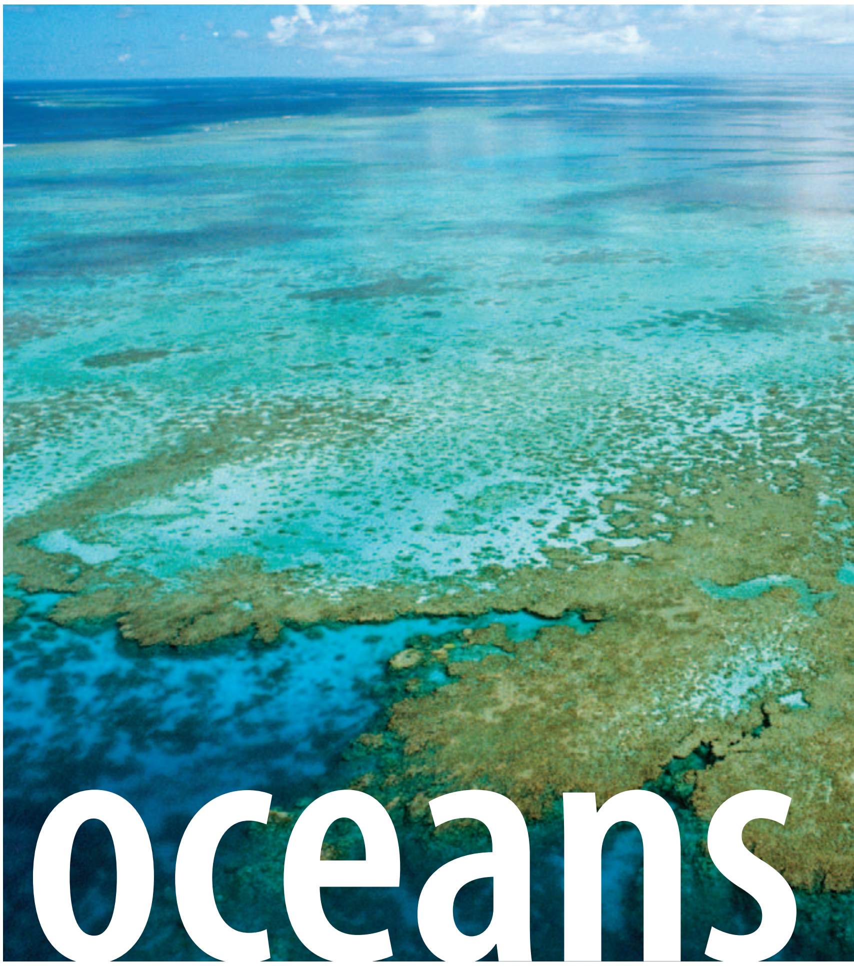
International scientists are now in little doubt about the cause of a threat confronting up to one-third of all marine life: the 27 billion tonnes of carbon dioxide released each year by human activity are gradually dissolving into the ocean's upper layers, turning them more acidic. **Julian Cribb** reports.



Acid oceans

How serious acidifying seas will be for all life on Earth, researchers cannot yet say. But they have already measured observable changes in the ocean's pH, and have also demonstrated that even tiny shifts can kill corals and various common marine plankton and algae that are a foundation of the ocean's food web.

'The oceans are absorbing carbon dioxide (CO_2) from the atmosphere and this is causing chemical changes by making them more acidic (that is, decreasing the pH of the oceans),' explains a paper by Britain's most eminent scientific body, the Royal Society.[1] 'In the past 200 years the oceans have absorbed approximately half of the CO_2 produced by fossil fuel burning and cement production. Calculations based on measurements of the surface oceans and our knowledge of ocean chemistry indicate that this uptake of CO_2 has led to a reduction of the pH of surface seawater of 0.1 units, equivalent to a 30 per cent increase in the concentration of hydrogen ions.'

The report continues: 'If global emissions of CO_2 from human activities continue to rise on current trends, then the average pH of the oceans could fall by 0.5 units by the year 2100. This pH is probably lower than has been experienced for hundreds of millennia and, critically, this rate of change is probably one hundred times greater than at any time over this period. The scale of the changes may vary regionally, which will affect the magnitude of the biological effects.'

'Ocean acidification is essentially irreversible during our lifetimes,' the Royal Society warns. 'It will take tens of thousands of years for ocean chemistry to return to a condition similar to that occurring at pre-industrial times (about 200 years ago).' Humanity's ability to reduce ocean acidification through artificial methods such as the addition of chemicals is unproven, and could have dangerous side-effects. Reducing CO_2 emissions to the atmosphere appears to be the only practical way to minimise the risk of large-scale and long-term changes to the oceans, the report cautions.

'Recent research into corals using boron isotopes indicates the ocean has become about 0.3 to 0.4 of a pH unit more acid over the past 50 years,' says earth scientist Professor Malcolm McCulloch of the ARC Centre of Excellence for Coral Reef Studies (CoECRS) and the Australian National University.

'This is still early days for the research, the trend is not uniform and we can't as yet say how much is attributable to human activity – but it certainly looks as if marine acidity is building up. It appears this acidification is now taking place over decades, rather than centuries as we originally thought. It is happening even faster in the cooler waters of the Southern Ocean than in the tropics. It is starting to look like a very serious issue.'

Corals and plankton with chalky skeletons are at the base of the marine food web. They rely on sea water saturated with carbonates and bicarbonates to form their skeletons. However, as more CO_2 dissolves out of the atmosphere and acidity intensifies, the carbonate saturation declines, making it much harder for these

1 The Royal Society (2005). Ocean acidification due to increasing atmospheric carbon dioxide. RS policy paper 12/05. http://royalsociety.org/displaypagedoc.asp?id=13539

Increasingly acidic oceans threaten the fundamental structure of the Great Barrier Reef. Teraxplorer, iStockphoto

Research on increasing levels of CO_2 above reefs has shown that the red calcareous algae that hold reefs together are significantly compromised. Terry Hughes

animals – and indeed all shellfish – to calcify, or form their shells and skeletons.

'Analysis of coral cores shows a steady drop in calcification has taken place over the last 20 years,' says coral authority Professor Ove Hoegh-Guldberg of CoECRS and the University of Queensland, a member of the Royal Society review team. 'There's not much debate about how it happens: put more CO_2 into the air above and most of it dissolves into the oceans.'

'When CO_2 levels in the atmosphere reach about 500 parts per million (ppm), you put calcification out of business in the oceans,' he warns.

The world's atmospheric CO_2 levels are presently about 385 ppm, having risen by 80 ppm since 1960. According to Antarctic ice cores and other fossil records, this is the highest they have been for at least three quarters of a million years – probably far, far longer. Even with our current efforts to cut greenhouse emissions, they are expected to reach 500 ppm by mid-century, driven by unbridled growth in China, India and continued expansion in fossil fuel use everywhere. At such a level, Professor Hoegh-Guldberg fears, the world's coral reefs will simply die off.

'It isn't just the coral reefs which are affected – a large part of the plankton in the Southern Ocean, the coccolithophorids, are also affected. These drive ocean productivity and are the base of the food web which supports krill, whales, tuna and our fisheries.'

An experiment he conducted at Heron Island on the Great Barrier Reef, in which CO_2 levels were increased in the air above tanks containing corals, showed the increased acidity of the water caused some coral species to shut down and cease forming their chalky skeletons. More troubling, red calcareous algae – the 'glue' that holds the fronts of coral reefs together against the might of the ocean's turbulence – actually began to dissolve. 'The risk is that this may begin to erode the Barrier of the Great Barrier Reef at a grand scale,' Professor Hoegh-Guldberg says.

'It isn't just the coral reefs which are affected – a large part of the plankton in the Southern Ocean, the coccolithophorids,[2] are also affected. These drive ocean productivity and are the base of the food web which supports krill, whales, tuna and our fisheries. They also play a vital role in removing carbon

2 A large group of very small marine algae 2–20 microns in size, covered with calcareous – chalky – scales known as coccoliths.

Australia's complex coral reef communities support a broader marine ecosystem while also providing a buffer to inshore areas. Mark McCormick

dioxide from the atmosphere.'

That a loss of corals on a global scale is possible is hinted at by the most catastrophic event ever to occur in the history of life on Earth – worse even than the extinction of the dinosaurs. Known from the fossil record as 'The Great Dying', this extinction occurred at the end of the Permian era 251 million years ago, when it eliminated 96 per cent of all sea life, including all of the early corals and trilobites. Scientists are still arguing about the precise causes of the Permian extinction, but a likely suspect is a vast outbreak of volcanic activity which formed the Siberian Traps[3] at about that time, belching so much CO_2 into the atmosphere that the seas turned sharply acid. The ensuing bacterial activity, as millions of organisms rotted, probably stripped the oceans of oxygen, killing those which had not already succumbed to acidity.

In all, says Charlie Veron, former chief scientist at the Australian Institute of Marine Science, there have been five mass extinctions which either wiped out or partly eliminated the corals. In each case it was probably that high CO_2 levels in the atmosphere and acid oceans played a key role in the loss of species. And as he points out in his new book, *A Reef in Time*, in every case it took 10 million years or longer for the ocean equilibrium to recover and for corals to appear again in the fossil record. His account goes on to predict the loss of the Great Barrier Reef over the next century or so due to a combination of acidification and bleaching.

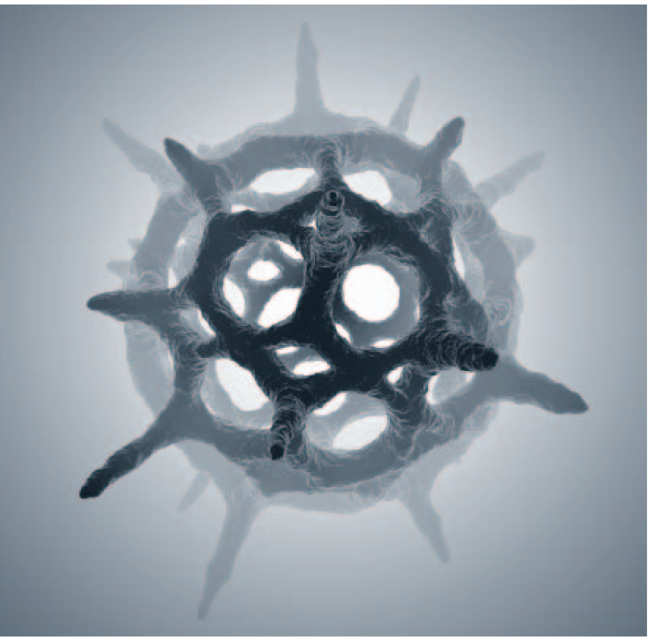
'It cannot rationally be doubted that we are now at the start of an event that has the potential to become the Earth's sixth mass extinction. This time there are no bolides (asteroids), no supervolcanoes and no significant sea level changes ... it is a case of humans changing the environment,' Veron says.

'The prospect of ocean acidification is frightening,' he argues. 'It is serious because of *commitment* – a word that will soon be used with increasing frequency in the scientific literature.' Commitment, essentially, means that a process is unstoppable. If the oceans turn acid – as they are already doing – the only known way to reverse this is the slow weathering and dissolution of limestone mountain ranges and carbonaceous rocks into the sea, a process that takes millions of years.

There is a second reason why ocean acidification is of concern, Professor Hoegh-Guldberg says. The oceans currently act as the world's main reservoir for carbon dioxide, and at present, the small creatures in the surface waters that take up the carbon die, and then sink into the ooze on the sea floor where their carbon is locked up for thousands or millions of years. As the oceans become more acidic, however, this process is expected to break down, saturating the upper layers with calcium carbonate and reducing their ability to absorb CO_2 from the air. At the same time there will be changes to the oceans' physical ability to buffer the rising acidity, while warmer conditions will also inhibit the dissolution of CO_2.

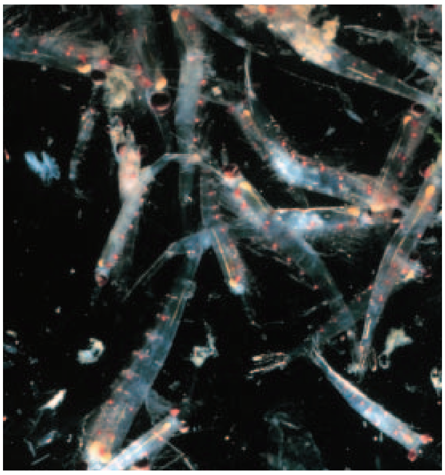
Together these factors mean the seas' ability to soak up excess CO_2 from the air may decline. This in turn will lead to a further rise in atmospheric carbon levels which, scientists fear, could trigger a runaway greenhouse effect. Today's international scientific predictions of global warming rates of a few degrees that have received prominence in the media do not yet factor in this possibility. It remains a sleeper dynamic that could cook

3 A huge outwelling of basalt lava 251 million years ago which covered an area of Siberia as big as Australia, and is thought to be linked with the extinction event.



A radiolarian skeleton. Phytoplankton like these are providers of much of Earth's oxygen. Ivan Dinev, iStockphoto

Apex predators balanced at the top of the marine food web, such as the leopard seal, ultimately rely on the health and abundance of plankton. Erlend Kvalsvik, iStockphoto



Increases in ocean acidity may affect the skeletons of plankton on which major marine food species like these krill rely, undermining the entire food web.
Jamie Hall, National Oceanic & Atmospheric Administration (NOAA)

the planet far more rapidly and to higher temperatures. How hot and how quickly remain uncertain.

Another issue is that the marine plankton at risk from acid oceans are also among the major producers of the Earth's breathable oxygen. Scientists are still unsure of the consequences if they shut down due to acidification. According to some, other algae and plant life will simply take over the role of producing oxygen. But there is an additional risk that a mass die-off will strip large amounts of oxygen from the seas, with lethal consequences for other marine life such as fish and shellfish.

Charlie Veron admits it all reads a bit like a science fiction horror story – which it isn't. He believes, however, there is still room for hope – and for action. Reductions in greenhouse emissions will soon be forced on humanity in any case, so we may as well get on with it – and at a far more drastic rate, he and the other marine scientists urge.

So far as the Great Barrier Reef is concerned, they say, the first and ultimately *only* step we can take to preserve it is to cease polluting the Earth with CO_2. At the same time we must minimise all the other stresses to which we subject it. This is the decade in which we must decide.

Then, though scarred, the corals will probably pull through.

More information:
CoECRS: www.coralcoe.org.au/index.html

Veron JEN (2008). *A Reef in Time: The Great Barrier Reef from Beginning to End*. Belknap Press, USA.

A Reef in Time is available from CSIRO Publishing: http://publish.csiro.au/nid/21/pid/5734.htm