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

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The state of the Great Barrier Reef (GBR) is often used to show that we are facing an imminent crisis 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 be destroyed, or damaged, by humanity.

The claimed imminent peril faced by the GBR has captured the public imagination. When Barack Obama was president of the United States and visited Australia he remarked that he wanted global action on climate change so maybe his daughters had 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 GBR. A majority of the world's population seem 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 sea water temperature can cause corals to bleach (Marshall and Schuttenberg, 2006). This is when the coral expels the symbiotic algae (zooxanthellae) which live inside the individual coral polyp. The polyps are the animals, generally a few millimeters across, which 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, which it shares 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 the symbionts give the polyp its colour, the coral turns white. Without the symbionts, the polyp will run out of energy and will die within a few weeks or months unless it takes on more symbionts which float around naturally in the water surrounding the coral.

The ghastly white skeletons of bleached coral, and 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; that it is a recent phenomenon which did not occur a hundred years ago when the water temperature of the GBR was 0.5^{o}C cooler (Hughes, 2016).

Despite this apparently plausible hypothesis, I argue in this chapter that there is perhaps no ecosystem on Earth better able to cope with rising temperatures. Irrespective of one's views about the role of carbon dioxide, I will show that the GBR corals are masters of temperature adaptability, and able to cope with the modest warming that has occurred over the last century – and are also so-far unaffected by ocean acidification. There are, however, issues with how GBR science is reported, and a desperate need for some basic quality assurance.

Corals like it hot

Most of the species of coral that live on the GBR also live in much warmer water, closer to the equator around Indonesia and Thailand where water reaches 29°C. Coral growth rates are closely linked to temperature, as shown in Figure 1. The warmer water allows the coral to be more prolific and grow faster than in the GBR. Coral growth rates increase with temperature to well above the average of the GBR where the temperature ranges from an average 25.0°C in the south to 27.4°C in the north (Lough and Barnes, 2000). So for example, in the southern GBR (25°C) the corals are calcifying at half the rate of corals in Indonesia and Thailand, as shown in Figure 1. It might thus be predicted that a modest increase in temperature, of a few degrees, would allow corals to grow faster on the GBR.

Corals are essentially a tropical species and corals grow best in the hottest places. There are some regularly temperature stressed corals in Queensland. For example, in Moreton Bay near Brisbane they are stressed because the temperature gets too low in winter.

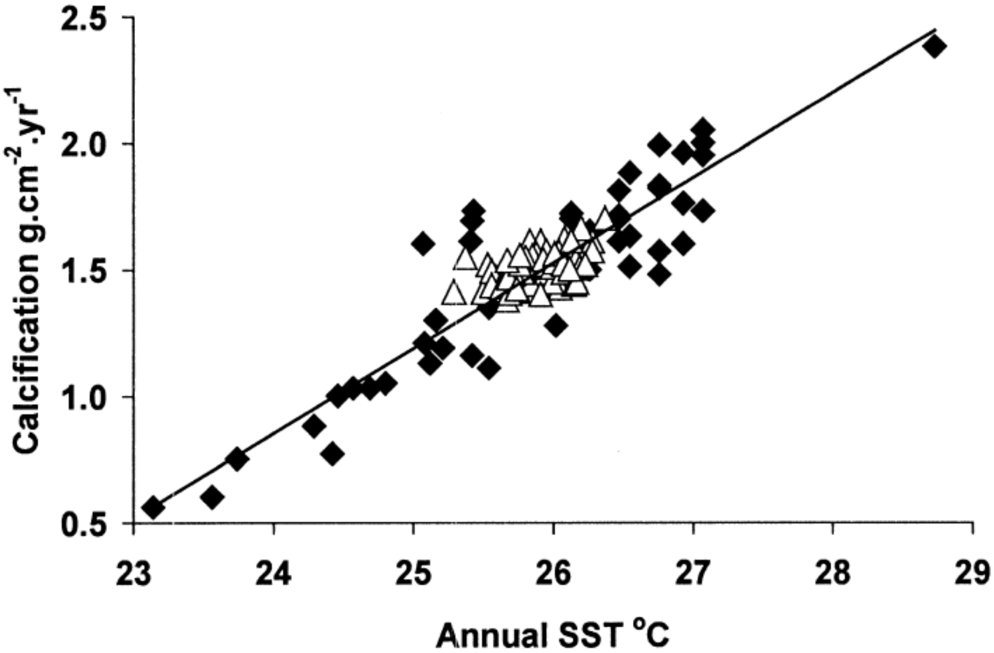

Figure 1: Average water temperature vs average calcification rate for Porites corals. (after Lough and Barnes, 2000). Corals grow faster in hotter water.

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 in 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 make the corals relatively insensitive to extreme temperatures. The corals can select the species of symbionts so that they have the ability to adapt to conditions. However, it is always a gamble with the weather - if they choose the “high octane” symbionts they could bleach, or they could choose the safe “low octane” symbionts and avoid bleaching but be out-competed by neighboring corals which might grow faster.

The relationship between the polyp and the symbiont is central to the survival mechanism of corals and is a masterpiece of adaptability. Most corals have no symbionts to start with in their larval phase, but then acquire them from the water – they select the strain of symbionts to suit. 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 can regrow over the dead coral in 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 (Guest et al. 2012). The bleaching, in effect, forces the corals to take on-board a better adapted strain of symbionts.

The important point is that for a particular species of coral, there is a variable upper temperature which they can tolerate. If these corals live in generally cooler waters of the southern GBR they may take onboard a species of symbiont which will mean they will bleach at 27 degrees. This would be suicide in Thailand but might be a good choice offshore from Gladstone, in the southern GBR.

It should be no surprise that corals have learnt 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 over this period, there is still a very good reason that a particularly coral needs to be able to deal with a variety of temperature maxima. This is because coral spawn may drift large distances before it has a chance to settle. It is thus quite possible that the progeny of a particular coral could drift hundreds of kilometers (or further) into water which could be hotter or cooler than the parent by easily two dgerees. It could also drift into shallow water where the temperature is generally hotter, or it could settle in deeper water where it is generally cooler. By simply varying the symbionts, the young corals can deal with these different temperature regimes.

Bleaching is not a new phenomenon

Bleaching is a defense mechanism of the corals and should be regarded as a strategy for survival rather than a death sentence. It generally stops them dying. Most corals that bleach fully recover (Marshall and Schuttenberg, 2006) albeit a bit shaken by the experience. A survival mechanism, such as bleaching is an indication that corals have adapted to periods of unusually high temperature in the past.

Professor Terry Hughes, a pre-eminent coral ecologist who works at James Cook University in Townville Australia, has claimed that bleaching is a new phenomenon. This professor who has been responsible for much of the publicity about the 2016 bleaching event stated on Australian national radio:

> "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 2 March 2016).

In fact, bleaching was first recorded early last century by Sir Maurice Yonge in the first major scientific study of the Great Barrier Reef (Yonge and Nicholls 1931). There are in fact "26 records of coral bleaching before 1982" (Oliver et al 2009). It was simply not until the 1960's that the phenomenon was discovered by scientists at the newly-established institutions on the GBR coast, the Australian Institute of Marine Science and James Cook University.

The long list of spurious claims

Climate change and bleaching is only one of the latest of the threats that scientists have been warning of for the GBR. In the 1960's it was claimed that the reef was being destroyed by plagues of Crown of Thorn Starfish (COTS) in a similar fashion to plagues of locusts (Pearson and 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 overfishing of triton shells which eat COTS. More recently it has been probably erroneously claimed that the nutrients in fertilizer coming from agriculture adjacent to the GBR 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, and long before marine biologists first got hold of scuba gear (Walbran et al., 1989).

It is remarkable how rapidly some scientists jumped to the conclusion that COTS outbreaks were a recent phenomenon; and the parallels between scientist's reactions to COTS and bleaching are strong. If there had been a mass bleaching event, or COTS outbreak, on the GBR in the 1930's, who would have noticed? It is possible that a few pearl or beche-de-mer divers might have, but they would hardly report the result to scientists or the world's media. In contrast to the 1930's, a bleaching or COTS event will now 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 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 GBR. The other is the mass spawning event which occurs late in the year after a full moon. Almost all the corals on the GBR spawn on one or two nights making huge floating pink-white "slicks" of eggs and sperm along the entire 2000 km length of the reef. From the air these slicks can be seen as pink-white lines, often kilometers 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 1980's (Harrison et al, 1984).

So did corals invent sexual reproduction in the early 1980's? No. It is more likely that it took a little while for scientists to discover something that many aboriginal people, fisherman and other mariners, must have witnessed repeatedly in the past. The same applies to bleaching – it is a phenomenon which has only recently been documented – not a phenomenon that has only recently occurred. It is interesting to note the different reaction of many scientists to these two discoveries. Mass coral spawning is a wonder of nature and a result of millions 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 crown of thorns starfish, 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. However, in the last 40 years we have learnt that they are also capable of rapid recovery: in a decade or so.

It is also notable that those corals species that tend to bleach are naturally short-lived species – generally the plate and staghorn corals (Marshall and Schuttenberg, 2006). These corals are very susceptible to other events such as cyclones. They perhaps have the philosophy of living fast and dying young. Pretty as they are, they are in many regards the weeds of the reef and we should not get too emotional when they get damaged by bleaching. The next cyclone will shortly spell their demise in any case.

In contrast, the "massive" corals, which grow as large solid blocks or spheres, are not easily smashed by the waves from a cyclone, or damaged by bleaching, but grow more slowly because they must lay down far more calcium carbonate skeleton. To grow perhaps 0.5 meters above the seafloor, a massive coral will have to lay down perhaps 10 to 100 times as much skeleton by mass compared with a delicate staghorn coral. These longer lived massive corals are more akin to the giant trees in temperate forests living 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 carbon dioxide is predicted to kill the coral reefs. Much has been written on the effect of carbon dioxide 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), and rising carbon dioxide concentrations will possibly reduce this to a little under eight.

Changes in pH have already been claimed to have caused a calamitous change in coral calcification rate on the GBR; a drop of 15 percent from 1990 to 2005 (De'ath et al 2009). Such claims, like so much research which supposedly shows massive decline of the GBR, was received by the world's media with much fanfare. It is, however, perhaps yet another example of research that has not been properly scrutinized, or subjected to proper quality assurance.

Like tree-rings, corals grow each year setting down a clearly identifiable layer of calcium carbonate skeleton and the thickness and density of the layers can be used to infer calcification rates. These are effectively a measure of the growth rate. Glenn De'ath and colleagues from the Australian Institute of Marine Science used cores from over 300 "massive' corals, some of which were hundreds of years old, to measure the changes in calcification over the last few hundred years (De'ath, 2009). They claimed precipitous decline in calcification since 1990, as shown in Figure 2.

I, however, have two issues with their analysis, with my concerns and alternative analysis are published in the journal Marine Geology (Ridd et al., 2013). Firstly, 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 to be much smaller than reality. This forced an apparent drop in the average calcification for the corals that were collected in the early 2000s – falsely implying a recent calcification drop. Secondly, an "age effect" was not acknowledged. When these two errors are accounted for the drop in calcification rate disappears, as shown in Figure 2.

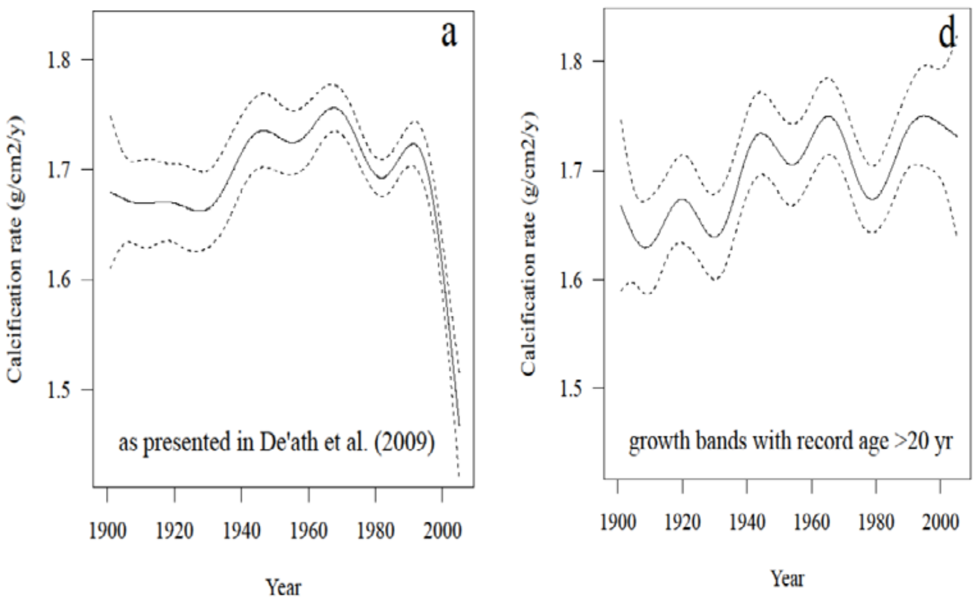

Figure 2: Coral calcification rates (left) as presented by De'ath et al (2009), and (right) corrected for errors (Ridd et al, 2013). Dotted line denote error margins.

The problem with the "age effect" mentioned above arose because the study by Dr De'ath and colleagues included data from corals sampled over 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 meters across. The second campaign occurred in the early 2000s due to increased interest in the effect of carbon dioxide. 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 centimeters in diameter. In summary, the second campaign focused on young small corals, in contrast the earlier campaign focused on old big corals. The two data sets 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

An entirely different data set of coral cores from the GBR was collected by Juan D'Olivo from the University of Western Australia (D'Olivo et al., 2013) to determine calcification rates. This study determined that there has been a 10% *increase* in calcification rate since the 1940s for offshore and mid-shelf reef, which is the location of around 99% of all the coral on the GBR. However, these researchers also measured a 5% decline in calcification rates of inshore corals, where roughly 1% of corals live very close to the coast. In summary, overall, there was an increase for most of the GBR, and a decrease for a tiny fraction of the GBR.

While it would seem reasonable to conclude that the results of D'Olivo et al. (2013) study would be reported as good news for the GBR, the actual article 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 CO2-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 2 years of the 65-year data set. 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

I was asked in this chapter 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 GBR; others include sediments, nutrients and pesticides from agriculture. I have worked on 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 which employs thousands of people whose job it is to "save the GBR". To question, as a scientist, 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 cannot any longer rely upon 'the science', or our major scientific institutions. There are major quality assurance shortcomings in the way we conduct what I will call 'policy-science', that is science which is used to inform public policy. In fact in most cases the only quality assurance measure is peer-review. Peer-review sounds impressive and I suspect the public think 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 fairly cursory read of the scientific paper, often for just a couple of hours, by perhaps two scientists. They rarely have the time to check the data properly, or to try to repeat analyses. Their main task is to make sure that the writing and diagrams are clear and that there are no obvious problems; their names are not published, they don't enter into any contract, they are not paid. Peer-review is seen as a voluntary community service – there is no real accountability.

Is this the quality assurance process that we need if we are going to spend public funds on decisions which are supposed to be based on solid science?

In contrast to government policy-science, research with an industry and medical focus typically includes some proper quality assurance. 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 them is to check and replicate the original peer reviewed research. Of concern, it is emerging 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 seem to be disastrous, but at least the checks were made to prevent the future waste of vast resources.

Policy-science concerning the GBR is almost never checked. Over the next few years, Australian governments will spend over a billion dollars on the GBR; 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 inability of drug companies to be able to replicate the original 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 and 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 up to 85% of science resources are wasted due to false or exaggerated findings in the literature (Ioannidis 2014). Professor Ioannidis focused on, amongst 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 GBR in particular? Marine biologists Mariana Duarte from the Federal University of Minas Gerais, Brazil, and Howard Browman from the Institute of Marine Research, Norway, have called for "organized skepticism" to improve the reliability of the environmental marine sciences (Duarte et al. 2015 and Browman 2016). Duarte et al. (2015) recommends that

> *"the scientific community concerned with problems in the marine ecosystem 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 GBR. I have carried out half a dozen audits on some of the research findings claiming damage to the GBR, and in every case I have discovered serious problems (Ridd, 2003; 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 GBR.

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 GBR also live in waters closer to the equator which are considerably warmer. Coral generally grow faster in warmer waters, so it should not be surprising that there has been, perhaps, a 10% increase in calcification rates at the GBR since the 1940s.

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

There are serious problems with quality assurance in many areas of science and possibly more so for GBR policy-science. Not only are there the normal science distorting factors such as only being able to get funding where 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 and 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 data, we can be skeptical of claims that the GBR is in peril.

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