Australian Government
Australian Institute of Marine Science
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14 November 2016

Christine McDonald
Secretary
Senate Standing Committees on Environment and Communications
PO Box 6100
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Canberra ACT 2600

Dear Christine

The Australian Institute of Marine Science (AIMS) is a Commonwealth statutory authority established under the *Australian Institute of Marine Science Act 1972*. As Australia's leading tropical marine research agency, AIMS conducts innovative, world-class scientific and technological research to support sustainable growth in the use, and effective environmental management and protection of, Australia's tropical marine estate.

Recently AIMS has been working to assess the extent of coral bleaching caused by warming ocean temperatures around Northern Australia. In conjunction with the ongoing work of the Institute to understand the impacts of climate change and other environmental stressors on tropical marine ecosystems, this puts AIMS in a strong position to provide advice to the inquiry into current and future impacts of climate change on marine fisheries and biodiversity.

With respect to the Terms of Reference of the inquiry, AIMS provides specific comments below relating to (i) the impact of recent changes in ocean temperatures on marine ecosystems; (ii) the effect of recent ocean chemistry changes (increasing acidification) on marine ecosystems; and (iii) the effect of extreme weather events on marine ecosystems – including the role these play in benefiting marine pest species.

Specific comments

(i) The impact of recent changes in ocean temperatures on marine ecosystems

Recent changes in ocean temperatures

As the global climate system warms, due to the increasing concentrations of atmospheric greenhouse gases, so do the tropical oceans – home to tropical coral reef ecosystems. Sea surface temperatures around Australia are warming and this warming is projected to continue into the foreseeable future – the magnitude of future warming being dependent on global greenhouse gas mitigation strategies.

Observed warming of Australia's tropical coastal waters has already resulted in climate zones shifting southwards along the east and west coasts. Over the period 1880-2015 when global average land and sea temperatures warmed by 0.88°C, surface water temperatures of the GBR warmed by 0.78°C (based on analyses of publically available global temperature data sets).

El Niño-Southern Oscillation events are the major source of natural, inter-annual climate variability with significant impacts on Australia's tropical terrestrial and marine environments. During La Niña events, while northeast Australia tends to experience above-average rainfall and tropical cyclone activity (for example as happened in 2010-2011), waters off southwestern Australia tend to be unusually warm due to strengthening of the Leeuwin Current. Sea-surface temperature reconstructions from massive corals extending back to the late 18th century show that such 'marine heat waves' are becoming more frequent.

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El Niño events are typically associated with a weaker summer monsoon and unusually warm late summer water temperatures along the Great Barrier Reef. This is the time of year when tropical corals are most at risk of exceeding their thermal optimum due to unusually warm sea surface temperatures and may bleach.

Mass coral bleaching occurred on the Great Barrier Reef during the 1997-1998 and 2015-2016 El Niño events. The magnitude of the thermal stress during these recent El Niño events was, however, compounded by the demonstrated increase in baseline water temperatures (as a result of global warming).

Record warm sea surface temperatures were observed on the Great Barrier Reef in March, April and May 2016 and on northern reefs of Western Australia (10.5-14.5°S) from January to July 2016.

The extent of effects of rising temperature on a given marine species will be directly related to several factors including, but not limited to:

- current species distribution and thermal thresholds
- generation time and capacity to adapt/evolve to changing conditions
- habitat dependence (e.g. obligate coral reef dwellers), and
- mobility (i.e. capacity to emigrate to new locations)

Species that are at their thermal limit have two main options: evolve to cope with the temperature, or move to an area where temperatures are more suitable. Movement to new areas would result in range shifts in distribution. Species that have low mobility or rely on specific habitats for survival may or may not be able move to new or more suitable habitats. Sessile species such as marine plants, corals and other invertebrates obviously cannot move. In these cases, if species cannot evolve quickly enough their distribution range may shrink as populations are no longer viable in areas beyond their thermal tolerance.

For corals specifically, higher temperatures will reduce the intervals for recovery after disturbances such as coral bleaching, by causing reduced calcification rates of corals and coral reproduction for several years.

The effects of recent bleaching on reefs of Western Australia

Western Australia (WA) has hundreds of coral reefs spanning tropical to subtropical latitudes. Most WA reefs have few local pressures but are increasingly exposed to elevated water temperatures. Since monitoring on some reefs commenced in the early to mid-1990s, coral bleaching has increased in frequency and severity.

As with many Indian Ocean reefs, the first record of severe bleaching (defined as affecting the majority of corals on an individual reef) and mortality of WA reefs was in 1998, with the greatest impacts being at the oceanic reefs (Scott, Seringapatam, Christmas Is). In the following decade (1998-2008), there were no records of severe bleaching, but minor bleaching events were documented at Christmas Island, Cocos-Keeling, the Rowley Shoals and at Ashmore reefs. In the summer of 2010/11 a 'marine heatwave' caused moderate or severe bleaching at several reefs across WA, and affected other ecosystems and fisheries. Since 2011, moderate or severe bleaching has been observed during most years on one or more WA reefs, including the oceanic reefs, and/or those in the Pilbara, Ningaloo, the Abrolhos Islands and Rottnest Island.

Although the patterns are not conclusive, the reefs at Ningaloo and further south seem most likely to bleach during strong La Niña conditions, as during the 2010/11 'marine heatwave', whereas the oceanic reefs and those in the Kimberley seem most likely to bleach during strong El Niño conditions.

The strong El Niño conditions during the recent summer of 2015/2016 caused the most severe coral bleaching event on record. Reefs at Christmas Island and Scott and Seringapatam reefs were severely bleached, while minor bleaching was documented at Cocos Keeling, Ashmore reefs and at the Rowley Shoals. Unlike the 1998 bleaching, deep-water corals (20-50m) were also affected.

Recent surveys (October 2016) at Scott and Seringapatam reefs confirmed that most of the bleached corals had died. Bleaching was also recorded for the first time by researchers and indigenous communities at the inshore reefs of the southern Kimberley, while indigenous communities reported coral bleaching for the first time in northern Australia; mass-mortality of fish and of mangrove areas also coincided with the temperature anomalies.

The frequency and consequences of coral bleaching in WA are best documented for Scott and Seringapatam reefs. The loss of 80% of corals from these reefs during the 1998 bleaching event was followed by recovery over 15 years, with the exception of the corals that were decades to centuries old when they died. This recovery was attributed to the favourable local conditions and lack of chronic pressures (e.g. poor water quality, overfishing), in contrast to other Indo-Pacific reefs that had not recovered from the 1998 bleaching.

At present we cannot predict how the WA reefs affected by the 2016 heat event will recover, i.e. over what time period and which species. As yet, there has not been a mass-bleaching of comparable severity at the other oceanic reefs (Cocos Keeling, Rowley Shoals, Ashmore reefs), at the inshore reefs of the Kimberley, or at Ningaloo reefs, but all have experienced moderate bleaching events in recent years

Severe bleaching and local pressures have affected some reefs in the Pilbara. Sub-tropical (Abrolhos Is.) and temperate (Rottnest Is.) reefs have also bleached in recent years, suggesting coral bleaching is a consequence of relative increases in ocean temperatures and lower latitudes do not provide a refuge. Further increases in ocean temperatures in the next decade will likely cause severe coral bleaching and mortality on many reefs across all regions of WA.

The effects of recent bleaching on the Great Barrier Reef

The 2016 global coral bleaching event has significantly affected the composition and diversity of benthic reef communities of the GBR. This stress event was caused by the record breaking ocean temperatures that exceeded typical summer maxima for prolonged periods of time.

Coral bleaching was observed across the entire length of the GBR, however the most severe levels of extensive bleaching and mortality has occurred in the Far Northern GBR, from Port Douglas to the Torres Strait Islands. In this region of the GBR, sensitive coral species were killed or were dying in March and April 2016, and tolerant long-lived century-old massive coral species – that typically resist thermal stress – were severely bleached and subsequently recorded as dead during repeated surveys in September 2016.

There have now been three documented mass coral bleaching events on the GBR in the past 20 years (1998, 2002 and 2016) and the severity of each subsequent mass bleaching event has increased, with the 2016 event the most severe on record. The number of reefs that were scored as severely bleached was more than four times higher than in the 2002 and 1998 observations. The frequency and severity of major, widespread coral bleaching events worldwide is expected to increase as climate change increases ocean warming.

The full extent of mortality from the 2016 GBR bleaching will be determined by assessing the loss of live coral cover throughout the GBR Marine Park prior to the 2017 summer. Surveys are ongoing in September, October and November by AIMS, the Great Barrier Reef Marine Park Authority and James Cook University teams.

Effects of rising water temperature on fish and megafauna

Rising water temperature is likely to have a variety of effects on fish and megafauna species including behavioural, physiological and biological changes. The evidence base of climate change effects on these animals is still developing.

Rising temperature may have more profound effects on long-lived species (which are unlikely to evolve quickly enough to adapt to the change) or those requiring specific temperature cues as part of their life cycle. Changing temperatures could alter the timing or route of migrations and even alter sex ratios in populations. For example, the sex of marine turtles is dictated by sand temperature with females typically more common in nests in warm sands. Recent evidence has indicated female bias in hatchling production for several species – which could have long-term implications. Increasing temperatures at nesting beaches will continue to create female biased populations.

It is also possible that increasing temperatures will have implications for eggs and larvae of fish populations and the vulnerability of individuals to predation if movement or behaviours are slowed or altered in ways that increase predation risk. Biological changes may also extend to individual size. For example, some species may be smaller size in warmer water and growth rates may change. The extent of these effects will vary by species.

The overall effects of rising temperatures are that we are likely to see some species moving into areas not previously inhabited, and some species disappearing from areas currently inhabited. Changes in distribution will be coupled with a variety of behavioural and biological changes which will vary by species and location. Implications for marine fisheries will also vary with productivity in some species potentially increasing while others decrease.

(ii) The effect of recent ocean chemistry changes (increasing acidification) on marine ecosystems

Concentrations of carbon dioxide (CO_2) are rising rapidly in the atmosphere, due to the burning of fossil fuels and deforestation, and about 25% of this extra CO_2 added to the atmosphere is being absorbed by the oceans.

When atmospheric CO_2 dissolves in seawater, it first forms carbonic acid and triggers a cascade of other chemical changes. The concentrations of hydrogen ions increase and carbonate ions decline. In fact, the concentrations of hydrogen ions have already increased by 30% in the seawater compared with pre-industrial times. This change in the seawater chemistry is called "ocean acidification" (OA). The surface ocean pH has declined overall by about 0.1 so far, and is predicted to further decline by 0.2–0.4 by the end of this century.

Although some scientists had recognised more than 50 years ago that rising CO_2 concentrations would affect seawater chemistry this phenomenon has only recently emerged as an important knowledge gap in marine science, and has now become a global research priority.

The evidence base of how the ongoing changes in the seawater chemistry will affect marine ecosystems continues to develop. Experimental studies suggest ocean acidification will profoundly affect the physiology and behavior of some marine organisms. For example, ocean acidification makes it harder for some marine animals (especially corals) to form their shells and skeletons. A lower pH in the seawater seems to also lead to behavioural changes in fishes and invertebrates.

AIMS scientists are researching the effects of ocean acidification on coral reef organisms and ecosystems, using a number of complementary approaches.

Field research at unique CO_2 seeps in Papua New Guinea

AIMS researchers are studying three shallow volcanic carbon dioxide seeps (also known as 'CO_2 vents') in eastern Papua New Guinea, in Milne Bay Province, to observe how ocean acidification is affecting marine ecosystems, such as coral reef and seagrass meadows. The seeps provide a unique "window into the future" to study how tropical marine ecosystems may adapt and how organisms may acclimatize after life-long exposure to high CO_2.

The findings from this ongoing research demonstrated major and often surprising responses to OA in numerous ecological processes and organism groups, such coral reef, seagrass, sedimentary and demersal plankton communities, showing clear winners and losers in a high CO_2 world. For example, at reduced pH, reductions were observed in coral diversity, recruitment and abundances of structurally complex framework builders, and shifts in competitive interactions between taxa. Demersal plankton (a major food source for planktivorous corals and fish) is severely depleted in areas of high CO_2, partly due to altered reef structure. Crustaceans are rare at the seeps despite being physiologically highly CO_2 tolerant, as the high CO_2 reefs lacks structural complexity that determines habitat quality. The seeps in Papua New Guinea are in the same zoogeographic province as the GBR, making the results relevant for predicting likely responses of the GBR ocean acidification.

Studies of the carbonate chemistry in the Great Barrier Reef

For open oceans, changes in the carbonate chemistry from rising atmospheric CO_2 are relatively well understood. This is not the case in nearshore and shallow marine environments such as the GBR where conditions are more variable due to biological processes.

GBR carbon chemistry data show that on many reef flats strong day-night variation in these parameters exist, as well as differences between winter and summer. Measurements of the carbon chemistry at inshore reefs indicated a decreased ability of corals to produce their carbonate skeletons, compared to reefs further offshore. Using historical data from the 1980s, that study also suggested that OA conditions have advanced much faster on inshore reefs. These and other data have recently been included in an inshore carbon model by CSIRO, confirming the findings.

Controlled CO_2 enrichment experiments in SeaSim

To complement field studies, researchers at AIMS are undertaking controlled aquarium experiments in the National Sea Simulator (SeaSim) in Townsville, Queensland, to better understand the effects of ocean acidification on all life stages of marine organisms. They are also investigating the joint effects of ocean acidification and other pressures like warming and reduced water quality. The SeaSim also allows researchers to conduct long term ('multi-generational') studies in large mesocosms. This is important to study the potential for adaptation across generations, develop strategies for improving resilience ("assisted evolution"), and to identify opportunities for reef restoration (see further below).

Because of the importance in population replenishment, many experimental studies focused on reproduction and recruitment of corals and other invertebrates. For example, the microbiology of crustose coralline algae and reef biofilms, both important as settlement substrata for many invertebrates, substantially changed under temperature increase and OA conditions, leading to reduced coral settlement.

Other studies showed impairment of reproduction and development, and physiology of reef invertebrates including corals. SeaSim experiments and studies on CO_2 vents demonstrated that CO_2 enrichment benefits tropical seagrass species, but only in areas with sufficient light and good water quality. Other tasks demonstrated the effect of OA on boring sponges. For instance, production and bio erosion rates of a common tropical sponge increased under high CO_2 future scenarios.

(iii) The effect of extreme weather events (and changes in intensity/frequency) on marine ecosystems – including the role these play in benefiting marine pest species

Increasing frequency of high river flow events

High summer rainfall can lead to substantial inputs of low salinity freshwater (and associated terrestrial contaminants) into the GBR, as happened during the 2010-2011 La Niña event.

Although there are no clear long-term trends in average northeast Queensland rainfall (due to high natural inter-annual variability), evidence from luminescence records in long-lived massive coral skeletons (over the period 1648-2011) shows that such high flow events in the central GBR have become more frequent and more extreme since the late 19th century.

Three of the most extreme high river flow events since 1648 (in 1974, 1991 and 2011) have occurred within the past 45 years, and such freshwater plumes are reaching mid-shelf reefs more often than in the past.

Long-term warming of the ocean around Australia has been shown to increase the likelihood of record rainfall in north-eastern Australia, as occurred in early 2011. Additionally, a new reconstruction of eastern

Australia summer Palmer Drought Severity Index based on tree rings and coral records shows that 2011 was likely the wettest summer in coastal Queensland within the period 1500-2012.

Crown of Thorns (CoTS) response to flood years/water quality

The Crown-of Thorns Seastar (CoTS) is a natural predator of corals in the Indo-Pacific region, including the Great Barrier Reef. CoTS have been identified, together with cyclones, as a major cause of the 50% decline in coral cover on the GBR observed during the last 27 years. Since the 1960's, CoTS populations have erupted at approximately 15 year intervals with three major outbreaks recorded and a fourth now in progress on the northern GBR.

When CoTS occur in plague proportions they can reduce the living coral cover on a reef to a few percent. Research continues to reveal more factors playing a role in initiating and maintaining CoTS outbreak, which means that the prediction of the effects of climate change on these processes has a high uncertainty.

Although there is evidence for contributing factors such as reduction of natural CoTS predators, the current most widely accepted hypothesis is that primary outbreaks are promoted through increased nutrient availability, such as observed after significant flood events. This increases phytoplankton, the food source of the planktonic CoTS larvae, which in turn increases their survival, ultimately increasing likelihood of CoTS population outbreaks.

The hypothesis is based on research showing that CoTS larvae growing under increased phytoplankton concentrations grow faster, which has recently been corroborated, and on observations that outbreaks on the GBR follow major flood events that occur early in the wet season. A change in the magnitude and timing of floods due to climate change, as indicated in an analysis of long-term rainfall records, might result in changes to the frequency and/or severity of CoTS outbreaks. Sources of nutrients other than land runoff may also be important, such as shelf-break upwelling of nutrient-rich water, but these are not yet well enough understood to make any prediction of their potential to change, due to the effects of climate change.

An additional factor for CoTS outbreak initiation appears to be the higher retention of CoTS larvae in the area between Cairns and Lizard Island where all primary CoTS outbreak have been observed, during periods of reduced current velocities associated with neutral Southern Oscillation Index (SOI) phases. Predicted changes in climate variability might have, as yet unknown, flow-on effects on CoTS populations by affecting currents and connectivity.

The direct influence of rising temperature and ocean acidification on CoTS is still debated. Recent research indicated positive effects on early life stages of CoTS, such as increased larvae survival and growth of juveniles, and that CoTS have a high potential for adaptation to climate change. Conversely, in other studies, ocean acidification decreased fertilisation rates and reduced settlement induction by crustose coralline algae.

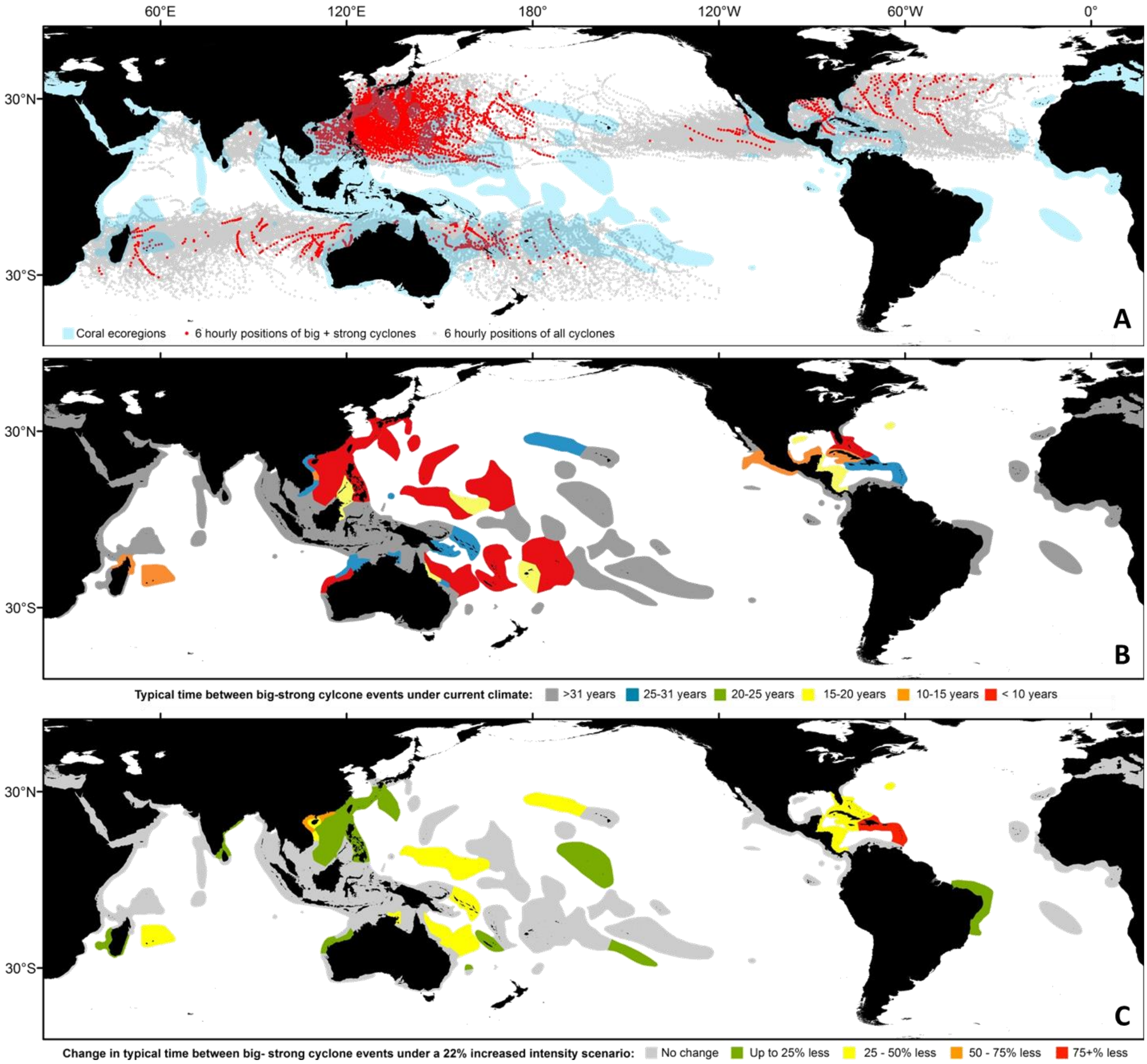
Implications for global coral reefs of projected increases in cyclone intensity

Coral reef communities are dynamic systems that are subject to a range of biophysical disturbances which kill the stony corals that provide the architecture and some of the productivity of reefs. There have always been tropical storms, and reef communities have recovered from them.

Many of the world's coral reefs are regularly exposed to tropical cyclones (Fig 1, grey and red dots on panel A). But not all cyclones are equal. Strong cyclones that are also big in size (Fig 1 – red dots on panel A) can damage reefs over a vast extent compared to smaller strong cyclones (400 km versus 60-150 km), because the high winds extend over a much greater area of water, maximising the development of damaging seas and swell.

Fig 1 - Panel B shows that reefs in the NW Pacific, parts of the Caribbean, central Western Australia, and the Coral Sea (shown in red) can currently expect to be hit by these particularly destructive cyclones at least once per decade. For the central GBR, this is every 15 years, and for the rest of GBR every 25+ years.

Average cyclone intensity is predicted to increase by 1 m/s per decade as the climate warms. For the southern GBR, currently hit by big and strong cyclones every 25+ years – this would change to every 6 to 12 years. For Western Australia's coast from the Pilbara to the southern Kimberley, this would change from a hit every 10 years to one every 7.5 years.



Cyclones can be a major driver of reef ecological condition in the GBR and the Caribbean. The extent of development of coral communities on a reef depend on the time since disturbances such as cyclones, on the intensity of disturbance (extent of damage), and the rate of recovery through recolonisation by coral larvae and through regrowth of coral fragments. Thus if disturbances of any kind become more intense (requiring more extensive recolonisation and regrowth) or more frequent (allowing less time for recovery) or the rate of recovery is slowed (for instance through adverse effects of poor water quality on larval survival) then the reef community will be degraded from its former state. The predicted increase in intensity of cyclones, as well as increased frequency of bleaching conditions will increase the overall rate of disturbances.

Loss of coral structure, especially after cyclones, affects a wide range of reef organisms that use corals for shelter. Coral cover provides surface complexity and is associated with greater abundance and diversity of fish communities. Two recent studies have indicated positive effects of protection from fishing on cyclone impacted reefs. Among reefs that were affected by TC Hamish, the biomass of coral trout declined after the cyclone on reefs that were open to fishing, while there was no substantial change in biomass on reefs that were protected from fishing. A 12 year study of recovery of both benthic communities and fish communities on GBR reefs following disturbances found evidence that time to recovery following storms was 9% shorter for benthic communities and 18% shorter for fish communities on reefs that were closed to fishing compared with reefs where fishing was permitted.

(iv) Potential solutions

This submission has provided an overview of the evidence and provided AIMS' interpretation on some of the environmental pressures on marine ecosystems and biodiversity, which have increased or are predicted to increase due to the effects of the changing climate.

It is essential to address the root cause of the changing climate. Australia's national commitment to significantly reducing greenhouse gases by 2030 is a key part of this.

It is also essential to address the other (and related) pressures on the reef ecosystems. In the case of Australia's Great Barrier Reef, the considerable efforts being undertaken to implement the Australian and Queensland governments' Reef 2050 Long Term Sustainability Plan (Reef 2050) will help.

However, these efforts, individually and collectively, are unlikely to be sufficient to protect marine ecosystems from the impacts of projected (and inevitable) increases in ocean temperature over the next few decades.

- Oceans will continue warm by a further 0.5°C over the next 30 years, regardless of whether we reduce emissions. As a result, we are "locked in" to an increased risk of bleaching events such as the one experienced this year. Further, if the global community fails to reach the 1.5°C Paris target by 2030, the GBR is at even greater risk.
- The Reef 2050 Plan sets ambitious targets for GBR water quality improvements. However, based on performance over the last decade significant uncertainty remains around our ability to achieve these water quality improvement targets over the next 30 years

Thus, in order to complement the management and conservation efforts that are focused on avoiding or minimising local pressures, for example those specified in the Reef 2050 Plan, and in recognition of the realities of latent warming in the ocean system, there is an increasing global focus on the active facilitation of ecosystem 'recovery, rehabilitation and restoration'.

Developing the capability to restore and rehabilitate stressed or degraded GBR ecosystems will provide a critical insurance against ocean warming continuing to increase over the coming decades, and also provide a way of assisting the recovery of reefs hit by cyclones and CoTS.

Reef restoration and recovery

'Protecting and restoring' is a key concept in the Reef 2050 Plan Actions. However, compared to terrestrial systems, restoration activities in coastal and marine environments are relatively new and are a global focus of active research and development with many small-scale trials underway. To date, there has been limited active restoration and remediation in the Great Barrier Reef Region, especially the Marine Park (but see the Raine Island turtle recovery project, involving activities ranging from better monitoring of turtles to earthworks and fencing to protect nesting sites: https://www.ehp.qld.gov.au/wildlife/animals-az/green-turtles-raine-island.html).

Options and techniques for the recovery, rehabilitation, repair and restoration of coral reefs range from coral propagation and "gardening" to "assisted evolution" (i.e. the development of corals with enhanced stress tolerance through breeding techniques which accelerate naturally occurring processes of adaptation).

There are critical knowledge gaps for the actual large-scale implementation of these techniques, which requires careful decision-making and planning and long-term commitment.

AIMS scientists currently actively study 'assisted evolution' (AE) as one technique for a potential future application in the recovery and restoration of coral reefs.

AE is the acceleration of naturally occurring evolutionary processes to enhance certain traits, in this case environmental stress tolerance and climate resilience. Various AE approaches have been widely used on the land for the improvement of commercial species, including crop species, wood trees and livestock. AE approaches include selective breeding and more recently, the manipulation of the microbial communities associated with plants and animals.

AIMS scientists have commenced a series of experiments to determine the feasibility of developing corals with enhanced stress tolerance using AE, while at the same time initiating a public dialogue on the risks and benefits of this approach. Researchers have demonstrated that in some cases corals have naturally adapted or acclimatised to elevated temperature or have become more tolerant to coral bleaching over successive bleaching events. AE techniques aim to promote and enhance this natural adaptive ability to increase reef resilience in the face of current and future climate change.

Further advice

Should any of these points require further clarification, please don't hesitate to contact me on
or at

Yours sincerely

John Gunn
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Appendix A: Scientific references

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