Submission to Senate Inquiry

"The identification of leading practices in ensuring evidence-based regulation of farm practices that impact water quality outcomes in the Great Barrier Reef"

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Dr Peter Ridd

Dr Ridd is a recently-independent[1] scientist who has worked on the GBR since 1984 at the Australian Institute of Marine Science (AIMS) and at James Cook University (JCU). He has over 100 publications in international journals mostly relating to Great Barrier Reef and marine applications. He coinvented the first instruments capable of taking long term measurements of sediment on the Great Barrier Reef and his group has done more measurements of sediment (mud) concentrations near reefs than any other group. He has also written papers on the effects of sediment on coral reefs, sediment transport, Great Barrier Reef ocean currents, temperature distribution, coral growth rates, coral cover, nutrient fluxes, effects of dredging, pollution potential of the GBR and many other topics. Most recently he has worked on Quality Assurance systems to further improve reliability of scientific evidence.

Through JCU, Dr Ridd ran a very successful commercial consulting operation (Marine Geophysical Laboratory). Services included monitoring of dredge operations close to coral reefs and technological development of commercial instrumentation for applications in oceanography, mining, and agricultural robotics.

Dr Ridd has not received any salary from the oil, coal, sugar, beef or tobacco interests, as often accused. While he worked at JCU and AIMS, all his salary and research funding was directed through those institutions – he did not receive anything but his regular institutional salary.

Dr Ridd is now working, without payment, to improve Quality Assurance systems in science.

[1] Dr Ridd was fired by James Cook University in 2018 after stating that two GBR science institutions are producing results that are untrustworthy due to insufficient quality assurance protocols.

Executive Summary

The Water Quality of the Great Barrier Reef (GBR).

Water surrounding the Great Barrier Reef is as pristine and sparkling blue as the Pacific Ocean due to massive ocean currents that sweep into and out of the Reef. These currents mean pollution from land cannot build up in the Reef. As much water flows into the Reef from the Pacific Ocean in eight hours as comes down all the rivers in a whole year. Reef water quality is determined by these enormous "rivers" of clean ocean water – not by the rivers flowing from land.

Only a very small part of the Great Barrier Reef falls under any direct influence of farm runoff

The Great Barrier Reef is a long way from the coast and almost totally unaffected by mud and pesticides from farms. Science institutions focus on the effect of agriculture on "Inshore" reefs. These are the fringing reefs close to shore not the GBR-proper, which is generally 40-100 km from the coast. The Inshore Reefs are only about 1 or 2% of the coral, a point never made by science institutions claiming agriculture is killing the GBR. Even the Inshore Reefs are only marginally affected by farm runoff.

Sediment from farms.

- Sediment from farm runoff generally does not reach the GBR where about 99% of the coral lives. On very rare occasions, perhaps for a few days in many years, a few of the 3000 reefs of the GBR are affected by very small concentrations of sediment. The risk, if any, is thus restricted to the tiny area of Inshore Reefs.
- For the Inshore Reefs, the churning of the muddy seabed by waves is the primary exposure of coral to mud. River plumes are a very minor factor. Many of these inshore regions have always been muddy due to mud deposited over millennia.

Pesticides.

- Science institutions almost never bother to measure pesticides on the GBR as they are generally undetectable even with the most sensitive scientific equipment. This is because the GBR water is well flushed by water from the Pacific Ocean.
- For the Inshore Reefs (1-2% of the coral), most pesticides are not detected. Very occasionally, and only for a few of the inshore coral patches very close to river mouths, do pesticides even occasionally reach concentrations that could cause even a very minor impact.

Fertilizer/nutrients.

- Science organisations claim that fertilizer from farms causes Crown of Thorns Starfish (COTS) plagues. However, the evidence for this is extremely weak and ignores the fact that plagues occur in regions well away from agriculture.
- The geological evidence indicates that COTS plagues have been around for millennia and there is little good reason to suspect they are worse now than before European settlement.

Reliability of Science Institutions.

- For many disciplines of science, it is regularly found that much of the peer reviewed literature, perhaps half, has serious flaws. This statement is uncontroversial and is accepted by most of the major national academies of science. It is called the “Replication Crisis”. GBR science is not exempt from this general problem.
- Even Dr Finkel, Australia’s Chief Scientist, accepts there are problems with the general scientific literature.
- The main system of scientific quality assurance, review by peers, is deficient in many ways not least being that it almost guarantees groupthink, and can often exclude views from dissenting scientist.
- Major errors in work coming from GBR scientific institutions have been identified and there is a general reluctance of the institutions to rectify problems. They are in denial about their serious deficiency of Quality Assurance protocols. In some cases, they actively cover up problems, and vilify or exclude those who raise concerns.
- There is thus considerable doubt that our GBR science institutions are providing reliable scientific evidence. This certainly does not imply all their work is wrong, but we cannot conclude that most individual parts of the scientific evidence, or the “consensus” documents, are reliable.

The Solution

There is thus serious concern that much of the evidence claiming adverse effects of agriculture on the GBR is highly questionable. There needs to be a thorough audit conducted by a group of independent scientists not attached to government institutions working on the GBR.

Noting that (a) The GBR is too precious to tolerate any significant damage, and (b) every major industry in Northern Queensland, including agriculture, is affected by regulations relating to the GBR, it is proposed that a full audit of the evidence relating to the potential effect of agriculture be carried out. It is estimated that this could be done for less than $5 million, about 1% of funds presently being spent on the Reef, and take less than 2 years. Governments would be in a better position to make decisions on a more solid science base.

Geography of the Great Barrier Reef.

The Great Barrier Reef (GBR) is not just one reef. It is 3000 individual coral reefs and it is huge – covering approximately the same area as Victoria or Germany. Each reef is usually a few kilometers across and separated from its neighboring reef by between a few hundred meters to 10 km (see figure 1). Importantly, from the point of view of nature conservation, most of the reefs are far off shore – over 100 km in the southern zone. The adjacent coast, for the whole of the 2,300 km length of the GBR, has a very low population – perhaps a little over half a million people. For the northern section of the GBR, along an almost 1,000 km length of coastline, the total human population is only a few thousand. Compare this with the Caribbean Reefs which have similar extent – there are perhaps 50 million people living nearby, roughly 100 times more than the number living near the GBR. The GBR is one of the most remote, unpopulated, untouched and unspoiled areas on earth.

The Inshore Reefs

Although most of the coral on the Queensland coast is on the GBR, there are also fringing or inshore reefs. Strictly, these are not part of the Great Barrier Reef (they do not form part of the "barrier") but they are nevertheless important in their own right. Almost all the risk to the GBR caused by sediment and pesticides washing off farms can be only associated to these Inshore Reefs, so they are the frontline when it comes to the effects of agriculture. The "Offshore" or "Midshelf" reefs are too far away.

In many of the major management documents about the GBR, such as the 2017 Consensus statement, the Inshore Reefs figure prominently as being affected by agriculture. The problem is that the name, "Inshore Great Barrier Reef", implies that these reefs are a major part of the GBR. But compared with the rest of the GBR, the Inshore Reefs are tiny. I estimate that those close to regions affected by agriculture are at most about 1-2% of all the coral on the GBR. Of course, all coral is important but it is important that the public gets the correct impression about how much of the GBR is affected by various stresses and the term "Inshore GBR" can give an impression that perhaps half the GBR is affected. In later parts of this submission, I will produce evidence that not even this 1-2% of the GBR is seriously affected by agriculture.

It is also important to note that the Inshore Reefs have evolved over millennia to high concentrations of sediment and nutrients. The Inshore Reefs are often mediocre in appearance when compared with the GBR-proper. For example, Paluma Shoals (figure 2 and 3) is an Inshore Reef surrounded by water with a relatively muddy bottom and during periods of strong winds, the waves stir up the sea-bed producing very dirty water. The geological evidence indicates that these reefs have always been very muddy since long before European settlement.

The conditions for corals on the Inshore Reefs are more difficult than on the GBR-proper and give some indication of the robustness of coral ecosystems. The coral species on the Inshore Reefs are often very different from the GBR as they have to be tolerant to lots of mud. They also have to deal with hotter water in summer and colder water in winter because the shallowness of the water allows much greater temperature swings to occur.

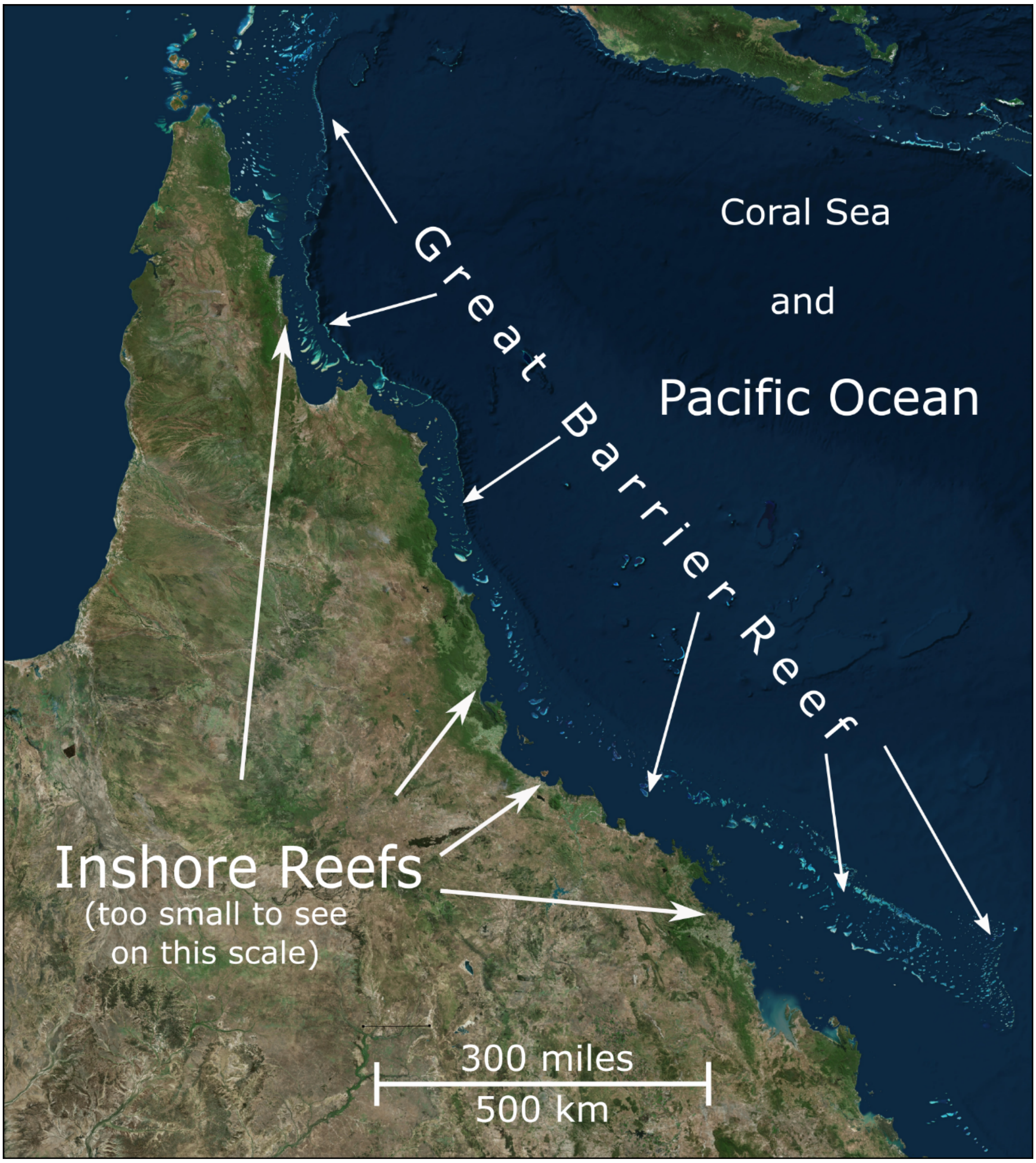

Figure 1: The Great Barrier Reef. It mostly a long way from the coast – about 100 km in the south. The Inshore fringing reefs are extremely small – too small to see on a picture of this scale unlike the 3000 GBR reefs. It is often claimed that sediment and pesticides from agriculture is killing the inshore reefs. Those at any risk from agriculture represent at most 1-2% of the coral. (Image J. Vlok)

Most importantly the Inshore Reefs can be affected by freshwater from river plumes - and freshwater is lethal to corals.

If nothing else, the Inshore Reefs demonstrate that corals are not like a "canary in a coalmine" that will die under the most modest change to their conditions. They form robust ecosystems that can live under apparently very adverse conditions.

Figure 2 Paluma Shoals. A very mediocre inshore reef north of Townsville. It is not the place to take tourists but it is a heathy reef and some parts have very high coral cover. Biologists often claim that reefs and shoals like this have been damaged by mud from farms and dredging, but the geology tells us they were always dirty reefs. (Photo: P Larcombe)

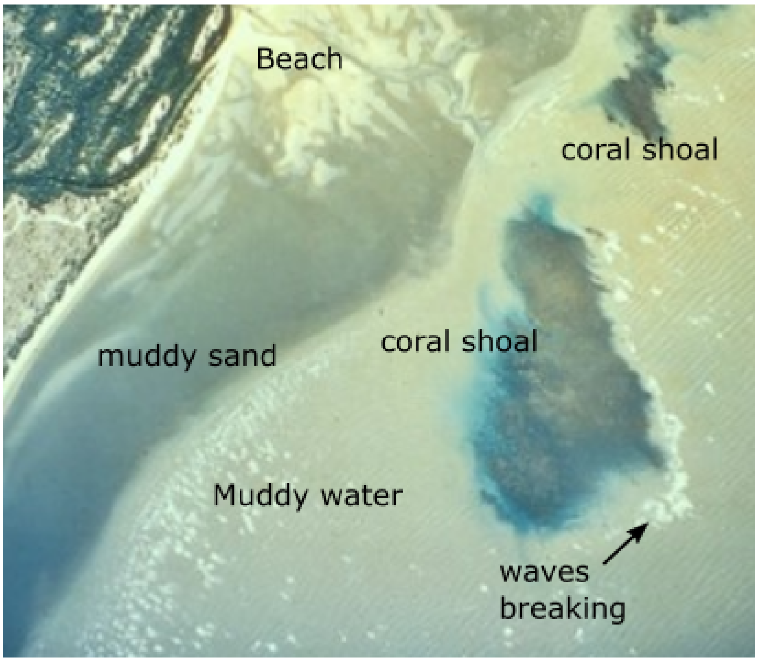

Figure 3:. Paluma Shoals viewed from the air. It is totally surrounded by muddy water caused by waves stirring the sea bed. But it is a very healthy reef system.

Coral death on the GBR is usually spectacular and makes big headlines.

A notable feature of the GBR is that the coral often dies in spectacular events, but invariably regrows very quietly. An area the size of a small European country can be wiped out overnight by a cyclone. Coral bleaching from an unusually warm summer can destroy near-surface corals over similarly sized areas in a few weeks. Occasionally starfish plagues eating the coral take a little longer, but the damage is spectacular and widespread. Freshwater plumes from major floods can also kill inshore coral. All these spectacular events of coral loss are entirely natural - and temporary.

The spectacular death of the corals makes good newspaper headlines, which have been repeating themselves for the last 50 years since scientists started studying the GBR in significant numbers. The unobtrusive recovery that has always occurred over the following decade is less well documented in the media. Science organizations have not helped this situation by failing to point out that recovery in past events has always been so strong that previous damage rapidly becomes invisible. It seems that the science organizations make the most of major coral mortality events to make the case to the public that the GBR is in dire peril.

Study of the GBR started very recently.

Spectacular corals death might make it easy to convince the world that the GBR is in trouble, but it is even more powerful if you can claim that "*it never happened before 1960*". For the GBR we knew almost nothing before 1960, when GBR research started, so it is easy to say that this spectacular death was unknown before the 1960s. To then claim it must be caused by humans is generally a statement based upon ignorance.

Crown of Thorns Starfish plagues, were the first big scare where the world was told that the GBR was facing a dire future. Plagues were first blamed by scientists on the harvesting of triton shells but blame shifted against farmers in the 1980s. The world was told that these plagues never occurred before the 1960's and that they must have been caused by humans. But the question must be asked, if a starfish outbreak occurred in 1920 who would have observed it, and would they have reported the fact? To whom would they have reported, as nobody was interested before scientists started to study the reef in the 1960s.

It is very notable that there are three very spectacular types of event that occur with regularity on the GBR and they have all been discovered to science only very recently. These are

(a) starfish plagues killing coral, discovered in the 1960's,

(b) mass coral bleaching events killing coral by hot water, discovered in the 1970's, and

(c) mass coral spawning events reproducing coral, discovered in the 1980's.

This latter event is where virtually every coral on the GBR simultaneously releases eggs forming massive slicks of pinky-white material that float on the water surface. These slicks are so big that they can easily be seen from aircraft and in satellite images.

Scientist are totally inconsistent in how they view these three events. The mass death events (the starfish plagues and mass bleaching) are blamed on humans but the mass reproduction event is deemed (correctly) to be a wonder of nature. If scientists were to be consistent in their argument, they would have to claim that mass coral reproduction never occurred before 1980. This is obviously ridiculous, but no more implausible than the proposition that mass coral death never occurred before 1960. Apparently, scientists accept that corals reproduced but never died before 1960. In reality, we did not know almost anything about the GBR before 1960 except from what the geological evidence tells us[2] – not even these massive events which would have undoubtedly been well known to early European fisherman and Indigenous people.

Science organisations should refrain from invoking doom scenarios, which are also extremely implausible, in the absence of any data.

Vital Statistics: Coral Cover, Coral Growth Rate and Crown of Thorns Starfish numbers.

Although we are often told by science organisations that the GBR is in great peril, the vital statistics would indicate otherwise. Here I will consider coral cover, coral growth rates and Crown of Thorns Starfish numbers.

Coral Cover: Coral cover is the fraction of the reef covered by coral and has been measured at the Australian Institute of Marine Science since 1985. The data has been collected in a very consistent and well quality assured method since the early 1990's[3] and from that date should be considered as a jewel of GBR data (Figure 4). Although there have been major fluctuations with time, the coral cover is roughly the same today as it has been over the last 25 years. The major reduction in coral cover around 2011 was mainly the result of a major cyclone (TC Hamish) but it should be noted that the reef recovered quickly and very strongly indicating a very robust system. For example, there was a 250% increase in coral cover in the southern region between 2011 and 2016.

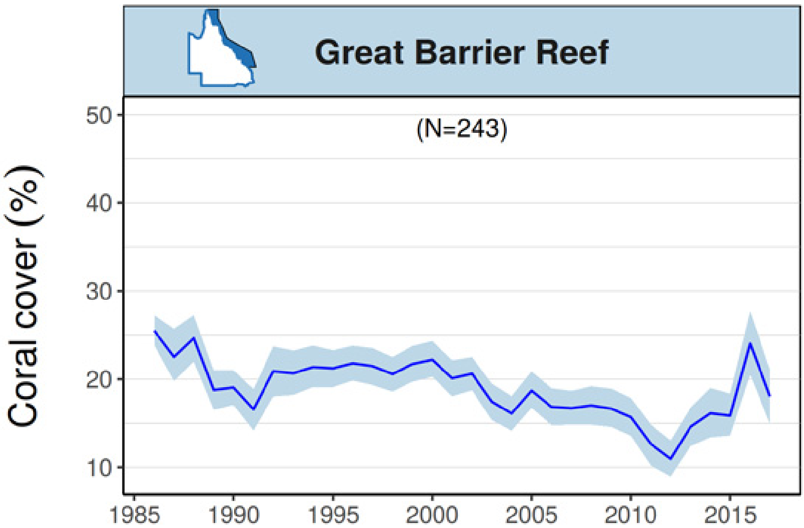

Figure 4: Coral cover on the GBR: Note since 2016 AIMS does not publish the aggregate coral cover for the entire GBR -just the results for each of the three major regions. (source AIMS)

The large fluctuations in coral cover, and the inevitable periods of lower cover, are used by science organisations to great effect to claim that the reef is in poor condition. For example, there were major news headlines following the release of a paper by De'ath *et al*. (2012) when

[2] There is good evidence that Crown of Thorns Starfish Plagues were very common over the millennia. (Walbran *et al*., 1989)

[3] There is some question about the earlier data.

the coral cover hit a record low. However, no similar fanfare occurred with the recovery by 2016. History has repeated itself with the very recent publication (Ceccarelli *et al*., 2019) of a paper showing that Inshore Reefs have hit a record low coral cover since records began less than 20 years ago – almost entirely due to cyclones.[4] With a system that is fluctuating dramatically, and a short period of data, science organisations should be more cautious about claiming long term declines have occurred.

Crown of Thorns Starfish (COTS): Plagues of COTS eat large amounts of coral, sometimes totally decimating individual reefs. Figure 5 shows that COTS numbers have fluctuated dramatically. There is no evidence of a growing trend in COTS numbers.

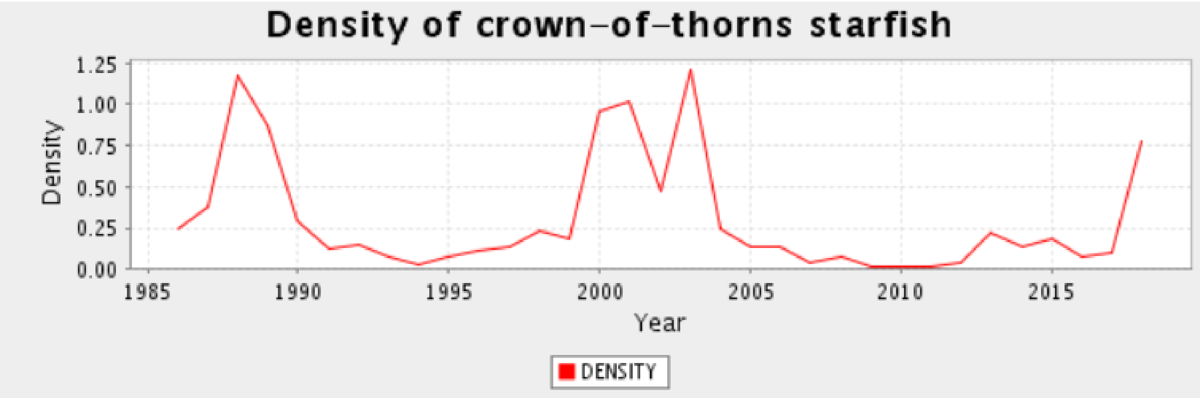

Figure 5: Crown of Thorns starfish numbers. They fluctuate dramatically and are no worse than when records began. The density is defined as the number of starfish per 130 m transect across the reef (Source AIMS)

Coral Growth Rate: Coral Growth rate has been measured in two major studies. The study by D'Olivo *et al*. (2013) showed that for the GBR-proper, there was an increase in coral growth rate of about 10% since the 1940's. The other study was done by De'ath et al. (2009) who found that coral growth rates had slowed by 15%. However, this study was later corrected by Ridd et al (2013) who found that the growth rates have if anything increased in the last 100 years (figure 6) as found by D'Olivo *et al* (2013) (Note this disputed data is referred to later in this submission).

[4] It should also be noted that this data shows that on many of these inshore reefs coral cover is often extremely high, much higher than on the GBR, which is far further from the coast and agricultural influence. This indicates that agriculture is not having a major impact on the inshore reefs, and that despite living in what are often considered to be marginal conditions, the inshore reefs are thriving.

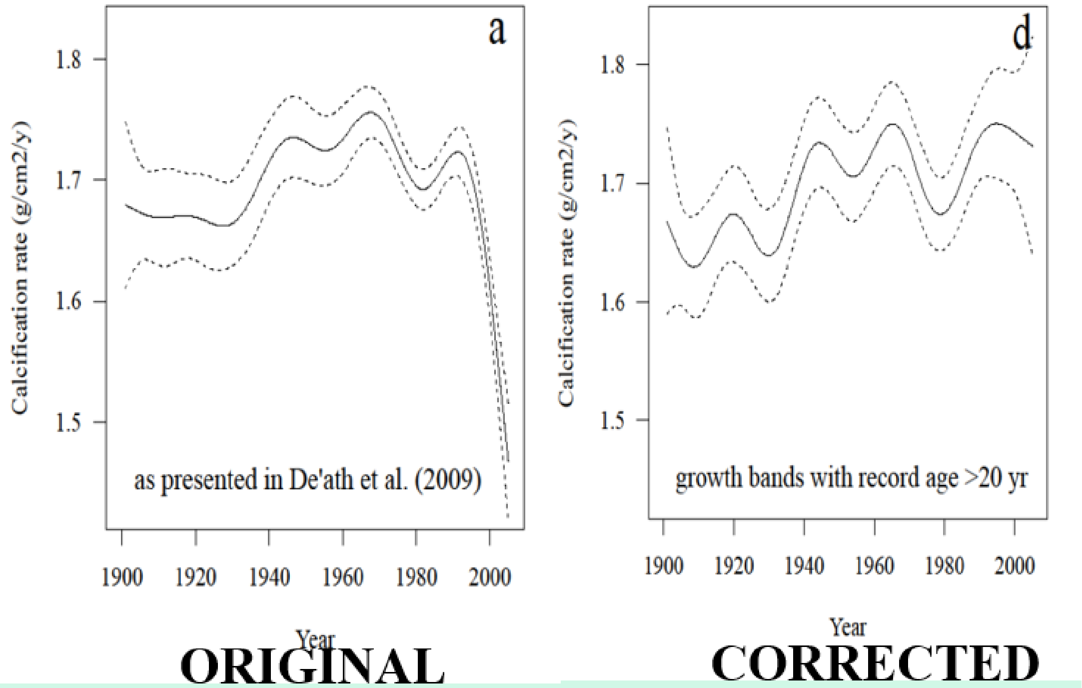

Figure 6: Coral growth rates (calcification) since 1900. The graph on the left is the original analysis from AIMS (De'ath *et al.*, 2009)). The right-hand graph is the analysis as corrected by Ridd *et al.* (2013). Note this disagreement has not been resolved by AIMS despite a simple experiment being suggested that would resolve the issue[5].

Common questionable claims about the GBR.

In this section I address 10 questionable claims about damage to the GBR. Not all relate directly to agriculture but all are important to the issue of the general quality of the scientific evidence and quality assurance systems being used to inform government policy on the GBR. A version of these 10 claims were published in the media in August 2019. It is notable that the Australian Coral Reef Society (ACRS) responded and did not dispute most of the questionable claims[6]. A detailed analysis of the ACRS response can be found in Appendix A.

Questionable Claim 1: The reef is being smothered by mud/sediment from farms.

In fact: It has been known for half a century that there is virtually no mud/sediment from the land that reaches the GBR-proper which is mostly over 50 km from the coast (Maxwell and Swinchatt, 1970; Hopley *et al*., 2007). The sand on the reefs are pristine white sand made from ancient pieces of broken coral (see figure 7 of Lodestone reef as an example). If there is almost no land-derived mud on these reefs, to claim they are affected by farm mud is totally unsupported by the evidence.

[5] This point is discussed later in this submission.
[6] https://australiancoralreefsociety.org/wp-content/uploads/Ridd-questionable-claims-statement.pdf

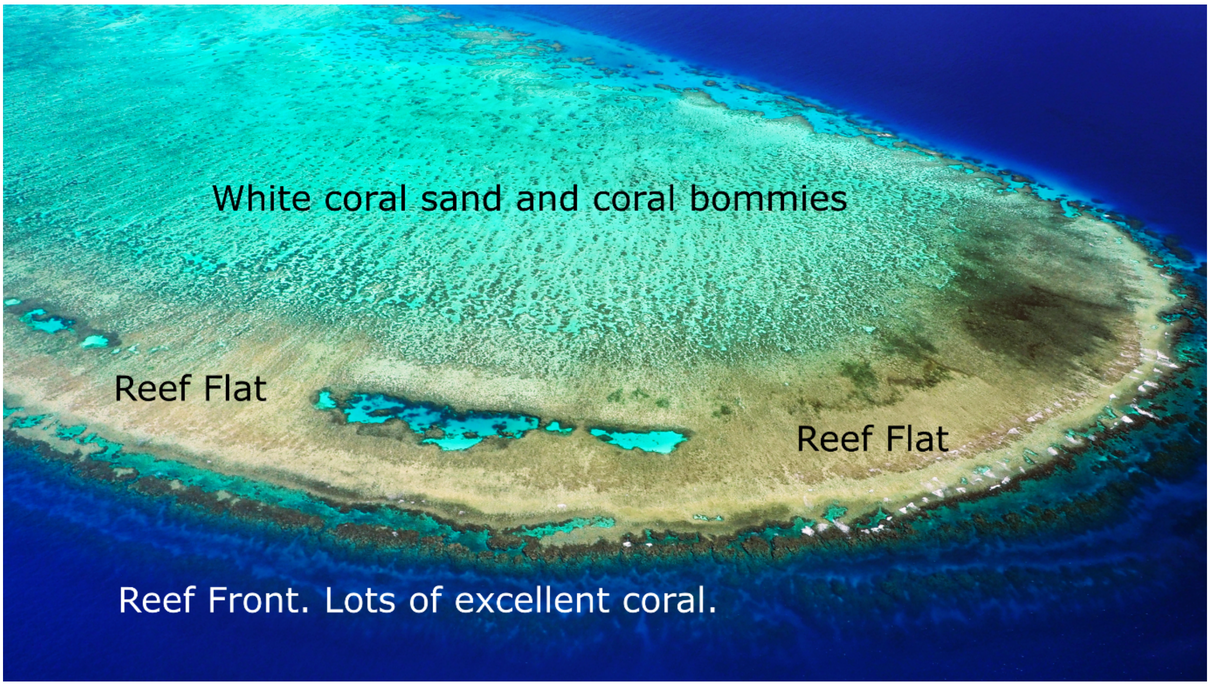

Figure 7: Lodestone Reef showing the white coral sand made almost entirely of broken coral and other organisms. There is almost no mud whatsoever from the land on the GBR so it is inconceivable that they are affected by sediment from farms. This fact seems to be undisputed by most science organisations. (Picture Shutterstock)

Even the Inshore Reefs close to the coast, which are not part of the Great Barrier Reef and only have about 1-2% of the coral, are unaffected by mud from the land. These Inshore Reefs are often naturally very muddy and well adapted to such conditions. They are surrounded by sediment that has been deposited over the last few thousand years and waves caused by strong winds stir the seabed and produce muddy water. Geological evidence indicates this has always occurred (Orpin and Ridd, 2012), and any extra affect from farming is so small that it is unmeasurable. Waves cause far higher concentrations of mud in the water, and for much longer periods, than river plumes for most of the Inshore Reefs (Fabricius *et al*., 2013).

Figures 8 and 9 show the muddy water caused by strong wind which produces large waves that churn-up the sea bed. Waves suspend sediment that has been on the sea bed for thousands of years. In many regions this mud is many meters thick on the sea bed and a little extra mud from recent river discharge makes very little difference.

The completely natural effect of wave resuspension causing muddy water around Inshore Reefs is a finding that has been replicated in literally hundreds of instrument records, which total millions of measurements, from multiple scientists over the last 25 years. It is a very solid piece of scientific evidence and demonstrates that our naturally muddy Inshore Reefs are highly tolerant of sediment and that the effect of river plumes is minimal.

Figure 8: The inshore water near the Port of Townsville showing muddy water due to waves. Coral reefs live just to the right of the picture. (Picture: PoTL)

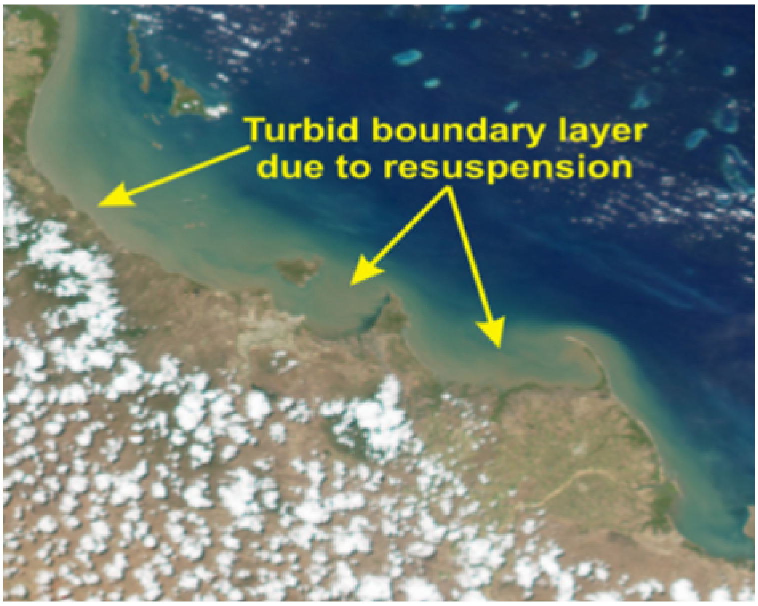

Figure 9 The muddy inshore water from the Burdekin Delta to the Herbert Rive mouth. Waves from strong winds are stirring the muddy seabed close to shore. This muddy inshore water occurs every couple of weeks and has very high concentrations of sediment.

In contrast, it has been claimed that during years with large river floods, the water clarity is slightly reduced for many months after the floods (Fabricius *et al*., 2014). This point featured prominently in the 2017 Science Consensus Statement even though it is a single paper which has not been subjected to rigorous audit or replication studies. In contrast, the massive body of evidence showing the primacy of wave resuspension is almost ignored in the consensus statement.

Questionable Claim 2: Plumes of farm mud carried in river floods are killing the reef.

In Fact: Plumes of river floodwater rarely reach the Great Barrier Reef. When they do, such as in early 2019 after the Townsville floods, they only reached a handful of the 3000 reefs for a few days (figure 10). Those reefs are unlikely to see another flood plume for many years or even a decade. In addition, by the time the flood water reaches the GBR, almost all the mud has dropped out of suspension as seen in (figure 10). After the mud settles, the water may remain discoloured due to leaf tannins (similar to tea) – it is naturally occurring, organic and harmless and does not settle on the reef.

Despite this, on the extremely rare occasions that plumes reach the GBR, science organisations can be almost guaranteed to make media statements showing graphic images of the plume without pointing out that it almost never occurs and never show how quickly the plumes disappear.

Figure 10: A very well publicised[7] example of a very rare occurrence of a river plume reaching the GBR. The main muddy area never reached the reef but slightly turbid water affected a few of the 3000 reefs of the GBR, with very low concentrations for a few days - so it barely affects the GBR. It is an event that may not recur for many years into the future. Satellite pictures which are taken every day demonstrate that the GBR is almost totally unaffected by sediment. Science organisations erroneously try to demonstrate the opposite by focusing on the short-lived brown plume.

[7] https://www.abc.net.au/news/2019-02-15/great-barrier-reef-muddy-flood-plume-fears/10812910

Questionable Claim 3: Fertilizer is causing Crown of Thorns Starfish plagues that eat coral.

In Fact: It is claimed that fertilizer from farms supplies food for the larvae of the coral-eating starfish. Up until about 1990, starfish plagues were attributed to harvesting of Triton shells but are now blamed on fertilizer from farm run-off. However, the experts on starfish plagues have stated that the link between farm fertilizer and starfish plagues is "unresolved" (Pratchett *et al.*, 2017). It is notable that the most prolonged starfish plagues have been in the Swains Reefs[8] which are the most distant from the coast (150 km) and completely unaffected by runoff from the land.

Questionable Claim 4: Crown of Thorns Starfish plagues are unnatural.

In Fact: Crown of Thorns Starfish are a native species and are as Australian as kangaroos and koalas. They are not a feral animal like cane toads or rabbits. Geological evidence indicates they reached plague proportions for thousands of years before European settlement (Walbran *et al*., 1989).

Questionable Claim 5: Pesticides from farms are killing the reef.

In Fact: Pesticides are in such small concentrations that in the ocean close to the coast they are mostly undetectable with the most sensitive scientific equipment (Gallen *et al*., 2014). Only very occasionally do they reach levels that would have even a very slight effect on corals, and only for a very few of the inshore reefs extremely close to river mouths, such as Round Top Island near the Pioneer River. Further offshore on the GBR-proper, scientists rarely try to measure pesticides because concentrations are far too low. Pesticides are utterly irrelevant to 99% of the GBR and are only a very tiny influence on a very small part of the Inshore reefs which are in total only 1-2% of the total coral.

Questionable Claim 6: Pharmaceuticals from human waste is a "medium" risk to the reef.

In Fact: Scientists claim that medical drugs that pass through the body into the sewage system are a "medium risk" to the reef (Kroon *et al*., 2015). Although this does not concern agriculture, I include this claim because it demonstrates how poor is the commitment to scientific quality of GBR science organisations. It might be assumed that this claim was based on actual measurements of various pharmaceuticals on the GBR itself. However, none of the measurements were taken on the reef, almost all were taken on the outlet pipe of sewage treatment plants and even these levels were very low. No account was taken of the massive dilution that occurs between the coast and the reefs that are generally about 50 km from the coast.

The conclusion that pharmaceuticals are a medium risk to the GBR is completely unfounded and indicative of a predilection to doom scenarios for the GBR, and hopeless quality assurance systems in science institutions.

[8] https://eatlas.org.au/content/crown-thorns-starfish-outbreaks-animation

Questionable Claim 7: The water quality around reefs is degraded.

In Fact: The water that surrounds the Great Barrier Reef is as pure and sparkling blue as the Pacific Ocean that surrounds it. The exchange of water between the GBR and the Pacific Ocean means that the water around the GBR is flushed out within a few weeks (Choukroun *et al.*, 2010). The same amount of ocean water comes into, and out of, the reef in 8 hours as come from all the rivers on the Queensland coast in a whole year. The water quality of the reefs is determined by the Pacific Ocean not the rivers and farms (Larcombe and Ridd, 2018).

It is notable that the effect of the Pacific water flushing into the GBR waters is not appreciated in the 2017 GBR consensus statement. But this one fact alone, extinguishes many claims of risk, danger or damage caused by run-off from the land along the entire coastline adjacent to the GBR.

Questionable Claim 8: Coral cover has declined

In Fact: Since reliable measurements began in the mid 1980s, the amount of coral on the reef has fluctuated but is about the same today as when monitoring started.

There have been periods when there has been a major loss of coral, for example in the central and southern zones around 2011 after major cyclones, and much has been made of this temporary decline by science organisations. For example, the Australian Coral Reef Society made this point in August 2019[9]. However, the total recovery of the coral cover between 2011 and 2016 was not mentioned at all.

Similarly, a recent paper (Ceccarelli *et al.*, 2019) has claimed that there has been a significant reduction in coral cover on Inshore Reefs since measurements started a little less than 20 years ago. But it is very likely that this decline is short-lived as many of these reefs have recently been affected by major cyclones.

Questionable Claim 9: Coral growth rates have slowed

In Fact: Coral growth rates have not fallen and, if anything, have probably marginally increased in the last century. See figure 6. (D'Olivo *et al.*, 2013; Ridd *et al.*, 2013)

Questionable Claim 10: Coral does not recover from mass mortality events such as cyclones and bleaching

In Fact: Although there have been many occasions where large quantities of coral have been killed from cyclones, crown of thorns starfish plagues and bleaching, in every case the reef has recovered strongly and rapidly. These events are like bushfires on land - they look terrible but are perfectly natural and recovery is swift. For example, as mentioned previously the southern

[9] https://australiancoralreefsociety.org/wp-content/uploads/Ridd-questionable-claims-statement.pdf

third of the reef increased coral cover by 250% from 2010 to2016 after being badly damaged by a major Cyclone Hamish.[10]

How much of the GBR has been killed by agriculture? Two unanswered questions.

(1) How much coral has been killed by farm sediment?
(2) How much coral has been killed by pesticides?

On these fundamental questions the science literature, including the 2017 Science Consensus Statement, is silent. Our science organisations do not even attempt an answer, but claim that agriculture must be greatly restricted and regulated.

The reason is simple enough – for sediment and pesticides the amount of coral lost is either zero or so close to zero as to be unmeasurable. For example, there is no instance where we can say with any certainty that a reef was degraded by sediment from the land let alone killed. After all, one can hardly find any sediment from the land on the GBR. Even for the naturally turbid (muddy) Inshore Reefs, with only 1-2% of the coral, there are no examples of significant areas of coral that have been permanently damaged by extra sediment from the land or from dredging.

Of course, there are plenty of examples where coral cover has temporarily collapsed, mostly due to cyclones and Crown of Thorns Starfish, and to a lesser extent bleaching. When they die, they do it in spectacular fashion, but they keep bouncing back because these cycles of growth and destruction are natural.

Death by a Thousand Cuts, Chronic Effects and Tipping Points

In order to make the case that agriculture is killing the reef in the absence of actual coral loss, the concepts of Death by a Thousand Cuts (DBATC), Chronic Effects and Tipping Points are invoked. These arguments are generally invoked in an unscientific way and mean that farmers can never prove they are having no effect on the GBR unless they cease operation altogether.

A Tipping Point is where the GBR might suddenly collapse under all the pressures from the combination of all the stresses put together. It proposes that the reef will remain in apparently good condition, but is actually stressed, until a point is reached when it rapidly tips over and collapses. It presumes that the reef is an extremely delicate and unstable system like a house-of-cards. When it is ready to tip, it still looks fine but the slightest push and it falls over. There is no evidence for this proposition.

The concept of Death by a Thousand Cuts is part of the Tipping Point argument and is very convenient because it does not matter how inconsequential and unmeasurable are each of the "cuts" – if you have enough of them, the system will supposedly collapse. In addition, it does not matter how small the effect of a particular stress is - it is still important as it might be the last thing that pushes the GBR over the Tipping Point. It means that farmers can always be accused of threatening the reef no matter how small their impact is.

[10] https://www.aims.gov.au/reef-monitoring/gbr-condition-summary-2017-2018

Examples of this thinking can often be found in the GBR science literature. For example, although pesticides, are generally undetectable, it is claimed that the "*compound effects of simultaneous stressors*" is the problem (Gallen *et al*. 2014). Once added to the other insignificant effects, pesticides somehow become a problem. In another example from the 2017 Scientific Consensus Statement, they identify that one of the major knowledge gaps was quantification of

> *tolerance thresholds and tipping points in key seagrass and coral reef species under exposure to single and multiple pressures from water quality, climate change and ocean and coastal acidification*;

Unfortunately, despite its appeal and apparently reasonable nature, the Death By A Thousand Cuts concept is flawed because it is impossible to counter. Any argument that cannot be falsified (or be disprovable) must be viewed with great caution as it is not science. It is virtually impossible to prove a negative, i.e. to prove that a specific factor **isn't** a problem. Essentially the question must be asked "how small must the proven damage from a particular stressor be before it is not considered to be a 'cut' which could send the GBR over the edge of a Tipping Point?" Without quantitative knowledge of the contribution of the effect of each stressor, the ultimate conclusion of the DBATC argument is that only zero effect from a particular stressor can be tolerated. In other words, every improbable threat must be considered and is important. This implicitly prevents discussion of what level of 'stress' is tolerable.

This is not a practically or useful conclusion. **It means for example that farmers can never reduce their fertilizer runoff to a low enough value to solve the problems claimed by science institutions.** Only closing down the farms and reducing the impact from its present insignificance to absolutely zero will satisfy the scientists. After all the effect of their pesticide use is unmeasurable on the GBR reef but the farmers are still blamed. They have no possibility of redemption unless they close down completely.

The Tipping Point argument, applied to the GBR, has other problems, less philosophical in nature. All the evidence from reefs around the world is that they are not fragile and can survive massive abuse without tipping into oblivion. I should point out that I am not making an argument that it is acceptable to abuse reefs just because they are robust. I would hate to see anything like the pressure that is applied to Caribbean reefs to occur on the GBR. But it does seem, as shown below, that the relatively pristine GBR is a long way from any tipping point.

The Caribbean reefs are very roughly the same size as the GBR but has a population of around 50 million people, and supports a large fishery where every small fish is fair game for the fishermen, and where the reefs are often very close to shore and frequently visited by people. There is huge people-pressure on Caribbean reefs. In contrast, the GBR has a population of a little over 0.5 million living adjacent to it, there is minimal fishing pressure especially of the small herbivorous fish which are so important to the coral reefs as they eat algae that compete with corals. In addition, the GBR is mostly a long way from the coast and rarely visited. Although the Caribbean reefs are apparently highly degraded, they are still mostly functioning coral reefs. Most have not yet tipped over the Tipping Point, but they are degraded and some may be approaching a tipping point. We certainly do not want the GBR reef system to approach the state of some of the Caribbean reefs, but if the Caribbean has not tipped over, then the GBR is nowhere near a tipping point.

Comparing the GBR with the Inshore Reefs also shows that the GBR cannot be near a tipping point. The Inshore Reefs live in conditions that are far from the classical blue water of the GBR. They live in dirty water where light can be extinguished for weeks. The nutrient concentrations can be ten times higher due to waves, and the temperature fluctuations are much greater than the GBR. It would not be unusual for the inshore reefs to be a degree or two hotter in summer, and a degree of two colder in winter. And yet despite these difficult conditions, Inshore Reefs thrive with often very high coral cover – often much higher than the GBR. The factor that limits inshore coral most is finding a suitable substrate on which to form. The GBR lives in conditions far more suitable for coral than the Inshore Reefs, but the Inshore Reefs have not tipped over so the GBR must be nowhere near a tipping point.

A little consideration of the recent history of the GBR also tells us that it is not close to a tipping point or particularly fragile. It started to reform after the last ice age 20,000 years ago under drastically changing conditions as the sea-level started its 120 m rise. Sea level rose sufficiently fast that coastlines were eroding by tens of metres per year in many locations, releasing large quantities of sediment into the GBR waters over thousands of years. Temperatures were also rising and peaked at around a degree hotter than today about 5,000 years ago when the sea-level was about 1 m higher than today. The GBR thrived under conditions which by today's standards would be considered to be stressing the corals

We must conclude that the GBR is nowhere near a tipping point and science organisations should stop invoking this concept against agricultural activity. There is no evidence to support it.

Replication Crisis: There is a well-recognised problem with our government funded science institutions generally.

The Replication Crisis is the term that describes the realisation that a very large part of the scientific literature, perhaps half, is flawed (Ioannidis, 2005; Larcombe and Ridd, 2018 and 2019). It is a remarkable statistic, and is a well-accepted fact. Even Australia's Chief Scientist Alan Finkel is concerned[11]. It has been a major topic of discussion for 5 years in all the big-name science journals and within many of the science national science institutions. I am still amazed that the media, who love a bad news story, do not seem to have woken up to the replication crisis which would be better termed a replication scandal. What other profession has such a huge failure rate?

Replication is fundamental to science. If the research cannot be repeated by another scientist, then there is a problem. If multiple attempts to replicate fail, then the original work must be regarded as wrong. If multiple attempts to replicate succeed, then one can start to rely on the work. Many areas of science are massively replicated and are utterly reliable. For example, we rely upon Newton's laws of motion and gravitation every day when we drive in a car, walk across a bridge, or fly in a plane. Einstein's laws of relativity are tested every time we use the

[11] https://theconversation.com/there-is-a-problem-australias-top-scientist-alan-finkel-pushes-to-eradicate-bad-science-123374

GPS on our phone and when aircraft navigate around the world. These basic laws of physics are completely reliable with an error margin of a tiny fraction of a percent.

But most science is not massively replicated. In fact, most science reported in the science journals is not replicated at all.

If there is one person who is responsible for the realisation that there is a Replication Crisis, it is Prof John Ioannidis, a Stanford University mathematician who specialises in statistics of health and medical research. In 2005, Ioannidis published a now classic paper with the remarkable title "Why most published research findings are false" (Ioannidis, 2005).

The financial costs of irreproducible biomedical research are large. In the US alone it has been estimated that the cumulative prevalence of irreproducible preclinical research exceeds 50%, and results in approximately US$28 billion per annum spent on research that is not reproducible (Freedman *et al*., 2015).

The Replication Crisis really started to become widely known when Prinz *et al*. (2011) of the German drug company Bayer, writing in the journal 'Nature Reviews Drug Discovery' claimed that 75% of the literature used for potential drug discovery targets is unreliable. For a drug company to take a promising scientific finding, perhaps made at a university laboratory, to a commercial drug will cost around $2 billion so the first thing they do is check the original finding. However, as written in The Economist Magazine (19/10/2013)

> *"A rule of thumb among biotechnology venture-capitalists is that half of published research cannot be replicated. Even that may be optimistic. Last year researchers at one biotech firm, Amgen, found they could reproduce just six of 53 "landmark" studies in cancer research*. (The Economist, 19/10/2013).

In a sense this appalling lack of replication is not a problem for the drug companies. They check the work, find it is wrong and move on. It is science working in the manner that it should and they spend a few hundred thousand dollars in their replication tests but saved a couple of billion. But does this happen in all areas of science particularly in the environmental sciences? The answer is "No".

The problem has also recently started to become recognized in the environmental science with a call by Duarte *et al*. (2015) and Browman (2016) for "organized skepticism" to improve the reliability of the environmental marine sciences. In particular, Duarte *et al*. (2015) argue that some of the major threats to ocean ecosystems may not be as severe as is portrayed in some scientific accounts, and that

> *"the scientific community concerned with problems in the marine ecosystem [should] undertake a rigorous and systematic audit of ocean calamities"*

and that such an audit should involve a

> *"large contingent of scientists coordinated by a global program"*

So, this is a big well-known problem although the true implications are still not being fully addressed especially in the environmental sciences. It is notable that when Dr Piers Larcombe and I wrote a paper explaining why we need to address the Replication Crisis in the context of the GBR (Larcombe and Ridd 2018), the response in a paper from a large group of senior GBR scientists (Schaffelke *et al*., 2018) was that although there may be a replication crisis in the rest of science, GBR science was just fine, and no further checking was required. I am not sure if this is arrogance or blind optimism. But considering that the potentially erroneous science of the GBR is affecting every major industry in North Eastern Australia, it is very surprising that such a strenuous argument was made to NOT do a little more checking. How can one argue against a little bit of checking?

Peer review: Patently Inadequate Quality Assurance.

The main Quality Assurance system used in science, including GBR science, is "peer review". It sounds impressive, and is often referred to as the gold standard - if science has been peer reviewed then it has supposedly been thoroughly checked. Unfortunately, nothing could be further from the truth and this is possibly the worst example of how the scientific professions have continuously and institutionally duped the general public. When I talk to the educated layperson about peer review, they seem to have the impression that it involves perhaps a dozen other scientists checking the work for months, repeating experiments and checking analyses. They think it is a substantial process worthy of the gold standard that scientists imply it should carry.

However, peer review is often just a quick read of the work, maybe for just a few hours, by a couple of anonymous people selected by an editor of one of the science journals. This review is a good first pass to make sure that the work is readable and will often pick up some problems, but falls far short of a decent error checking system. I have done hundreds of peer reviews of other scientist's papers and I think my experiences would be fairly representative. It works like this. You get an email from a journal editor asking if you would be able to do a review on a paper. They attach a summary of the paper and ask if you can do it by a certain date. You do not get paid but generally you don't like to say no because you know that it is your duty as a scientist to do this review. But there is also another more self-interested motive. You may submit a paper to the same journal sometime in the future. It is a good idea to stay in the good books of the editor so that you have a better chance of getting your work accepted. Editors are also increasingly having difficulty getting reviewers and are greatly appreciative when you agree to do the review. Nowadays they are often so desperate that they ask the original authors to name some possible reviewers, and it is unsurprising that the authors will often nominate their friends or other scientists who are likely to agree.

One's review is generally anonymous, so the original author will probably not know who you are. This has the perverse effect that if the paper ends up being wrong, nobody will know that you reviewed the paper and failed to detect the error. There is little responsibility on the reviewer so there is little incentive to do the job properly. But the biggest problem is that you are busy doing other things and just want to do the review as quickly as possible. I often find that the editor is starting to send me reminder emails when I am running a bit late returning the review so I do the review as quickly as I can and move onto other things. Some reviewers are doubtless more conscientious than I am but I am sure, after seeing hundreds of reviews of my own papers that many reviewers must have barely read my papers.

So, peer review will almost never involve replication of experiments, reanalysis of data, reworking of calculations, or lengthy reconsideration of assumptions. It is hardly the quality assurance system that we would expect to guide big government decisions worth billions of dollars.

If peer review sounds pathetic to you then let me finish with the appraisal of Horton (2000), the editor of medicines most prestigious journal, *The Lancet*, who stated

> *"we know that the system of peer review is biased, unjust, unaccountable, incomplete, easily fixed, often insulting, usually ignorant, occasionally foolish, and frequently wrong'"*

That is a little dramatic, but essentially correct. Is it any wonder that we have a replication crisis given this total lack of a decent Quality Assurance mechanism? In addition, this is another betrayal of the community's trust by science institutions.

Evidence of Failure of GBR Science Quality Assurance Systems.

The GBR science literature can be broken into two components. These are

(a) The "primary" science literature which generally consists of individual papers and reports on specific and detailed topics that are peer reviewed.
(b) The "secondary" science literature are the much larger reports that "synthesise" the knowledge about the state of the GBR. The two most important are the 2017 Science Consensus Statement, and the 2019 GBR Outlook Report. This secondary literature is often written by large teams of scientists within the "consensus" group.

In this section it will be shown that both the primary and secondary science literature is often unreliable. More importantly it will be shown that the science organisations are not only in denial about these problems, they have been guilty of specific examples where they have failed to investigate major problems about which they have been made aware.

Specific examples of faulty primary science literature.

The Quality Assurance system for almost all of the primary literature is peer review, and we have already seen that peer review is now acknowledged to give a high failure rate. It should thus be expected that an audit of primary GBR literature will also reveal a high failure rate. Since about 2005, I have been concerned that many of the keystone papers claiming damage to the GBR have serious deficiencies. The culmination of this work has been presented in two papers co-authored with Dr Piers Larcombe[12], which among other matters raised doubt about nine scientific papers that include a wide suite of conclusions directly relevant to policy. These nine papers have between them been cited thousands of times. Questionable findings in these papers include:

(a) Halving river-borne nutrient and sediment concentrations will halve concentrations of nutrients and sediment in Great Barrier Reef waters

(b) Riverine discharge is significantly related to GBR water turbidity

(c) Nutrients from agricultural runoff are largely responsible for Crown-of-Thorns starfish plagues

(d) Minimizing pollution from agricultural runoff would reduce mean macroalgal cover on coral reefs by 39%, and would increase the mean ‘richness’ of hard corals and phototrophic octocorals by 16% and 33% respectively.

(e) There was a 50% reduction in coral cover in the GBR from the early 1960’s to 2000

(f) There was a 14% reduction in coral growth rates between 1990 and 2005.

(g) Coral cover will fall to 5%-10% by 2022.

(h) The outer and inner GBR are 28% and 36%, respectively, down the path to ecological extinction.

As this has been dealt with in detail in Larcombe and Ridd (2018/9), I will not go into more detail here. The list above is not intended to be exhaustive but it does include some very important issues relating to the supposed effect of agriculture on the GBR.

The main point is that if these nine very important papers on fundamental issues about the GBR have serious flaws, one has to question others papers. Almost none have been subjected to more rigorous quality assurance protocols than peer review.

Examples of faults in secondary science literature.

In this section I will give examples of some general problems that can be found in either the 2017 Science Consensus Statement, or the 2019 GBR Outlook report.

<u>Ignores contradictory evidence</u>

- Sediment: The sections on the effect of agricultural sediment on the GBR largely ignore the very large body of geological evidence that demonstrates that many of the Inshore Reefs have always been highly turbid environments. The dominant influence of strong winds causing waves that stir up the sediment on the seabed is also largely ignored as is the relatively small influence of river plumes. In one case a paper that is completely

[12] Larcombe and Ridd 2018 and 2019

discredited is used in the 2019 GBR outlook report (reference 745) to supposedly show the damaging effect of sediment on coral.

- Pesticides: The fact that, for the Inshore Reefs, pesticides are generally in extremely low concentrations or are undetectable is not reported. The fact that for the GBR reefs measurements are almost never attempted because concentrations are too low to detect is also not reported.
- Nutrients and Crown of Thorns Starfish plagues: The fact that there is about 100 times more cycling of nutrients across the seabed than comes down the rivers (Furnas *et al*., 2011) is ignored. There could hardly be a more important omission considering that reduction of fertilizer use is one of main targets of recent Queensland legislation. There is also no consideration of whether or not starfish plagues are entirely natural, thus ignoring the evidence by of Walbran and Henderson (1989) and Pratchett *et al*., (2018). In one case a paper (Wolfe *et al* 2017) is cited to link nutrients and starfish plagues in the 2017 Consensus Statement, but in actual fact Wolfe *et al*. (2017) shows exactly the opposite. The fact that contradictory evidence is almost never mentioned is bad enough but to cite contradictory evidence as supporting an argument further adds to the evidence that the secondary literature has not been subject to a rigorous quality assurance process.
- Cyclones: The fundamental role of cyclones on the ecosystem is ignored (see Dr Piers Larcombe's submission on this point). Cyclones entirely dominate the GBR ecosystems. As Dr Piers Larcombe points out, they "reset" the seabed due to the action of waves destroying coral and massively stirring up the sea bed. The amount of sediment moved by cyclones is roughly 100 times greater than comes down the rivers and yet this effect is totally ignored. Vast areas of the sea bed are churned up to a few tens of centimetres depth, and huge sand dunes smother sea-bed communities.

Failure to give an indication of the potential scale of the problem from agriculture.

- No indication is given of the amount of coral on the Inshore reefs that is influenced by agriculture, i.e about 1-2% of the coral.
- The importance of the inshore systems to the GBR is exaggerated. There is no evidence to indicate that even if the Inshore Reefs were degraded, there would be any significant effect on the offshore GBR reefs, as is often claimed. Indeed, for much of the geological history of the GBR when the sealevel was lower, the Inshore Reefs did not exist and the GBR was fine.
- No indication is given of the amount of coral killed by sediment or pesticides. It is probably zero or unmeasurably close to zero.

Faulty Review Process

- The many errors and omissions in the secondary literature point to an inadequate review process.
- The peer review process of the 2019 GBR Outlook Report was a sham. Of the four peer-reviewers chosen, two are from James Cook University's coral reef centre that is responsible for much of the work in the report. They are therefore not independent and are reviewing their own institution's work. The other two reviewers, in my opinion, are not scientists with a deep knowledge of the GBR. One trained as a political scientist and economist and undertakes research in the field of public policy and governance,

with a particular interest in public policy relating to sustainable development. The other has a background in law, particularly relating to indigenous issues. One can only guess why such friendly or seemingly unknowledgeable reviewers were selected to "scrutinize" the report. In any case, it demonstrates completely inadequate quality assurance protocols.

Institutional unwillingness to accept GBR science Quality Assurance is inadequate

Given the major problems with replication in many other areas of science, it is not surprising that GBR science is similarly afflicted, and we should not be too quick to ascribe blame. In fact, all scientists who are working on the GBR, including myself, have been part of a fundamentally inadequate system.

What is far less excusable is when a problem is identified, and nothing is done to rectify it. Worse still is when it is denied entirely. GBR science institutions are in denial that there is a problem as evidenced below.

- Schaffelke *et al*. (2018), representing the major GBR science institutions, denied any of the evidence provided by Larcombe and Ridd (2018) about inadequate Quality Assurance systems. In addition, and even more remarkably, they did not accept that there were any problems whatsoever with the nine faulty papers that were analysed. Although Dr Larcombe and I expected some debate about many of the issues that we raised, it is inconceivable that these influential papers had no issues whatsoever.

  In response to statements by Dr Piers Larcombe and I that peer review is insufficient QA, GBR science organisations have stated that there are other systems which are used to ensure fidelity of the scientific evidence. This was also articulated in the paper by Schaffelke *et al.* (2018) who said other groups such as Traditional Owners, GBR Reef Water Science Taskforce, authors of Reef 2050 Long-Term Sustainability plan, Independent Expert Panel, Reef Advisory Committee that are "chaired by eminent Australians" fulfilled this role. However, none of these groups do the necessary checking, testing or replication of the primary evidence that is required. They simply "synthesise" the primary evidence, that may well be faulty, to make a seemingly cogent case that the GBR is in trouble.

  It is worrying that Schaffelke *et al*. (2018), with authors from the major GBR science institutions, do not seem to grasp the fundamental deficiency in Quality Assurance.

- The Australian Coral Reef Society responded to a document that I produced on common questionable claims about the GBR by denying any major faults with the GBR quality assurance systems and failed to acknowledge problems in other areas of science due to deficiencies in peer review[13]. In addition, they claimed that "Ridd suggests that no science is to be believed because he doesn't believe in the scientific process". This

[13] https://australiancoralreefsociety.org/wp-content/uploads/Ridd-questionable-claims-statement.pdf

could not be further from the truth and such comments and misrepresentation of my position indicate they do not understand what the "scientific process" is.

- The GBR Independent Expert Panel, which is composed of some very influential GBR scientists within the "consensus group", issued a communique[14] denying any problems with GBR science Quality Assurance. Incredibly, the communique seemed to verge on defamation by comparing those who disagree with their view on the GBR with people who deliberately spread doubt about the effect of tobacco on health. They also claim that the motivation for those of us who are challenging the conventional wisdom is "usually money" implying scientific corruption of the worst kind.

  The GBR Independent Expert Panel thus denies the right of anybody to challenge their "consensus". Anybody who does is effectively labelled as an evil person who must be ignored. Resort to such *ad hominem* tactics may well be indicative of the Independent Panel's realisation that their scientific arguments have serious weaknesses.

Institutional unwillingness to investigate serious problems with the primary science literature.

It is evident from the previous section that GBR science institutions are in denial about the obvious Quality Assurance issues. However, there are a few examples which will be discussed shortly where the institutions are not willing to investigate potentially extreme problems with very important specific science papers, in the worst case involving possible scientific fraud.

<u>Coral Growth Rates:</u>

As mentioned previously Schaffelke *et al*. (2018), with authors representing the major GBR science organisations, failed to accept that there were any faults whatsoever with nine important publications as outlined by Larcombe and Ridd (2018). For one of these papers, there is considerable doubts about the coral growth rate data, which Schaffelke *et al*. claim declined dramatically to 2003, as there are two major errors. More importantly, simply repeating the experiment would completely resolve all doubt about this result. Although this has been suggested in a formal journal article and informal conversations with the institutions, to my knowledge, nothing has been done. There can be no more important piece of data than whether the coral growth rates are slowing.

AIMS claims growth rates are slowing dramatically and refuse to accept the obvious deficiencies with their analysis, or contradictory data from other workers. They have then failed to do the replication study that would not only resolve the issue but also update the coral growth rate data which presently ends at 2003. In my view the growth data is questionable from about 1990 and, to my knowledge, AIMS and other organisations are doing nothing to rectify the problem.

[14] https://www.environment.gov.au/system/files/pages/abff0d5e-b94d-4495-b79b-90dc52274f69/files/expert-panel-communique-13-aug-2019.pdf

Coal Dust:

In 2014 a paper that attracted considerable media and political attention[15] Burns (2014) claimed that coal dust had spread up to 200 km from coal loading ports such as Hay Point and was reaching worrying levels. However, there appears to be a major problem with the calculations that was first detected by CSIRO scientists[16] who are world leaders in the field of detecting pollutants such as coal dust. The concentrations of coal dust quoted in Burns (2014) are up to 3000% higher than reality. In addition, there is considerable doubt that Burns (2014) methods were even measuring coal dust at all as it can be easily confused with other material such as bush-fire ash.

However, the main issue here is not the original error in the peer reviewed paper as errors in peer reviewed papers are known to be extremely common. The main problem is what happened after the error was pointed out - nothing. There has been no correction and refusal by multiple science institutions to correct the problem.

I contacted the CSIRO scientists about this matter in 2018, after reading Burns (2014) and noting some obvious errors.[17] I recall a conversation with one of the scientists, and have some email correspondence, from which it is evident that the CSIRO group went to great effort to rectify the problem. My recollection is that I was told that they were asked to check Burns (2014) by a staff member from the Great Barrier Reef Marine Park Authority (GBRMPA) and when the mistake was found, the author and GBRMPA were informed. However, my recollection of the conversations and emails is that there was no acceptance of any mistake. The CSIRO group then attempted to publish a “comment” (see appendix B) in the original journal arguing that there was a serious mistake. This is the conventional way that such disputes are handled. However, it seems that the journal did not publish CSIRO’s comment so the work remains unchallenged in the scientific literature.

In addition, the results of Burns (2014) were presented by a very eminent scientist to a Senate Inquiry[18] looking into whether coal ports were a danger to the GBR. Presumably by mistake,

[15] https://www.couriermail.com.au/news/queensland/report-says-coal-dust-spread-across-great-barrier-reef-is-toxic-near-shore/news-story/762eec169160525c8fd6074a0a2f6c87

[16] I have deliberately not named the scientists but can do so if requested by the Senators. See footnote below.

[17] I wish to make it very clear that I contacted the CSIRO scientists after making a guess that they would know something about this paper as they are the undisputed experts. I had no idea initially that they had done such a rigorous review and correction to Burns (2014). I am also aware that the CSIRO group are very concerned that by communicating with me, they could be victimised by others in the GBR science community. I share their concern and am at pains to point out that they responded to my questions in a professional way and did not initiate the discussion. In my view they have at all times acted with total integrity.

[18] https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;db=COMMITTEES;id=committees%2Fcommsen%2F3d3c1287-e082-4945-b842-c4dbd5a5771a%2F0004;query=Id%3A%22committees%2Fcommsen%2F3d3c1287-e082-4945-b842-c4dbd5a5771a%2F0000%22

he stated that the coal dust had "accumulated **everywhere** on the Great Barrier Reef" rather than only 200km from the ports as stated by Burns (2014). It thus appears that there was a further exaggeration in terms of the area affected by about 1000%. The eminent scientist went on to state that "permits to undertake dredging should be revoked". This would have a very grave effect on one of Australia's biggest industries as coal ports require dredging.

Thus, a paper with a 3000% error in coal concentration, was exaggerated by a further 1000% in terms of area affected, to a Senate Inquiry, and it seems that the journal refused to publish a correction, and personnel at GBRMPA and AIMS (which collected the original data) were informed but have done nothing to correct the problem. Burns (2014) was cited in the highly influential 2017 Science Consensus Statement and the 2019 Outlook report - but it is wrong on a monumental scale.

This case shows that multiple institutions took no interest in correcting an extremely influential piece of the scientific literature. The faulty evidence concerns Australia's biggest export industry. Those institutions do not have sufficient commitment to the quality and integrity of science evidence that is being used to inform public debates of great importance.

I will leave the last word to the CSIRO scientists who stated that "…… *it is the responsibility of scientists to ensure that sound data are presented to government inquiries dealing with such issues*"

Coral Cover.

One of the most important and influential papers ever published on the GBR (Bellwood *et al.*, 2004) claimed that coral cover (the amount of coral on the GBR) has halved between 1960 and 2000[19]. However, full scrutiny of this finding has been impossible as the scientist responsible (not Prof Bellwood) for the data has, in my opinion, failed to provide the raw data or given the details of his analysis procedures. With Dr Piers Larcombe, I tried to get the journal that published the paper (*Nature*) to obtain the raw data and analysis methods from the author[20]. We were only given the final worked-up data not the raw data. However, *Nature* failed to insist that the raw data be provided.

It should be noted that scientists from AIMS (Sweatman *et al.*, 2011) have also cast great doubt on this claimed reduction of coral cover. The main problem is the change in methodology between the pre and post 1985 data. In addition, an attempt by Boer *et al.*, (2014) to replicate the study failed completely.

We thus have the situation that for one of the most cited GBR science papers, that is referenced in the 2019 Outlook Report, shows "long term decline" of the GBR, (a) we cannot get the raw data, (b) there are obvious methodological errors, and (c) it can't be replicated.

[19] See details in Larcombe and Ridd 2018 and 2019
[20] Email trail can be supplied on request.

The paper should be retracted but instead, the journal and other science institutions that are aware of the problem have failed to demonstrate commitment to science integrity.

Possible data fabrication at a GBR science institution not properly investigated.

Almost two years ago Oona Lonnstedt was found to have committed "misconduct in research" for having "intentionally fabricated data"[21] at Uppsala University in Sweden shortly after she left James Cook University's Coral Reef Centre (Australian Research Council Centre of Excellence for Coral Reef Studies) where she had been a high-flying researcher. The question was naturally asked whether her work at the Coral Reef Centre also used fabricated data? This involves around 15 papers, some in very high-profile journals, that attracted world-wide publicity.

A whistle-blower, who has still not been able to identify him/herself presumably for fear of career damage, had raised concerns about Lonnstedt's work at the Coral Reef Centre[22] shortly after her misconduct was discovered in Sweden. In addition, early this year it was demonstrated that some of her work on lionfish was extremely suspicious[23]. The case has now been taken up by the highly influential journal *Science* which commissioned its own investigation into some of Lonnstedt's work and found very plausible evidence to be seriously concerned[24].

The reaction of the science institutions has been to do nothing. The science journal that published some of the highly suspicious work (*Biology Letters*) has not retracted the papers (at the time of writing). More importantly, JCU, which hosts the Coral Reef Centre have been promising for almost two years to investigate but (as of October 2019) have failed to get as far as appointing an external review panel. It is scandalous that a supposedly prestigious science organisation has failed to investigate possible data fabrication. It has the appearance of a cover-up. It shows, yet again, that our science institutions have no real commitment to scientific integrity, even where potential data fabrication is implicated.

Lonnstedt's work was not particularly important to matters relating to agriculture. However, as a test of institutional commitment to science Quality Assurance, it is very revealing.

The institution failed.

JCU's failure to investigate possible data fabrication is a far greater failure than any individual scientists who may have fallen into committing data fabrication. JCU's and the Coral Reef Centre's inaction represents an institutional failure which is far more serious.

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[21] https://www.nature.com/articles/d41586-017-08321-2
[22] https://www.sciencemag.org/news/2019/09/can-you-spot-duplicates-critics-say-these-photos-lionfish-point-fraud
[23] https://www.theaustralian.com.au/nation/inquirer/james-cook-university-reviews-exstudents-fishy-findings/news-story/8c428a0bd81f8af2eed37f51d482b03e
[24] https://www.sciencemag.org/news/2019/09/can-you-spot-duplicates-critics-say-these-photos-lionfish-point-fraud

Conclusion and Solution:

The following has been demonstrated

(a) a significant part of the body of literature that affects agriculture is questionable,
(b) there are insufficient institutional quality assurance protocols,
(c) there is institutional denial about the quality assurance problems, and
(d) institutions are willing to cover up problems - even possible data fabrication.

It is thus necessary to urgently review and audit the scientific evidence. Together with Dr Piers Larcombe (Larcombe and Ridd, 2018, 2019), we have proposed this audit needs to be carried out by an "Office of Science Quality Assurance".

I have worked (unpaid) with the Invicta Canegrower's organisation and we believe an audit of the main parts of GBR evidence can be audited for around $5million and take less than two years to complete. This is a tiny percentage of the funds that government will spend on the GBR in the next few years, and it will likely help to create much more reliable evidentiary base for government decisions making.

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Appendix A: Comments about the Australian Coral Reef Society (ACRS) response to the "Questionable Claims" document written which is similar to the "Questionable claims" outlined in this document. See https://australiancoralreefsociety.org/wp-content/uploads/Ridd-questionable-claims-statement.pdf

ACRS provide almost no evidence to refute my objections to the Questionable claims. Their statement is most notable for its lack of dispute on most of the points. On the issues that face agriculture (sediment, pesticides, and nutrients) they do not dispute that the GBR-proper (where 99% of the corals live) is unaffected.

Crown of Thorns Starfish (COTS): ACRS don't dispute my comment that COTS plagues are natural and merely say they "may" be more prevalent today. They also do not dispute my point that the COTS experts say that the link between farm nutrients and COTS is "unresolved". So they effectively admit that farmers now have to reduce their use of farm fertilizers based upon very tenuous science. This contrasts with the 2017 GBR consensus statement which claims without any doubt that farm nutrients are killing the reef. It is useful that the ACRS has clarified this matter.

Pesticides: ACRS agree that pesticides are not killing the reef. They also do not dispute that pesticides do not reach the GBR-proper (often termed the outer GBR) where 99% of the coral is. They talk about the inshore reefs where a very small amount of coral lives. Here they clearly have not looked closely at the data which shows that pesticide levels are extremely low or undetectable almost all the time.

Sediment: ACRS do not dispute that there is virtually no sediment from land on the GBR.

Pharmaceuticals: ACRS do not dispute that the threat of sewage-born pharmaceuticals, which is claimed to be a "medium Risk" to the GBR has been exaggerated to an absurd extent.

Coral Cover Decline: ACRS make a big deal of the massive decline in coral cover around 2012 (mostly due to cyclones), but fail to mention it totally bounced back by 2016. Why did they fail to mention that? In addition, they make a big deal about the 2016 bleaching event but fail to mention that the fall in coral cover was not particularly large considering the ability of coral to recover. For example the southern GBR increased coral cover by 250% between 2011 and 2016.

Coral Growth Rates: ACRS claim coral growths rates have declined (without citation). The work I cited claims the opposite. At least they should accept there is some doubt and support my call for more QA on this point.

Recovery: ACRS claim that recovery has not occurred in some instances on the GBR. I would like to see what evidence they have for this. None was forthcoming.

Bleaching: ACRS claim mass bleaching only started in 1979, a statement often made. It may have not been observed by scientists until this date but science of the GBR was only just getting started by 1979. There are now about a thousand times more scientists working on the reef than in the early 1970's. Science did not "discover" mass coral spawning until the early 1980's even though this produces massive slicks of eggs on the water surface that are extremely easy to see. Nobody would claim that mass spawning was a new phenomenon that only started in 1980. We must also remember that Sir Maurice Yonge, in the first scientific expedition to the GBR in 1929 observed bleaching. He had one boat, no aeroplanes or satellites, so we will never know if the event he saw was a big enough event to be “mass” coral bleaching.

The replication Crisis: The ACRS are in denial

Efficacy of Peer Review: The ACRS are in denial

Astonishingly, the ACRS interpret my call for better quality assurance as me not believing in the scientific process. Nothing could be further from the truth. My main point is that the scientific process has not been applied in much of GBR work because of lack of replication, testing or checking.

Appendix B: Comment on Burns (2014) by CSIRO scientists demonstrating major errors - sent to me by the CSIRO scientist on request. It is my understanding from the CSIRO scientists that the science journal refused to publish this correction. The CSIRO group have acted with perfect integrity in this matter.

Errors in the evaluation of results in "PAHs in the Great Barrier Reef Lagoon reach potentially toxic levels from coal port activities: [Estuar. Coast. Shelf Sci. 144, 39-45]

NAMES AND ADRESSES REDACTED

The corrections provided by Burns to her paper "PAHs in the Great Barrier Reef Lagoon reach potentially toxic levels from coal port activities" fail to adequately address all of the comments that we raised in our correspondence with her, to the point that the risks posed by PAHs to the Great Barrier Reef Lagoon continue to be overestimated.

An underlying problem is a failure to understand how to normalize PAH data to 1% organic carbon (OC) which has resulted in the normalized data reported in Table 3 of the paper, being a factor of 10 too high. This is because the organic carbon normalization equation presented on page 41 of the paper is incorrect.

The general normalization equation is:

[Toxicant concentration in mg/kg] x [Target % OC] / [% OC in the sample]

so if normalizing to 1% OC, the target %OC is 1.

Normalization is used because the presence of OC in a sediment binds PAHs (and other hydrophobic organics) making them less bioavailable, so the more OC, the more PAHs can be tolerated in sediment without having adverse biological impacts. Note that the USEPA approach also applies a similar normalization procedure but to a final organic carbon concentration of 100%.

The data presented in Table 2 for PAHs as µg/g OC when converted to PAHs normalized to 1% OC in Table 3 differ by a factor of 10 when the factor should be 100. For example, for Station IS9 (Sediment Trap) the sum of 16 PAHs in Table 2 is 58.8 µg/gOC (note table caption incorrectly uses μg^{-1} g OC), i.e. for 100% OC, but when normalized to 1%OC in Table 3, the value is incorrectly shown as 5.9, when it should be 0.59.

We also noted a number of errors (highlighted in yellow) in the calculations of Table 2 data from the previously published data in Burns and Brinkman (2011). Our revised Table 2 is shown below. A revised Table 3 is presented that uses the data in the revised Table 2 and the factor of 100 (not 10) as discussed above. It is worth noting that in one instance the %OC in the samples is below 0.2%. It is not recommended that normalization be applied outside of the range 0.2 – 10%. At lower organic carbon concentrations, other physical and chemical factors influence the partitioning process for hydrophobic organics, while at higher values the organic carbon is likely to be dominated by oils or tars (ANZECC/ARMCANZ, 2000).

The consequence of the above errors is that the risk posed by PAHs, based on the recommended ANZECC/ARMCANZ (2000) approach, is seriously over-exaggerated. All of the total PAH concentrations normalized to 1%OC are less than a factor 3% of the recommended trigger value of 10 mg/kg, so clearly pose no risk to aquatic biota. The comments made by Burns in the Corrigendum on the ANZECC/ARMCANZ approach are of a minor concern compared to this oversight.

Clearly an inability to correctly evaluate the previously published data has resulted in an erroneous conclusion as to the risks posed by PAHs from coal spillage, whereas other stressors may well be a concern. This is particularly important as the issue of expansion of coal ports is currently a politically sensitive one in Australia and it is the responsibility of scientists to ensure that sound data are presented to government inquiries dealing with such issues.

Revised Table 2. Parent and alkyl PAHs as μg gOC^{-1} for selected sediment layers (cm) as indicated and sediment trap (ST) samples

Station	**IS10**	**IS9**	**IS9**	**IS9**	**IS9**	**MS7**	**GR1**	**PRC4**	**PRC5**	**PRC4-PRC5**	**PRC4**	**SB13**
Layer (cm)	0-1	0-1	2-6	6-10	ST	0-2	ST	ST	ST	ST	0-1	0-1
TOC (%)	0.1	0.96	0.56	0.42	1.51	0.23	2.14	1.71	2.14	0.5	0.7	0.3
Naphthalene	0.39	0.05	0.09	0.07	0.06	0.02	0.04	0.02	0.02	0.00	0.00	0.00
C1-Naphth	1.63	0.17	0.32	0.31	0.66	0.26	0.03	0.02	0.00	0.46	0.06	0.16
C2-Naphth	4.92	0.71	1.83	2.03	4.28	0.93	0.44	0.41	0.16	3.44	0.24	0.82
C3-Naphth	7.13	1.28	3.52	4.23	8.27	1.08	1.53	1.47	0.68	3.94	0.66	0.92
C4-Naphth	22.78	4.47	10.32	12.39	27.89	1.60	11.47	13.07	4.54	5.61	2.72	1.34
Fluorene	0.03	0.03	0.09	0.17	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01
C1-fluorene	0.03	0.01	0.02	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.00	
C2-fluorene	0.59	0.10	0.28	0.36	0.70	0.09	0.31	0.35	0.17	0.15	0.07	0.04
Phenanthrene	1.56	0.28	0.66	0.81	1.80	0.02	1.05	1.32	0.67	0.16	0.22	0.02
Anthacene	4.54	0.83	1.90	2.16	4.89	0.32	4.97	5.49	3.10	0.47	0.66	0.32
C1-Phen/Anth	1.68	0.24	0.53	0.63	1.53	0.06	1.66	2.00	1.33		0.23	0.10
C2-Phen/Anth	1.68	0.25	0.53	0.62	1.61	0.11	2.02	2.25	1.69	0.15	0.26	0.16
C3-Phen/Anth	5.35	0.69	1.91	2.17	5.56	0.67	6.65	7.12	6.36	0.82	0.78	0.60
C4-Phen/Anth	3.42	0.59	1.20	1.37	4.45	0.50	5.24	5.66	4.87	0.61	0.69	0.36
Fluoranthene	7.80	1.60	3.71	4.52	8.36	1.73	10.57	12.23	10.11	1.67	1.49	1.00
Pyrene	5.15	0.86	2.53	5.32	3.11	0.65	11.60	11.01	2.64	1.11	1.17	0.41
C1-Fl/Pyr	0.77	0.13	0.33	0.39	0.86	0.26	0.77	0.80	0.78	0.21	0.14	0.18
C2-Fl/Pyr	0.57	0.49	1.21	2.72	0.91	0.10	1.04	1.19	1.07	0.10	0.08	0.06
C3-Fl/Pyr	0.00	0.45	1.14	2.29	1.37	0.16	2.00	2.25	2.07	0.19	0.15	0.11
Dibenzanthracene	0.22	0.23	0.60	1.33	0.46	0.04	0.23	0.19	0.26	0.03	0.04	0.05
Chrysene	0.21	0.21	0.76	1.14	0.56	0.04	0.14	0.12	0.15	0.05	0.01	0.11
C1-BDA/chrys	0.05	0.12	0.33	0.47	0.31	0.01	0.01	0.04	0.03	0.01	0.01	0.05
C2-BDA/chrys	0.11	0.27	0.68	1.81	0.25	0.01	0.03	0.02	0.02	0.02	0.00	0.03
C3-BDA/chrys	0.09	0.19	0.50	1.11	0.26	0.00	0.05	0.01	0.01	0.04	0.00	0.03
C4-BDA/chrys	0.10	0.18	0.58	1.03	0.52	0.02	0.02	0.03	0.03	0.03	0.01	0.27
Benzo(b)fluoranthene	0.11	0.26	0.71	1.43	0.26	0.02	0.01	0.01	0.01	0.00	0.00	0.02
Benzo(k)fluoranthene	0.04	0.12	0.34	0.81	0.09	0.01	0.00	0.00	0.00	0.01	0.00	0.01
Benzo(e)pyrene	0.13	0.29	0.79	1.63	0.34	0.02	0.02	0.01	0.02	0.03	0.00	0.11
Benzo(a)pyrene	0.12	0.33	0.81	2.09	0.24	0.01	0.00	0.00	0.00	0.02	0.00	0.02
Perylene	0.17	1.02	3.43	4.07	1.14	0.04	0.00	0.00	0.00	0.00	0.00	0.01
Indeno(1,2,3-cd)pyrene	0.11	0.22	0.59	1.26	0.18	0.02	0.01	0.00	0.00	0.02	0.00	0.02
Dibenz(a,h)anthracene	0.02	0.04	0.12	0.29	0.04	0.00	0.00	0.00	0.01	0.01	0.00	0.01
Benzo(ghi)perylene	0.12	0.23	0.63	1.12	0.23	0.02	0.05	0.04	0.04	0.00	0.00	0.03
Sum of all PAHs	71.6	16.9	43.0	62.2	81.3	8.8	62.0	67.2	40.8	19.4	9.7	7.4
Sum of 16 parent PAHs	20.20	5.04	12.95	21.20	19.85	2.87	28.44	30.26	16.75	3.52	3.56	1.97

Revised Table 3. PAH data reported in Burns and Brinkman (2011) normalized to 1% organic carbon (µg g^{-1}) for sediments (cm) and sediment traps (ST)

Station	IS10	IS9	IS9	IS9	IS9	MS7	GR1	PRC4	PRC5	PRC4-PRC5	PRC4	SB13
Layer (cm)	0-1	0-1	2-6	6-10	ST	0-2	ST	ST	ST	ST	0-1	0-1
TOC (%)	0.1[a]	0.96	0.56	0.42	1.51	0.23	2.14	1.71	2.14	0.5	0.7	0.3
Naphthalene	0.0039	0.0005	0.0009	0.0007	0.0006	0.0002	0.0004	0.0002	0.0002	0.0000	0.0000	0.0000
C1-Naphth	0.0163	0.0017	0.0032	0.0031	0.0066	0.0026	0.0003	0.0002	0.0000	0.0046	0.0006	0.0016
C2-Naphth	0.0492	0.0071	0.0183	0.0203	0.0428	0.0093	0.0044	0.0041	0.0016	0.0344	0.0024	0.0082
C3-Naphth	0.0713	0.0128	0.0352	0.0423	0.0827	0.0108	0.0153	0.0147	0.0068	0.0394	0.0066	0.0092
C4-Naphth	0.2278	0.0447	0.1032	0.1239	0.2789	0.0160	0.1147	0.1307	0.0454	0.0561	0.0272	0.0134
Fluorene	0.0003	0.0003	0.0009	0.0017	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
C1-fluorene	0.0003	0.0001	0.0002	0.0003	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
C2-fluorene	0.0059	0.0010	0.0028	0.0036	0.0070	0.0009	0.0031	0.0035	0.0017	0.0015	0.0007	0.0004
Phenanthrene	0.0156	0.0028	0.0066	0.0081	0.0180	0.0002	0.0105	0.0132	0.0067	0.0016	0.0022	0.0002
Anthacene	0.0454	0.0083	0.0190	0.0216	0.0489	0.0032	0.0497	0.0549	0.0310	0.0047	0.0066	0.0032
C1-Phen/Anth	0.0168	0.0024	0.0053	0.0063	0.0153	0.0006	0.0166	0.0200	0.0133		0.0023	0.0010
C2-Phen/Anth	0.0168	0.0025	0.0053	0.0062	0.0161	0.0011	0.0202	0.0225	0.0169	0.0015	0.0026	0.0016
C3-Phen/Anth	0.0535	0.0069	0.0191	0.0217	0.0556	0.0067	0.0665	0.0712	0.0636	0.0082	0.0078	0.0060
C4-Phen/Anth	0.0342	0.0059	0.0120	0.0137	0.0445	0.0050	0.0524	0.0566	0.0487	0.0061	0.0069	0.0036
Fluoranthene	0.0780	0.0160	0.0371	0.0452	0.0836	0.0173	0.1057	0.1223	0.1011	0.0167	0.0149	0.0100
Pyrene	0.0515	0.0086	0.0253	0.0532	0.0311	0.0065	0.1160	0.1101	0.0264	0.0111	0.0117	0.0041
C1-Fl/Pyr	0.0077	0.0013	0.0033	0.0039	0.0086	0.0026	0.0077	0.0080	0.0078	0.0021	0.0014	0.0018
C2-Fl/Pyr	0.0057	0.0049	0.0121	0.0272	0.0091	0.0010	0.0104	0.0119	0.0107	0.0010	0.0008	0.0006
C3-Fl/Pyr	0.0000	0.0045	0.0114	0.0229	0.0137	0.0016	0.0200	0.0225	0.0207	0.0019	0.0015	0.0011
Dibenzanthracene	0.0022	0.0023	0.0060	0.0133	0.0046	0.0004	0.0023	0.0019	0.0026	0.0003	0.0004	0.0005
Chrysene	0.0021	0.0021	0.0076	0.0114	0.0056	0.0004	0.0014	0.0012	0.0015	0.0005	0.0001	0.0011
C1-BDA/chrys	0.0005	0.0012	0.0033	0.0047	0.0031	0.0001	0.0001	0.0004	0.0003	0.0001	0.0001	0.0005
C2-BDA/chrys	0.0011	0.0027	0.0068	0.0181	0.0025	0.0001	0.0003	0.0002	0.0002	0.0002	0.0000	0.0003
C3-BDA/chrys	0.0009	0.0019	0.0050	0.0111	0.0026	0.0000	0.0005	0.0001	0.0001	0.0004	0.0000	0.0003
C4-BDA/chrys	0.0010	0.0018	0.0058	0.0103	0.0052	0.0002	0.0002	0.0003	0.0003	0.0003	0.0001	0.0027
Benzo(b)fluoranthene	0.0011	0.0026	0.0071	0.0143	0.0026	0.0002	0.0001	0.0001	0.0001	0.0000	0.0000	0.0002
Benzo(k)fluoranthene	0.0004	0.0012	0.0034	0.0081	0.0009	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001
Benzo(e)pyrene	0.0013	0.0029	0.0079	0.0163	0.0034	0.0002	0.0002	0.0001	0.0002	0.0003	0.0000	0.0011

Station	**IS10**	**IS9**	**IS9**	**IS9**	**IS9**	**MS7**	**GR1**	**PRC4**	**PRC5**	**PRC4-PRC5**	**PRC4**	**SB13**
Layer (cm)	0-1	0-1	2-6	6-10	ST	0-2	ST	ST	ST	ST	0-1	0-1
Benzo(a)pyrene	0.0012	0.0033	0.0081	0.0209	0.0024	0.0001	0.0000	0.0000	0.0000	0.0002	0.0000	0.0002
Perylene	0.0017	0.0102	0.0343	0.0407	0.0114	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Indeno(1,2,3-cd)pyrene	0.0011	0.0022	0.0059	0.0126	0.0018	0.0002	0.0001	0.0000	0.0000	0.0002	0.0000	0.0002
Dibenz(a,h)anthracene	0.0002	0.0004	0.0012	0.0029	0.0004	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001
Benzo(ghi)perylene	0.0012	0.0023	0.0063	0.0112	0.0023	0.0002	0.0005	0.0004	0.0004	0.0000	0.0000	0.0003
Sum of all PAHs	**0.72**	**0.17**	**0.43**	**0.62**	**0.81**	**0.09**	**0.62**	**0.67**	**0.41**	**0.19**	**0.10**	**0.07**
Sum of 16 parent PAHs	**0.20**[a]	**0.05**	**0.13**	**0.21**	**0.20**	**0.03**	**0.28**	**0.30**	**0.17**	**0.04**	**0.04**	**0.02**

[a] %OC is outside the acceptable range for normalization of 0.2-10%