Coral bleaching - causes and prospects of recovery

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Photos by Dr Tom Bridge and T. E. Roberts

Coral bleaching has long been a 'heated' issue among coral reef scientists, managers, tourist operators and the general public. The issue received has worldwide attention in the last 12-18 months as dramatic reports and photographs of large-scale coral mortality have emerged across the world. Unfortunately, many of the media reports on coral bleaching can be misleading - after all, the primary aim of media outlets is to attract readers, and journalists will often look for the most 'dramatic' aspect of a story rather than providing an objective view. This problem of partisan agendas and 'alternative facts' occurs on both sides of the political spectrum. The aim of this article is to provide a clear, factual outline of both the causes of bleaching - in particularly the 2016 event on the Great Barrier Reef (GBR) – and what this means for the future of the GBR and reefs more broadly.

As divers and underwater photographers who regularly spend time in the water, we are generally more acutely aware of the effects overfishing, unfettered coastal development or climate change can have on marine environments than the broader public. Any of us who has spent time diving in parts of South-East Asia will appreciate the damaging effect that single-use plastic can have on the marine environment. Likewise, anyone who has dived on a reef before and after a hurricane or a severe coral bleaching event will appreciate the dramatic effects these events can have on the ecosystem. While the immediate effects of these disturbances are readily apparent, in my other role as scientists I try to use these observations to understand both the underlying causes of these disturbances, in the hope that we can do something about them, and also

Healthy reef dominated by hard corals of the genus Acropora (top); and a nearby reef where corals have been removed by a recent cyclone and replaced by green slime algae. These photos were taken one day and only a few kilometres apart, but on opposite sides of the reef. Photos Dr Tom Bridge

Scientist surveying coral diversity at Mantis Reef in the far northern Great Barrier Reef in 2011. Photo Dr Tom Bridge

the prospects for and factors influencing recovery, so that we can implement actions that give reefs the best change for recovery.

Coral reefs are considered among the ecosystems most vulnerable to climate change. This is largely because modern coral reefs are dependent on corals that live in symbiosis with microscopic algae, called zooxanthellae, which the corals with a large proportion of their nutritional requirements. This partnership enables corals that possess zooxanthellae to harness sunlight for energy, making them capable of growing much more rapidly than corals that do not contain zooxanthellae. For corals, having zooxanthellae is like covering yourself with millions of tiny solar panels, and the energy produced by these panels is put towards building the huge limestone reefs that we all enjoy as divers and photographers. This partnership works very well when conditions are suitable, but if conditions become unfit for either partner, the relationship breaks down. Coral bleaching is the breakdown of this symbiotic relationship, where the zooxanthellae are no longer providing the coral with the right combination of nutrients and are therefore expelled by the coral.

Water temperatures in 2016 got so hot that even bleaching-resistant species such as massive Porites were bleached. Photo Dr Tom Bridge

There are numerous factors that can induce coral bleaching, including unusually high or low temperatures or changes in seawater salinity due to extreme rainfall events. However, by far the most common cause of coral bleaching in recent years, particularly over large spatial scales, is high water

Bleaching Acropora stands on the Mid-Shelf of the GBR off Cairns, April 2016. The colony has begun to die, with brown algae covering the exposed skeleton. ISO:200, F-Stop: 7.1, 1/200 sec, Tokina 10-17 at 10mm. Photo T. E. Roberts temperatures. The thresholds that induce bleaching varies considerably among geographic locations, habitats and coral species.

For example, corals that live in cool subtropical latitudes such as Lord Howe Island, the world's southernmost coral reef, bleach at around 28°C. In contrast, some corals in the Persian/Arabian Gulf tolerate waters up to an incredible 35°C, but nonetheless bleach if temperatures reach 36°C.

Corals that live in habitats such as lagoons, where temperatures are typically higher than in the open ocean, can be much more tolerant of high water temperatures than those on the outer-reef slope only a few hundred metres away. Natural variability in temperatures is also important – corals that are regularly exposed to large fluctuations in temperature due to oceanographic phenomena such as upwelling may be more tolerant than those from more stable environments.

Despite this spatial variability, it is clear that exceeding the maximum temperature that corals are used to by just 1-2°C causes considerable stress, which can be measured by looking at coral physiology. If this stress occurs for a prolonged period (i.e. more than 1-2 weeks), corals will start to bleach.

At first corals will appear pale and sometimes fluorescent, but even at this stage are highly stressed. If temperatures do not return to normal within a few more weeks, the coral will start to die.

Since bleaching thresholds are relative to local thermal histories, increasing sea temperatures due to increased atmospheric carbon dioxide have caused coral bleaching on reefs across the world, from high-latitude subtropical locations such as the Solitarty Islands and Abrolhos Islands in Australia to the most warm-adapted reefs in the world in the Persian/ Arabian Gulf.

Although sea temperatures have been rising steadily since the Industrial Revolution, mass coral bleaching affecting reefs over thousands of kilometres tends to occur when atmospheric weather events combine with the underlying warming trend to push temperatures beyond the corals' range of tolerance.

There have been suggestions that the 2016 bleaching event to El Nino, and it is true that the two most severe bleaching events globally, in 1997-98 and 2015-16, coincided with strong El Nino events. However, we also know that mass coral bleaching is a recent phenomenon, while El Nino events have been occurring for millienia and did not result in large-scale bleaching events until the 1980s. We know this because as corals lay down their limestone skeletons, they leave

Massive Porites such as this colony are hundreds of years old, and can provide information on environmental conditions going back hundreds of years. Photo Dr Tom Bridge

characteristic annual growth bands much like the growth rings on a tree.

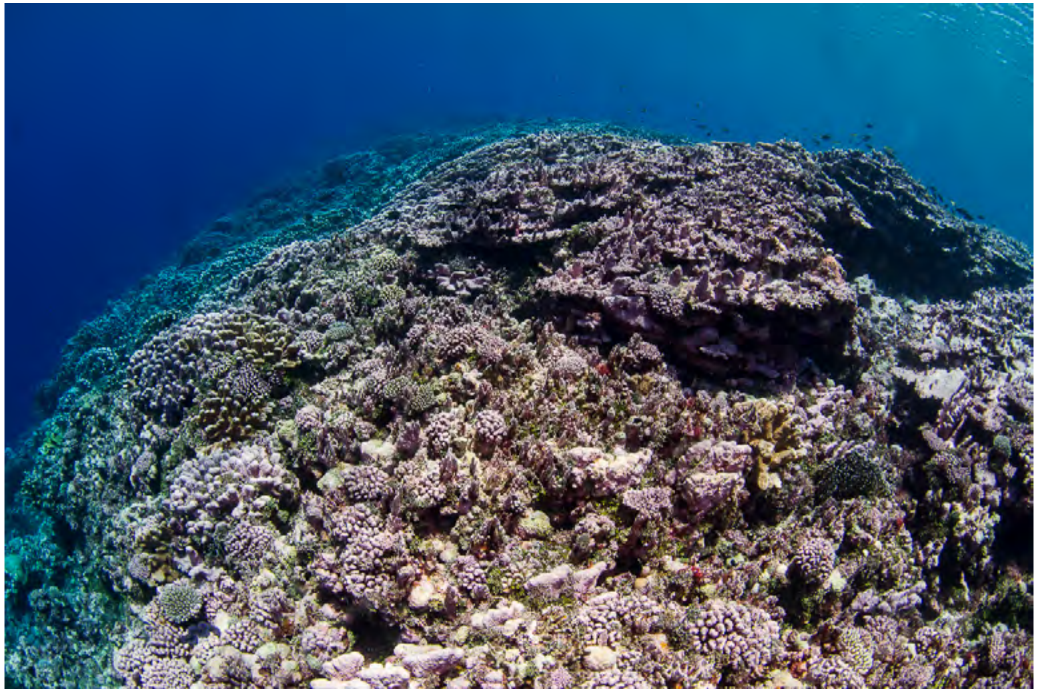
By analyzing the chemistry of the skeleton in different places, we can learn about the seawater conditions at different times in the past.

Bleaching also leaves clearly identifiable signatures in these growth bands, so by examining very old corals we can learn about things such as the frequency of bleaching events or changes in seawater chemistry across hundreds, sometimes thousands, of years. These studies tell us that although there have always been El Nino events and potentially localized, mild bleaching events, mass bleaching was not seen until the 1980s.

'Background' warming caused by increased carbon dioxide means that every year, corals are closer to their maximum thermal limit; consequently, meteorological or climatic events that result in increased temperatures are now capable of causing mass bleaching when they would not have in the past. Indeed, scientists are increasingly able to attribute specific weather events to the influence of climate change. In this case, it has been shown that the conditions that caused the bleaching are virtually impossible to replicate without accounting for the influence of climate change, and that the effect of El Nino on temperatures in the Coral Sea was weak.

Furthermore, we are increasingly seeing mass bleaching events during neutral and La Nina cycles of the Southern Oscillation Index, providing further evidence that because warming has pushed corals towards their maximum temperature thresholds, any atmospheric conditions that increase water temperatures above average can cause bleaching. Consequently, bleaching events are becoming much more frequent than they were in the past.

It is clear that mass coral bleaching is a recent phenomenon that can be definitively linked to warming driven by increasing atmospheric carbon dioxide. In addition, thermal stress, even when it is not severe enough to cause bleaching, is linked to increased incidence of coral disease, and disease outbreaks often occurring in surviving corals following a mass bleaching event. Rising sea temperatures also result in more severe cyclones, which also results in considerable coral loss. So, what does this mean for the recovery



Dead skeletons of corals that died due to elevated water temperatures on a remote atoll in Micronesia in 2016. Photo Dr Tom Bridge

of the GBR and the future of coral reefs more broadly? That is a harder question to answer, but by examining several lines of evidence we can make some informed predictions about how ecosystems may change.

There is no doubt that coral reefs naturally experience a range of disturbances, and that they can recover if given sufficient time. However, the idea that coral reefs have recovered from disturbances in the past and therefore will always recover again represents a form of confirmation bias, like suggesting that because someone recovered from cancer once they will definitely recover if their cancer re-occurs. For obvious reasons, recovery from more severe disturbances is more challenging than more mild ones: a mild bleaching event that kills 10% of corals may be hardly noticeable to the untrained eye, and recovery is likely to be rapid. In contrast, a severe bleaching event that kills 90% of the corals on a reef will be readily apparent to anyone who sees it. In cases where a reef has lost a substantial proportion of its corals,

Completing surveys of the coral bleaching impact at Hastings Reef, on the GBR off Cairns, April 2016. Using set distances measured by tapes over the substrate allow the influence to be quantified. ISO:200, F-Stop: 13, 1/250 sec, Tokina 10-17 at 10mm. Photo T. E. Roberts

there are numerous factors that can influence reef recovery.

The first factor to consider with regards to reef recovery is time; generally, the more severe the disturbance, the longer a reef will take to recover. The beautiful,

A butterflyfish searches for food around bleached coral colonies. These fish rely on the corals as food sources, and a drastic decline in the living coral, or even the health of the corals will inevitably impact these species as well. ISO:200, F-Stop: 22, 1/320 sec, Nikkor 60mm. Photo T. E. Roberts

The killing fields of the 2016-2017 bleaching event. Shallow reef communities at Michaelmas Reef off Cairns in various stages of bleaching stress, and death. April 2016. Some colonies are still fluorescing, where the iridescent proteins in the tissues show through once the symbiotic algae are lost. This creates a bright neon display of what are essentially death colours, before the corals bleach to white, and die. ISO:200, F-Stop: 11, 1/320 sec, Tokina 10-17 at 10mm. Photo T. E. Roberts

diverse coral assemblages we observe underwater are invariably decades old, and even assemblages composed of the fastest-growing corals generally take at least ten years to mature. Consequently, a reef that is hit by a severe storm or bleaching requires a minimum of ten years to recover. In the past, most reefs would have experienced disturbances relatively infrequently, if at all. However, rising sea surface temperatures mean that the time between disturbance events is decreasing; worldwide the average time between bleaching events, known as the 'return time' is currently 6 years. Furthermore, disturbances do not exist in a vacuum, and a coral assemblage recovering from bleaching can be set back by other disturbances, such as a hurricane, even if they escape bleaching.

In addition to time, there are several other factors that can influence reef 'resilience', which is the term used to describe the reef's ability to recover from disturbance. One important factor is recruitment of juvenile corals onto the reef. Following spawning, coral larvae are transported by currents away from the parent colony. The amount of time spent in open water depends on the species, but generally varies from a few days to a few weeks. Although many corals settle on the same reef as their parents, some can be carried large distances to other reefs. For this reason, having a network of reefs can improve the changes of recovery, because it increases the chances that some corals have survived somewhere.

Although the 2016 bleaching event killed a huge number of corals on the GBR, it is a very large reef system and a very large number survived, improving the chances that reefs that were severely impacted will recover compared to more isolated reef systems such as remote oceanic atolls. Even in the far northern region where bleaching was most severe, there are pockets where the corals remained virtually untouched by bleaching, probably because of unique oceanographic conditions. For example, some parts of the outer-shelf of the GBR are exposed to upwelling of cold waters that can alleviate bleaching. These areas are likely to be very important for recovery of other reefs in the region, and because of their unique oceanography, may represent long-term refuges for corals in the region. Importantly, they also continue to provide dive operators with spectacular dive sites. Identifying these special areas and protecting them from other stressors such as overfishing is critical for enhancing reef recovery.

Even corals that survive bleaching often exhibit signs of stress, such as increased vulnerability to disease and reduced fecundity, which can inhibit reef recovery. In the case of the GBR, many of the colonies that survived the bleaching spawned as they have following previous mass bleaching events. However, there is some indication the proportion of colonies breeding was lower than in non-bleaching years. For example, researchers estimated that a total of 45% of the Acropora colonies at Orpheus Island in the central GBR spawned in 2017. As always, spawning was split over three different months – despite the common misconception that all corals on the GBR spawn simultaneously. At Orpheus in 2017, 1 % of colonies spawned in October, 37 % in November and 7% in December.

For those corals that were able to spawn, the next step in reef recovery is for the larval corals to find a spot on the reef and start to grow into an adult colony. This process, known as 'settlement', is influenced by numerous factors including the topography of the reef itself and the amount of algae present. If large, fleshy macroalgae have grown over the reef, juvenile corals fail to settle and the reef may remain in a permanent algal-dominated state. Ensuring a sufficient abundance of algae-eating fish such as surgeonfish, unicornfish and rabbitfish is important for keeping algal abundance low in order to give the corals the best chance to recover.

Topographic complexity also appears important for coral settlement and reef recovery, as well as for other things like providing habitat for reef fish. Since corals provide a lot of the topographic complexity on reefs, disturbances such as bleaching and cyclones cause loss of reef complexity. For many reef fish, the complexity provided by corals is more important than live coral per se. Consequently, loss of corals can lead to a loss of complexity, which in turn leads to declines in fishes which then prevents coral recovery. Since the 1970s, there have been numerous long-term studies that have documented the effects of disturbances on reefs over decadal timescales. Some of the reefs have recovered whereas others have shown little signs of recovery after years or even decades. Others have shown recovery of corals but a shift in the composition of coral species, particularly a shift from thermally-sensitive Acropora towards species that are more tolerant of high temperature, such as Porites. In recent years we have learnt a great deal about the factors that influence coral reef recovery, and therefore we should try to do everything we can to give reefs a fighting chance.

Corals differ in their susceptibility to disturbances such as bleaching, both among species and habitats. The genus Porities, shown here, is generally more resistant to temperature stress than Acropora. This photo was taken after the 2016 bleaching event, which killed many of the Acropora on this reef. Photo Dr Tom Bridge

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