Introduction

Coral reef systems have existed for over 500 million years. The Great Barrier Reef (GBR) is relatively young at 500,000 years of age, with the most recent addition developing only 8,000 years ago as the global climate rose to near present conditions following the last glacial maximum that peaked about 20,000 years ago. The reef now spans 344,400 km$^2$ and is home to 5,988 aquatic species (Australian Government Great Barrier Reef Marine Authority, 2018). Accounting for 10% of the world’s coral reef systems, the GBR is one of the planet's most extraordinary natural wonders and is registered as a UNESCO world heritage centre (McKelvie, 2018).

Corals are dynamic and persistent creatures. Throughout changing climates, they have continued to exist also through over 100-metre changes of rising and falling sea levels. For instance, the GBR has decreased and recovered five times over the past 30,000 years (Langin, 2018). However, with the increase of human interference through anthropogenic greenhouse gas emissions, the extent, liveliness and diversity of coral reefs across the world are expected to be drastically reduced.

The Effect of Climate Change on Reef Ecosystems

According to the Intergovernmental Panel on Climate Change (IPCC), an increase in global temperatures by 1.5 °C is projected to lead to a decline in living coral reefs of 70-90% (The Economist, 2019). The planet is now 1 °C warmer than it was at the start of the 20th century, which has already inducing structural changes in reef systems. Climate change is impacting reefs in three different ways; in particular, through: global heating and thermal extremes; floods and cyclones; and sea-level rise induced by thermal expansion and melting ice sheets. Research has shown that coral reefs are more likely to die from heat stress – also known as bleaching – than ocean acidification from an increase in oceans’ absorption of carbon dioxide (Hughes, 2019).
The first truly global bleaching event occurred beginning in 1998. Over a few years, ~30% of coral reefs around the world were damaged from a severe El Niño event followed by an equally strong La Niña event several years later (Hughes, 2019). Observations indicate that the periods between bleaching events are becoming shorter. Following the initial event, others occurred in 2002, 2016 and 2017 (Hughes, 2019). Between 2014 and 2017, bleaching affected approximately three-quarters of the world’s reef systems. The fastest-growing coral species require roughly a 10-year regeneration period (Hughes, 2019). Therefore, the likelihood of reefs regenerating to their full capacity is becoming increasingly unlikely.

Bleaching is a physiological stress response triggered by environmental changes, such as an increase in sea level rise from the melting polar regions which is instigated from the release of greenhouse gases warming the planet (University of Sydney, 2018). Warming of ocean waters causes coral to expel their symbiotic counterpart, algae. The coral then becomes nutritionally compromised and dies slowly from starvation (National Oceanic and Atmospheric Administration U.S. Department of Commerce, 2017). However, bleaching is selective. Different species of coral have different thermal tolerances. An aerial perspective from the 2016 bleaching event of the GBR demonstrated that reefs subjected develop a white facade. (Hughes, 2019).

Despite the threat bleaching poses to coral and associated aquatic life and the demonstrated increasing prevalence of bleaching, there is hope that the GBR could regenerate and persist into the future. This possibility has recently been associated with the presence of floating pumice rock that had been expelled from an underwater volcanic eruption off the coast of Tonga (Queensland University of Technology, 2019). The pumice formed when frothy molten rock cooled rapidly and formed a lightweight, bubble-rich solid that floated on the sea surface. The pumice can also serve as a means of transport for billions of marine organisms and, when present, could act as a potential mechanism for restocking the Great Barrier Reef (Queensland University of Technology, 2019).
Queensland University of Technology (QUT) Associate Professor of geology Scott Bryan and his team have been studying pumice rafting events over the past 20 years. Based on their studies, they are confident that the recent eruption will bring new healthy corals and other reef dwellers to the Great Barrier Reef, making clear, however, that “although it won’t solve all the problems the Great Barrier Reef is facing, having more corals on hand to help speed recovery will be beneficial.” (Queensland University of Technology, 2019).

**Reef Regeneration Projects**

There are other diverse projects designed to combat coral bleaching, one of which is coral ‘gardening’. Approaches of this type could help restore the GBR by repopulating bleached sites. One such project is directed by The Reef Restoration Foundation (RRF), which has been responsible for creating Australia’s first coral garden, where small pieces of coral are taken from Fitzroy Island and suspended from a tree-like structure to promote quick growth (Tourism Town Australia, 2019). Every 6 to 12 months, cuttings are planted on the reef to restore damaged sites. The site is expected to double in size in the next year, with the successful installation of 20 growing coral farms in two different locations around Fitzroy Island (Tourism Town Australia, 2019). For instance, some damaged areas are growing to 90% of their original size.

Initially, the project commenced with approximately 24 corals and in seven months there are now ~400 (Hartley, 2018). Rob Giason from the RRF has expressed hope that this project will encourage scientists to work creatively on solutions to save the GBR (Hartley, 2018).

This particular project is being supported by the founder of the RRF, Stuart Christie, who believes that heat-tolerant coral stock will eventually be harvested and placed on parts of the reef affected by bleaching. Such an approach is based upon other successful programs developed in Florida and the Caribbean. This approach would also allow tourists to participate in the regeneration through purchasing pieces of coral that can be planted back on the reef (Rafferty, 2017). Such localised conscientiousness could assist reef survival through times of difficulty and to recover more quickly after disturbances. Marine Scientist Nathan Cook believes that this
approach would be a step in the right direction and work on reef restoration should not deteriorate from the challenge of dealing with climate change (Rafferty, 2017). However, when a seventh bleaching event occurred in 2019, the coral nursery located in French Polynesia was wiped out, so it may not be both possible and cost-effective to utilise coral gardening approaches in the open ocean (Hughes, 2019).

Another way to reduce the effects of coral bleaching is through the movement of water. Scientists at the Reef and Rainforest Research Centre have proposed the idea of building a slow turning impeller. This would mix water vertically to reduce the variations in water temperature within and around the reef (Hartley, 2018). It is hoped that field testing of this approach will commence as early as December 2019 (Hartley, 2018).

Another project would involve creating a biodegradable ‘sun shield’. Such a shield could consist of only a one molecule-thick film designed to sit on the surface of the ocean. In allowing less sunlight to pass through, it is suggested that this could prevent bleaching from occurring (Hartley, 2018). The shield would not be intended to cover the complete area of the GBR, but only areas that are particularly amenable to such an approach. This project, currently in the trial phase with field-testing proposed for 2021, is being led by the Australian Institute of Marine Science and the University of Melbourne (Hartley, 2018).

Assisted migration could also serve as a possible approach to sustaining the reef (Hughes, 2019). This process would involve capturing coral larvae as they float on the ocean surface. However, this pathway may not be feasible because of the need for 1000 larvae to produce adults, and fast larval motility would make it a difficult avenue to pursue (Hughes, 2019).

A promising complementary approach to limiting bleaching would be to reduce other adverse impacts on the coral, such as those that are occurring in nearby terrestrial areas. For example, previous research has shown that high levels of sediment are harmful to coral larvae because the sediment tends to smother them and hinders their development (Hughes, 2019); thus sediment runoff poses a considerable threat to the GBR (Hughes, 2019). Focusing on improving the
quality of nearby land areas, such as the re-growth of forests, may, therefore, also reduce damage to the GBR.

**Conclusion**

With the persistence of climate change and resultant increases in ocean temperature, sea level, and ocean acidity (so lower pH levels), recurrent bleaching is becoming the new normal. The increase in bleaching events over the past 21 years has forever changed the northern and central (so warmest) areas of the GBR. What was once a thriving ecosystem is becoming a barren wasteland. Yet, some corals are proving themselves strong enough to withstand the stress of environmental changes. Some scientists are finding that addressing land sediment issues is likely to be a more effective consideration in reef survival as compared to pursuing restoration projects. They also reiterate that, unfortunately, the situation is very likely to get worse before the current trends can be reversed. Therefore, hope for reef systems remains, but taking early action to slow further change will be essential.

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