1 The Extraordinary Resilience of Great Barrier Reef Corals, and Problems with Policy Science

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The Great Barrier Reef is often used to show the imminent crisis we are supposedly facing from climate change. It is photogenic, the water sparkles blue, the fish and corals are beautiful and delicate, and most who see it – particularly marine biologists – fall in love with it. It is abhorrent to even contemplate that it could be destroyed or damaged by humanity.

The claimed imminent peril faced by the Great Barrier Reef has captured the public's imagination. When then US president Barack Obama visited Australia, he remarked that he wanted global action on climate change, so that maybe his daughters would have a chance to see the Great Barrier Reef. A visiting architect to my university revealed that his daughter, on discussing the latest reef bleaching event at school, came home depressed that she would probably never be able to see the Great Barrier Reef. Most of the world's population seems to have been persuaded that it has no more than a few years left.

There is no doubt that every decade or so, abnormally high seawater temperatures can cause corals to bleach (Marshall & Schuttenberg 2006). Bleaching is when the coral expels the symbiotic algae (zooxanthellae) which normally live inside an individual coral polyp. The polyps are the animals, generally a few millimetres across, that make the calcium carbonate structure of the coral.

Thousands or even millions of polyps make up an individual coral. The symbiotic algae live inside the polyp and make energy from sunlight; they share this energy with the polyp in exchange for a comfortable environment. However, when the water gets much hotter than normal, something goes wrong with the symbionts and they effectively become poisonous to the polyp. The polyp expels the symbionts and – because it is the symbionts that give the polyp its colour – the coral turns white. Without the symbionts, the polyp will run out of energy and die within a few weeks or months, unless it takes on more symbionts that float around naturally in the water surrounding the coral.

The ghastly white skeletons of bleached coral, particularly when seen on a massive scale, make graphic and compelling images to demonstrate the perils of climate change. The fact that this only happens when the water gets much hotter than normal makes it a plausible hypothesis that coral bleaching is caused by anthropogenic climate change. It is also often claimed by scientists that mass bleaching has only occurred since the 1970s, and that it is a recent phenomenon that did not occur 100 years ago when the water temperature of the Great Barrier Reef was 0.5 °C to 1.0 °C degrees cooler (Hughes 2016).

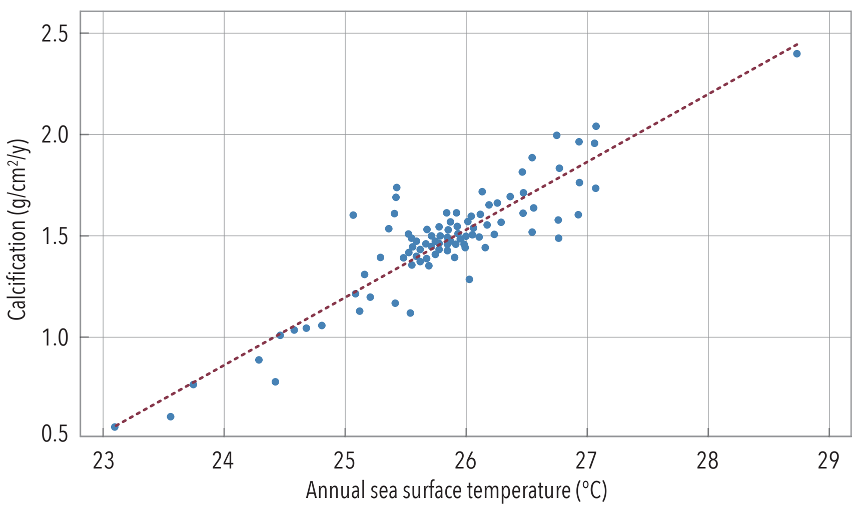
Despite this apparently plausible hypothesis, it will be argued in this chapter that there is perhaps no ecosystem on Earth better able to cope with rising temperatures than the Great Barrier Reef. Irrespective of one's views about the role of carbon dioxide (CO_2) in warming the climate, it is remarkable that the Great Barrier Reef has become the ecosystem, more than almost all others, that is used to illustrate and claim environmental disaster from the modest warming we have seen over the course of the last century.

Corals like it hot

Most species of coral that live on the Great Barrier Reef also live in much warmer water, closer to the Equator around Indonesia and

Thailand, where the water temperature reaches 29.0 °C. Coral growth rates are closely linked to temperature, as shown in Figure 1.1. The warmer water allows the coral to grow faster and more prolifically than it does on the Great Barrier Reef. The Great Barrier Reef has a temperature range from an average 25.0 °C in the south to an average 27.4 °C in the north (Lough & Barnes 2000). Coral growth rates increase with temperature to well above these averages. So, for example, in the southern Great Barrier Reef (25.0 °C) the corals are calcifying at half the rate of corals in Indonesia and Thailand, as shown in Figure 1.1. Therefore, it might be predicted that a modest increase in temperature, of a few degrees, would allow corals to grow faster on the Great Barrier Reef.

Figure 1.1 Calcification rate versus water temperature for *Porites* corals



Source: Adapted by permission from Elsevier – Lough, JB & Barnes, DJ, 'Environmental controls on growth of the massive coral Porites', *Journal of Experimental Marine Biology and Ecology*, vol. 245, pp. 225-243, copyright 2000.

Corals are essentially a tropical species and the best corals live in the hottest places. Which is why there are some corals in Queensland that are regularly temperature stressed. In Moreton Bay near Brisbane, for example, they are stressed because the temperature gets too *low* in winter.

Juggling symbionts: incredible adaptability

Corals use a remarkable mechanism to reduce their susceptibility to large temperature changes (Steele 2016). There are a large variety of species of symbionts that can live inside particular species of coral. Some species of symbionts will allow the coral to grow faster, but will make them more susceptible to bleaching; other species of symbionts will give slower growth rates, but will make the corals relatively insensitive to extreme temperatures. Corals can select the species of symbionts that give them the ability to adapt to the prevailing conditions. However, it is always a gamble with the weather – if they choose the 'high octane' symbionts they could bleach; if they choose the safe 'low octane' symbionts and avoid bleaching they could be out-competed by neighbouring corals that grow faster.

The relationship between the polyp and the symbiont is central to the survival mechanism of corals, and is a masterpiece of adaptability. In their larval phase, most corals have no symbionts, but acquire them from the surrounding water, selecting the strain of symbionts to suit their conditions. In addition, a colony of coral may have a wide variety of symbionts in its multitude of different polyps. In the event of a severe bleaching, where much of the colony dies, those polyps with the strain of symbiont that mitigate against bleaching are able to regrow over the dead coral in the following years (Roff et al. 2014).

This ability to shuffle symbionts means that corals that undergo bleaching in one year will then be relatively unsusceptible to similar high temperatures in following years. The bleaching, in effect, forces the corals to take onboard a better adapted strain of symbionts.

The important point is that for a particular species of coral there is a variable upper temperature that they can tolerate. If these corals live in the generally cooler waters of the southern Great Barrier Reef, they may take onboard a species of symbiont that will mean they will bleach at 27.0 °C. This would be suicide in Thailand, but could be a good choice offshore from Gladstone, in the southern Great Barrier Reef.

It should be no surprise that corals have learned a thing or two about dealing with large temperature swings over 200 million years of evolution. But even if there was never any climatic variability, there is still a good reason for a particular coral to be able to deal with varying maximum temperatures. This is because coral spawn may drift large distances before they settle. It is therefore quite possible that the progeny of a particular coral could drift hundreds of kilometres (or further) into water that is hotter or cooler than where they originated. They could also drift into shallow water where the temperature is generally hotter, or they could settle in deeper, cooler, water. By simply varying the symbionts, young corals can deal with these different temperature regimes.

Great Barrier Reef corals truly are masters of temperature adaptability.

Bleaching is not a new phenomenon

Bleaching is one of corals' defence mechanisms and should be regarded as a strategy for survival rather than a death sentence. Generally, it stops them dying. Most corals that bleach fully recover (Marshall & Schuttenberg 2006) albeit they are a bit shaken by the experience. A survival mechanism such as bleaching indicates that corals have adapted to periods of unusually high temperatures in the past.

Professor Terry Hughes, a pre-eminent coral ecologist who works at James Cook University, Townsville, Australia, has claimed that bleaching is a new phenomenon. Professor Hughes has been responsible for much of the publicity about the 2016 bleaching event. He stated on Australia's ABC Radio National (RN):

> A critical issue here is that these bleaching events are novel. When I was a PhD student 30 years ago, regional scale bleaching events were completely unheard of; they are a human invention due to global warming (ABC RN 2016).

In fact, bleaching was first recorded early last century by Sir Charles Maurice Yonge in the first major scientific study of the Great Barrier Reef (Yonge 1930). In addition, there are '26 records of coral bleaching before 1982' (Oliver et al. 2009). It was not until the 1960s that the phenomenon was discovered by scientists at the newly established institutions on the Great Barrier Reef coast – the Australian Institute of Marine Science, and James Cook University.

Spurious claims

Climate change and bleaching is only one of the latest threats to the Great Barrier Reef that scientists have been warning about. In the 1960s, it was claimed that the reef was being destroyed by plagues of crown-of-thorns starfish (COTS) (*Acanthaster planci*), in a similar fashion to plagues of locusts (Peason & Endean 1969). The cause of the plagues was immediately attributed to human activity, and a search for the specific culprit began. The first suspect was thought to be the overfishing of triton snails (*Charonia tritonis*), which eat COTS. More recently, it has been claimed, probably erroneously, that the run-off from agricultural land adjacent to the Great Barrier Reef, high in nutrients from the fertilisers used, is the cause (Brodie et al. 2007). In the meantime, we have learned that reefs rapidly recover from COTS outbreaks – within about ten years – and that the geological evidence suggests that COTS have been around for millennia – long before marine biologists first got hold of scuba gear (Walbran et al. 1989).

It is remarkable how rapidly some scientists have jumped to the conclusion that COTS outbreaks are a recent phenomenon.

It is noteworthy that there are strong parallels between scientists' reactions to COTS and to coral bleaching. If a mass bleaching event or a COTS outbreak had occurred on the Great Barrier Reef in the 1930s, who would have noticed? It is possible that a few pearl or *bêche-de-mer* divers might have, but they would have been unlikely to report their findings to scientists or the world's media. Contrast that to today, when a bleaching or COTS event will be documented by hundreds of scientists who may have been waiting and preparing for the event for years. They monitor the reef with satellite images of water temperature, giving them time to prepare massive aerial surveys of the reef. I've seen this research executed with military precision.

Spawning is not a new phenomenon, either

Bleaching is not the only visually spectacular, but recently discovered, event that occurs on the Great Barrier Reef. The other is the mass spawning event that occurs late in the year after a full moon. Almost all the corals on the Great Barrier Reef spawn on one or two nights of the year, making huge floating pink–white 'slicks' of eggs and sperm along the entire 2000 km length of the reef. From the air these slicks are seen as pink–white lines, often kilometres long and tens of metres across. From a boat, the slicks cannot be missed. However, this spawning event was not 'discovered' to science until the 1980s (Harrison et al. 1984).

So, did corals invent sexual reproduction in the early 1980s? Or is it more likely that it took a little while for scientists to discover something that many Aboriginal people, fishermen and other mariners, must have witnessed repeatedly in the past? The same applies to bleaching – it is a phenomenon only recently documented – not a phenomenon that has only recently occurred. It is interesting to note the different reactions of scientists to these two discoveries. Mass coral spawning is a wonder of nature and a result of millions of years of evolution; mass coral bleaching is new and caused by burning coal.

Corals: born together and die together

One of the features of coral reefs is the almost continuous change that occurs due to the succession of extreme events, of which high water temperature is just one. A picture-postcard reef today may be obliterated tomorrow by a large cyclone, a plague of COTS, a plume of freshwater from a nearby river during a flood event, or even from a period of cold water. The corals often all die together in a spectacularly massive event. However, in the last 40 years we have learned that they are also capable of rapid recovery – in a decade, or so.

It is also notable that the corals species that tend to bleach are the naturally short-lived species – generally, the plate and staghorn corals (Marshall & Schuttenberg 2006). The 'massive' corals, which resemble solid blocks or spheres and which can live for centuries, rarely bleach. The plate and staghorn corals are very susceptible to other events, such as cyclones, while the massive corals – which grow more slowly because they must lay down far more calcium carbonate in their skeleton – are not easily smashed by the waves from a cyclone. To grow perhaps 0.5 m above the sea floor, a massive coral will lay down between 10 to 100 times as much skeleton by mass.

The staghorn and plate-like corals have the shared philosophy of living fast and dying young. Pretty as they are, in many regards they are the weeds of the reef and we must not get too emotional when they get damaged by bleaching. The next cyclone will shortly spell their demise in any case. The longer lived massive corals are more akin to the giant trees in temperate forests that live hundreds of years. These corals are rarely bleached or killed by cyclones.

In between such destructive events, the reef quietly grows and waits for the beginning of the next cycle of death and regrowth. And, just recently, the attention of the world media fed by our science organisations.

Corals and ocean acidification

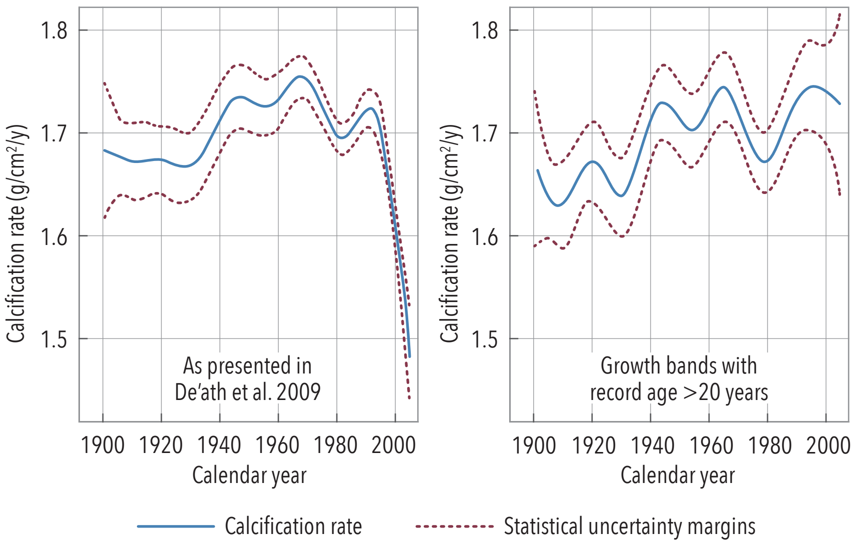
Rising water temperature is not the only way that CO_2 is predicted to kill the coral reefs. Much has been written about the effect of CO_2 on lowering the water pH, which it is claimed will retard the ability of corals to calcify or lay down their skeletons (De'ath et al. 2009). Ocean water is slightly alkaline (pH a little over 8, neutral is 7), and rising CO_2 concentrations will possibly drop this to a little under 8.

Changes in pH have already been claimed to have caused a calamitous change in coral calcification rates on the Great Barrier Reef – a drop of 15% from 1990 to 2005 (De'ath et al. 2009). Such claims, like so much research that supposedly shows a massive decline of the Great Barrier Reef, were received by the world's media with much fanfare. However, it is perhaps yet another example of science that has not been properly scrutinised, or subjected to proper quality assurance.

Like trees, which produce rings as they grow, corals set down a clearly identifiable layer of calcium carbonate skeleton each year, as they grow. The thicknesses and density of the layers can be used to infer calcification rates and are, effectively, a measure of the growth rate. Dr Glenn De'ath and colleagues from the Australian Institute of Marine Science used cores from more than 300 corals, some of which were hundreds of years old, to measure the changes in calcification during the last few hundred years (De'ath et al. 2009). They claimed there was a precipitous decline in calcification since 1990, as shown in Figure 1.2.

However, I have two issues with their analysis. I published my concerns, and an alternative analysis, in the journal *Marine Geology* (Ridd et al. 2013). First, there were instrumental errors with the measurements of the coral layers. This was especially the case for the last layer at the surface of the coral, which was often measured as being much smaller than the reality. This forced an apparent drop in the average calcification for the corals that were collected in the early 2000s – falsely implying a

Figure 1.2 Coral calcification rates



Coral calcification rates (left chart) as presented by De'ath et al. (2009), and (right chart) corrected for errors (Ridd et al. 2013). The dotted lines denote statistical uncertainty margins.

Source: Reprinted by permission from the American Association for the Advancement of Science – De'ath, G, Lough, JM & Fabricius, KE, 'Declining coral calcification on the Great Barrier Reef', *Science*, vol. 323, pp. 116-119, copyright 2009; and reprinted by permission from Elsevier – Ridd, PV, DaSilva, ET & Stieglitz, TC, 'Have coral calcification rates slowed in the last twenty years?' *Marine Geology*, vol. 346, pp. 392-399, copyright 2013.

recent calcification drop. Second, an 'age effect' was not acknowledged. When these two errors are accounted for, the drop in calcification rates disappear, as shown in Figure 1.2.

The problem with the 'age effect', mentioned above, arose because in the study De'ath and colleagues included data from corals sampled during two distinct periods and with a different focus; I will refer to these as two campaigns. The first campaign occurred mostly in the 1980s and focused on very large coral specimens, sometimes many metres across. The second campaign occurred in the early 2000s due to the increased interest in the effects of CO_2. However, presumably due to cost cutting measures, instead of focusing on the original huge coral colonies, the second campaign measured smaller colonies, many just a few tens of centimetres in diameter. In summary, the first campaign focused on large old corals, while, in contrast, the second campaign focused on small young corals. The two datasets were then spliced together, and wholly unjustifiable assumptions were implicitly made, but not stated – in particular that there is no age effect on coral growth (Ridd et al. 2013, De'ath et al. 2013).

Reporting good news as bad news

Dr Juan D'Olivo Cordero from the University of Western Australia collected an entirely different dataset of coral cores from the Great Barrier Reef (D'Olivo et al. 2013) to determine calcification rates. This study determined that there has been a 10% increase in calcification rates since the 1940s for offshore and mid-shelf reefs, which is the location of about 99% of all the coral on the Great Barrier Reef. However, these researchers also measured a 5% decline in calcification rates of inshore corals – the approximately 1% of corals that live very close to the coast. Overall, there was an increase for most of the Great Barrier Reef, and a decrease for a small fraction of the Great Barrier Reef.

While it would seem reasonable to conclude that the results of the study by D'Olivo et al. (2013) would be reported as good news for the Great Barrier Reef, their article in the journal *Coral Reefs* concluded:

> Our new findings nevertheless continue to raise concerns, with the inner-shelf reefs continuing to show long-term declines in calcification consistent with increased disturbance from land-based effects. In contrast, the more 'pristine' mid- and outer-shelf reefs appear to be undergoing a transition from increasing to decreasing rates of calcification, possibly reflecting the effects of CO_2-driven climate change.

Imaginatively, this shift from 'increasing' to 'decreasing' seems to be based on an insignificant fall in the calcification rate in some of the mid-shelf reefs in the last two years of the 65-year dataset. Why did the authors concentrate on this when their data shows that the reef is growing about 10% faster than it did in the 1940s?

Science quality assurance

In this chapter, I was asked to focus on climate change. I have highlighted just a few examples of questionable science – the list is long. Furthermore, climate change is only one of many claimed stressors causing damage to the Great Barrier Reef; others include sediments, nutrients and pesticides from agriculture. I have investigated these supposed threats and they are even less convincing and more contrived than the claimed effects of climate change (Ridd et al. 2011; and 2012). But challenges to the conventional wisdom are typically ignored, largely drowned out and sidelined by the majority. There is now an industry that employs thousands of people whose job it is to 'save the Great Barrier Reef'. As a scientist, to question the proposition that the reef is damaged is a potentially career-ending move (Lloyd 2016).

So, what is the solution?

The fundamental problem is that we can no longer rely on 'the science', or for that matter our major scientific institutions. There are major quality assurance shortcomings in the way we conduct what I will call 'policy science' – that is science used to inform public policy. In fact, in most cases, the only quality assurance measure is peer review. Peer review sounds impressive; I suspect the public thinks it is where, like a jury, a dozen scientists consider the scientific arguments and the data for many days before passing their verdict on whether it is good science or not. Unfortunately, peer review usually consists of a cursory read of the scientific paper, often for just a couple of hours, by two scientists. They never have the time to check the data properly, or to try to repeat the analyses. Their main task is to make sure that the writing and diagrams are clear, and that there are no obvious problems. Usually, we do not even know who these reviewers are. Is this the quality assurance process that we need if we are going to spend public funds on decisions that are supposed to be based on solid science?

In contrast to government policy science, research with an industry or medical focus usually includes some proper quality assurance, with good reason. For example, a company hoping to develop a drug from promising university trials will typically need a billion dollars to take it to market. The first step for the company is to check and replicate the original peer-reviewed research. It is of concern that when these checks are done, conclusions from the original work are found to be in error more than half the time (Prinz et al. 2011). This could be disastrous, but at least the checks were made to prevent wasting vast resources.

Policy science concerning the Great Barrier Reef is almost never checked. Over the next few years, Australian governments will spend more than a billion dollars on the Great Barrier Reef; the costs to industry could far exceed this. Yet the keystone research papers have not been subject to proper scrutiny. Instead, there is a total reliance on the demonstrably inadequate peer-review process.

The lack of quality assurance in science has become a hot topic, particularly in medical science. The failure of drug companies to replicate the findings of scientific institutions is just the tip of the iceberg. In the biomedical sciences, many authors have reported the level of irreproducibility at around 50% (Vasilevsky et al. 2013; Hartshorne & Schachner 2012; and Glasziou 2008). More recently, John Ioannidis, Professor of Medicine and of Health Research and Policy at Stanford University School of Medicine, and a Professor of Statistics at Stanford University School of Humanities and Sciences, suggested that as much as 85% of science resources are wasted due to false or exaggerated findings in the literature (Ioannidis 2014). Professor Ioannidis focused on, among other matters, the lack of funding for replication studies, which are so important in the medical area. Indeed, replication of already 'known' results is one of the fundamental processes upon which the reliability of science rests, but this is generally seen as mundane and not the way to advance a scientific career. Funding bodies are rarely keen to spend money on such work.

The problem is so acute that the editor of *The Lancet*, one of medicine's most important journals, stated that:

> The case against science is straightforward: much of the scientific literature, perhaps half, may simply be untrue. Afflicted by studies with small sample sizes, tiny effects, invalid exploratory analyses, and flagrant conflicts of interest, together with an obsession for pursuing fashionable trends of dubious importance, science has taken a turn towards darkness. (Horton 2015)

Similar concerns have also been raised for the psychological sciences (Wagenmakers et al. 2011).

How long will it take before we finally address this issue when it comes to policy science in general, and for the Great Barrier Reef, in particular? Marine biologists Dr Mariana Duarte from the Federal University of Minas Gerais, Brazil, and Dr Howard Browman from the Institute of Marine Research, Norway, have called for 'organised scepticism' to improve the reliability of the environmental marine sciences (Duarte et al. 2015; and Browman 2016). Duarte et al. (2015) argue that:

> the scientific community concerned with problems in the marine ecosystem [should] undertake a rigorous and systematic audit of ocean calamities, with the aim of assessing their generality, severity, and immediacy. Such an audit of ocean calamities would involve a large contingent of scientists coordinated by a global program set to assess ocean health.

This is what must occur for the Great Barrier Reef. I have carried out half-a-dozen audits on some of the science claiming damage to the

Great Barrier Reef, and in every case I have discovered serious problems (Ridd 2007; Ridd et al. 2011, 2012, 2013). However, individuals can be easily ignored. There is a need for a properly funded group of scientists whose sole job is to find fault in the science upon which we are basing expensive public policy decisions regarding the Great Barrier Reef.

Conclusion

Due to the remarkable mechanisms that corals have developed to adapt to changing temperatures, especially the ability to swap symbionts, corals are perhaps the least endangered of any ecosystem to future climate change – natural or man-made. The corals found on the Great Barrier Reef also live in waters closer to the Equator, which are considerably warmer. Coral generally grows faster in warmer waters, so it should not be surprising that there has been a 10% increase in calcification rates at the Great Barrier Reef since the 1940s.

Yet, so many are convinced that the Great Barrier Reef is under threat due to the fact that when corals die, they tend to do it in spectacular ways with events that make excellent images for the media. Then there are the many 'scientific studies' that have never been replicated or properly checked, that conclude the imminent demise of the Great Barrier Reef.

There are serious problems with quality assurance in many areas of science, and possibly more so for Great Barrier Reef policy science. Not only are there the normal science distorting factors, such as only being able to get funding when there is a problem to be solved, there is also the problem that many marine scientists are emotionally attached to their subject. The world needs people who care for the environment; many of these scientists have signed up for a career of relative poverty to pursue marine biology. However, given these emotional pressures, together with the lack of a formal quality assurance mechanism, and documented examples of misinterpretation of calcification rates, we can be sceptical of claims that the Great Barrier Reef is in peril.

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