SCIENCE

Ocean acidification: a newly recognised threat

Global warming and ozone holes are well-known consequences of atmospheric pollution. Ocean acidification may be worse.

In June 2005, the Royal Society of London released a major review that alerted the world to the dangers of ocean acidification. This acidification is caused by mankind's release of carbon dioxide (CO_2) to the atmosphere, which subsequently dissolves in the ocean to form carbonic acid. The Southern Ocean was identified as particularly vulnerable to acidification due to the higher solubility of CO_2 in cold water and the ecological importance of species vulnerable to increased acidity. Dramatic changes in ecosystem structure and function are foreseen.

Background

Human activities currently release some 7.1 billion tonnes of CO_2 to the atmosphere per year, mainly by burning fossil fuels, production of concrete and land clearing. Since the beginning of the industrial revolution, the atmospheric concentration of CO_2 has risen from 280 ppm (parts per million) to 380 ppm, increasing the greenhouse affect and increasing global temperatures.

Recent calculations have shown that almost half of the additional CO_2 released to the atmosphere over this period has dissolved in the ocean. While this uptake by the ocean has ameliorated the increase in CO_2 in the atmosphere and slowed global warming, it has made the ocean more acidic. Sea water is buffered by relatively large concentrations of bicarbonate and carbonate ions and, in the very long term, by calcium carbonate in ocean sediments. Nevertheless, the pH has fallen by 0.1 units in the past 200 years. While this may not seem significant, pH is measured on a logarithmic scale and this change represents a 30% increase in the concentration of acidic hydrogen ions. Models predict that the pH of the upper ocean may fall by 0.5 units by the year 2100 and 0.77 units eventually – a nearly six-fold increase in the concentration of hydrogen ions (acidity) in the ocean.

The effects of acidification on ecosystems are difficult to predict in detail because of their complexity, however acidification is expected to have dramatic effects through three main avenues: disruption of calcium carbonate formation, affecting the oxygen metabolism of animals, and changing the availability of nutrients.

Calcium carbonate ($CaCO_3$) is very important in marine ecosystems, as the major structural component of shells for several important algal and animal groups. It comes in two forms, calcite and aragonite, of which aragonite is the more soluble. The solubility of $CaCO_3$ increases with acidity, with depth and with lower temperatures. The temperature dependence renders the Southern Ocean ecosystems particularly vulnerable to increased acidity. Models predict that by the end of this century it will be impossible for aragonite-producing organisms to form their shells in waters south of 60ºS. Such organisms include pteropods (planktonic organisms related to snails), which are extremely important in southern waters, often outnumbering krill. Calcite-producing organisms include single celled algae, the coccolithophorids, the most abundant algal group in the world's oceans, and foraminifera, which are planktonic animals. These organisms are important in the flux of calcium carbonate to the deep ocean where the carbon is stored for geological time scales. Calcium carbonate is also dense and acts as ballast, accelerating deposition of particulate organic carbon to the deep ocean. Thus increased acidity may not only threaten the survival of key components of the Southern Ocean ecosystem, but will also impair a significant mechanism for removing CO_2 from the atmosphere in the long term.

Increased acidity also affects larger organisms. Fish find it more difficult to transport oxygen when their tissues become more acidic, slowing their growth. Squid are particularly affected because their energetic swimming requires good oxygen exchange.

As well as direct effects on organisms, increased acidity profoundly affects the chemical environment of the ocean. Acidification changes the chemical form of dissolved nutrients and toxins, in most cases making them more available for organisms. While this may appear beneficial in the case of nutrients, such a process may enhance local productivity in the regions where there is already upwelling of nutrients or wind-blown input of nutrient-laden dust, but in doing so may deprive larger oceanographic regions of such nutrients.

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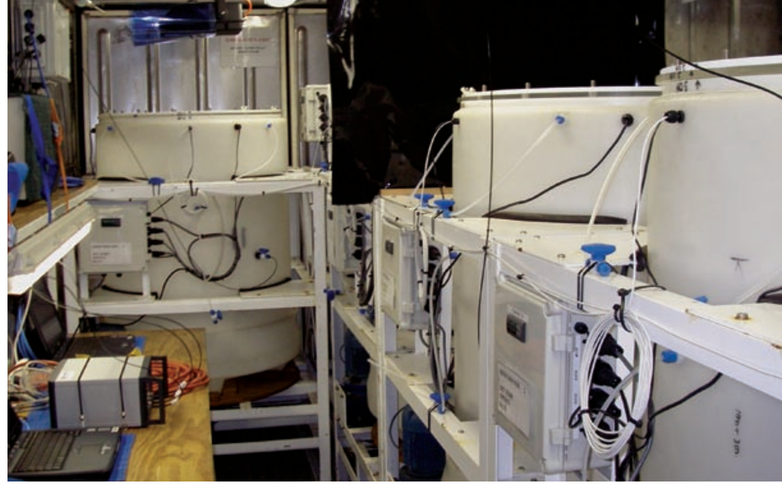

The interior of the ship-board minicosm container showing some of the 650 litre minicosms. Minicosms aim to replicate the ecosystem on a small scale, allowing processes such as photosynthesis, respiration, grazing and gas exchange to be studied in the same patch of water over periods of a week or more. Such experiments are otherwise difficult to achieve from a ship. The six temperature-controlled airtight vessels have artificial lights and are equipped with multiple sampling ports.

Research

Ocean acidification is being targeted through research within the Australian Antarctic Division's (AAD) newly created Environmental Protection and Change programme, and the Antarctic Climate and Ecosystems Cooperative Research Centre's (ACE CRC) Ocean Control of Carbon Dioxide programme. The effects of ocean acidification are being studied on key organisms, particularly coccolithophorids and other phytoplankton and foraminifera, as well as sedimentary processes. This research is coupled with reconstructions of past carbonate chemistry and models of future ocean carbon scenarios.

In 2005, investigations were made into the morphology and degree of calcification of cells of the coccolithophorid *Emiliania huxleyi* in surface samples from repeat southward transects of the Southern Ocean from *l'Astrolabe*. The research compared variations observed to those of cells cultured under a range of pH and temperature. Significant changes were observed in field samples in relation to latitude and time of the season. These changes are currently being followed up in studies of samples taken along the same transect from *Aurora Australis* that include depth profiles and physiological investigations.

Next season we will study the effect of elevated CO_2 on microbial communities using incubations in 'minicosms'. The AAD Marine Microbial Ecology group and Science Support group have developed a minicosm system comprising six 650 litre minicosms housed in a refrigerated shipping container. This system allows experimental investigation of processes such as photosynthesis, respiration, and grazing that cannot be readily addressed by conventional sampling methods. These measurements will be done under CO_2 concentrations matching the present day and those predicted for 2100.

Conclusions

Ocean acidification has the potential to cause large-scale changes in the structure of ecosystems and may pose a greater threat to ocean ecosystems than the effects of global warming or local effects of fishing. The Royal Society report makes it clear that ocean acidification is irreversible within our lifetimes, and that it will takes tens of thousands of years to recover. It questions whether ecosystems can adapt, noting that acidification is additional to, and may exacerbate, the effects of climate change. It recommends additional research into ecosystem effects.

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Further Reading

Raven J *et al.* (2005). Ocean acidification due to increasing atmospheric carbon dioxide. The Royal Society. London 57 pp. (Download at: <http://www.royalsoc.ac.uk/document.asp?id=3249>)

IPCC (1996) *Climate Change 1995: The Science of Climate Change.* Report of the Intergovernmental Panel on Climate Change, edited by J. T. Houghton, L. G. Meira Filho, B. A. Callander, N. Harriss, A. Kattenberg and K. Maskell. Cambridge University Press, Cambridge, England, 1996

The coccolithophorid *Emiliania huxleyi* showing a: one of six healthy morphotypes (cell forms) observed in ocean samples, b: incomplete growth, c: malformed coccoliths (shell plates). The latter types are more common as acidity increases. Scale bar equals one micrometre.

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