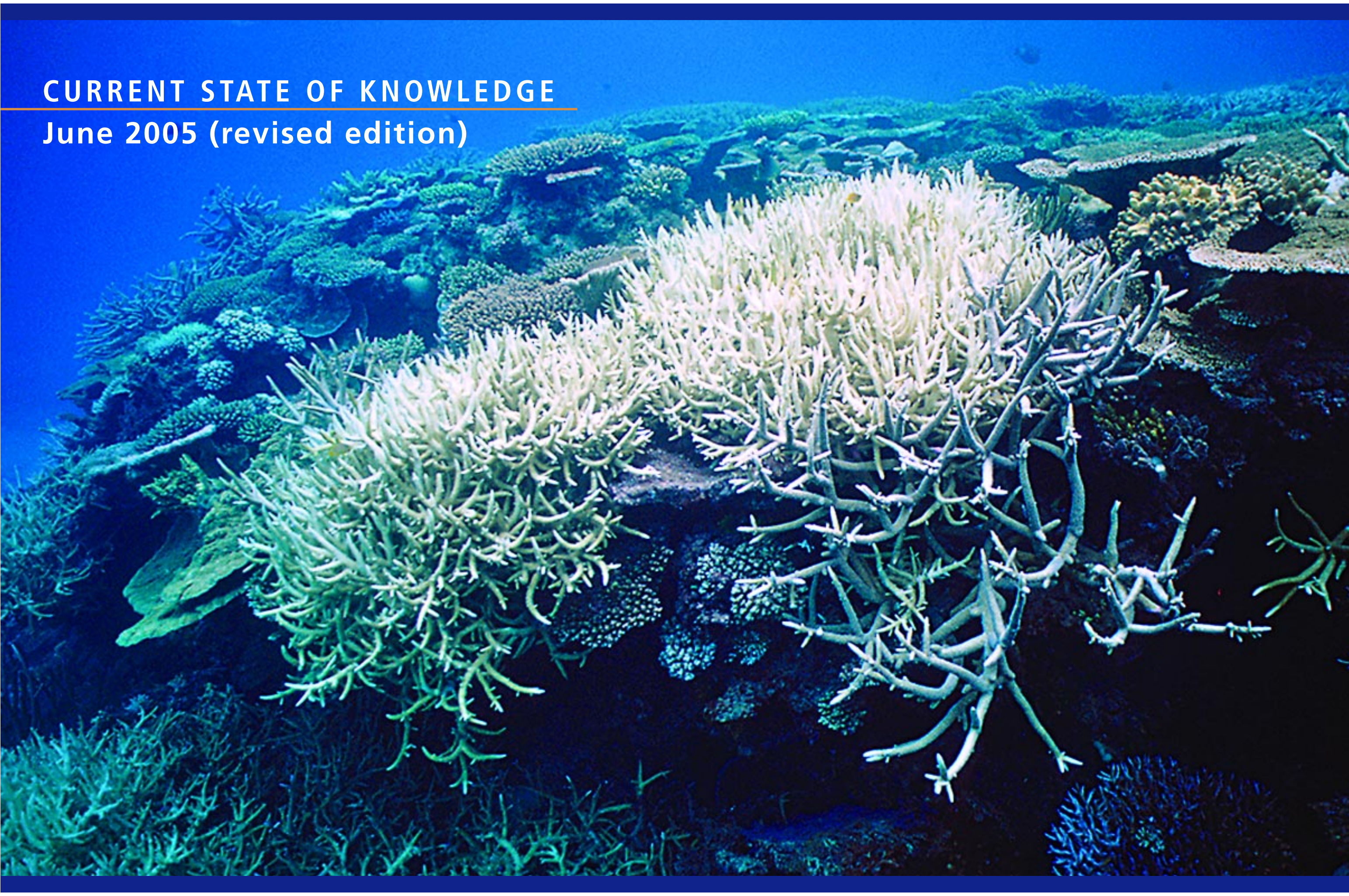
Coral bleaching

and global climate change

CURRENT STATE OF KNOWLEDGE

June 2005 (revised edition)



Coral bleaching is the loss of colour from corals under stressful environmental conditions. While several sources of stress can cause corals to bleach, unusually high water temperature and light intensity has been the major cause of coral bleaching events worldwide in recent decades. In 1998 and 2002, major bleaching events in waters of the Great Barrier Reef raised concerns about the health of the reef. With predictions that temperatures will continue to increase as a result of global climate change, there is growing concern about the future of tropical coral reefs.

Global climate change

In the past, global climate has changed due to a variety of causes. Increasing amounts of greenhouse gases in the atmosphere as a result of human activity since the industrial revolution has added a new, relatively rapid source of climate change. The most significant greenhouse gas is carbon dioxide, which has increased in concentration by more than a third in the last 200 years due to burning of fossil fuels and to deforestation. The concentrations of other gases, such as methane and nitrous oxide, and the ozone-depleting halocarbon gases have also greatly increased over the same period. Enhanced greenhouse gases in the atmosphere warm the air by trapping heat from the Sun that would otherwise radiate from Earth back towards space. The warming that results is similar to that which occurs inside a greenhouse.

Complex computer models are used to project climate change due to enhanced greenhouse gases. Models have to take into account that atmospheric temperature rises with increasing

Photo by GBRMPA

Bleached reefs can be seen from the air

carbon dioxide but is decreased by other gases such as aerosols, and also by the reduction in ozone. Importantly, the longevity of different gases in the atmosphere varies. Carbon dioxide is particularly long-lived and likely to persist at elevated levels for centuries. About 30% of the increased carbon dioxide in the atmosphere has been absorbed by the oceans and is changing ocean chemistry. There is concern that the oceans are becoming more acidic which will negatively affect the ability of corals to deposit carbon from the oceans into their skeletons and form reefs. Some carbon dioxide has also been taken up by plants and will only be released when the plant decomposes, is eaten or is burnt.

Since the end of the 19th century (for which there are instrumental climate records), the average global temperature has warmed by 0.6°C. During the same time, average water temperatures of the Great Barrier Reef have warmed by 0.4°C. According to a recent international study, global average temperatures are projected to warm by another 1.4 - 5.8°C over the next 100 years. This average warming is greatest at higher latitudes. Tropical ocean temperatures where coral reefs live are likely to warm between 1-3°C by the end of this century. Warmer global temperatures will have dramatic effects on current global climate patterns. These include changes in ocean circulation patterns; increased frequency of storm events; and rising sea level due to expansion of warmed oceanic water and loss of land ice.

The biology of coral bleaching

Corals belong to the group of animals called Cnidarians which include anemones, jellyfish, bluebottles and hydroids. Most corals are classified as a soft coral or a hard coral. Both types of corals are colonies of small polyps. In hard corals, the polyp secretes a small limestone cup (or corallite) that surrounds it and protects the soft polyp tissue. Soft corals lack a limestone corallite structure but have tiny internal skeletal parts. Both hard and soft corals are affected by coral bleaching.

A reef-building coral is in a mutually beneficial partnership (or symbiosis) between the coral animal (polyps) and plants (millions of tiny, single-celled algae called zooxanthellae). The zooxanthellae are packed into every cell of one layer of coral tissue and usually occur at densities of more than one million per square centimetre. Like land plants, zooxanthellae use light and dissolved carbon dioxide in the process of photosynthesis to produce energy-rich compounds, some of which are transferred to the host coral. In return, the coral protects the zooxanthellae. Because most corals rely on the zooxanthellae to supply much of their food, they are usually restricted to shallow seas where sufficient light can reach the coral and its zooxanthellae.

Like all living things, corals and zooxanthellae survive and grow well within a preferred range

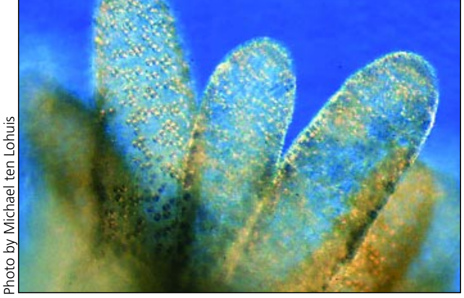


Photo by Michael ten Lohuis

The tissues of corals are packed with small algae called zooxanthellae

of environmental conditions. Temperatures outside their operating range are detrimental to them. Unlike fish that can move to habitats with more suitable environmental conditions, corals cannot escape areas of high temperature because they are attached to the reef structure. If temperatures are too hot for too long, the symbiotic relationship between the coral animal and its tenants, the zooxanthellae, collapses. Reef-building corals appear to be living only 1-2°C below their upper thermal tolerance limit.

Under these conditions, the Sun's energy which is normally used to produce food for the algae and coral, is diverted into the production of oxygen radicals. These oxygen radicals, similar to the chemicals implicated in human aging, are highly corrosive. They damage the parts of the zooxanthellae (the chloroplasts) where photosynthesis takes place. The coral polyps can also be damaged as a result of heat stress. The result is that large numbers of zooxanthellae are expelled from the coral.

The photosynthetic pigments in the zooxanthellae give the coral its distinctive colour, so when the number of algae in the tissues are greatly reduced due to stressful conditions, the corals appear pale. If stressful conditions persist, most of the algae can be lost which leaves the tissues transparent and reveals the white skeleton beneath so that the coral looks 'bleached'.

If high temperatures are relatively short-lived, the zooxanthellae that remain within the coral tissue divide rapidly once the stress diminishes and the coral gradually regains its colour and survives. However, even corals that survive bleaching can suffer long-term effects such as reduced growth and reproduction, and they can be more susceptible to disease. If the stressful conditions are prolonged or particularly severe, the density of zooxanthellae remains low, and many corals will die. There is great variation in the susceptibility to bleaching events between different coral species, and even colonies within a species.

Map courtesy of GBRMPA and AIMS

1998 coral bleaching event

The summer of 1997-1998 was the hottest recorded on the Great Barrier Reef since records began in the late 19th century. Mild bleaching began in late January and intensified by February/March. Extensive aerial surveys of 654 reefs showed great variation in the extent of bleaching between inshore (<10km from the coast) and offshore reefs; and between reef regions along the coast. While only 14% of offshore reefs surveyed were reported to have high levels of bleaching, 67% of the inshore reefs surveyed had high or extreme levels of bleaching. The most severely affected reefs were inshore reefs in the Cairns to Whitsunday coast, and reefs in the Keppel Island group. Most coral bleaching and mortality was seen in shallow water.

These surveys revealed that high sea temperatures combined with periods of slack winds, calm seas, high light, and in some areas, reduced salinity due to flooding, caused the major bleaching event. During the bleaching period, sea temperatures were 1-2°C higher than long-term average values in the central and southern Great Barrier Reef. Water closer to the Queensland coast was generally warmer.

On the most severely bleached areas of reef, subsequent coral mortality was patchy. On some reefs, such as those in the Palm Island group north of Townsville, up to 80% of corals died in the next few months. On other reefs, mortality was low to negligible, including most reefs in the Keppel Island group.

In 1999, surveys of reefs throughout the Great Barrier Reef showed that coral cover declined as a result of bleaching on only a small percentage of the 48 reefs surveyed. The most severely affected reefs were inshore between latitudes 17-19°S. One year after the event, most offshore reefs had changed very little as a result of bleaching.

In 1998, the bleaching impacts on the Great Barrier Reef were relatively small compared with other reefs around the world. Every coral reef region in the world was affected by bleaching that year, making the 1998 bleaching event the worst ever recorded on a global scale.

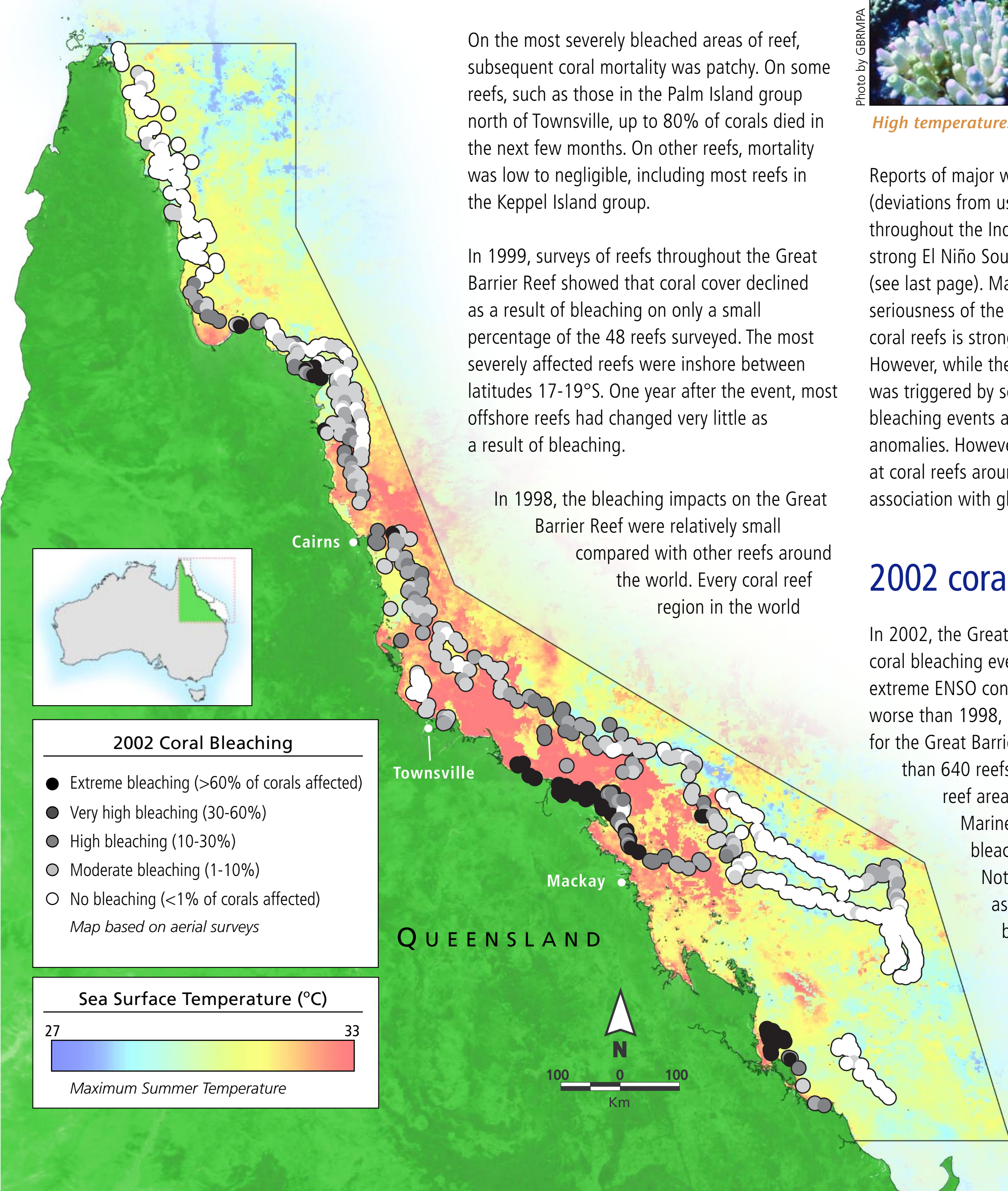
In many cases, the bleaching events were predicted by advanced reports of water temperature 'hot-spots' from satellite measurements of water temperature patterns.

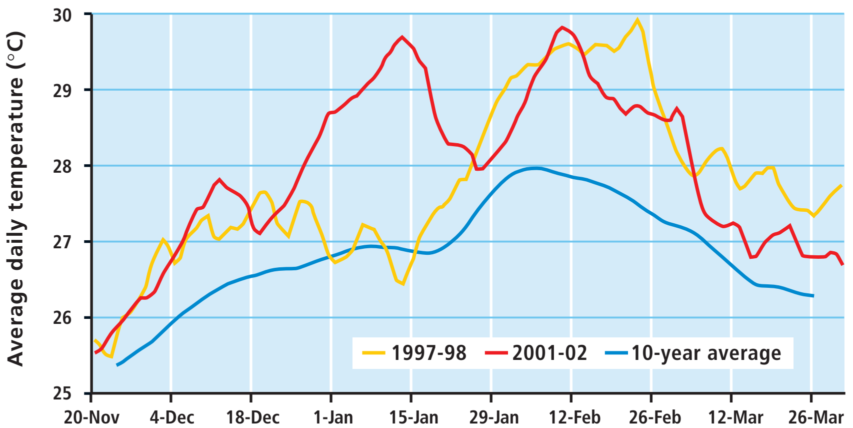
High temperatures will cause corals to bleach

Reports of major water temperature anomalies (deviations from usual values) were recorded throughout the Indo-Pacific as a result of a very strong El Niño Southern Oscillation (ENSO) event (see last page). Many reports assert that the seriousness of the impacts of this ENSO event on coral reefs is strong evidence for global warming. However, while the 1998 coral bleaching event was triggered by severe ENSO conditions, not all bleaching events are associated with ENSO anomalies. However, average water temperatures at coral reefs around the world have warmed in association with global climate change.

2002 coral bleaching event

In 2002, the Great Barrier Reef suffered another coral bleaching event. It was not associated with extreme ENSO conditions, but the effects were worse than 1998, making it the worst on record for the Great Barrier Reef. Aerial surveys of more than 640 reefs found that nearly 55% of the reef area in the Great Barrier Reef Marine Park showed some degree of bleaching as a result of heat-stress. Not all reefs bleached as severely as others and the impacts of bleaching were not evenly distributed throughout the Great Barrier Reef.





Sea temperatures at Halfway Island (in the Keppel Group) during the 1998 and 2002 bleaching events were higher than the 10-year average

The coral bleaching event in 2002 event was considered worse than the 1998 event because more reef area was affected. The most severe bleaching occurred on reefs closest to shore in both bleaching events, but the 2002 event affected a greater area of reefs further offshore.

The aerial surveys found that bleaching was most severe in the Princess Charlotte Bay region; near the Turtle Island Group; on inshore reefs from Cape Upstart to the Whitsundays, in some reefs in the Sir James Smith Group; and in the Keppel Island area. Moderate to very severe bleaching was seen inshore and offshore from around Cape Flattery to Mackay. Little or no bleaching was seen in the Far Northern Section from the tip of Cape York to the northern Princess Charlotte Bay area, in the Swains area and in the Capricorn Bunker Group.

Underwater surveys were used to confirm results from the air and determine whether corals were likely to recover from bleaching or would die. The underwater surveys found that few reefs escaped bleaching, but that most reefs recovered with only 5% of reefs suffering long-term damage. However, some reefs were devastated with 50-90% of corals dead at some sites.

Australia has been relatively fortunate in escaping widespread death of corals despite experiencing two major bleaching events in recent years. However, the devastation at some sites provides a vivid warning of what could happen if hot water events become more frequent and severe in the Great Barrier Reef region.

The temperature tolerance limits of corals

Maximum summer sea temperatures that are just 2-3°C above normal values can kill corals. The upper temperature limit for corals varies between species and places. Corals that usually live in cooler conditions, where summer maximum temperatures are 28°C, will bleach at lower temperatures than corals that usually live in hotter parts of the reef where summer temperatures reach 31°C.

The extent of bleaching also depends on the length of time that the water temperature is raised. A coral which normally grows in summer temperatures of 29°C may show few signs of stress if exposed to temperatures of 32°C for a few hours, but could bleach if temperatures reach 31°C for a week. It is a combination of the length of time, and the amount by which water temperature exceeds normal maximum values, that is critical in determining the extent of bleaching.

Can corals adapt to warmer temperatures?

For corals to survive the increases in seawater temperatures predicted for this century, they would need to adjust to the higher temperatures. There are several ways that they might do this.

Firstly, corals could alter their physiology in a process known as acclimatisation. Corals have several internal mechanisms to cope with stresses such as increased temperature and sunlight. However, these mechanisms are usually only effective for short periods and up to defined limits. They are unlikely to prepare corals for a future bleaching event. There is evidence that many corals have bleached two or three times during successive bleaching events, suggesting that acclimatisation may not be a reliable way for corals to adjust to climate change. If global temperatures rise in the predicted way, water temperatures in 100 years will be much greater than those that trigger bleaching now, so corals would need to acclimatise continually to survive. Most research indicates that acclimatisation is limited and unlikely to allow corals to adapt to the predicted water temperatures.

Photo by GBRMPA

It is unknown whether corals can adapt to warmer seas or will continue to bleach.

A second process by which coral populations could adapt to new conditions is by natural selection. This results in a gradual change in the temperature-tolerance of the population through the elimination of the coral colonies that cannot tolerate higher temperatures. Different colonies of the same coral species may respond to thermal stress differently. If only the most temperature-tolerant corals survive a bleaching episode, the offspring from those corals might be on average more temperature-tolerant than the previous generation. Again, there might be limits in how high the temperature can rise before corals reach the limits of adaptation. Such adaptations are thought to occur slowly, over several generations (with most corals having generation times of at least five to 10 years), but potential rates of adaptation have never been estimated.

A third process is one in which larvae from warm-adapted coral populations may disperse to cooler areas as they warm, thereby changing the distribution of species. However, this is likely to be a slow process.

Corals can have several types of zooxanthellae in their tissues. Some scientists have suggested that corals may adapt to warmer conditions by changing the dominant type of zooxanthellae within their tissues. Corals with a certain type of zooxanthellae can tolerate temperatures of 1-1.5°C higher than corals of the same species without that type. Scientists do not yet know how many of the 400 or so species of hard corals can change the type of dominant zooxanthellae or, indeed, what stimulates the change. Increased temperature tolerance may also come at a cost. For example, juvenile corals with heat-tolerant zooxanthellae grow up to three times slower than those with a different zooxanthellae type. The type of zooxanthellae that occur in the corals may also affect other aspects of coral fitness.

It is possible that a combination of natural selection and switching of zooxanthellae may help corals cope with climate change over the next few decades. Faster rates of change are possible for zooxanthellae than for the coral animal because the algae have shorter generation times. However, adaptation of corals and zooxanthellae to high temperatures has not yet been studied. Research is underway to investigate these different adaptation possibilities.

Can coral reefs recover from bleaching?

Coral reefs can recover from bleaching events in the short-term. When a reef is only slightly stressed, a few scattered corals will die, and the effect will be barely noticeable. When a reef has been exposed to prolonged and extreme heating, most corals will die, and it can take decades for the area to recover, particularly if large, old corals have been killed.

Coral reefs recover as the surviving corals grow, and new recruits (coral larvae) settle and grow. The rate at which a reef recovers from coral bleaching depends on many factors. Some reefs are more likely to receive large numbers of coral larvae carried with ocean currents. The reefs that receive large numbers of larvae can have many young corals growing on them within a few years. However, conditions need to be suitable for their survival and growth. If a recovering reef is subject to high levels of dissolved or organic nutrients or has few grazing animals, the reef can become dominated by algae which inhibit the recovery of the corals. Where conditions are ideal, coral communities can recover within about 10 years. Other reefs that do not receive a plentiful supply of coral larvae, or are polluted or degraded, will take considerably longer to recover, perhaps decades.


Photo by GBRMPA

Underwater surveys check whether corals survive bleaching

The coral communities on a recovering reef may be different from those that were present before the reef was bleached. A few species appear quickly after a reef is damaged and grow rapidly. Other species that are slower to appear and slower growing may not be present on the reef at their previous levels for some decades. The community on a reef may shift from coral species that are prone to bleaching to those with higher resistance or a more rapid recovery rate.

The status of coral reefs in the long-term will depend substantially on the frequency and severity of future bleaching events. If maximum temperatures become higher and bleaching becomes more frequent in the 21st century, reefs may change greatly in character. Unless corals have a greater capacity for adaptation than scientists currently believe is likely, today's diverse community of corals may be replaced by a smaller number of tolerant species; some vulnerable species may only be found in cooler areas. A major shift in the nature of tropical reefs is possible.

An additional potential stress to coral reefs is changing ocean chemistry due to the absorption of carbon dioxide. Several experimental and modelling studies have demonstrated that ocean acidification can decrease the rates of coral calcification which would weaken the structure of coral reefs. Other reef organisms such as fish that depend on hard corals to provide habitat or food may also be seriously affected.

What can be done?

The impacts of climate change on ecosystems such as the Great Barrier Reef are complex, and to some extent, uncertain. However, most evidence suggests serious impacts for both ecosystems and the people that depend on them. Impacts may be minimised through planning and mitigation i.e. reduce greenhouse gas emissions. However, even if all greenhouse gas emissions were reduced today, because of lags in the system, we are still committed to significant climate change by the end of this century.

Urgent efforts to mitigate the ultimate extent of climate change and its impacts are necessary, but this will require global cooperation and comprehensive solutions. The effectiveness of these efforts will be governed by complex political and socio-economic drivers that are largely unpredictable. Adaptation will remain an essential strategy to cope with unavoidable climate changes, and is a task requiring involvement of all Australians.

Continued research into the causes and consequences of global climate change is important. Accurate predictions of the geographic patterns and rates of change, and the best ways to respond to them, must be available to governments and the community. Sharing scientific resources is particularly important in addressing this global issue. Much research effort is also being focused on understanding the capacity of corals to adapt to warmer waters.

In the short-term, we must maintain coral reefs in the best possible condition. Recovery from the 1998 coral bleaching event was much better on healthy reefs such as the Great Barrier Reef than on reefs that were degraded by other stresses. Reefs that are already stressed by environmental factors, such as poor water quality or overfishing, will be more vulnerable to changes in sea temperature. Conservative use of resources and liberal application of strategies to protect biological diversity, productivity and resilience are needed.

For human enterprises, such as tourism and fishing, to survive and thrive in the 21st century, it means:

- working with scientists to determine the implications for different industries of projected future environmental trends;
- implementing best practices to protect the biological diversity, productivity and ecosystem processes that underpin their industries; and
- working in the broader society to raise awareness of the implications of climate change, and influence policies that will reduce the rate of climate change and its associated impacts, and improve our ability as a society to adapt to the unavoidable changes.

El Niño Southern Oscillation (ENSO)

The El Niño Southern Oscillation or ENSO has a major influence on world climates. ENSO refers to the seesaw of climatic conditions near the Equator in the Pacific Ocean that influences global weather.

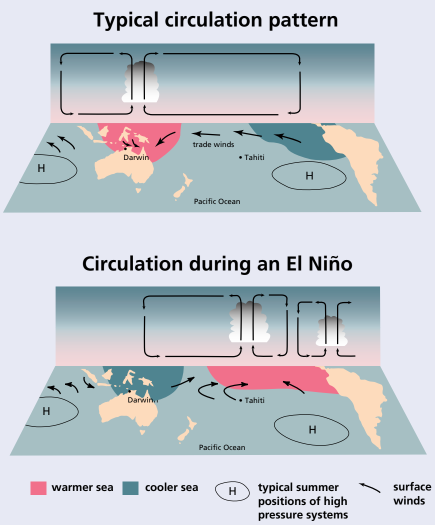


Diagram courtesy Bureau of Meteorology

Normally, there is low atmospheric pressure over northern Australia and Indonesia, while there is high pressure over the eastern Pacific Ocean. The difference in air pressure drives the trade winds from east to west across the Pacific. The trade winds hold water on the surface in the western Pacific so it gets hot. The warm, surface waters bring rain to northern Australia and Indonesia. Meanwhile, cold deep water is drawn up to the surface along the coast of Peru and Ecuador bringing nutrients from the depths that support large anchovy stocks, making this region one of the world's most productive fisheries.

Every two to seven years, this air pressure pattern reverses. The usually low atmospheric pressure over Australia is replaced by high pressure. Over the central Pacific and along the South American coast, the air pressure drops, slackening the westward trade winds. The easing winds and influx of warm water in the east stop the upwelling of cool, nutrient rich water along the South American coast. These unusual conditions were first noticed around Christmas near Peru and were called El Niño, which is Spanish for 'the boy child'.

The effects of El Niño are far-reaching. Along the South American coast, fisheries collapse and the warm moist air brings torrential rains and flooding. In contrast, there are droughts and bushfires in Australia, Indonesia and other south-east Asian countries. With global warming, it is possible that El Niño events could be more frequent and intense.

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Other information: Reports of the Intergovernmental Panel on Climate Change 2001; Climate Change: an Australian guide to the science and potential impacts, edited by B Pittock.

CRC Reef Research Centre

Ensuring the future of the world's coral reefs

CRC Reef Research Centre Ltd is a knowledge-based partnership of coral reef ecosystem researchers, managers and industry. Its mission is to provide research solutions to protect, conserve and restore the world's coral reefs.

CRC Reef Research Centre Ltd is a joint venture between the Association of Marine Park Tourism Operators, Australian Institute of Marine Science, Great Barrier Reef Marine Park Authority, Great Barrier Reef Research Foundation, James Cook University, Queensland Department of Primary Industries and Fisheries, Queensland Seafood Industry Association and Sunfish Queensland Inc. The University of Queensland is an associate member.

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