J.-P. GATTUSO/CNRS

An experiment off the coast of Spitsbergen tests the effects of elevated carbon dioxide concentrations on marine life.

EARTH'S ACID TEST

As the oceans rapidly grow more acidic, scientists are scrambling to discover how marine life is likely to react.

BY QUIRIN SCHIERMEIER

The Friday night beers made Sam Dupont forget all about his sea urchins. Earlier that day, in April 2010, the young Belgian eco-physiologist had put a batch of urchin larvae into a bath of highly acidic water to see how their skeletons would fare. When nothing obvious happened after a few hours, Dupont decided to join some friends at the pub and check on the experiment later in the evening. But he didn't remember until Sunday, at which point he was sure that the precious larvae would be dead.

But when Dupont returned to work at the Sven Lovén Centre for Marine Sciences in Kristineberg, Sweden, on Monday, he found the larvae still swimming around in their tank. Their internal skeletons had dissolved away, but otherwise the creatures seemed to be functioning well.

Dupont's chance finding underscores how much scientists have yet to learn about the growing threat of ocean acidification, which is caused by rapidly rising atmospheric concentrations of carbon dioxide. The acidity of sea water has climbed by 30% over the past 150 years, and some regions have already become corrosive enough to inhibit the growth of corals and other species for part of the year. According to projections, most creatures with calcium carbonate shells, such as mussels and snails, could run into problems within a few decades. By the end of this century, the acidification could even impede the growth of important groups of plankton, thus endangering entire marine ecosystems, from fisheries to coral reefs.

Although the urchin experiment hints that some organisms are able to survive brief exposures to highly acidic water, other studies are revealing unexpected problems that might threaten even creatures without hard shells, such as fin fish. Preliminary work suggests that responses could be highly variable, depending on factors such as water temperature, a creature's evolutionary history and the availability and quality of food.

Countries are only now revving up the coordinated research programmes needed to assess how marine ecosystems will react to the increasingly acidic waters. “We simply have not conducted the basic experiments,” says Richard Feely, an oceanographer with the US National Oceanic and Atmospheric Administration in Seattle, Washington, which last year launched a US$5.5-million programme of research into the problem. But with the current pace of acidification, scientists do not have much time to come up with answers.

CARBON SINK

Without the oceans and their vast ability to absorb carbon dioxide, Earth would be warming up much faster than it currently is. The seas take up about 9 billion tonnes of the gas each year — almost one-third of the 30 billion tonnes emitted globally.

Once it enters the ocean, CO_2 reacts with water to produce carbonic acid, which releases positively charged hydrogen ions. Acidity is measured in pH, a logarithmic scale on which low numbers mean high acidity; neutral water has a pH of 7, but sea water is naturally alkaline, owing to the salts dissolved in it. Since the mid-nineteenth century, the average pH of ocean surface waters has dropped by 0.1 units, to a current value of about 8.1. Unless nations sharply curb their emissions, atmospheric CO_2 is expected to at least double from its preindustrial concentration by sometime in the second half of this century, and scientists project that ocean pH will fall by a further 0.3–0.4 or so units. Sea water could then contain at least 150% more hydrogen ions than it did at the onset of the industrial era.

Those extra ions cause problems by binding with dissolved carbonate ions to form bicarbonate. With fewer free carbonate ions in the water, organisms struggle to absorb enough to build shells and skeletons made of calcite and aragonite — two different forms of calcium carbonate. And if sea water becomes permanently undersaturated with respect to those minerals, hard parts made of them will start to dissolve.

“There is absolutely no doubt that calcifying organisms will calcify less if conditions become more acidic,” says Jean-Pierre Gattuso, an oceanographer at the National Centre for Scientific Research in Villefranche-sur-mer, France, who coordinates the European Project on Ocean Acidification (EPOCA).

This has happened before. Some 55 million years ago, during an episode of extreme global warming driven by a spike in atmospheric CO_2, the pH of sea water is thought to have dropped to levels similar to those expected at the end of the twenty-first century. Ocean sediment deposited during that period contains very little carbonate and no fossils of microorganisms with calcium carbonate shells, indicating that the sea water became too corrosive for calcifying algae such as deep-sea foraminifera, driving many to extinction[1]. Today, acidification is progressing at least ten times faster than it did 55 million years ago.

Researchers expect to see problems pop up first in polar seas, because cold water absorbs more CO_2 than warmer water (and because the melting of sea ice dilutes the concentration of carbonate ions). In 2008, measurements showed that regions of the Arctic Ocean had become undersaturated with respect to aragonite for part of the year[2], and scientists suggest that further portions of the Arctic and Southern Oceans will cross that chemical threshold within the next decade. If CO_2 continues to rise at current rates, half of the Arctic Ocean could be undersaturated with respect to aragonite year-round by 2050 (see ‘Into the red zone’).

Even in temperate waters, pH changes may already be having an impact. In the United States, the West Coast shellfish industry has asked scientists to study a dramatic rise in oyster mortality seen in hatcheries off Oregon and Washington since 2005.

During the summer, upwelling currents in these seas carry deep-ocean water, naturally under-saturated with respect to calcium carbonate, onto the continental shelf. Researchers wonder whether the acidification of surface waters has combined with these upwelling currents to cause some of the recent shellfish problems.

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At the moment, scientists can offer few conclusions. Although they can make broad predictions about the progress of ocean acidification, they know very little about how it will affect marine animals in different climate zones, alter the composition of ecosystems and, ultimately, influence the marine food web.

To complicate matters, acidification is just one of many environmental changes confronting marine life. Organisms also face increasing stress from ocean warming, pollution, fishing pressure, sea-ice loss and shifting patterns of currents and mixing of deep and shallow water. Some scientists think that progressive ocean acidification will limit the ability of marine organisms to survive such stresses.

SEA OF VARIABLES

Dupont and his colleagues in Kristineberg tried to answer some of the basic questions about acidification by filling 264 tanks with a range of organisms, including scallops, halibut, brittle stars, sea urchins and lobsters. In a four-month lab experiment that ended this week, they observed the performance of the various animals in each combination of six temperatures (6–18 °C) and two pH values (8.1 and 7.7), measuring growth, respiration, shell and tissue structure, internal pH and survival rates. They are just starting to analyse the data.

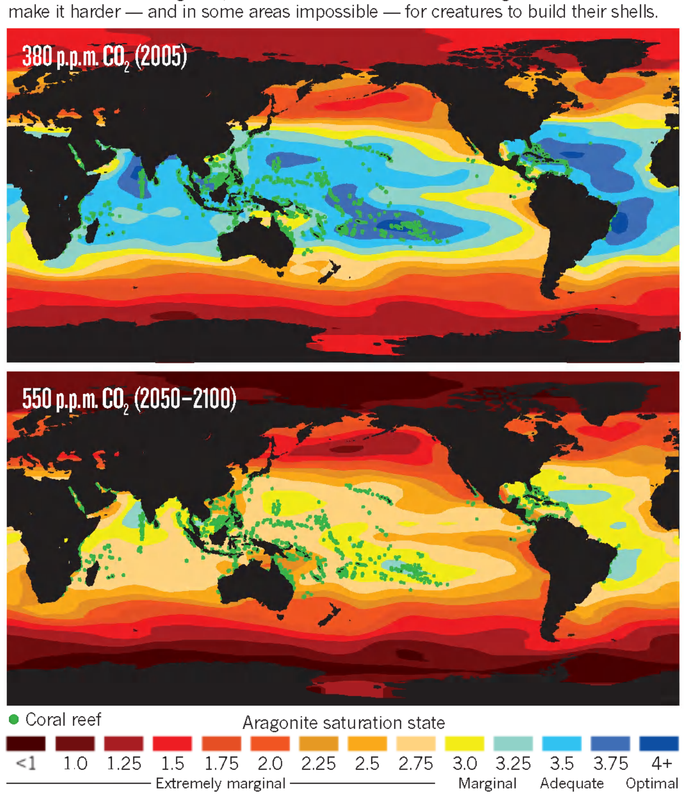
With his previous urchin test, Dupont says, “we’ve seen that some species can cope with extremely low pH values, at least in the short term”. But that might not be true for longer exposures and higher temperatures. “We expect that the response to combined stressors is very site- and species-specific.”

A separate study of two populations of spider crabs (*Hyas araneus*) suggests that how animals respond to acidification depends on their climate zone. In lab experiments, the growth rate and fitness of larvae from the North Sea decreased markedly in acidic waters, whereas an Arctic population from 3,000 kilometres farther north was more sensitive to warming than increased acidity[3].

Even individuals from the same species and climate zone can react

INTO THE RED ZONE

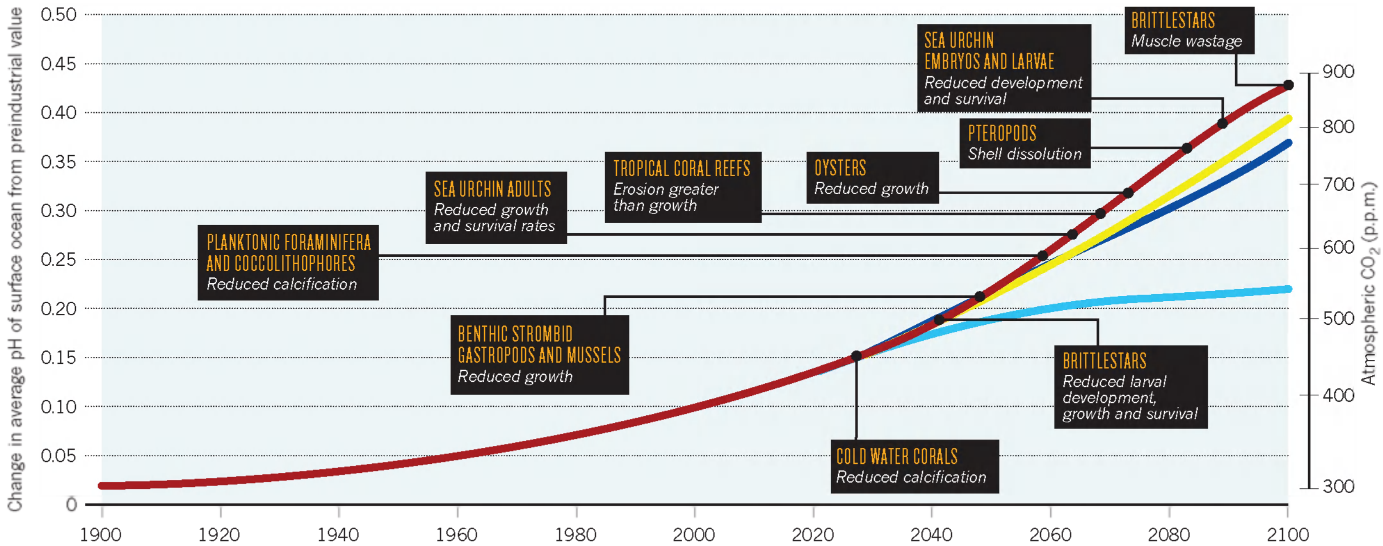
Models suggest that rising levels of atmospheric carbon dioxide will reduce the oceans’ saturation state of aragonite, a mineral in the shells of marine organisms. That will make it harder — and in some areas impossible — for creatures to build their shells.



SOURCE: L. CAO & K. CALDEIRA *GEOPHYS. RES. LETT.* **35**, L19609 (2008); *REEFS AT RISK REVISITED* (WRI, 2011)

FUTURE SHOCKS

Experiments suggest that marine organisms will respond differently to rising ocean acidity, depending on their physiology and habitat. The speed of acidification, and the timing of effects, will depend on future emissions of carbon dioxide (four scenarios are shown, in different colours).



SOURCE: C. TURLEY *ET AL. MAR. POLLUT. BULL.* **60**, 787–792 (2010)

quite differently. In one lab study[4], blue mussels (*Mytilus edulis*) from the North Sea showed a 25% drop in calcification rates at values of atmospheric CO_2 of 740 parts per million, about what is expected by 2100 if emissions are not curbed. But a different population seemed to do just fine in such waters: these mussels live in the nearby Baltic Sea, where CO_2-rich waters well up for parts of the year, causing the pH in the sea to drop as low as 7.5 (ref. 5). Frank Melzner, an environmental physiologist at the Leibniz Institute of Marine Sciences (IFM-GEOMAR) in Kiel, Germany, who led the Baltic study, suggests that the mussels can survive there because they have developed the physiological capacity to regulate the pH in their cells and build up a protective layer of proteins and carbohydrates that shelters their shells. But only well-nourished organisms can afford such defences, he says. “It seems that some organisms can biologically control the effects surprisingly well — but it certainly requires energy.”

There is plenty of food in the Baltic. Where nutrition is less abundant, populations seem to decline when faced with increased acidity. That is one of the lessons from a study off the Italian island of Ischia in the Gulf of Naples, where underwater volcanic vents have been spewing CO_2 into the comparatively food-poor Tyrrhenian Sea for millennia. A survey of life around the site found that normally common calcifying organisms, including corals and sea urchins, were absent from the spots with low pH. Instead, the researchers discovered a thriving community of species that are immune to elevated CO_2 or even benefit from it, such as sea grasses and invasive algae[6].

Jason Hall-Spencer, a marine biologist at the University of Plymouth, UK, who oversees the research off Ischia, says that the massive difference between the responses of animals there and in the Baltic illustrates how little is known. To really understand the problem, “you’d like to test the combined effects of ocean acidification and other stressors on hundreds of species and their interactions”, he says.

And calcifying organisms are not the only creatures at risk (see ‘Future shocks’). Even fish could be vulnerable: experiments have shown that elevated CO_2 impairs the sense of smell in juvenile clownfish (*Amphiprion percula*), which could make it difficult for them to find the sea anemones in which they like to live[7].

GROWING URGENCY

In the past few years, nations have started to devote resources to the research challenge. Europe’s €16.5-million (US$22.9-million), four-year EPOCA project, which began in 2008 and encompasses 31 laboratories in 10 countries, aims to monitor the effects of ocean acidification on marine organisms at various scales, from cells to ecosystems and then across the entire globe. One of the programme’s priorities is to determine whether there are any tipping points, beyond which any increase in acidity would hurl marine ecosystems towards catastrophic changes.

In the United States, President Barack Obama’s administration plans to submit a proposal to Congress in the next month or so for an integrated national research programme on ocean acidification, which would draw together researchers from across the federal government. The president’s 2011 budget called for $11.6 million for research on the subject, but Congress has yet to pass a budget for the current fiscal year. National research programmes are also under way in Germany, Britain, Japan, China, South Korea and Australia.

The largest field experiment conducted so far is an offshore study by EPOCA, involving algae and bacteria in large floating containers exposed to varying levels of CO_2. The research took place between May and July last year, off the island of Spitsbergen in the Arctic Ocean. A group of 35 researchers collected daily measurements of 45 variables affecting the ‘mesocosm’ within the oversized containers, from nutrient cycling to trace-gas production by calcifying algae. The experiment is to be repeated in April and May this year off Bergen in Norway, where the team hopes to observe how acidification affects a bloom of coccolithophorids — important calcifying algae that produce dimethyl sulphide, a trace gas that seeds the formation of clouds.

“We need to understand much more about how ocean acidification affects real ecosystems than we can hope to learn from dose-response experiments on isolated species,” says Ulf Riebesell, a biological oceanographer at the IFM-GEOMAR, who leads the study.

A sense of urgency is propelling these studies. Governments have shown no signs of stemming CO_2 emissions any time soon, and there is talk of tackling the problem of methane and other greenhouse gases first, leaving the tougher issue of CO_2 for a later generation. That might slow the global temperature rise, but it won’t keep the seas from growing ever more corrosive. ■

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