THE Socioeconomic Costs OF Ocean Acidification

Seawater's falling pH may have dire impacts on food supplies, livelihoods, and societies

by Cherie Winner

The increasing acidification of the oceans is measured in pH units, but its impacts on people will be measured in dollar signs, says Sarah Cooley. Commercial and recreational fishing, tourism, the protection of shorelines by coral reefs—all could be harmed by ocean acidification that is already well under way.

In other words, ocean acidification is not just a problem for corals and other marine life. It has the potential to change the way we humans feed ourselves, earn our livings, run our communities, and live our lives.

"What goes around comes around," said Cooley, a research associate at Woods Hole Oceanographic Institution (WHOI). "Ocean acidification is definitely a problem resulting from human activities, and it *will* come back and influence human communities."

A marine chemist by training, Cooley sought a way after graduate school to apply her scientific know-how to socioeconomic problems. Working with WHOI marine chemist Scott Doney and Hauke Kite-Powell from the WHOI Marine Policy Center, she studies what ocean acidification will do to the marine resources that people living in coastal areas and island nations depend on.

"We're working on ways to put a dollar value on the potential losses that could occur as a result of ocean acidification, so we can go to policymakers and say, 'It's going to cost this many dollars in lost jobs and lost fishing revenues, but if we do this many dollars' worth of planning now, we'll be in good shape,' " she said.

Like climate change, ocean acidification is a global problem that results from the enormous increase of carbon dioxide, or CO_2, released into the atmosphere, primarily from burning fossil fuels. Although ocean acidification and global warming stem from the same source, they are different problems, said Cooley.

Acidification is a matter of simple chemical reactions that have been understood for more than 100 years. Excess CO_2 in the air dissolves in seawater and forms carbonic acid and, through a series of other reactions, reduces the amount of carbonate in seawater.

That is bad news for many of the so-called calcifying sea creatures that use carbonate and calcium to build their shells or skeletons. "The waters are becoming less and less welcoming for shelled organisms," Cooley said.

Experiments done at WHOI and elsewhere show that in seawater containing high levels of CO_2, corals have difficulty making new skeleton and may have existing skeleton dissolve away, many calcifying plankton and mollusks such as oysters and scallops find it harder to build and maintain shells, and juvenile mollusks grow more slowly and have more abnormalities and lower survival rates. Among calcifying organisms, many crustaceans such as crabs and lobsters appear to tolerate low carbonate levels. Some even make thicker exoskeletons under such conditions. On the whole, though, more acidic seas and lower carbonate levels could spell trouble for hundreds of species, the ecosystems they belong to, and the human communities that depend on them.

'Not just a dollar thing'

In a 2009 paper in *Oceanography*, Cooley, Doney, and Kite-Powell described how ocean acidification could endanger some "ecosystem services"—the benefits healthy ecosystems provide to human societies. Coral reefs, for instance, bring tourism income, protect shorelines from erosion, and provide habitat for fish that may be the main source of protein for local people.

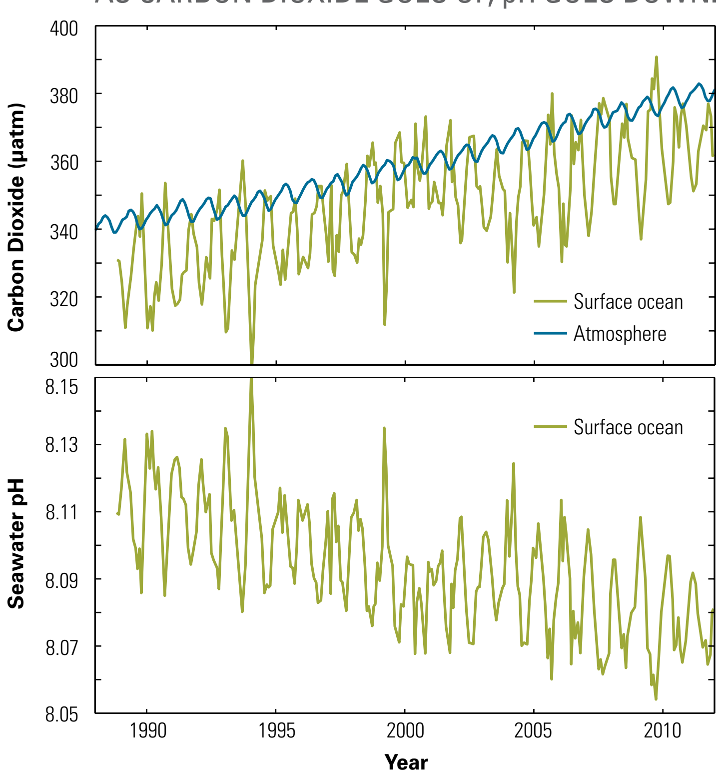
Trying to put a dollar value on the benefits provided by coral reefs is difficult, said Cooley. "If my property doesn't get destroyed by storms because the reef is there, does that save the entire property value? How do I count it over time? Do I amortize it? It's a squishy thing to value."

Squishy or not, one thing is certain: The figure is very, very high. The worldwide value of shoreline protection by coral reefs has been estimated at $9 billion a year; shoreline protection plus reef-supported fisheries was valued at $30 billion a year.

For island nations, the exact figure could be less important than how much their economy depends on the reefs. In 2006, direct income from coral reef tourism provided 15 percent of the gross domestic product of the Caribbean island of Tobago. Add indirect income—"dinners tourists ate, tchotchkes and umbrella drinks they bought"—and the total doubles. "Without healthy coral reefs, the economy of Tobago would be one-third smaller," Cooley said. "And how many people would be out of work?"

Healthy reefs and mollusk populations also are a key element in the cultures of many island and maritime societies. "Quality of life is not just a dollar thing," Cooley said. "Even if we can't put this into an equation, there's still an intrinsic value that we need to preserve."

AS CARBON DIOXIDE GOES UP, pH GOES DOWN.



Adapted from: Dore, J.E., R. Lukas, D.W. Sadler, M.J. Church, and D.M. Karl, 2009, Proc Natl Acad Sci.
Atmosphere data: Pieter Tans, NOAA/ESRL and Ralph Keeling, Scripps Institution of Oceanography

People, protein, and pressures

Cooley found that ocean acidification's likely impacts on the seafood industry are easier to predict. According to the Food and Agriculture Organization of the United Nations, in 2006 the first-sale value of ocean fisheries worldwide was more than $91 billion. Aquaculture of marine organisms generated another $79 billion.

Although the oceans are global, ocean acidification isn't uniform, and its effects are not the same everywhere and on every species. Fisheries that depend heavily on mollusks, such as those in New England, would likely be hit harder. Fisheries in Hawaii and Alaska should be less vulnerable, because mollusks make up a much smaller fraction of the catch there.

Then again, Cooley said, the finfish catch may also decline, because many of the fish we like to eat, such as haddock, halibut, herring, flounder, and cod, depend heavily on mollusks for their own nourishment. Even top predators, the animals that eat the haddock, herring, and cod, could be affected. Swordfish, tuna, shark, and salmon are on that list.

Cooley said ocean acidification could be especially harmful to island nations and parts of the developing world where seafood is a major source of protein. Simulations show that carbonate will become increasingly scarce in the oceans over the next 90 years, squeezing most calcifying organisms into a shrinking zone of tropical waters where carbonate levels will be highest (though still much lower than today's levels). Tropical regions will come under simultaneous stresses from ocean acidification and increasing demand for dietary protein. Many places will face additional stress from other environmental pressures, such as warmer temperatures and pollution.

"We're layering pressure upon pressure, and as a result, things are *not* going to be the same any more," said Cooley. In particular, "more people may be going hungry."

Working with projections of ocean chemistry, human population growth, and expected demand for mollusks, Cooley and her colleagues estimated the time when future ocean chemistry may no longer support the mollusk harvest that individual countries will need. Their sobering conclusion: For many island and coastal nations, the crunch is likely to come in just 20 to 40 years. Their study was published in 2011 in the journal *Fish and Fisheries*.

Coping with the changes

Ocean acidification won't empty the oceans, Cooley said. Some animals will tolerate higher acidity. Some may even thrive on it. But there will probably be fewer species overall, and the mix of species in a given locale will almost certainly change—and how human communities fare as a result will depend on how adaptable they are and how soon they start planning for the changes.

"The world is probably going to march on without these species, but it might be darn uncomfortable" for us and force our economic and cultural systems to change, she said. "The marine ecosystems are going to be very, very different. And different might be OK—*maybe*. But a lot of the things that we really enjoy, that our human communities depend on, are not going to be there. We may be able to find other awesome things about the new ecosystems, but chances are, the options will be limited."

The only long-term remedy for ocean acidification is to reduce the amount of CO_2 we discharge into the atmosphere. That will involve the same sorts of actions touted to combat climate change: conserve energy, use renewable energy sources, and so forth. But, Cooley said, even if we were to end CO_2 emissions tomorrow, there is so much already in the atmosphere that the oceans would continue to acidify for centuries to come.

In other words, we *have* to deal with ocean acidification.

"We need to make adaptations first, as we look toward longer-term solutions," Cooley said. One example is establishing and maintaining marine protected areas that provide refuges for species that might be under a number of stresses. Another is to shift from single-species to ecosystem fisheries management strategies—to focus less exclusively on managing one species such as cod and instead consider the many factors, such as weather, human-caused pressures, and interactions with other organisms, that affect the ecosystem where the cod live.

Aquaculture operations, which are already a major source of protein for many human communities, could begin cultivating species that are fairly resistant to ocean acidification, or join forces to adjust the pH of ocean water brought into their facilities. For example, West Coast oyster growers have begun timing the intake of seawater into their hatcheries to avoid currents that bring up deeper, lower-pH water thought to be partly responsible for recent die-offs in hatcheries.

Global problem, regional answers

When people are put out of work by ocean acidification and other pressures on ocean ecosystems, said Cooley, "we need to have community measures in place to retrain them and help them move into jobs that are equally valuable for themselves and the community." If a person who has lost his maritime job "is flipping burgers or greeting people at a big-box store, is he going to be a happy guy? No, because he went into fishing as a career because he loved the water and he loved doing that. And some kind of dramatic shift from what his traditional role has been may not be all that satisfying to him."

Any proposed strategies will have to be regional, because impacts from ocean acidification are regional, said Cooley. Policymakers and communities in each locale will have to ask, "How are we going to manage *our* fisheries in the face of this additional pressure? There's definitely no one-size-fits-all answer, unfortunately."

Cooley said she's glad that communities and policymakers are starting to think about the problem.

"Our ultimate goal is to talk to people about ocean acidification and how it might affect their endeavors," she said. "One of the best currencies to do that, no pun intended, is economics. Because people always want to know when their interests are at stake." ▲

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Small drop in pH means big change in acidity

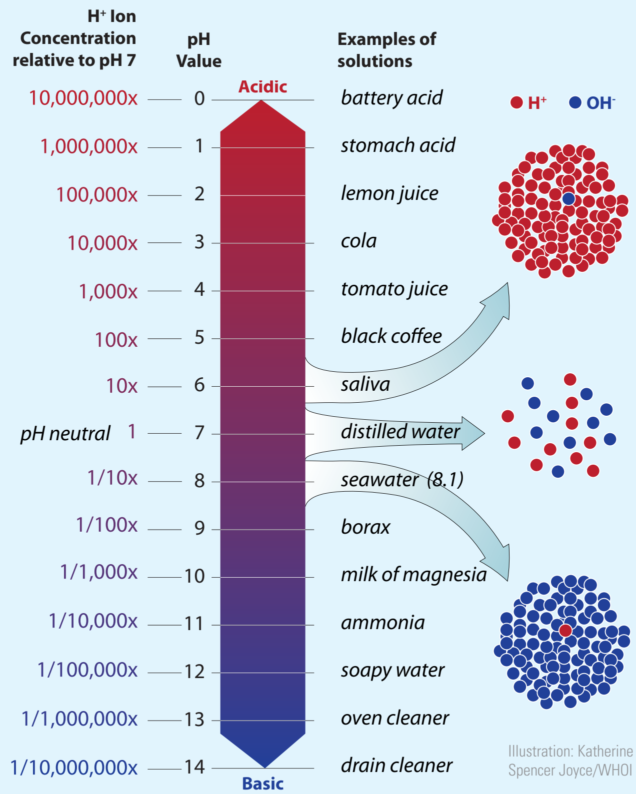

Illustration: Katherine Spencer Joyce/WHOI

A common response Sarah Cooley gets when she speaks to community groups about ocean acidification is, "What do you mean, ocean acidification? The ocean is not acidic! Seawater is never going to get below pH 7."

The term "ocean acidification" is somewhat confusing, said Cooley. The pH of seawater is near 8, which makes it mildly alkaline, or basic—but *any* decrease in the pH of a liquid is considered "acidification."

"It's a lot easier to say 'ocean acidification' than 'ocean de-alkalinization,' " she said.

The term pH is an index of how many protons, or hydrogen ions (H^+), are dissolved and free in a solution. The pH scale goes from 0 to 14. A fluid with a pH of 7 (like distilled water) is neutral. Below 7, it is acidic. Above 7, it is alkaline.

The more below or above 7 a solution is, the more acidic or alkaline it is. The scale is logarithmic, not linear, so a drop from pH 8.2 to 8.1 indicates a 30 percent increase in acidity; a drop from 8.1 to 7.9 indicates a 150 percent increase in acidity. Bottom line: Small-sounding changes in ocean pH are actually quite large and definitely in the direction of becoming less alkaline, which is the same as becoming more acidic.

If you think about it, we use descriptive words like this all the time. A person who stands 5'5" tall and weighs 300 pounds isn't thin. If he loses 100 pounds, he still won't be thin, but he will be thin*ner* than he was before he went on the diet. (And we are more likely to comment that he's looking trimmer than to say he's not as fat as he used to be.)