

Scientists, White House say ocean acidification is well under way

The oceans aren't vast enough to absorb growing amounts of carbon dioxide without ill effects to marine life and to the 1 billion people who make their living on the seas.

Longer heat waves, drought, rising sea levels, more intense storms—these are some of the better-known impacts of climate change. Less familiar is the acidification of the oceans, which is well under way and will continue as the amount of atmospheric carbon dioxide rises.

The oceans absorb about one-quarter of the CO₂ emitted from fossil-fuel combustion, about the same proportion taken up by land. The rest remains in the atmosphere, where its concentration steadily increases. The rate at which the oceans are acidifying, through chemical reactions with the CO₂, is faster than has occurred in at least 65 million years and possibly 300 million years, according to Ove Hoegh-Guldberg of the University of Queensland. Marine organisms that require carbonate ions to build their shells likely won't have sufficient time to adapt to the changing pH. "We're taking life outside the conditions that it actually evolved for," Hoegh-Guldberg said at the Our Ocean Conference, sponsored by the US Department of State and held 16–17 June in Washington, DC.

A much slower acidification event that occurred 55 million years ago (the Paleocene–Eocene Thermal Maximum) caused a mass extinction of deep-sea plankton and a collapse of coral reefs, according to research published in May's *Paleoceanography*.

Since the Industrial Revolution, the acidity of the oceans has jumped 25%, from a pH of 8.2 to 8.1, according to the US Global Change Research Program's 2014 National Climate Assessment. If current trends in CO₂ emissions continue unchecked, acidity will increase by 100–150% from preindustrial levels by the end of the century, said Carol Turley of the Plymouth Marine Laboratory in the UK. "It is happening now, it's happening rapidly, and it's happening at a speed we haven't seen for millions of years," said Turley at the State Department conference.

The physical chemistry of ocean acidification caused by increased atmospheric CO₂ is straightforward: Some of the dissolved gas reacts with water to

form carbonic acid, H₂CO₃. However, "it gets much more complicated in coastal waters, around a coral reef or shellfish beds and estuaries, because there's other processes besides invasion of fossil-fuel CO₂," says Scott Doney of the Woods Hole Oceanographic Institution (WHOI). "Coastal waters can be affected by a variety of biological processes, by chemicals, and by materials from the land," he says. "In some places, fossil-fuel carbon may not even be the biggest contributor."

Shellfish are endangered

Marine life is already beginning to feel the impacts of acidification. Like other shellfish, the sea butterfly, or pteropod, a swimming snail that is an important food source in many fisheries, has a tiny shell made of calcium carbonate. Due to increasingly acidic seawater and the corresponding reduction in carbonate ions, the pteropod has been unable to form its shell properly. It is disappearing from polar and subpolar oceans, where the colder water absorbs more CO₂. "There are now hundreds of experimental studies showing that organisms and ecosystems—a whole range of

organisms, including corals, calcifying algae, plankton, shellfish, and sea urchins—are all showing changes," Hoegh-Guldberg said.

Tropical corals are particularly vulnerable to the combination of acidification and warming of the oceans. Clues to what coral reefs may look like in 2100 with unchecked CO₂ emissions are available today near naturally occurring CO₂ vents off Papua New Guinea. Fewer and less diverse communities of corals and calcifying organisms exist just adjacent to those vents, compared with communities just a few meters away, said Yimnang Golbuu of the Palau International Coral Reef Center, at the conference.

The cold waters of the deep ocean naturally hold more CO₂ than do warmer waters closer to the surface. Ocean upwellings, such as those that sometimes occur along the US West Coast during periods of northerly winds, bring those CO₂-rich waters to the surface. In 2008 and 2009, shellfish farmers in Washington State and Oregon saw oyster production decimated. One oyster grower, Bill Dewey, told the State Department conference that output at one of his company's hatcheries plummeted by 75%. Once scientists figured out the cause was the acidic seawater, shellfish farmers installed sophisticated monitoring equipment to



The Rock Islands of Palau have naturally acidic waters where corals, which are normally adversely impacted by lower pH, are thriving.

JAMES MCEVY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

provide them with advance warning of upwelling events. Bivalve growers then reacted by closing off seawater intakes to their beds and using recirculated water instead. They also added sodium carbonate to raise the carbonate ion concentration, Dewey said.

Although mitigation is fairly straightforward at the hatchery level, it isn't clear how acidification in estuaries such as the Chesapeake Bay or Puget Sound could be countered, says Doney. Other sources contribute to acidification there; sulfur dioxide and nitrous oxides directly reduce alkalinity. Excess nutrients indirectly drive down pH by causing phytoplankton blooms: The atmospheric CO_2 drawn in by the blooms is released organically into the water when they die. "Perhaps by reducing those sources of pollution, you could improve the ability of the ecosystem to survive," Doney says.

Acid-tolerant corals

There may be hope for some species. Researchers have recently discovered corals that somehow have thrived in naturally more acidic waters—at a pH level of 7.8, comparable to what is projected for the ambient ocean in 2100. In a December 2013 paper published in *Geophysical Research Letters*, Golbuu and colleagues describe finding low-pH-tolerant coral communities on the back sides of reefs in the Rock Islands of Palau, a tiny island nation in the western Pacific Ocean (see photo, page 20). WHOI's Anne Cohen, a co-investigator, says several factors are responsible for the acidic waters there. First, ocean waters flowing over the tops of the surrounding coral reefs and into lagoons have been depleted of carbonate ions by the reef's calcifying organisms. Those corals respire additional CO_2 into the same ocean waters. Finally, fresh water from the rainfall flowing into the lagoons creates a low-density, low-salinity surface layer that also lowers the pH.

Such conditions are typical of coral reefs elsewhere, Cohen says, but the labyrinthine structure of the Rock Islands lagoons causes an unusually long residence time for the waters—and their high acidity. And the CO_2 concentration in the calm lagoon water is constant, unlike the levels in waters surrounding CO_2 vents, which are continuously churned by the wind, waves, and currents.

Cohen and her colleagues have hypothesized that either the thriving corals are genetically predisposed to tolerate acidic conditions or some favorable environmental factors have combined to

reduce other stressors on the organisms and thus allowed them to adapt to the low pH. In the Rock Islands, those favorable conditions may be lower light levels, warmer water, and more abundant food sources. More research is needed to determine whether acidification-tolerant corals may be found elsewhere, possibly in the Philippines or Indonesia. "Is it possible that corals everywhere can adapt if pushed, as these corals were? And how many low-pH-adapted communities are there? We haven't found any because we haven't looked," she says, blaming a lack of funding.

A mind-boggling task

Although reducing anthropogenic CO_2 emissions is the only sure way to slow ocean acidification on a global scale, a few researchers have explored the concept of buffering the seas to elevate their pH. Atmospheric geoengineering proposals to limit Earth's warming by reflecting sunlight with aerosols (see *PHYSICS TODAY*, February 2013, page 17) would do nothing to address acidification. In one mitigation scheme, Greg Rau of the University of California, Santa Cruz, has proposed using a limestone flue-gas scrubber to capture and sequester CO_2 . The carbonic acid solution formed in the process would react with limestone and convert the CO_2 to calcium bicarbonate, which could be dumped into the sea to increase its alkalinity. The process might work for CO_2 -emitting power plants located on the ocean, where seawater is already used for cooling.

But the scale of effort required to buffer the ocean's acidity is mind-boggling. The annual mass of the compounds required is about an order of magnitude more than the 2 gigatons of carbon absorbed by oceans each year, says Ken Caldeira of the Carnegie Institution of Washington. That works out to about 30 cubic kilometers of limestone per year, he says. According to WHOI, that is 30 times the amount of limestone mined each year for cement production and all other purposes. That material would somehow need to be distributed more or less evenly throughout the oceans.

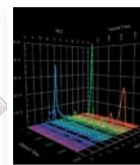
The cost of such a monumental undertaking is unknown, but Doney says it might be on a scale similar to operating the entire world's fossil-fuel industries. He suggests it is far better to spend such resources on limiting CO_2 emissions through energy conservation, fuel-switching, and carbon capture and sequestration.

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