Australian ClimateChange SciencePrograme

What is ocean acidification and how will it impact on marine life?

Australian Government
Department of the Environment
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CSIRO

The Australian Climate Change Science Programme – An Australian Government Initiative

At a glance

- Human emissions of carbon dioxide are being absorbed by the oceans, increasing the acidity level of seawater. This is called ocean acidification.
- Ocean acidification affects the ability of marine organisms to build and maintain shells and skeletons. It also changes marine organisms' physiological processes and disrupts ecosystem services.
- Further ocean acidification is predicted to have significant impacts on marine environments.
- Australian research efforts are focusing on the Southern Ocean and Great Barrier Reef.

WHAT IS OCEAN ACIDIFICATION?

Ocean acidification refers to the increasing acidity levels of the world's oceans. This is due to human activity.

Human activities such as burning fossil fuels have increased the amount of carbon dioxide in the atmosphere by about 40%[1] above pre-industrial levels. Carbon dioxide levels are now unprecedented in at least the last 800,000 years.

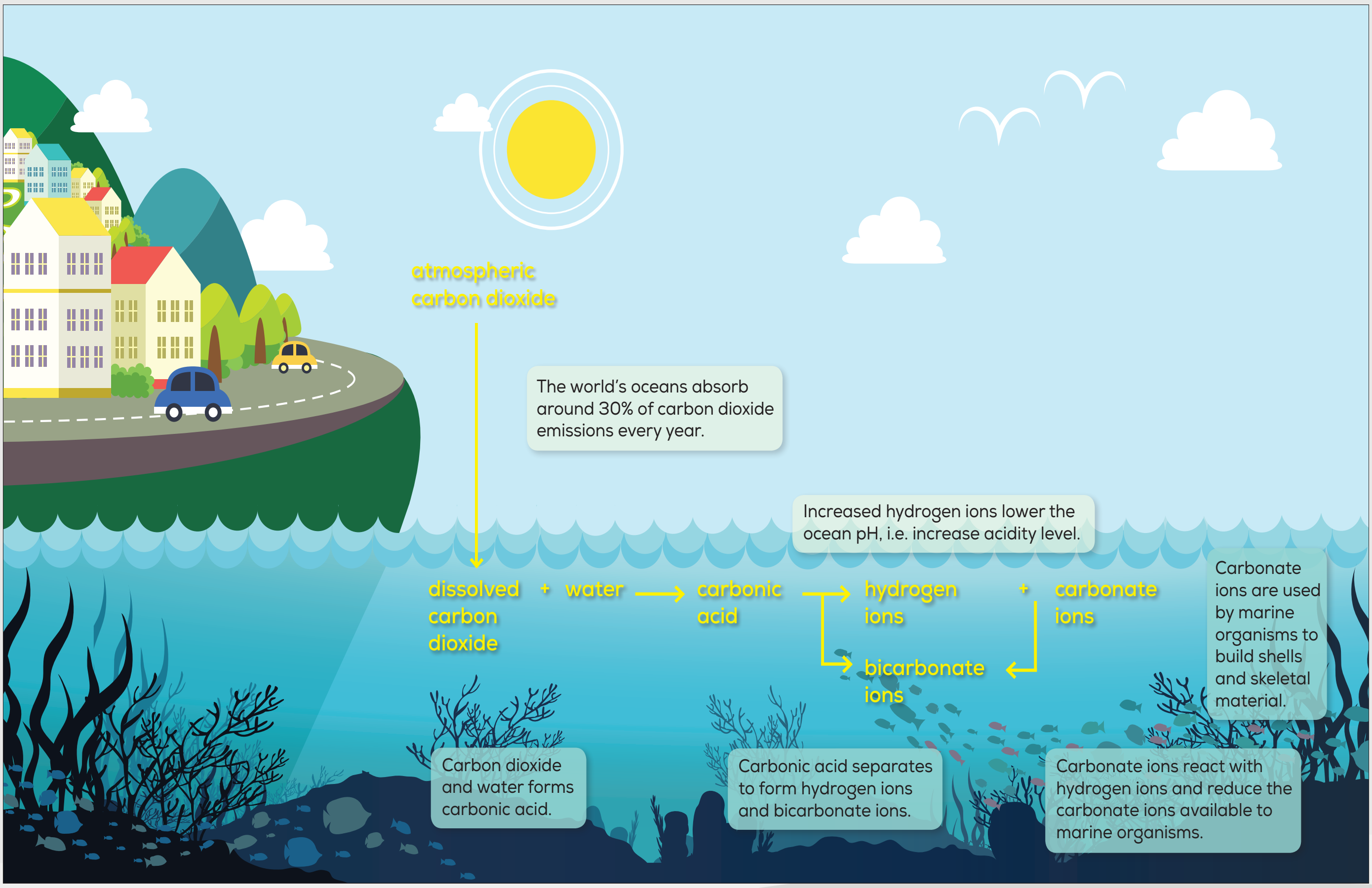
The world's oceans are important carbon sinks, absorbing around 30%[2] of the additional carbon dioxide emissions every year. This slows the rate at which carbon dioxide levels are rising in the atmosphere, but it is also changing the chemistry of the oceans.

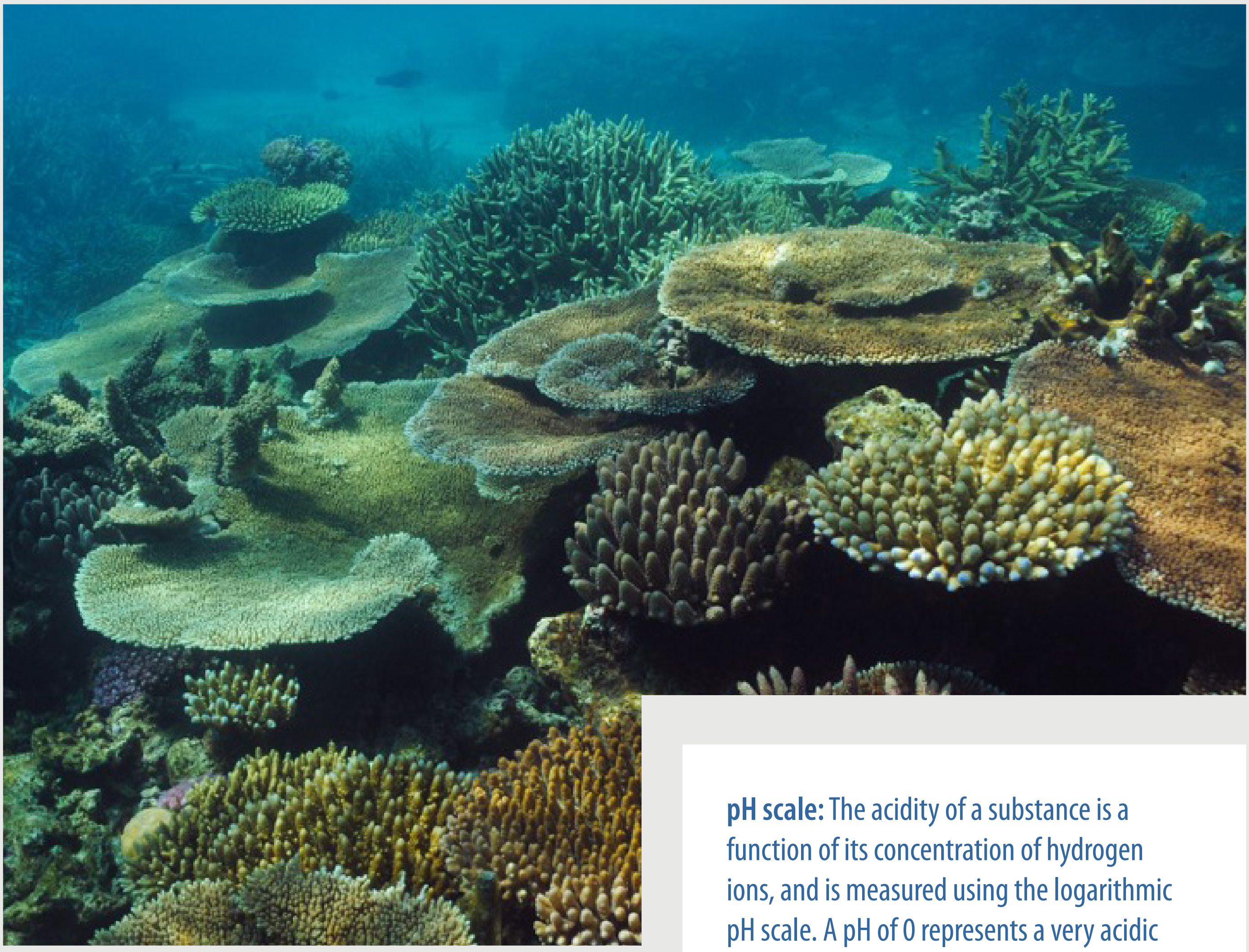
The capacity of the ocean to act as a carbon sink decreases as it acidifies[3].

When carbon dioxide is absorbed in seawater two reactions occur.

Firstly, carbonic acid is formed which separates to form hydrogen ions and bicarbonate ions. It is the increase in hydrogen ions that lowers the pH of the water. That is, it makes the ocean more acidic. Secondly, the concentration of carbonate ions in the ocean is reduced. Under normal conditions, these ions form calcium carbonate, which is used by many marine organisms to build shells and skeletal material. Under elevated carbon dioxide levels, carbonate ions readily react with the excess hydrogen ions in the ocean, making more bicarbonate and reducing the carbonate available to these calcifying organisms.

The changes to the oceans' chemistry are collectively referred to as ocean acidification.





pH scale: The acidity of a substance is a function of its concentration of hydrogen ions, and is measured using the logarithmic pH scale. A pH of 0 represents a very acidic solution (high concentration of hydrogen ions), while a pH of 14 represents a very alkaline solution (low concentration of hydrogen ions). A neutral substance has a pH of 7. The pH of seawater is around 8. Because the scale is logarithmic, a one-unit decrease in pH represents a ten-fold increase in the concentration of hydrogen ions.

MEASURING OCEAN ACIDIFICATION

Ocean acidification is measured by recording the pH of the ocean. Over the past 200 years, there has been a 26% increase in the concentration of hydrogen ions in the seawater, making it more acidic. The current rates of ocean acidification are 10 to 100 times greater than those experienced at the end of the last ice age[4].

Monitoring the saturation state of different forms of calcium carbonate (aragonite and calcite) is an indicator of ocean acidification. The higher the pH of the water, the fewer carbonate ions of either type are available, so the lower the saturation state. Since industrialisation, the aragonite saturation state has decreased globally by approximately 16%[5] and for the Great Barrier Reef, calcification has declined by 14.2% since 1990[6].

IMPACTS OF OCEAN ACIDIFICATION

In their Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) reported that the ocean will continue to take up carbon dioxide emissions throughout the 21st century and beyond, with higher uptake for higher emissions scenarios (referred to as Representative Concentration Pathways or RCPs). This will lower ocean pH (increase ocean acidification) with a range of impacts.

Emissions scenario	Projected decrease in surface ocean pH by 2100
RCP2.6	0.06 to 0.07
RCP4.5	0.14 to 0.15
RCP6.0	0.20 to 0.21
RCP8.5	0.30 to 0.32

Building and maintaining calcium structures

Many marine organisms have shells or skeletons made up of calcium carbonate, including shelled-plankton, corals, molluscs and sea urchins. As ocean acidification continues, the amount of carbonate available for calcifying marine organisms will diminish. This means that calcifying organisms will have difficulty maintaining calcification. As pH lowers (i.e. the ocean becomes more acidic) their shells and similar structures may in fact dissolve, or they will need to redirect energy to maintaining these structures at the expense of growth or reproduction.

With increasing acidification of the oceans, corals will take longer to build reefs and the structures that they do build are likely to be more fragile and vulnerable to erosion. Shelled-plankton, although tiny, are a critical link in the marine food chain. A reduced ability for calcification could see impacts on many calcareous plankton species, as well as on the larger marine animals that eat them.

If carbon dioxide emissions continue on the current trajectory, coral reef erosion is likely to outpace reef building sometime this century.[7]

Some organisms in the Southern Ocean are already feeling the effects of lowering pH. Foraminifera (tiny, single-celled, shelled organisms) have 30-35% less shell weight than their fossil counterparts[8]. In addition, juvenile pteropods (lentil-sized snails) have been observed to have dissolved shells as a result of exposure to aragonite-undersaturated Southern Ocean waters[9].

Modelling suggests that aragonite undersaturation will occur as early as 2030[10] in winter, and could affect Southern Ocean pteropods (small marine snails), a major part of Southern Ocean food webs as a source of food for krill and fish.

Changes to physiological processes

The changing chemistry of the oceans may also affect a number of physiological processes in marine organisms, such as metabolism. Organisms in early stages of development – such as larvae – are particularly vulnerable, and may not survive to adulthood. This creates a bottleneck in the reproductive cycle and will have a significant impact on the populations of both calcifying and non-calcifying species.

The combination of ocean acidification and increased temperatures harms many organisms.[11]

Disruption to ecosystem services

In addition to their intrinsic value, and the service they provide through carbon dioxide absorption, marine ecosystems provide food and employment to people across the globe, worth many billions of dollars annually. In Australia alone, the combined value of marine industries and ecosystem services is estimated to be in excess of $100 billion per year[12]. Disruption to these services will have significant and far-reaching economic and social impacts.

WHAT WE CAN SAY WITH SOME CERTAINTY ABOUT OCEAN ACIDIFICATION[19]

CONFIDENCE			
VERY HIGH	HIGH	MEDIUM	LOW
Ocean acidification is caused by carbon dioxide emissions from human activity to the atmosphere that end up in the ocean. The capacity of the ocean to act as a carbon sink decreases as it acidifies. Anthropogenic ocean acidification is currently in progress and is measurable. The legacy of historical fossil fuel emissions on ocean acidification will be felt for centuries. Reducing carbon dioxide emissions will slow the progress of ocean acidification.	The ocean is acidifying more rapidly than it has in millions of years. Molluscs (such as mussels, oysters and pteropods) and corals are the groups most sensitive to ocean acidification. If carbon dioxide emissions continue on the current trajectory, coral reef erosion is likely to outpace reef building sometime this century. Cold-water coral communities are at risk, and may become unsustainable. Some seagrass and phytoplankton species may benefit from ocean acidification. The combination of ocean acidification and increased temperatures harms many organisms. The varied responses of species to ocean acidification and other stressors are likely to lead to changes in marine ecosystems, but the extent of the impact is difficult to predict. Multiple stressors add to the effects of ocean acidification.	Declines in shell fisheries will lead to economic losses, but the extent of the losses is uncertain. Negative socio-economic impacts of coral reef degradation are expected, but the cost is uncertain. Anthropogenic ocean acidification will adversely affect many calcifying organisms. Pteropod (marine snail) shells are already dissolving. Ocean acidification may have some direct effects on fish physiology, behaviour and fitness. Nitrogen fixation in some cyanobacteria may be stimulated by ocean acidification.	Impacts of ocean acidification on ecosystems may affect top predators and fisheries. Ocean acidification will alter biogeochemical cycles at a global scale.

THE AUSTRALIAN RESEARCH EFFORT

Australian ocean acidification research is focusing on the Southern Ocean and the Great Barrier Reef. The impacts of ocean acidification are likely to appear first in the Southern Ocean as it absorbs a greater proportion of human carbon dioxide emissions. While the impacts of ocean acidification may occur first in the Southern Ocean, they are likely to be most obvious in Australia's iconic Great Barrier Reef. This region of high ecologic and economic importance is not only vulnerable to ocean acidification, but is also susceptible to compound affects from rising temperatures and coral bleaching.

The recognition of ocean acidification as a problem is relatively 'new', in that its associated threats have only been recognised in the past decade (the first *Ocean in a High CO_2 World Symposium* was held in 2004). In this time, CSIRO scientists have been able to take advantage of data from long-term ocean monitoring programs to establish trends in ocean pH and changing carbonate chemistry. This information is also helping to unravel the detail of the processes involved in ocean acidification.

Work is currently under way to improve estimates of current and likely future acidification in the Southern Ocean and Australian regional seas, as well as to assess changes in the Southern Ocean carbon dioxide sink.

Forecasting ocean acidification through ocean carbon models is another important component of CSIRO's work in this area. This modelling is providing views of the future under different carbon conditions and is informing research, policy and decision-making, and adaptation strategies.

The vast stores of data are also being used to inform the development of the carbon cycle module for the Australian Community Climate and Earth-System Simulator (ACCESS), Australia's next generation weather and climate model.

Researchers are modelling the variability in large-scale carbon chemistry on the Great Barrier Reef and in Coral Sea waters, including assessing the influence of riverine and near-shore inputs and coastal-offshore carbon exchange.

A number of other research centres are investigating ocean acidification in the Australian marine realm, including:

- The Australian Institute of Marine Science (AIMS), where researchers recently found that increased carbon dioxide will reduce the structural diversity of reefs. This reduced richness and complexity will result in fewer habitats for other reef species.[13]

- The Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), where researchers are expanding their work from single-species effects[14] to whole-of-community responses in the natural polar setting[15].

There is also a great deal of ocean acidity data being collected through Australia's Integrated Marine Observing System (IMOS). This data, collected around Australia from moorings and research and commercial vessels, is available to researchers and is building a valuable profile of the effects of increased carbon dioxide levels in Australian waters.[16]

GLOBAL ADVANCES AND CHALLENGES IN THIS FIELD: INTERNATIONAL PROGRAMS

Beyond Australia, the global effort to monitor ocean acidification and assess its impacts is being coordinated by the Ocean Acidification International Coordination Centre (OA-ICC), based in Monaco. The Centre facilitates, communicates and promotes international activities in ocean acidification research and observation, and works closely with the Global Ocean Acidification Observing Network (GOA-ON). The network collects and processes measurements of chemical and ecosystem variables to provide the information needed to assess the impacts of ocean acidification. This information is used for priority research areas including:

- determining the responses of key species and ecosystems, particularly over longer time periods
- examining the potential for organisms to acclimate, adapt or relocate
- identifying food chain and socio-economic impacts
- investigating biogeochemical feedbacks on the climate system.[17]

RESEARCH NEEDS IN AUSTRALIA

Although we have learned a great deal about ocean acidification in a relatively short time, there are still many key questions that remain unanswered. Ongoing research in Australia is focusing on:

- the variability of ocean chemistry and ecosystems in Australian seas, for improved predictions and to have a reference against which future systematic change can be identified
- how key species in their various life stages will respond to ocean acidification and how those responses will alter marine food webs and affect biodiversity
- how the combined effects of climate related changes (ocean temperature, nutrient availability and circulation) and commercial activities (such as fishing, tourism and aquaculture) interact with ocean acidification
- how rapidly change will occur and whether there are thresholds that once breached, will lead to major, persistent changes in Australian marine ecosystems.[18]

Collaboration and coordination is the key to addressing the major research questions facing Australia with regards to ocean acidification. The Australian Climate Change Science Programme, research institutions and universities, are working together to maximise resources and integrate results.

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