Australian Government | Australian Institute of Marine Science

TOWNSVILLE | DARWIN | PERTH

8 November 2019

Committee Secretary
Senate Standing Committees on Rural and Regional Affairs and Transport

Department of the Senate
PO Box 6100
Parliament House
Canberra ACT 2600

Dear Committee Secretary

The Australian Institute of Marine Science (AIMS) is pleased to make a submission to the Rural and Regional Affairs and Transport References Committee inquiry into the identification of leading practices in ensuring evidence-based regulation of farm practices that impact water quality outcomes in the Great Barrier Reef.

AIMS has three bases: Perth, Darwin and our oldest one in Townsville, initially established in 1972 to build Australia's knowledge base about the Great Barrier Reef (GBR) but we have since extended our efforts to cover all of Australia's tropical marine ecosystems. Our establishment was motivated to increase understanding of the GBR because of its economic importance (tourism, fisheries, recreation, coastal protection) and high environmental, social and cultural value, later recognised when it was declared a World Heritage site. Our three bases, two research vessels, and world-leading research aquarium (the National Sea Simulator) allow AIMS to conduct world-class scientific research to support sustainable use of Australia's tropical marine estate.

AIMS has a strong foundation from which to provide quantitative advice to the Committee's inquiry. For almost 50 years, AIMS has conducted field observations on the health of the Great Barrier Reef, complemented by innovative laboratory experiments to understand cause-and-effect, and has published thousands of research papers in internationally refereed journals. AIMS is ranked in the top three marine research institutions globally for marine and fresh-water biology.

Drawing on our expertise, AIMS' submission focusses on terms-of-reference parts a) and b):

a. the existing evidence-base on the impact of farm water runoff on the health of the Great Barrier Reef and catchment areas; and
b. the connectivity of farm practices throughout the Great Barrier Reef catchment areas to water quality outcomes in the Great Barrier Reef Marine Park

In response to recent public interest in quality assurance practices underpinning Great Barrier Reef science and subsequent policy decisions, we also provide some background material on how AIMS conducts its science to ensure high quality and integrity (see Appendix). These measures ensure AIMS research and subsequent reporting is robust and high quality which underpins the deep trust in our advice from stakeholders in

Commonwealth and State governments, industry, other science organisations, and the wider community.

Yours sincerely

Dr Paul Hardisty
Chief Executive Officer
Australian Institute of Marine Science

Brief Introduction to the Great Barrier Reef

Before responding to the Terms of Reference (ToRs), we believe it is worthwhile to understand some of the key relevant processes within the Great Barrier Reef (GBR) lagoon.

The GBR lagoon is a complex biological and physical structure bounded to the east by the oceanic waters of the Coral Sea and to the west by the Queensland coastline with its many catchments, rivers, and estuaries. In general, the GBR can be divided into two distinct regions: 1) a near-shore, shallow region strongly affected by waves, wind and rivers, and 2) deeper offshore waters more influenced by oceanic currents and exchanges with the Coral Sea, including upwelling of nutrient-rich water from the deeper ocean. The influence of surface wind and waves can reach the seafloor of this near-shore region and resuspend sediments. The influence of rivers and ocean currents varies along the GBR because the lagoon is wide in the south and significantly narrower in the north, and the offshore reefs which form a barrier to exchange with the Coral Sea are dense in some areas and more scattered in others. Despite regional variations, the prevailing south-east Trade Winds push water against the coast and northwards, concentrating the influence of river run-off on inshore ecosystems

The distinct wet and dry seasons, characteristic of tropical Australia, are strong drivers of many processes occurring along the GBR. River flow, for example, varies with the amount of wet season rainfall, which can be large when tropical cyclones occur. Freshwater discharge from rivers is more buoyant than salty ocean water, and thus forms plumes during heavy rainfall events that can extend far out into the GBR lagoon. Winds associated with tropical cyclones drive large waves, which damage corals and seagrass beds, can resuspend and move large amounts of sediment and associated nutrients, and increase mixing and water movement. When conditions are calmer, sediment settles and gradually compacts, making it more resistant to resuspension in the future[1]. As a result, only the more recently deposited sediments are likely to be mixed or resuspended.

The GBR lagoon is relatively shallow and much of the seafloor is within reach of sunlight, so photosynthetic organisms such as corals and seagrasses can flourish. Nutrients like nitrogen and phosphorous are important for GBR ecosystems as they support organism production and growth. However, the GBR lagoon is a naturally low-nutrient and high-light environment, so GBR corals and seagrasses have evolved under these conditions. Other photosynthetic organisms like macroalgae and microalgae (phytoplankton) are excellent competitors in high-nutrient and low-light environments and are able to grow quickly given excess nutrients. Long-term inputs of excess nutrients disrupt the balance between algae and corals, leading to algal-dominated reefs. When microalgae take up nutrients for growth, some of those nutrients enter the food chain when higher animals (such as fish and larger plankton) eat them. However, many of those nutrients are released back into GBR waters

[1] Lewis et al 2014 Complex sediment deposition history on a wide continental shelf: Implications for the calculation of accumulation rates on the Great Barrier Reef. *Earth & Planetary Science Letters* **393**, 146–158.

when microalgae die and break down. Nutrient inputs do not disappear once river plumes dissipate but have the potential to 'cycle' through the GBR ecosystem on long time-scales.

In addition to introducing the physical processes that describe the GBR, we believe it is also worth briefly noting that, while the near-shore region of the GBR comprises only a small percentage of the entire system, this still contains thousands of square kilometres of coral reef and vast seagrass beds. The proximity of this portion of the GBR to the Queensland coastline – and its comparatively easy access to recreational users and tourism – magnifies its social and economic value. This closer proximity also proportionally increases its cultural value – due to the strong links of indigenous communities and traditional owners to their sea country.

AIMS Great Barrier Reef Science

In Australia, AIMS has the longest records on the state of the GBR from various monitoring programs complemented by targeted field studies and extensive experimentation. This includes monitoring programs that have been assessing the status and trends of inshore water quality of inshore coral reefs. These monitoring programs, as well as other field studies and laboratory experiments, are often conducted in collaboration with other research providers (e.g. JCU, CSIRO), management agencies (e.g. GBRMPA, Department of Environment) and industry (e.g. AMPTO). This means that AIMS does not conduct its science in isolation but in the process of building our critical mass through collaboration, we also expose our science to external scrutiny. This scrutiny is further exemplified by the fact that most of our scientific publications and reports are collaborative, i.e. co-authored by personnel from organisations other than AIMS.

AIMS informs key stakeholders and decision makers across government and industry through our participation in, and/or advice to, decision-making forums like the advisory committees of the Reef 2050 Plan (the Independent Expert Panel, and Senior Advisory Committee), the Queensland Government's GBR Water Science Taskforce, and regional bodies such as the Gladstone Healthy Harbor Partnership and the relevant Natural Resource Management (NRM) organisations and their Monitoring, Evaluation, Reporting and Improvement (MERI) plans . AIMS also provides advice and specific briefings to industry bodies including at their public events, such as the recent Cane growers Nitrogen Forum in Cairns, 2019, as well as hosting and briefing interested industry and community representative, including Traditional Owners, at our Townsville site.

From the decades of science by AIMS, our collaborators and other research organisations, AIMS has concluded **there is strong evidence that broadscale changes in land use and management have altered the quality of coastal water in parts of the Great Barrier Reef**. Land use changes have increased sediment, nutrient and pesticide runoff into the GBR. A major component of this increase has come from farming and associated activities to support the sector (e.g. land clearing, infrastructure development). These changes affect the health and resilience of coral reefs and other key ecosystems such as seagrass beds. Importantly, they reduce their ability to tolerate chronic effects from climate change and withstand and recover from acute impacts from tropical cyclones, bleaching and crown-of-thorns starfish outbreaks.

Responding to the Terms of Reference

ToR (a) Existing evidence-base on the impact of farm water runoff on the health of the Great Barrier Reef and catchment areas

Multiple lines of evidence exist that modern river runoff contains elevated loads of sediments, nutrients, and contaminants due to extensive land clearing and catchment modification in Queensland. The greatest change in land-use has been the conversion of pre-European vegetated landscapes to ones modified to suit animal grazing and agriculture. As the largest historical change in land-use, broad-scale farming is most responsible for the changed river loads entering the GBR Lagoon. It is important to recognize that these changes started in 1870 with the introduction of hoofed animals into cleared erodible landscapes and that fertiliser use grew rapidly in the 20th Century to increase agricultural yields (especially in the sugar industry). With 150 years of profound change on the land, it is highly likely that all modern marine monitoring programs, which started after 1980, are based on observing an already changed system.

Despite the difficulty of knowing what was changed historically, we know that farm run-off continues to reach the GBR today because of the widespread signatures of agricultural pesticides in reef waters and in GBR plants and animals[2]. Almost 30 different pesticides have been detected in nearshore waters of the GBR with some of them relatively recent entrants to the agricultural market in the GBR catchment[3], demonstrating that the influence is current. The levels of detected pesticides vary between reef regions in a way that corresponds with different farming practices in the catchments that influence these regions. For instance, regions exposed to runoff from Mackay-Whitsunday rivers have higher levels of the herbicide diuron which is used mostly in sugar cane farming[4]. In contrast, one of the dominant herbicides detected in the Fitzroy river region, with a high proportion of grazing, is tebuthiuron (used to control woody weeds on grazing land)[5]. While the levels of individual pesticides are often low and considered sub-lethal in terms of acute exposure, many of the

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[2] Haynes et al (2000), Pesticide and herbicide residues in sediments and seagrasses from the Great Barrier Reef World Heritage Area and Queensland Coast. *Marine Pollution Bulletin* **41**, 279-287; Bartley et al (2017). 2017 Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition. Chapter 2: Sources of sediment, nutrients, pesticides and other pollutants to the Great Barrier Reef. Reef Water Quality Protection Plan Secretariat, Brisbane, Australia, p. 77.

[3] Devlin et al (2015) Advancing our understanding of the source, management, transport and impacts of pesticides on the Great Barrier Reef 2011-2015. A report for the Queensland Department of Environment and Heritage Protection. Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University, Cairns, 134pp.

[4] Kennedy et al (2012) Long term monitoring of photosystem II herbicides – Correlation with remotely sensed freshwater extent to monitor changes in the quality of water entering the Great Barrier Reef, Australia. *Marine Pollution Bulletin* **65**, 292-305.

[5] Packett et al (2009) Agricultural lands are hot-spots for annual runoff polluting the southern Great Barrier Reef lagoon. *Marine Pollution Bulletin* **58**, 976-986.

most common pesticides are long-lived[6] and are not detected in isolation. Some of these chemicals magnify each other's effect[7], and the effect of the total cocktail on ecosystem function and communities is more important and the focus of current research. The scale of the risks posed by long-term exposure to combinations of pesticides, in addition to other pressures, is not yet quantified but is not nil.

Further lines of evidence that farm water run-off reaches the GBR comes from studies on sediment and nutrient run-off at individual farm scale, and linking this with monitoring data and modelling results at catchment and GBR scale[8]. Collaborative on-farm studies confirm that sediment and nutrients can end up in rivers through erosion and fertiliser application[9]. Combined findings from the GBR Catchment Loads Monitoring and Modelling, using this farm-scale information, demonstrate that end-of-river loads of sediment and nutrients are now higher than pre-European loads[10]. Similarly, combined findings from the Inshore Marine Monitoring Program[11] and a whole-of-GBR model linking catchment to reef (i.e. eReefs[12]), further support that these elevated levels of sediment and nutrients are being delivered to inshore GBR waters[13]. Finally, the detection of changes in freshwater, sediment and nutrient runoff signals in coral cores dating back to pre-European times provides additional lines of evidence that farm water run-off has been reaching the GBR.

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[6] Mercurio et al (2016) Degradation of herbicides in the tropical marine environment: Influence of light and sediment. *PLoS ONE***11**, e0165890.

[7] Devlin et al (2015) Advancing our understanding of the source, management, transport and impacts of pesticides on the Great Barrier Reef 2011-2015. A report for the Queensland Department of Environment and Heritage Protection. Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University, Cairns, 134pp.

[8] Bartley et al (2017). 2017 Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition. Chapter 2: Sources of sediment, nutrients, pesticides and other pollutants to the Great Barrier Reef. Reef Water Quality Protection Plan Secretariat, Brisbane, Australia, p. 77.

[9] Eberhard et al. (2017) Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 4: Management options and their effectiveness. State of Queensland, 2017.

[10] Bartley et al (2017) Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 2: Sources of sediment, nutrients, pesticides and other pollutants to the Great Barrier Reef. State of Queensland, 2017; Kroon et al. (2012) River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon. *Marine Pollution Bulletin* **65**:167-181.

[11] Gruber et al (2019), Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2017-18. Report for the Great Barrier Reef Marine Park Authority (and annual reports from previous years); Shaw et al (2010) Monitoring pesticides in the Great Barrier Reef. *Marine Pollution Bulletin*, **60**, 113-122

[12] Steven et al (2019) eReefs: An operational information system for managing the Great Barrier Reef. *Journal of Operational Oceanography* **12**, 1-17.

[13] Schaffelke et al. (2017) Scientific Consensus Statement 2017. Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 1: The condition of coastal and marine ecosystems of the Great Barrier Reef and their responses to water quality and disturbances. State of Queensland, 2017.

Does this runoff then affect the health of the GBR? One of the most pronounced and enduring effects of increased river loads of sediment and nutrients is reduced water clarity, particularly in inshore waters. In clear water, sunlight can penetrate to coral reefs and seagrass beds and photosynthesis is not impaired. Observations from satellites[14] and field measurements[15] have clearly shown variations in reef water clarity related to river runoff. There is both an acute effect from immediate turbidity in river plumes and longer-term effects (over many months) resulting from subsequent phenomena like sediment resuspension and transport as well as increased phytoplankton growth (which may become blooms). These effects can occasionally be seen on the outer reef as well. Even longer-term effects may arise from nutrient levels, as increased nutrients may also play a role in initiating crown-of-thorns starfish (CoTS) which may start a year of more after the right conditions occur and may mast for many years (see Box).

Crown-of-Thorns starfish and land-based run-off

Population outbreaks of the native Crown-of-Thorns Starfish (CoTS) are a reoccurring phenomenon on the GBR and cause significant losses of living coral cover. Four major outbreaks have been observed since the early '60's, all starting north of Cairns and spreading south. Nutrient enrichment is one of the hypothesized causes of CoTS outbreaks but may act in concert with other drivers. As a highly fecund species, COTS outbreaks are inevitable but there is evidence from long-lived corals that outbreaks must have been significantly less frequent in the past. Currently, this starfish erupts in mass outbreak episodes each time that there is sufficient coral cover in the initiation area to sustain large spawning populations. A more productive lagoon enhanced by land-based nutrients is the most likely reason for a faster rebound of the founding populations of coral-eating starfish.

Direct effects have been well studied by exposing key species to biologically and ecologically relevant stressors[16] and by investigating reef heath along water quality gradients from inshore to offshore[17], and along the reef[18] (reflecting regional differences linked to rivers, their catchments and dominant farming practices). Links between health and exposure to reduced water quality is evident in either acute impacts on physiology[19] or chronic changes like reduced water clarity [20].

[14] Fabricius et al (2016) Changes in water clarity in response to river discharges on the Great Barrier Reef continental shelf: 2002–2013. *Estuarine, Coastal and Shelf Science* **173**, A1-A15,

[15] Gruber et al (2019), Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2017-18. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville (and multiple annual reports from previous years)

[16] Humanes et al (2017) Effects of suspended sediments and nutrient enrichment on juvenile corals. Marine Pollution Bulletin 125, 166-175.

[17] Jupiter et al (2008) Linkages between coral assemblages and coral proxies of terrestrial exposure along a cross-shelf gradient on the southern Great Barrier Reef. *Coral Reefs* **27**, 887-903.

[18] Uthicke et al (2010) Effectiveness of benthic foraminiferal and coral assemblages as water quality indicators on inshore reefs of the Great Barrier Reef, Australia. *Coral Reefs* **29**, 209–225.

[19] Kroon et al (2014) Effects of atrazine on endocrinology and physiology in juvenile barramundi, *Lates calcarifer* (Bloch). *Environmental Toxicology & Chemistry* **33**, 1607-1614; Flores et al (2013) Phytotoxicity of four photosystem II herbicides to tropical seagrasses. *PLOS ONE* **8**: e75798.

[20] Ceccarelli et al. (2019) Long-term dynamics and drivers of coral and macroalgal cover on inshore reefs of the Great Barrier Reef Marine Park. *Ecological Applications* 10.1002/eap.2008

To summarise, there is a water quality gradient across the GBR which has been accentuated by farming and other land-based activities. Coastal and mid-shelf reefs, particularly those close to large rivers more frequently experience exposure to river plumes of dissolved and suspended material, and resuspension of this material by wind, waves and tides. Diminished water quality impacts the health of corals, seagrass and other key ecosystems. Offshore reefs are less exposed to this material and its effects but they are not immune.

ToR (b) Connectivity of farm practices throughout the Great Barrier Reef catchment areas to water quality outcomes in the Great Barrier Reef Marine Park

Current farm practices throughout the GBR catchment area are connected to water quality outcomes in the Great Barrier Reef Marine Park. Agricultural development has altered river flows, sediment and nutrient loads around the world and the Queensland reef coast is no different[21]. Most GBR catchments and floodplains have been extensively modified, including the construction of dams, barrages and weirs, water extraction from aquifers and groundwater reservoirs, Other major modifications include large scale clearing of vegetation including riparian and wetlands disturbance by non-native livestock, and extensive use of fertilisers and pesticides. These modifications have supported farming, mining and urban development, among other demands with more than 70% of the catchment area adjacent to the GBR now supporting agricultural land uses[22]. These changes in land use and management have altered the quality of coastal water in the GBR.

In addressing the impacts of farm water runoff on the health of the GBR (ToR (a), above) we also presented evidence of the connectivity of farming practices to GBR water quality, including the presences of historic and contemporary pesticides in GBR waters, remote and in-situ observations of water turbidity and links to river flows, and simulation models that are informed by observations and experimental data. The lines of evidence present a compelling case that GBR water quality is connected to, and influenced by, water and material discharged from rivers that includes inputs from agriculture and other land uses.

Summary

In conclusion, AIMS considers that broadscale changes in land use and management in the GBR catchment since European settlement have degraded the quality of coastal water in the Great Barrier Reef. These changes have resulted in increased sediment, nutrient and pesticide runoff into rivers, and ultimately into the GBR Lagoon. The Institute endorses the 2017 scientific consensus that broad-scale farming practices are the main driver of these changes. These changes affect light-dependent organisms in shallow-water coastal ecosystems through changes in water clarity. This has produced detectable historical change

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[21] Bartley et al (2017). 2017 Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition. Chapter 2: Sources of sediment, nutrients, pesticides and other pollutants to the Great Barrier Reef. Reef Water Quality Protection Plan Secretariat, Brisbane, Australia, p. 77.

[22] Waters et al. (2014) Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR, Technical Report, Volume 1, Queensland Department of Natural Resources and Mines, Toowoomba, Queensland (ISBN: 978-1-7423-0999).

in some inshore communities and continues to impede the ability of modern assemblages to tolerate or recover from other disturbances, such as increasing sea surface temperatures, severe tropical cyclones, and CoTS outbreaks. The good news is that the AIMS Marine Monitoring Program (MMP) shows that inshore reefs retain resilience and can be expected to respond positively to improved water quality.

Further Reading and Evidence

There is substantial evidence and knowledge about the quality of water on the GBR, its drivers and how the GBR responds. We commend the following to the Inquiry for their breadth and currency.

1. Waterhouse et al (2017) Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition, - and supporting chapters
2. Bainbridge et al (2018) Fine sediment and particulate organic matter: a review and case study on ridge-to-reef transport, transformations, fates, and impacts on marine ecosystems. *Marine Pollution Bulletin* **135**, 1205-1220.
3. Kroon et al (2016) Towards protecting the Great Barrier Reef from land-based pollution. *Global Change Biology* **22**: 1985-2002.

Appendix AIMS Science Quality and Integrity

AIMS approach to science is to adopt best practices where they are available and integrate different disciplines to develop knowledge and understanding about one of the world's largest and most complex ecosystems, the GBR. This has involved observations and measurements over decades - such as through the AIMS Long Term Monitoring Program and Inshore Marine Monitoring Program, of the health of reefs in inshore waters influenced by river runoff to mid- and offshore reefs - complemented by a deeper look into the past using coral cores which provide a continuous record going back over 400 or more years. These records capture many of the change events in the GBR marine environment.

Like the environment we study, our approach also changes and adapts. The scientific method requires us to continually update, challenge, improve, and refine because science does not produce black and white answers. It is a continual process of developing hypotheses, collecting empirical data, refining interpretations, challenging results, and recognising uncertainty and reducing it where we can and accounting for it in our advice.

Therefore, our understanding of the marine environment and its ecology is continually improving as we collect more data, observe long-term trends and identify drivers of variability and change, and as new technologies allow us to peer more deeply into underlying processes and monitor trends at larger and smaller scales than before.

Thus, we are continually refining our approaches in all the research elements (observation, experimentation and modelling), by filling in our knowledge gaps and increasing the scope, scale and timespan of our research efforts.

Maintaining AIMS' high quality and scientific rigour

AIMS is committed to research of the highest quality and integrity. We underpin our science (from the field to the laboratory to the modelling) with extensive quality assurance procedures married with measures to ensure the highest scientific integrity. These include (but are not limited to) the following key measures:

- *a.* Requiring our scientists to follow the *Australian Code for the Responsible Conduct of Research* and to comply with our own internal research code of conduct policies in order to ensure our objectivity.
- *b.* Subjecting all reports and papers to rigorous internal peer and supervisor review.
- *c.* Participation in the international peer review publication and acceptance process. This is the world-wide standard practice used in all science publishing.
- *d.* An organisational credo of continuous improvement, including the use of red-on-blue challenges involving internal and external experts.
- *e.* Five-yearly complete organisational science reviews by an independent panel of international experts.