



The End of Reefs?

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Hot water can kill corals. But even if corals could adapt to the heat of global warming, they'll still run into the pH problem: carbon dioxide is not just warming the world; it's also changing the ocean's chemistry, making the water more acidic.

Chemistry: When a molecule of carbon dioxide (CO_2) enters the ocean, it soon finds itself attracted to water (H_2O). These two molecular parents spawn carbonic acid (H_2CO_3), which then releases one hydrogen ion (H^+), leaving a molecule of bicarbonate (HCO_3^-). The concentration of those hydrogen ions is measured as "pH," and the more hydrogen ions, the more acid, and the *lower* the pH (a pH of 1 is a very strong acid). Because increasing carbon dioxide increases hydrogen ions that push seawater pH toward the acid end of the scale, it's being called "ocean acidification" (even though the ocean is still slightly alkaline). Compared to before the Industrial Revolution, the upper ocean already has about 30 percent more hydrogen ions (is more 30% more acidic).

In seawater, carbon dioxide immediately forms carbonic acid by binding to, and locking up, carbonate molecules. Corals, clams, various plankton, crusting coralline algae and other creatures that make skeletons and shells of calcium carbonate need those same carbonate molecules that carbon dioxide steals. Carbonate scarcity slows their growth, making them more fragile, and sometimes fatally deformed. Carbonate concentrations in the upper few hundred feet (tens of meters) of the ocean have already declined about 10 percent compared to seawater just before steam-engine times.

To see where this is heading, put a clamshell or an egg in vinegar (a weak acid) for a day. You'll see the shell start dissolving.

Already, some corals are growing thinner, weaker walls. I've talked to Pacific shellfish growers who are now seeing their larval oysters dying when lower-pH seawater reaches their hatcheries.

Carbonate concentration varies regionally. It's normally highest in the tropics, lowest near the poles. It's low around the Galapagos Islands. But Indonesia's waters have plenty of dissolved calcium carbonate of the form hard corals need (that form is called *aragonite*, by the way). So Indonesia's corals should be OK for decades. But only decades.

Since around 1800, the atmospheric carbon dioxide concentration has risen about 35 percent, from 280 molecules per million molecules of air to about 385 (early in the year 2010). It's increasing by about 2 parts per million annually. When it reaches 450 parts per million—as it almost certainly will in this century—the

aragonite concentration around Australia's Great Barrier Reef will fall below the lowest concentration now bathing any coral reef on the planet.

At 500 parts of carbon dioxide, large swaths of the Pacific and Indian Ocean will fall below the minimum aragonite concentration required by hard corals. If the atmosphere's carbon dioxide hits 550 (actually expected a little after mid-century) the aragonite concentration that coral reefs require will essentially cease to exist. So, it appears that carbonate availability will drop too low for reef growth before 2100.

If we keep running civilization with fire and the carbon dioxide concentration reaches about 560—the world's seawater will begin to *dissolve* shellfish and coral reefs. There's a tiny room for optimism, though, as some coral could adapt in time to a more moderate rise in carbon dioxide, provided they are very healthy otherwise (no overfishing on the reefs or pollution in the form of run-off from land).

And at the base of the food-chain, some of the most important ocean drifters use calcium carbonate. They include organisms like single-celled foraminifera and coccolithophorids, which drift the ocean in uncountable trillions, plus certain pteropods (silent 'p'; they're related to snails). In the world's colder waters, pteropods can swarm at densities of up to 1,000 per cubic meter (35 cubic feet) of water. Foraminifera shells are now a third thinner than those from before the Industrial Revolution.

Trouble for them means trouble for everything that eats them. Most people haven't heard of pteropods, but they're well known to hungry young mackerel, pollock, cod, haddock and salmon. Copepods are often the first animal link in the food chain, transferring the energy made by single-celled plants to all the other animals. The pH of the ocean's surface has already dropped by about 0.11 units. When experimenters lowered seawater pH by 0.2 units, half their copepods died within a week.

In other laboratory experiments mimicking conditions predicted between 2040 and 2100, clams, oysters, mussels, urchins and snails all have problems growing and reproducing. Life often finds ways, but it needs time. Adaptation becomes less likely as changes accelerate.

Acidification will be bad for the things people care about, like shellfish and coral reefs, and all the associated fish, turtles, seafood, tourism—.

On Australia's Great Barrier Reef, coral growth rates have declined by 14.2% since 1990. The two reasons: seawater is getting too warm, and there's already too little carbonate for normal coral growth because of "acidification."

"Such a severe and sudden decline," researchers have written, is "unprecedented." One study's lead author said, "If this rate continues—which is accelerating—then the coral growth will hit zero round about 2050." Charlie Veron, former chief scientist of the Australian Institute of Marine Science, who attended the

Kava Bowl Summit conference in Honolulu in 2011, has said, "There is no way out, no loopholes. The Great Barrier Reef will be over within 20 years or so."



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