Dr Ray Berkelmans with clownfish on the Great Barrier Reef.
Photo: Eric Matson

The Acid Test

BY STEPHEN LUNTZ

Carbon dioxide emissions are being absorbed by the oceans, making them more acidic. How long can corals survive?

A Townsville forum has heard from some of the world's leading researchers into the effects of ocean acidification on coral reefs, and the news is not good. Acidification represents a threat to even the most well-protected reefs, and is likely to have a cumulative effect with other sources of reef damage, such as warmer temperatures, overfishing and pollution.

The basic science behind ocean acidification is not new. When carbon dioxide is dissolved in water some of it forms carbonic acid (H_2CO_3). H_2CO_3 loses a hydrogen atom to form H^+ and HCO_3^-, creating a weak acid and bicarbonate. The more carbon dioxide there is in the air, the more dissolves in water and the more acid is produced.

Seawater is naturally slightly alkaline (a pH of 8.2 in pre-industrial times) so the term "ocean acidification" is something of a misnomer. However, higher carbon dioxide levels in the atmosphere are reducing the pH slowly, and it is now approaching 8.0.

This might sound harmless but it has devastating implications for marine organisms that build calcium carbonate ($CaCO_3$) skeletons, as this relies on the supersaturation of calcite and aragonite in the waters around them. Less alkaline water means less aragonite, and corals become unable to form skeletons while shellfish and coccolithophore algae, among others, become unable to form shells.

If the alkalinity of the water drops far enough existing coral structures dissolve. However, until recently not much was known about the effects of acidification on specific species, and how low the pH can drop before effects will be observed.

Tanking Corals

The Australian Institute of Marine Sciences (AIMS) has been studying the effects of ocean acidification on the Great Barrier Reef. In March it hosted several leading experts on the issue from around the world at a forum entitled *The Silent Climate Change Issue*.

The news was bleak. Dr Chris Langdon of the Rosenstiel School of Marine and Atmospheric Science at the University of Miami grew corals for 4 months in a tank the size of an Olympic swimming pool, before lowering the pH of the water for the next 4 months. The corals didn't cease calcifying entirely until the pH was at a level predicted for the year 2150. There was no sharp tipping point; rather, calcification rates declined linearly. By the time the waters were as acidic as is projected for 2100, calcification rates were 20–40% of those in pre-industrial conditions.

Langdon's projections suggested that calcification rates should already be falling by 0.6% per year. He referred to research suggesting that global declines have been 0.8% per year, although the samples for this are not widespread.

In the protected environment of Langdon's tanks, corals with slow calcification rates can still be healthy. "The fear is the coral will lose the ability to recover from damage," he told *Australasian Science*, referring to the occurrence of cyclones, crown-of-thorns starfish attacks and biological decay.

Mass bleaching events as a result of warmer sea temperatures have left large areas of reefs lifeless, but it is hoped that more heat-tolerant species may come to colonise these reefs and that there may be some migration of tropical coral species towards the poles. However, reduced calcification rates threaten this, even on reefs where corals are not under threat

Dr Ray Berkelmans examines gorgonian coral off far north Queensland. More acidic oceans are making it harder for corals like these to form skeletons. Photo: Eric Matson

from algal takeover as a result of increased nutrient run-off and declining numbers of herbivorous fish (*AS*, May 2006, p.11).

Dr Ray Berkelmans of AIMS notes that even corals that survive bleaching events tend to have zooxanthellae capable of sustaining 30% slower growth rates than the more heat-sensitive species (see box). "If we add 30% from acidification and 30% from bleaching it's conceivable it won't keep pace with erosion, and reef building will stop," he says.

Wild Examples

It is possible that, given time, species will adapt to high levels of carbon dioxide in the atmosphere. However, it is known that the oceans are now less alkaline than they have been for 800,000 years, and more likely 25 million years. Consequently it is questionable whether species will be able to adapt to a pH-neutral ocean.

Dr Jean-Pierre Gattuso of the Laboratoire d'Oceanographie at the University of Paris points to further evidence that even when calcium carbonate-dependent species have time to adapt, they may not be able to do so. Gattuso noted that the waters surrounding thermal vents off the coast of Italy are highly acidic. There are no coral reefs in the area, but shellfish thrive some way from the vents. "As you get closer to the vents the mussels' shells are so soft you can crush them with your hand," he said. "Nearer to the vents there are none at all."

Dr Joanie Kleypas of the National Centre for Atmospheric Research in Colorado pointed out that the Galapagos Islands have extreme upwellings nearby that make their waters naturally acidic compared with most of the oceans. "After a recent bleaching event there was 95% mortality. The reefs were immediately eroded away by the pencil sea urchin," she said. "Three thousand years of reef growth were lost in 10 years.

"I'm not saying this will happen to the Great Barrier Reef," she said, but no one seems too sure. There is some evidence that coral species largely disappeared the last time the atmosphere had very high levels of carbon dioxide.

Uncertainties

One major unknown in predicting reef decline is whether the oceans will continue to take up as much carbon dioxide as they do now. Since humans started releasing billions of tonnes of CO_2 into the atmosphere, the oceans have absorbed about one-third of it. There is evidence that this is dropping (*AS*, Jan/Feb 2008, p.11).

Reduced ocean uptake will slow acidification, but this is hardly something to hope for. It is only because the oceans have absorbed as much carbon as they have that temperatures have not already risen disastrously. If the oceans continue to absorb CO_2 at the current rate, acidification will kill the reefs. If they don't the reefs will die from warmer waters, and the rest of the biosphere faces all the other anticipated effects even sooner than we have predicted.

It is known, however, that some species are more affected by acidification than others. Dr Ken Anthony of the Centre for Marine Studies at the University of Queensland said that our knowledge in this area was still at an early stage but warned: "It looks as though the species we value the most are the ones that will be most affected".

Adapt or Prevent?

When faced with the threat of climate change, many politicians and commentators suggest we are better off adapting to the changes than trying to prevent them at the cost of the fossil fuel industry. However, Janice Lough of AIMS was blunt. "Adaptation is not the preferred answer," she says.

For one thing, we really have no idea how to adapt to such a disaster. The Great Barrier Reef is worth $5 billion per year in tourism and fisheries, and reefs such as Ningaloo are growing in importance. However, Australia would survive without it – albeit poorer financially and spiritually.

On the other hand, coral reefs and the fish they support are essential to the livelihood of millions of people in the developing world, particularly Indonesia. It is hard to imagine how they will adapt to the loss of their major source of protein and income.

Global warming has drawn many ideas for cooling the planet, including giant mirrors in space and the dispersal of sulfur dioxide in the upper atmosphere. However, sulfur dioxide contributes to acid rain, and would accelerate the problem.

The idea of pumping vast quantities of carbonate into the oceans was raised at the forum, but it was noted that to balance the effect of carbon dioxide would require an industry comparable in size to the ones driven by fossil fuels.

The deep oceans are so far largely unaffected by anthropogenic carbon. If the oceans mixed more freely, acidification would be too small to matter for the foreseeable future. However, most of the absorbed carbon remains in the top few hundred metres of the oceans, and the likelihood of engineering greater ocean mixing seems remote.

Action, Action, Action

The answer seems to rest with reducing carbon emissions. Lough quoted Californian Governor Arnold Schwarzenegger calling for "Action, Action, Action".

Given the slow response to the multitude of threats posed by global warming, it might be anticipated that acidification will not spur faster movement. However, Lough expressed hope that "this is so direct it will be convincing to people in power".

In some ways, ocean acidification is global warming stripped of the complexity. For one thing, only carbon dioxide is a significant culprit. Other greenhouse gases such as methane have little or no role, taking industries such as livestock out of this part of the debate.

Dr Ray Berkelmans changing a temperature logger as part of measurements of the effect of temperature on coral growth.

Photo: Eric Matson

Moreover, while acidification is much less studied than climate change, it is also simpler. Where the debate on climate change has been clouded by denialists playing on a lack of public understanding of the science involved, it is harder to disguise that carbon dioxide changes the chemistry of the oceans.

That carbon dioxide in the air affects the acidity of water can be demonstrated by placing a lighted candle in a jar, the bottom of which is filled with water. By the time the candle has turned the oxygen in the jar to carbon dioxide and burnt out, much of it will be absorbed into the water, and the effect on the acidity is easy to measure. The effect on calcium carbonate skeletons is not hard to observe.

Certainly such simple experiments aren't all we need to know, which is why forum participants called for further research on how species, and ecosystems, are responding. Nevertheless, the dishonest arguments that have wasted so much time in the climate change debate may struggle to get an airing when the general public really can see for itself.

Stephen Luntz attended the forum as a guest of AIMS.

Corals Beating the Heat

Corals can adjust to higher sea surface temperatures by changing the algal partners with which they have a symbiotic relationship. The finding is not entirely surprising, but represents the first observation of this adaptability.

The study makes ocean acidification a more important issue, confirming that corals may be able to survive other damage that humans are inflicting on them. It is less likely they will be able to adjust to acidification, as it is not something they have had recent preparation for.

Acropora millepor off Miall Island in the Keppel group responded to a 2006 bleaching event with "symbiont shuffling", taking on more of the symbiotic zooxanthellae that are most adapted to high temperatures. This should make them more able to cope with future warmth.

"There has been a dramatic shift in the Miall Island coral's symbiotic community, mainly as a result of the change in the predominant algal types after bleaching," said Alison Jones, a PhD student at the Australian Institute of Marine Science (AIMS) and the lead author of a paper published on the study in the prestigious *Proceedings of the Royal Society B*.

Before 2006, 94% of zooxanthellae living on target species in the area were heat-sensitive. Afterwards, 71% of the coral colonies had shifted to heat-tolerant species.

"This work shows that the symbiont communities of inshore corals such as those in the Keppels are much more dynamic than we have given them credit for so far," said AIMS scientist and co-author Dr Ray Berkelmans. "This may give them a natural advantage over those corals without this flexibility to change predominant symbiont type."

However, the symbiont species observed are far more common in the area studied than across most of the reef, so the results may not be universally applicable.

The area suffered bleaching events in 1998 and 2002, and Berkelmans says there is evidence that in the latter case at least some symbiont shuffling occurred. However, the cooler summers in between appear to have caused a shift back to faster-growing, more heat-sensitive species.

Areas exposed to repeated high temperatures, such as a reef near Magnetic Island, have low biodiversity, being dominated by a few varieties of heat-tolerant zooxanthallae.