coral refers to marine invertebrate organisms belonging to the Phylum Cnidaria, Class Anthozoa, or to the hard, calcareous structures made by these organisms. An individual coral animal, known as a *polyp,* resembles a minute *anemone.* It is the ability of these polyps to remove dissolved calcium from seawater and to deposit it as part of their rocky skeleton that allows the formation of coral reefs. How coral animals do this is not precisely known. What *is* known is that corals need algae actually living in their tissues in order to precipitate the $CaCO_3$. (More about this below.) This type of relationship, termed *symbiosis* (or more specifically, *mutualism*) occurs among a wide variety of marine organisms.

Coral reefs represent some of the most important real estate on the planet. They cover approximately 600,000 km^2 (230,000 mi^2) in the tropics, an area roughly comparable to the state of Texas. They are a major oceanic storehouse of carbon and may contain up to a million species of organisms, only a tenth of which have been identified.

Coral reefs are increasingly under threat from human actions. For example, nearly half a billion people live within 100 km (62 mi) of coral reefs (see Issues 1-3). This issue focuses on the importance of coral reefs, their role in global carbon balance, and what can be done to protect them.

BACKGROUND

While reef environments have been fairly common in Earth's history, and reefs have been built by organisms on and off for the past several billion years, not all reef structures have been built by corals. Corals have been important contributors to reefs only since about 400 million years ago, and only within the past 50 million years have modern corals assumed their reef-building roles. Noncoral reefs built by cyanobacteria were accumulating more than 3 billion years before present and thus are among the most ancient structures built by organisms.

Along with tropical rainforests, coral reefs, particularly those in the tropical Indo-Western Pacific Ocean, have the highest known biodiversities of any ecosystem on earth. But globally, coral reefs are not prospering; indeed, their very existence is being threatened by nutrient pollution, sedimentation, overfishing, global warming, and even ecotourism. The severity of this problem can be appreciated if you realize that tourists spend upwards of $100 billion each year to visit locations near reefs. Florida reefs, for example, bring in nearly $2 billion annually to that state's economy.

CORAL REEFS AND FISHING

Although reefs cover less than 0.2% of the ocean surface, they harbor a quarter of all marine fish species. Fish in coral communities are of two basic types—herbivores that feed on algae and carnivores that eat other animals.

Fishers have been plying reefs for millennia, and today reefs provide food and employment for millions. During the past few decades, however, the intensity of fishing has begun to degrade reef communities. Damage to Philippine reefs has resulted in the loss of 125,000 jobs. You may be able to anticipate some of the reasons for the degradation of coral reefs: If too many herbivores are removed, the marine algae that they eat may grow out of control and smother the coral. Removing carnivorous fish can also upset the reef's ecological balance. Can you see why?

While removal of the fish may harm reefs ecologically, some methods of collection, such as dynamiting, kill the hard coral colonies directly. Another method, called muro-ami, involves using young boys as divers who bounce rocks tethered to lines off the coral to herd the fish. This method, which originated in Japan and is employed in the Philippines, typically destroys about 17 m^2 (183 ft^2) of coral cover per hectare (10,000 m^2 = 108,000 ft^2) per operation. Typically thirty muro-ami boats repeat the process about ten times a day. It may take forty or more years for reefs that are destroyed by fishing practices to recover (if allowed to).

Macroscopic marine algae grow amid and on the coral. Some of these algae are themselves carbonate producers and may be second only to corals in their carbonate production. These algae, as well as noncalcareous algal species, may be eaten by parrotfish and other herbivores, who find safety in the numerous nooks and crannies of the reef itself. These fish in turn become food for predators.

CONDITIONS THAT FAVOR REEF GROWTH

That coral reefs are widely distributed in the tropics does not imply that the coral animals themselves are very hardy. In fact, quite the opposite is true; corals are sensitive to such a variety of environmental factors that it is a wonder they exist at all. These factors are light, temperature, salinity, sedimentation, and nutrient levels.

Light

Reef-building (also called *hermatypic*) corals are restricted to shallow waters because they require a certain quality and quantity of light. Why would simple, eyeless, invertebrate animals such as corals have a need for light? This requirement is due to the presence of one-celled algae known as zooxanthellae, which live within coral cells.

Zooxanthellae are dinoflagellates, a group that also includes the organism responsible for red tides. These organisms, thousands of which live within the cells of a polyp, require light to carry on photosynthesis. The high-energy end-products of photosynthesis are used to nourish not only the zooxanthellae but the coral as well. Some of the organic products are transferred to the coral polyp as a nutritional supplement to the food obtained when the coral feeds using its tentacles. Zooxanthellae also contribute oxygen and remove some waste materials, and they are involved in calcification.

Temperature

In addition to light, corals require a relatively constant, moderately high (but not too high) temperature. The global distribution of coral, in fact, correlates best with surface temperature: Corals are not generally found where winter surface water temperatures fall below 20°C, and they generally expel their algae and may die if water temperatures exceed 30°C. Thus, reefs are generally confined to waters between the Tropics of Cancer and Capricorn. This location protects them from low water temperatures, but means that most corals live near their upper thermal limit of tolerance.

Salinity

Salinity cannot vary much from the 35 part per thousand average for sea water for corals to survive except for Red Sea corals, which are adapted to higher salinities.

Sedimentation

Sedimentation rates should be low and grain size relatively coarse or corals can be easily smothered. First, the corals' filtering apparatus can be clogged, making it difficult for them to feed on the tiny creatures that comprise their diet, and second, the sediment can blanket the colony and keep the zooxanthellae from photosynthesizing. Sedimentation due to runoff from construction sites onshore or mining activities is one of the reefs' most lethal enemies.

Nutrient Levels

Nutrient levels (that is, the concentrations of phosphorus and nitrogen compounds) must also be low. In fact, most coral reefs flourish in nutrient "deserts." The reason again is fairly easy to understand. High nutrient concentrations may stimulate the growth of algae, which can smother the corals. Expansion of intensive, western-style agriculture on land (with its massive doses of water-soluble, nutrient-rich fertilizer) may lead to die-offs in offshore reefs. And in the United States, treated, nutrient-rich sewage from Florida's West Coast may be among sources of degradation affecting the once-healthy coral reefs in the Florida Keys.

Reefs and the Carbon Cycle

Coral reefs are an integral part of the planet's carbon cycle, which may ultimately help control the earth's surface temperature range. The living polyps of a coral reef represent only a thin film covering a massive rock skeleton built up over centuries or millenia by generations of coral polyps. This hard foundation is made of calcium carbonate, which is derived from calcium ions and carbon dioxide dissolved in seawater. As the coral polyps grow, they (along with calcareous algae) precipitate calcium carbonate (that is, convert it from a dissolved form to a solid form), which supports the growing colony of coral and helps to cement coral rubble together. In the process, carbon dioxide is removed from the water. This carbon dioxide "deficit" in the water is replenished from the CO_2 in the atmosphere.

Corals are extremely efficient at fixing carbon (remember, we are talking about the carbon cycle, and carbon is a key component of calcium carbonate). Each kilogram of $CaCO_3$ contains almost 450 grams (1 lb) of carbon dioxide. (You can see why if you figure out the atomic weight of $CaCO_3$ and then determine the proportion of this that is CO_2.)

Geologists, by the way, believe that the earth's early atmosphere was greatly enriched in carbon dioxide, mainly from volcanic gases. As life evolved, some marine bacteria began to precipitate calcium carbonate, in effect storing or fixing carbon dioxide, removing it from the atmosphere. As the CO_2 was gradually removed from the early atmosphere and stored in rocks, the ability of the atmosphere to absorb heat diminished.

Today, immense volumes of carbonate sedimentary rock on continents attest to the enormous amount of carbon dioxide removed from the atmosphere. If this CO_2 were restored to the atmosphere, the earth's surface temperature might approach that of Venus, where surface temperatures (460°C) are hot enough to melt lead.

Thus, for a variety of reasons, coral reefs should be protected and their growth encouraged. Yet, in 1998, scientists documented one of the severest threats to coral survival in recorded history. The threat is called "bleaching" and it happens when corals expel the zooxanthellae living in their tissue (Figure 24-1). The greatest stress seems to come from high water temperature, which would be a consequence of global warming. Data from the past century suggest that such bleaching events could become more severe and persistent as the planet warms. This global event compounds the stresses on reefs from local human-induced sources that we described above. Exposure of coral to increased UV radiation due to a seasonal thinning of the ozone layer could be yet another significant problem.

What is the future of coral reefs? Unless humans take these threats seriously and act together to mitigate them, the future is not bright.

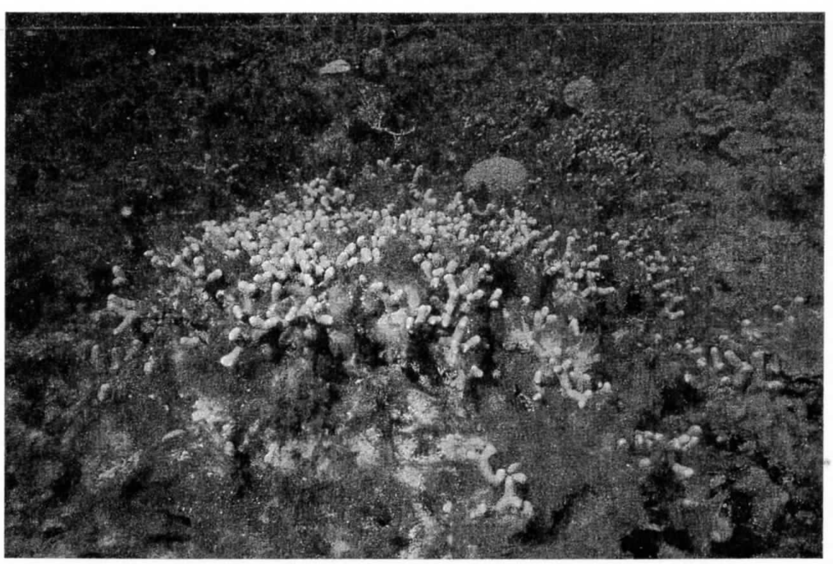

FIGURE 24-1 Brain coral in the Caribbean showing extensive bleaching. (© Stephen Frink/CORBIS) Corbis ID: IH089860

HOW FAST ARE CORAL REEFS DISAPPEARING?

Consider these figures:

Radius of Earth:	6,378 km
Total area of world's oceans:	360×10^6 km^2
Total area covered by coral reefs:	>600,000 km^2
Total area of ice-free land:	1.31×10^{14} m^2

First, let's see what percentage of the planet they cover.

Question 1: We need to calculate the earth's surface. If we assume that the earth is a perfect sphere, we can calculate the total surface area using the formula $A = 4\pi r^2$. Perform this calculation below.

Question 2: If coral area is approximately 600,000 km^2, what percent of the earth's surface is covered with coral reefs?

How fast are coral reefs disappearing? One estimate, widely cited, is that 30% of the world's coral reefs will decline significantly in the next twenty years.

Question 3: Calculate the annual rate of destruction by using the compound growth formula: $k = (1/t)\ln(N/N_0)$, where k = the annual rate, t = the time in years, ln = the natural log, N = the area of reefs after twenty years, and N_0 = the area of coral reefs at the start of the twenty years. (We know the current area of coral reefs (N_0). Twenty years from now there will be 30% less coral area. You must first calculate the area of coral in twenty years before proceeding.)

Question 4: Using the annual rate of destruction for coral reefs you just calculated and a rearrangement of the formula you just used [$t = (1/k)\ln(N/N_0)$], determine how long it would take to destroy half of the remaining coral reefs. Repeat the calculation to determine how long it would take to destroy 99% of the world's corals. Remember to first calculate the area of coral after 50% and 99% have been destroyed. Also: Remember to use the +/- key on your calculator to enter the negative rate.

Question 5: A key assumption in your previous calculations was that the rate of destruction remains constant. Repeat the calculations in Question 4 assuming that the rate of destruction doubles.

If the rate of reef loss increases with increasing human population, the impact will be much more severe. Your calculations should have shown, even if we double the present rate of reef loss, that there is still adequate time to save this irreplaceable ecosystem, given the will to act.

BIODIVERSITY

In recent years, scientists have begun to focus on biodiversity as a central feature of ecosystem health. E.O. Wilson[1] defines biodiversity as "the variety of organisms considered at all levels, from genetic variants belonging to the same species to arrays of genera, families, and still higher taxonomic levels." One index of biodiversity is the number of species. In 1995, United Nations Environment Programme (UNEP) scientists estimated that there were currently 1.7 million named species out of a likely total of 14 million (although the range may be from 3 million to 111 million!).[2] Of these, nearly 60% are thought to be insects. UNEP projections to 2015 are that *1% to 11% of the total number of existing organisms will become extinct per decade.*

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[1]Wilson, E.O. 1992. *The Diversity of Life* (New York: W.W. Norton).

[2]United Nations Environment Programme (UNEP) (http://www.grida.no/geo1).

Question 6: Using a computer spreadsheet or your calculator, fill in the table below, assuming an extinction rate of 0.5% per year. For 2020, estimate using the compound interest formula, future value = present value * $e^{(kt)}$. In this case, the rate of growth, k, is negative since the present value is declining.

Year	Starting Number	Number Extinct	Number Remaining
1997	14,000,000	69,825	13,930,175
1998	13,930,175		
1999			
2000			
2010			
2020	XXXXXXXXX	XXXXXXXX	

Question 7: With a starting number of 14 million species, use the compound growth equation again to project the number of species remaining in 50 years; in 100 years. What is the total percentage of species lost over those intervals?

Question 8: Even though the total number is declining, the doubling-time calculation introduced earlier, 70/rate, can be used here as well. What is the doubling time (or more precisely here, the halving time) for an extinction rate of 0.5% per year? In other words, when will the number of extant (i.e., living) species number 7 million?

Question 9: When will the number of species be 1/1000 of the current level? Speculate whether humans or cockroaches, rats, mosquitoes, and crows will be among the survivors. Discuss your reasoning.

Question 10: Extinction is forever. What coral reef species would you be willing to let disappear forever? Why?

FISHING PRACTICES AND CORAL REEFS

In the United States there are approximately 565,000 marine aquarium owners and 12,000 aquarium specialty shops. To begin our analysis of the impact of removing fish from coral reefs, we need to know approximately how many fish there are currently in homes and pet stores in the United States.

Question 11: Estimate the total number of marine fish in homes and pet stores in the United States. State the assumptions on which your estimate is based.

Even though your estimate may vary substantially from reality, it is important to at least attempt to quantify the issue. Let's see how close you actually came. According to the Pet Industry Joint Advisory Council,[3] an industry group, each of 565,000 households has 1.1 tanks, each containing 7.7 fish.

Question 12: Assume that the cost per fish is $10.00 (a very conservative estimate for marine fish). What is the total monetary value of these fish?

The monetary value of these fish to the Filipinos who catch them is about 1% of this retail value. Estimates of the number of collectors vary, but it is likely more than 1000, and perhaps as many as 2500 full- and part-time fish and coral gatherers.[4] Despite adverse publicity and public pressure, fish capture primarily involves the use of the potent poison cyanide. As many as 90% of the tropical fish collected in the Philippines are caught by squirting them with a solution of sodium cyanide, which stuns them and facilitates their capture. Each of the 1000 or more collectors squirts about 50 coral heads each of the

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[3]Pet Industry Joint Advisory Council. 1996. http://petsforum.com/PIJAC.

[4]Rubec, P.J. 1986. The effects of sodium cyanide on coral reefs and marine fish in the Philippines. In J.L. Maclean et al. (Eds.), *The First Asian Fisheries Forum,* (Manila, Philippines: Asian Fisheries Society).

225 days per year that reefs are fished. Although the effect of the poison on the coral polyps depends on the concentration of poison, it is known that cyanide can kill coral.

Question 13: How many coral heads are squirted with cyanide in the Philippines annually, assuming there are 1000 collectors?

Question 14: Only about 35% of the fish captured on coral reefs survive longer than 6 months in captivity, which means that 65% do not. For 7,200,000 fish surviving 6 months, how many were initially captured? How many thus died?

Question 15: Fish in coral communities are of two basic types: herbivores that crop algae and carnivores that eat other animals. Identify ways in which removal of both types of fish from reefs could adversely affect the reefs.

Although removing the fish may harm reefs ecologically, some methods of collection, such as dynamiting, kill the hard coral colonies directly. Muro-ami, which you will recall involves bouncing rocks on the coral to herd the fish, typically destroys about 17 m^2 of coral cover per hectare (10,000 m^2) per operation. There are 30 muro-ami boats repeating the process about ten times a day.

Question 16: If the coral reefs are fished 225 days a year, how many hectares of coral will be destroyed annually?