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Reef 2050 Plan Review Options

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Contents

1 Preface

This report supplements the main report on Reef 2050 Plan Review Options. It documents the in-depth results of the gap analysis and the analysis of GBR change trajectories summarised in the main report. Details of the methods used are provided in the main report and therefore only summarised here. In essence the main approach comprised desktop reviews of published scientific journal papers, reports, and documents pertaining to deliberations of the main Reef 2050 Plan advisory bodies (RIMReP Steering Committee; Independent Expert Panel; Reef Advisory Committee).

The purpose of this document is to provide access to the material that provided the base for selecting the initial review options, and for determining the scope and design of the midterm review. It also provides the background against which the review team formulated a set of recommendations in support of foundational actions that are likely need to be undertaken in preparation for a more substantive review of the Reef 2050 Plan in 2020.

This appendix report is divided into two main chapters. Chapter 2 presents the key results of the gap analysis, which is structured around the seven themes of the Reef 2050 Plan. Hence this chapter largely takes a plan-centric perspective with the exception of two additional themes relating to Governance and Traditional Owners. Within each theme, we follow a similar breakdown, initially providing a synopsis of what the Reef 2050 Plan sets out under each theme, followed by a high level assessment of gaps and opportunities to improve the plan, as well as providing commentary on changes since the plan was launched in 2015. This is then synthesised into implications for the midterm and the 2020 review processes.

Chapter 3 documents the analysis carried out to determine the range of future change trajectories potentially affecting the GBR. The approach of this analysis is based on the Drivers, Pressures, State, Impact and Response (DPSIR) framework used by the GBRMPA. It forms the base of the Outlook reports as well as being the core framework around which the Reef Integrated Monitoring, Modelling and Reporting Program (RIMReP) is being designed.

The DPSIR framework does not readily translate to the Reef 2050 Plan theme based structure. Hence the review team saw merit in juxtaposing both perspectives, although this does lead to some overlap of results. The complementarity of both approaches not only enables us to draw key conclusions with more confidence, but the trajectories analysis, being based on the DPSIR, is likely to also provide direct guidance to the final RIMReP design stages.

2 Gap Analysis of Reef 2050 Plan

2.1 Ecosystem Health and Biodiversity[1]

Ecosystem Health and Biodiversity are two of the overarching themes at the core of the Reef 2050 Plan's Outcomes Framework. Understanding how environmental drivers and pressures represent risks to ecosystem health and diversity, and what actions can alleviate those risks, will be key to ensuring the Plan can deliver against objectives (by 2035) and ultimately deliver outcomes (by 2050).

In this gap analysis, these themes are combined as they are functionally connected and are both central to many GBR values. For example, the Outstanding Universal Value (OUV) of the GBRWHA is tightly linked to both Ecosystem Health and Biodiversity. Specifically, criteria 9 and 10 for determining OUV are underpinned by healthy ecosystem processes as well as biodiversity. Also, for the purpose of policy and management strategies, achieving biodiversity is in many respects contingent on the ability to achieve ecosystem health.

Context

Ecosystem Health

While ecosystem health is referred to as a key Reef value, it is not defined directly in the Reef 2050 Plan. However, the Plan does offer a more operational proxy for ecosystem health: resilience. This is useful because managing for resilience (and thereby health) means helping the system absorb shocks, recover from disturbances, and adapt while maintaining key functions (Gunderson 2000, Mumby et al. 2014).

However, for a Plan that fundamentally aims to support ***resilience*** to sustain ***ecosystem health and diversity*** (and thereby to keep the Reef in good ***condition***), the causal links between environmental drivers/pressures and these key performance indicators are vague in the Reef 2050 Plan. This is partly due to the complexity of GBR ecosystems and the problem of disentangling cumulative impacts. To be able to set meaningful targets for environmental indicators and develop specific expectations for ecosystem condition (and health and resilience) at those targets, the Review should tighten cause-and-effect relationships for key ecosystem types (coral reefs, seagrasses, mangroves). This gap analysis proposes avenues to address this below.

Biodiversity

Biodiversity is an indicator of ecosystem resilience (Oliver et al. 2015) and, by extension, health. A highly diverse and species-rich coral reef is one where processes that reassemble the ecosystem after disturbances are (at least partially) intact and where multiple species share functions that underpin resilience (Nyström 2006, Cheal et al. 2013). Cumulative impacts that lower resilience will by extension threaten biodiversity. Conversely, maintaining key functions and key species are critical for sustaining biodiversity (Nyström et al. 2008). Importantly, maintaining biodiversity is critical for supporting ecosystem services in the ocean in general (Worm et al. 2006) and for the GBR in particular (Deloitte Access Economics 2013).

[1] Ken Anthony (AIMS)

Again, while the Reef 2050 Plan demonstrates good intentions to protect biodiversity by supporting resilience, it is unclear how specific actions will in fact contribute to protecting biodiversity given risks and uncertainty under global environmental change. The Review will be an opportunity to clarify the uncertainty around these cause-effect-relationships and produce more realistic expectations for biodiversity given environmental scenarios and management actions.

How does the Reef 2050 Plan aim to achieve outcomes for Ecosystem Health and Biodiversity?

The Reef 2050 Plan proposes a set of mechanisms that can help deliver outcomes for ecosystem health and biodiversity. These include *Cumulative Impacts Guidelines,* a *Net Benefit Policy, Reef Integrated Monitoring and Reporting Program* (RIMReP) and *Reef Recovery Actions*. While these initiatives all can and will inform policy and management actions that work in the ***direction*** of improving ecosystem health, the ***extent*** to which they can effectively ensure ecosystem health and biodiversity are protected under different scenarios remains unclear.

A specific objective in The Reef 2050 Plan for ecosystem health (*EH03*) states that "*Trends in the condition of key ecosystems including coral reefs, seagrass meadows, estuaries, islands, shoals and inter-reefal areas are improved over each successive decade.*" Give recent coral bleaching events and climate change projections under intended commitments to mitigation globally (Rogelj et al. 2016) , a question is whether proposed actions in the Reef2050 Plan (*Supporting Traditional Management*, *Protecting and Restoring*, and *Reducing Impacts*) can still achieve that objective? If not, does the portfolio of actions under Reef 2050 need to be revised or expanded? While all proposed actions to restore ecosystem health and help protect biodiversity are valid, the Review should explore whether they need to be complemented by additional actions to be able to achieve objectives.

The importance of resilience support as a management approach to aid ecosystem health and biodiversity is laid out in several places in the Reef 2050 Plan (including in the specific actions in Section 4.5), but how such resilience support is produced is often unclear. Supporting recovery between disturbances is a proposed avenue in the Plan, but mechanisms to achieve this at scale is limited to actions such as no-take areas, special management areas, water quality improvements and CoTS controls. Under frequent and/or severe disturbances outside of management control, such support of recovery may be insufficient or impossible (Anthony et al. 2015). Here it will be important for the Review to provide deeper insight into the scope as well as limitations of the Reef 2050 plan in supporting resilience under different circumstances using both conventional and new approaches.

Because GBR ecosystems are complex, and processes and species are interconnected and interact in their responses to pressures and management interventions, the Review should clarify pathways to impacts informed by at least qualitative but ideally quantitative models (Dambacher et al. 2003, 2009, Fulton et al. 2011, Marzloff et al. 2011, Anthony et al. 2013). This approach could produce more realistic expectations for actions that can deliver against Reef 2050 Plan objectives. For example, recent data on the impacts of warming events on reef resilience has now improved our understanding of how climate change might impact on the GBR and how it influences management options. As a consequence, the assumption that effective control of Crown-of-Thorns Starfish (CoTS) can turn the negative trend in coral cover into a positive one may no longer be valid under a scenario of high bleaching risk (Anthony et al. 2017a, 2017b, Hughes et al. 2017a). While regional and local actions to improve water quality, reduce impacts of CoTS and manage fishing may still contribute to supporting coral reef resilience (Fabricius 2011a, Emslie et al. 2015, Mellin et al. 2016), their ability to influence outcomes may be reduced (see also section 3). The Review will thus be an opportunity to clarify the relationships between likely environmental scenarios, predicted impacts on ecosystem resilience (and as a consequence, dynamic condition) and the effectiveness with which management interventions can indeed improve ecosystem resilience, protect biodiversity and thereby sustain key ecosystem values.

What has happened since Reef 2050 Plan and gaps identified

Since the Outlook report was published in 2014 and Reef 2050 Plan in 2015, the GBR has been subjected to two severe bleaching events in 2016 and 2017, the first back-to-back events on record (Hughes et al. 2017b). The 2016 event affected 90% of reefs on the GBR, and led to widespread damage of reef habitats in the northern section (see Figure 10 in Chapter 3). In 2017, large areas of the central section bleached followed by tropical Cyclone Debbie, both exacerbating the damage done in 2016 (Australian Institute of Marine Science 2017). These events have led to large-scale loss of critical reef habitats in the northern and central sections, with likely temporary consequences for reef biodiversity. The extent to which coral habitats can recover and the associated fauna reassemble will depend on two key factors:

(1) the time window until the next major acute (pulse-type) disturbance, for example a cyclone, CoTS outbreak or a bleaching event (Ortiz et al. 2014); and

(2) the extent and intensity of chronic (press-type) disturbances, such as reduced water quality (De'ath et al. 2008, Fabricius 2011b) and elevated mean temperatures suppressing recovery rates (Anthony et al. 2015) during that time window.

While ocean acidification has lowered the rate of reef calcification by around 7% on the southern GBR (Albright et al. 2016) significant impacts of ocean acidification on growth, repair and recruitment processes are mainly predicted for the longer term (Kleypas et al. 2006, Albright and Langdon 2011).

Outlooks for cumulative impacts from climate change (cyclones, bleaching and ocean acidification) on the resilience and consequently ecosystem health and biodiversity of GBR reef systems between now and 2050 will in part be a function of the Representative Concentration Pathway (RCP) (Moss et al. 2010, Schleussner et al. 2016). However, even if global warming is kept within 1.5^{o}C above preindustrial levels (RCP 2.6, van Vuuren et al. 2011), GBR surface waters are predicted to warm another 0.4 ^{o}C in the coming decades (see Chapter 3). Because key habitat-building coral species already live close to their upper thermal limits (Ainsworth et al. 2016), even mild warming would mean more frequent bleaching events and consequent damage to reefs and species.

Other GBR ecosystems such as seagrass also demonstrate sensitivity to climate change (Waycott et al. 2009, Cullen-Unsworth and Unsworth 2016) and the biodiversity associated with healthy seagrass meadows could equally be at risk under extreme warming events. Lastly, mangroves, which also support a diverse fauna (Ellison 2008) have recently demonstrated sensitivity to climate change, in particular the alignment of heat and low precipitation (Duke et al. 2016). This new knowledge around the sensitivities of seagrasses and mangroves can be used in the Review to update policies and management strategies for these ecosystems.

Recent assessments of the likelihood of keeping global warming below 2°C based on Intended Nationally Determined Contributions to mitigation, however, indicate that warming is more likely to approach 2.6 - 3.1°C (Rogelj et al. 2016). The consequence of such a scenario will be frequent exceedance of the thermal threshold of many reef-building species on the GBR and likely dramatic changes to species compositions on coral reefs (Graham et al. 2014) and potentially other ecosystems (Walther et al. 2002). These new circumstances can be used in the Review to assess to what extent different climate change scenarios have now changed the scope for Reef 2050 Plan to deliver against objectives using conventional means. Here, a discussion of the role of new interventions including emerging technologies in ecosystem restoration could inform what management strategies might be most effective under continued climate change (Anthony et al. 2017a).

Fisheries species are also likely to be sensitive to continued warming. Results of a recent global analysis indicated that warming above 1.5°Celsius relative to pre-industrial could lead to a dramatic decline in the catch potential of global marine fisheries including tropical marine systems (Cheung et al. 2016). Trophic

relations within and between pelagic and benthic ecosystem are likely to shifts or become disrupted as the environmental tolerances of different species are exceeded. As most species targeted by commercial and recreational line fisheries on the GBR are predators, they are likely to be sensitive to such tropic shifts or disruptions under climate change, lowering the scope for the GBR to provide a key ecosystem service. A challenge for the midterm review will be to identify such sensitive processes (i.e. lesion points) in GBR ecosystems and explore strategies for prevention or remediation.

In summary, in the absence of explicit climate change adaptation actions, the Reef 2050 Plan is in its present form not equipped to deal with what has now become the main driver of detrimental change in the GBR.

Emerging implications for Reef 2050 Plan and opportunities to improve

Under current and projected climate and use scenarios, a more realistic understanding of the consequences of cumulative impacts for GBR ecosystem health and biodiversity needs to be developed. Climate pressures outside of management control (cyclones: Cheal et al. 2017, Emanuel 2013); bleaching: van Hooidonk et al. 2016, Frieler et al. 2012; and ocean acidification: Doney et al. 2009) are predicted to increase in frequency and/or severity even under the most optimistic carbon emissions scenarios. Therefore, a key challenge for the Review will be to re-assess the scope for specific on-the-ground actions under Reef 2050 Plan to enhance ecological resilience and protect biodiversity. Without such understanding, tolerance thresholds for vulnerable can be exceeded with consequences for habitats, species and people. Actions to improve water quality (Fabricius 2011b), reduce fishing pressures (Mellin et al. 2016) and control CoTS (Pratchett et al. 2014, GBRMPA 2016) all take pressures off coral reef ecosystems. However, they cannot fully compensate for the biological resilience lost to climate change impacts (Anthony 2016). In other words, GBR policy and management under climate change will be working against a ceiling of resilience that cannot be overcome by pulling harder on conventional management levers. The cumulative impacts management framework developed by GBRMPA to support the Reef2050 Plan is a start to addressing this gap, but needs to be developed further using response models for key species groups to multiple stressors under different plausible scenarios.

For biodiversity, a specific case in point is the major habitat-forming groups of corals on GBR mid-shelf and outer-shelf reefs. These are coral species of the genus *Acropora*, which constitute around 70% of the approximately 400 species of reef-building corals in the Indo Pacific (Wallace 1999). Their ecosystem function is not dissimilar to that of rainforest trees: they provide foundation, habitat and food for a rich diversity of associated species (Knowlton 2001, Fisher et al. 2015). Following major acute disturbances on the GBR, the reef fish fauna shows dramatic changes in community composition with the temporary loss of entire functional groups (Emslie et al. 2014). Importantly, the most critical habitat-forming species of *Acropora* (Jones et al. 2004, Komyakova et al. 2013) are also among those most sensitive to ocean warming (Marshall and Baird 2000), storms (Madin et al. 2008) and ocean acidification (Anthony et al. 2008). An opportunity for the Review will be to assess the downside risks of biodiversity loss (including vulnerable and endangered species) associated with losing these habitat builders under environmental change. Further, it will be an opportunity to assess what specific suite of actions can preserve key habitats in general (e.g. branching corals, seagrasses, mangroves), and consequently help maintain biodiversity including key fisheries species.

The Reef 2050 Plan is vague on how the achievement of environmental targets for water quality will translate to the protection of biodiversity. While improved water quality can provide some resilience support, e.g. by reducing the likelihood of coral disease (Pollock et al. 2014) and enhance bleaching tolerance (Wooldridge and Done 2009), and potentially reduce the likelihood of environmental triggers of primary CoTS outbreaks (Fabricius et al. 2010, Wooldridge and Brodie 2015), an understanding of the

ecological consequences of achieving or not achieving specific water quality targets is lacking. Here, the Review should assess more specifically the biodiversity consequences of exceeding thresholds for water quality tolerance, versus what actions would be required to stay on the safe side of those thresholds given their dynamics in time and space.

Zoning is stated in the Reef 2050 Plan as one mechanism by which biodiversity will be protected (page 25). But as explained above, no-take areas will offer limited protection for fish and other species groups if ecosystem resilience becomes eroded by cumulative pressures dominated by climate change. While zoning remains a critical management tool, its capacity to build resilience against continued and perhaps severe climate change might require it to be combined with restoration strategies or other measures of climate adaptation (van Oppen et al. 2017).

Recent coral bleaching events in the northern GBR demonstrate that areas under minimal human influence are now also vulnerable (Hughes et al. 2017b). Here ecosystem resilience could be overwhelmed by pressures from global drivers. Consequently, conventional management actions will have limited capacity to compensate for lost resilience (Anthony 2016). This raises a potentially contentious question for the Review. If OUV and biodiversity of the GBR as we know it cannot be sustained under continued or worsened climate change, what version of the GBR can? Transitions to altered and new, albeit functional, systems have been accepted in the terrestrial domain (Hobbs et al. 2009, 2011) with the objective of continued provision of services and values (Kareiva et al. 2007). A similar path could become necessary for the GBR under the Reef 2050 Plan.

Implications for the midterm and 2020 review processes

The main implication of the above analysis is that the Reef 2050 Plan will require a substantive overhaul in order to not only accommodate climate change actions, but to possibly review and reformulate its overarching goal statement. This is because it is likely that the vision for the Reef 2050 Plan can no longer be achieved in its original formulation (Figure 4 of the Plan) unless the world follows a strongly mitigated carbon path (see Chapter 3). The basis for this review recommendation is that the capacity to improve OUV hinges in part on the capacity to "*maintain diversity of species and ecological habitats*" and that "*the status and ecological functions … are in at least good condition with a stable to improving trend*". Importantly, a scenario that sees the world limiting warming within 1.5°C above preindustrial levels provides the best opportunities for the Reef 2050 Plan to deliver against objectives and produce outcomes, however with some elevated risk of damage from heat waves in particular. Whether OUV can be increased decade by decade under this scenario is uncertain as the environmental tolerances of some species will continue to be challenged, including key ecosystem engineers and habitat-forming species that underpin ecosystem resilience, function, diversity and services.

Recognising that maintaining or even enhancing the original OUV as stated in the Reef 2050 Plan is possibly no longer realistic and that it needs to be replaced by a new statement on preserving reef ecological function entails a substantive review, which is beyond the scope of the midterm review and will need to form the main focus of the 2020 review. The main reason is that the underpinning science to determine what the new goal statements and related intermediate and short term outcomes and targets might entail is still highly uncertain.

Hence, the midterm review might have to focus on what immediate, no regrets actions (eg as identified in the recent GBR Summit) can be incorporated in the Plan, relegating the task of a major restructure of the Plan into the 2020 review, underpinned by a suite of actions that better defines a set of revised ecological thresholds, targets and ensuing outcomes. In the interim, in addition to identifying and incorporating

immediate, no–regrets, the midterm review could also assess whether climate adaptation should form part of a portfolio strategy for the Reef Plan. Here, one option could be for the *Principles in decision making* (section 4.4. of the Plan) to be updated to account for the uncertainty of future scenarios, the role of global drivers in influencing management outcomes, and the possibility of exploring emerging technologies in supporting the resilience of key species.

In light of the possibility that the world will not adhere strictly to the most optimistic warming path (Rogelj et al. 2016), further analysis in preparation for the 2020 review should explore whether possible compromises should be made in the characterisations of ecosystem health, diversity and OUV while still achieving against some objectives and producing the best possible outcomes within management control. This could mean aspirations to altered ecosystems that still perform key functions and support key ecosystem services such as tourism and fisheries, but where some sensitive species, and potentially some locations, cannot be accommodated. The challenge here will be to deepen our understanding of how such key functions (e.g. the provision of habitats) and key species are best supported in a changed environment using conventional and new interventions. Such an analysis will require use of model predictions of ecosystem impacts under different scenarios and management strategies, and the identification of impact pathways that best deliver outcomes despite some necessary trade-offs.

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2.2 Heritage[2]

Context

The Reef 2050 Long-Term Sustainability Plan (hereafter 'Reef 2050 Plan') outlines actions, targets and objective for heritage in section 4.7 (Commonwealth of Australia, 2015). The heritage theme focuses on the "… cultural significance of the Reef, comprising all human values and meanings that might be recognised, including aesthetic, historic, scientific, social and spiritual. It encompasses Indigenous and non-Indigenous values" (Commonwealth of Australia, 2015b). The programmes and activities within the heritage theme are designed to ensure that the 2050 outcome will be that "Indigenous and non-Indigenous heritage values are identified, protected, conserved and managed such that the heritage values maintain their significance for current and future generations" (Commonwealth of Australia, 2015b).

Heritage values are considered as part of the total value of the GBR following the 2008 amendment to the Great Barrier Reef Marine Park Act 1975; thus an assessment of the condition of heritage values of the GBR was first considered as part of the Outlook Report 2014 (Great Barrier Reef Marine Park Authority, 2014a). This report assessed heritage values within six criteria (with further sub-divisions within each criteria) with the majority of the values assessed with the grade 'good'. However, one criteria, Indigenous heritage values, and six sub-criteria (three each within Indigenous heritage values and Historic heritage values criteria) were assessed with the grade 'poor'. This grade indicates that heritage values have either not been systematically identified, or known heritage values are degrading and generally lack integrity, and thus indicates a threat to the outstanding universal values (OUVs) of the reef. The concerns described within the report to explain these grades are as follows (Great Barrier Reef Marine Park Authority, 2014a):

- Indigenous heritage values
  - Sacred sites, sites of particular significance, places important for cultural tradition – some sites are under pressure from coastal development and severe weather
  - Stories, songlines, totems and languages – some are being affected by coastal activities and uses, especially in central and southern areas
  - Indigenous structures, technology, tools and archaeology - have not been systematically identified and many are under pressure
- Historic heritage values
  - Historic voyages and shipwrecks – Whilst two historic shipwrecks are well documented, and many have been mapped, others remain to be located and assessed. There are no structured monitoring arrangements for historic wrecks. Some have been affected by cyclones.
  - World War II features and sites – some have been identified but many have not, and little is known of their condition. Some are being damaged by activities in the region.
  - Other places of historic significance – these are poorly recorded and their conditions are not well understood.

[2] Diane Jarvis (JCU)

The report concluded that an overarching theme of all aspects of the heritage values of the GBR is that they are poorly recorded and rarely monitored, and that this directly affects the ability to protect and manage these values (Great Barrier Reef Marine Park Authority, 2014a).

Building on the findings to this earlier report, the Reef 2050 Plan states the main threats to achieving the desired 2050 outcome are as follows:

- Lack of capacity and opportunities for traditional owners
- Poor community awareness and appreciation of heritage values

Thus, the heritage theme has two distinct but related components, Indigenous heritage and non-Indigenous heritage, and seeks to maintain the OUVs of both of these. Whilst being firmly grounded within general environmental protection and specific GBR related legislation and policies, the foundational policies and programs for this theme also encompass the Government's Closing the Gap, and Indigenous Advancement, policies (Commonwealth of Australia Department of the Prime Minister and Cabinet), and legislation, policies and programs relating to the rights of Indigenous peoples, including the Native Title Act 1993.

The Reef 2050 Plan identifies 11 actions to be conducted over the period 2015-2020 (discussed in section 2 below) which together are expected to deliver three targets by 2020, as follows:

HTI New and effective cooperative management practices are developed for protection and conservation of GBR Indigenous and non-Indigenous heritage.

HT2 Indigenous and non-Indigenous heritage values are identified, documented and protected in decision making and planning processes.

HT3 Partnerships between Traditional Owners and all stakeholders are increased to ensure key Reef heritage values are identified, documented and monitored.

What happened since Reef 2050 Plan and additional gaps identified

As already discussed, a significant proportion of the actions, targets and objectives within the heritage theme relate to Indigenous heritage values and practices, and require significant leadership/involvement from the Indigenous communities of the region if these elements of the plan are to be successfully achieved within the required timeframes. Therefore, this theme should be considered in conjunction with the related analysis focusing on Indigenous perspectives of the Reef 2050 Plan (see item 1.7 Indigenous values).

Since the commencement of the Reef 2050 Plan progress has been made on a number of the actions specified, and according to the 2016 Annual Report all actions due to have commenced by that date are on track (Commonwealth of Australia, 2016d). However, the 2016 Investment Framework report reveals that a number of these actions are currently underfunded or have unknown funding needs (Commonwealth of Australia, 2016e). Progress regarding each of the actions are considered below in turn.

Summary of progress regarding specific actions

HA1 Build capacity for the involvement of Traditional Owners and community members in cooperative management, planning and impact assessment

This is one of the 23 actions within the Reef 2050 Plan that relate to Traditional Owners. A number of Traditional Owner groups developed the Indigenous Implementation Plan, released during 2016, which aimed to address the relevant actions, including this one. This plan identifies three key focus areas; the first relates to the coordination of activities between Indigenous and non-Indigenous groups, and the third

relates to the need to foster business capacity within the Traditional Owner groups. Both of these focus areas strongly relate to this action from the Reef 2050 Plan. The Traditional Owners proposals in relation to these actions (revealing gaps in the Reef 2050 Plan?) are as follows:

i) a coordination unit be established to act as a bridge between the Indigenous and non-Indigenous communities
    a. independent from but collaborating with government agencies to facilitate delivery of Traditional Owner actions required in the Reef 2050 Plan
    b. coordinate and monitor reporting on delivery of these Traditional Owner commitments
    c. support forum for longer term strategies around the themes within Reef 2050 Plan
    d. develop/maintain network facilitating understanding of who speaks for country, and the interests/concerns of Traditional Owner in particular areas
    e. provide guidance, support and brokering role to Traditional Owner groups

ii) fostering business capacity for Traditional Owner groups by
    a. developing information resources in collaboration with universities, training providers and other stakeholders
    b. mapping opportunities for business ventures, partnering people with opportunities
    c. facilitating Traditional Owners to develop and implement agreements with partner agencies
    d. assisting groups to expand existing capacity through facilitation, mentoring, training
    e. support business management initiatives
    f. develop and deliver training

There has been some further actions beyond the Indigenous Implementation Plan that relate to this action. GBRMPA has developed guidelines for various aspects of the permissions system, to be used by applicants and Marine Park managers (discussed under HA5 below), and has been advised by IRAC (Indigenous Reef Advisory Committee) on those that relate to Traditional Owners and Indigenous values. These draft guidelines were released for consultation in September 2016. The summary of consultation released February 2017 revealed specific comments regarding improving meaningful partnership between GBRMPA and Traditional Owners (discussed under HA5 below). Final versions of guidelines are expected to be released and implemented during 2017.

This action is considered to be 'on track/underway' but funding needs for delivery are unknown. The action is targeted for immediate (December 2016) priority.

<u>HA2 Work with and support Traditional Owners to collect, store and manage their cultural heritage information</u>

This action is addressed in some detail within the Indigenous Implementation Plan; being the second of the three focus areas identified in that plan. This reveals that a mistrust of governments is felt by the Indigenous communities, resulting in a reluctance to provide governments with sensitive information. The Traditional Owners provide a proposal for the development of a cultural heritage database that would provide high security and a high degree of control for Traditional Owners over their information, whilst improving knowledge retention and data management of cultural heritage information (this also relates to action HA3 in the *R*eef 2050 Plan).

This action is considered to be 'on track/underway' but funding needs for delivery are unknown. The action is targeted for medium term delivery (June 2018).

<u>HA3 Improve engagement processes for assessment of cultural heritage values to inform decision making</u>

As for the actions above, this action is addressed within the Indigenous Implementation Plan (Commonwealth of Australia, 2016a), under their first two focus items, coordination (discussed under HA1 above) and cultural heritage database (discussed under HA2 above).

The establishment of processes/systems for collecting and sharing cultural heritage information should also form part of the RIMRep programme. However, the Indigenous Implementation Plan (Commonwealth of Australia, 2016a) notes that it was unable to propose a monitoring and reporting process due to low levels of interest and response from Traditional Owner groups. Furthermore, the RIMRep programme would not appear to be making progress regarding this theme, based on the lack of information provided on the relevant website (http://www.gbrmpa.gov.au/managing-the-reef/reef-2050/reef-integrated-monitoring-and-reporting-program). RIMRep is not discussed in detail here as this is discussed within related analysis focusing on monitoring, evaluation and reporting under the Reef 2050 Plan (see item 1.8).

This action is considered to be 'on track/underway' but a funding gap of up to $1m has been identified. The action is targeted for immediate (December 2016) priority.

HA4 Update the Great Barrier Reef Marine Park Heritage Strategy 2005 to more comprehensively address Indigenous and non-indigenous heritage

As for the action above, this action should be addressed within the Indigenous Implementation Plan (Commonwealth of Australia, 2016a).

This action is considered to be 'on track/underway' but funding needs for delivery are unknown. The action has been prioritised and projects relating to this were apparently to be undertaken during 2016/17 (Commonwealth of Australia, 2016c), but no update is available with regard to progress.

HA5 Develop impact assessment guidelines for cultural heritage values in the GBR Region

GBRMPA has developed guidelines for Indigenous heritage (Great Barrier Reef Marine Park Authority, 2016b) and non-Indigenous Historic heritage values (Great Barrier Reef Marine Park Authority, 2016a), to be used by applicants and Marine Park managers. These were released for consultation in September 2016. The summary of consultation released February 2017 (Great Barrier Reef Marine Park Authority, 2017) revealed no specific comments had been received on these draft documents; final versions are expected to be released and implemented during 2017. However the consultation (Great Barrier Reef Marine Park Authority, 2017) did reveal some more general comments relating to improving meaningful partnerships between GBRMPA and Traditional Owners (revealing gaps/improvements for plan?), as follows: i) development of a Memorandum of Understanding to involve Traditional Owners in a stronger capacity, such as paid consultancies and participation in research activities. ii) mandatory Traditional Owner consultation, with an appropriate fee to be chargeable, in the process for public notification for permission assessments. (This suggestion also noted that any activities likely to impact cultural heritage should be considered by Traditional Use of Marine Resource Agreement committees.) iii) financial compensation to Traditional Owners for use of their sea country which could then be used for joint management of the Marine Park. This was noted as a way of ensuring equitable distribution of community benefits.

The 2016 Annual Report (Commonwealth of Australia, 2016c) also states that the Whitsunday Plan currently being reviewed includes consideration of cultural heritage values. The report also states that GBRMPA is working with QLD Govt. to progress the development of the Conservation Management Plans for three of the six priority Historic shipwrecks. Furthermore, the report states that Cultural heritage statements are under development for known historic shipwrecks.

This action is considered to be 'on track/underway' but no information regarding the funding position of this action has been provided. The action has been prioritised for future completion by June 2020.

HA6 Facilitate robust consideration of heritage values in planning processes, including port development and associated activities

As for the action above, this action should be addressed within the Indigenous Implementation Plan (Commonwealth of Australia, 2016a).

The 2016 Annual Report (Commonwealth of Australia, 2016c) states that 18 new State Planning Schemes have commenced in basins within the GBR region that include local heritage provisions, with 9 further schemes to be finalised.

This action is considered to be 'on track/underway' and is also considered to be fully funded. The action is already prioritised.

HA7 Consolidate Reef heritage data and identify priorities for protective action

This action is considered to be not yet due, and work is expected to be progressed as part of the RIMRep programme. No information regarding the funding position of this action has been provided. The action has been prioritised for future completion by June 2020.

HA8 Complete heritage management plans for Low Isles and North Reef light stations

The 2016 Annual Report (Commonwealth of Australia, 2016c) explains that development of the Low Isles Light station heritage plan has commenced, but work has not yet begun on the management plan for the North Reef Light station.

This action is considered to be 'on track/underway' but a funding gap of up to $1m has been identified. The action is targeted for future completion, by June 2020,

HA9 Update existing conservation management plans for historic shipwrecks – SS Yongalla, Gothenburg, SS Llewllyn

This action is considered to be 'on track/underway' but no information regarding the funding position has been provided. This action has been already prioritised, and work is apparently underway (Commonwealth of Australia, 2016c). No information regarding the funding position has been provided.

HA10 Complete and implement conservation management plans for key historic shipwrecks – HMS Pandora, HMCS Mermaid, Foam

This action requires the three sites to be visited and records updated, and is considered to be 'on track/underway'. Inspections of the Pandora site are planned for 2017, whilst a management plan for Mermaid has commenced, and records for Foam are being updated following the 2015 site inspection (Commonwealth of Australia, 2016c). No information regarding the funding position has been provided.

HA11 Further identify, map, monitor and report on key Reef heritage values and sites including comprehensive maritime surveys in priority sections of the Reef

It is expected that this action will be based on fieldwork, identifying up to 5 targets in each district, ascertaining significance, reporting on findings, and implementing management outcomes identified. Annual report states that desktop research begun for two proposed target areas.

This action is considered to be 'not yet due' but a funding gap of up to $1m has been identified.

Summary of gaps identified from detailed review of specific actions

The key gaps identified within the plan are as follows:

- A historical legacy of the GBR being listed for its natural but not its cultural values tends to result in a persistent lack of focus on heritage issues.
- Insufficient coordination between Indigenous and non-Indigenous communities, and the actions each are trying to deliver. There is a need to develop meaningful partnerships between Traditional Owners and GBRMPA.
- Further requirement to provide guidance, support and funding to Traditional Owner groups to build their capacity to deliver their proposed actions.

- Insufficient focus on, or insufficient ability to deliver, monitoring, evaluation and reporting systems, by Indigenous communities and through RIMRep process.
- Likely insufficiency of funding. For some actions, funding available has been noted as being insufficient whilst funding needs for other actions have not been determined, hence sufficiency of funding for delivery of the heritage theme actions is unknown.

Implications for the midterm and 2020 review processes

From the review of the literature it would appear that little concern or focus is being directed at the Heritage theme compared to some of the other themes within the Reef 2050 Plan; the impact of the recent bleaching events, and issues relating to the water quality theme, are receiving most of the attention.

Publications of the Independent Expert Panel (IEP), a Reef 2050 Plan advisory committee, have made reference to the need to work with people on ground, including Traditional Owners and others, to consolidate information as it becomes available and ensure that data collection methods are comparable and robust (Reef 2050 Plan Independent Expert Panel, 2016). The IEP also have noted that Traditional Owners, and others, should be better supported to deliver on-ground actions that will benefit the reef; including being eligible for financial support for activities consistent with a revised plan.

However, the lack of high profile criticisms of progress under this theme does not mean there is no opportunity to improve this section of the plan.

The most obvious opportunities to improve the implementation of the actions within the current plan, and to improve the plan itself, relating to the heritage theme fall within three broad categories:

- Developing the capacity of Traditional Owners and the Indigenous community to deliver their actions under the Reef 2050 Plan.
- Address the apparent weaknesses/issues with RIMRep or develop alternate monitoring, evaluation and reporting systems relating to this theme.
- Identify funding requirements, and sources for this funding.

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2.3 Water Quality[3]

Context

The Reef 2050 Long-Term Sustainability Plan (hereafter '*2050 Reef Plan*') outlines actions for *Water Quality* in section 4.8 (Commonwealth of Australia, 2015c). Based on the Outlook Report 2014 (Great Barrier Reef Marine Park Authority, 2014b), the Reef 2050 Plan lists the main threats to the quality of water entering the World Heritage Area as:

- Diffuse sources: nutrient run-off, sediment run-off, crown-of-thorn starfish outbreaks, pesticide run-off, terrestrial discharge
- Point sources: dredging, damage to seafloor, disposal of dredge material, acid sulphate soils

The main foundational programs and activities to improve the quality of water entering the Reef, as outlined in the *2050 Reef Plan*, are:

- Reef Water Quality Protection Plan (hereafter 'Reef WQ Plan') (Reef Water Quality Protection Plan Secretariat, 2013c)
- Water quality improvement planning
- Sewage treatment plants upgrade to tertiary grade treatment
- Regulatory standards for stormwater run-off, dredging, sewage outfalls, mine discharges and industrial contaminants - for the regulatory standards, the 2050 Reef Plan refers specifically to four Commonwealth and six Queensland Acts

The *2050 Reef Plan* lists five water quality targets (WQT) for 2020, two of which are drawn from the Reef WQ Plan, namely WQT1 (Table 1) and WQT2 (Table 2). To achieve these targets, the *2050 Reef Plan* outlines a total of 24 actions under five headings.

[3] Frederieke Kroon (AIMS)

Table 1. Water quality targets for the Reef WQ Plan (2013) and the Reef 2050 Plan (2015). WQT1 refers to Water Quality Target 1 in the Reef 2050 Plan.

Plan	Reef WQ Plan (2013)	Reef 2050 Plan (2015) (WQT1)
2018 target	At least a 50 per cent reduction in anthropogenic end-of-catchment **dissolved inorganic nitrogen** loads in priority areas	At least a 50 per cent reduction in anthropogenic end-of-catchment **dissolved inorganic nitrogen** loads in priority areas, on the way to achieving up to an 80 per cent reduction in nitrogen by 2025
	At least a 20 per cent reduction in anthropogenic end-of-catchment loads of **sediment and particulate nutrients**	At least a 20 per cent reduction in anthropogenic end-of-catchment loads of **sediment** in priority areas, on the way to achieving up to a 50 per cent reduction by 2025
	At least a 60 per cent reduction in end-of-catchment **pesticide** loads in priority areas	At least a 60 per cent reduction in end-of-catchment **pesticide** loads in priority areas
	-	At least a 20 per cent reduction in anthropogenic end-of-catchment loads of **particulate nutrients** in priority areas

Table 2. Land and catchment management targets for the Reef WQ Plan (2013) and the Reef 2050 Plan (2015). WQT2 refers to Water Quality Target 2 in the Reef 2050 Plan.

Plan	Reef WQ Plan (2013)	Reef 2050 Plan (2015) (WQT2)
2018 target	90 per cent of **sugarcane, horticulture, cropping and grazing lands** are managed using best management practice systems (soil, nutrient and pesticides) in priority areas	90 per cent of **sugarcane, horticulture, cropping and grazing lands** are managed using best management practice systems (soil, nutrient and pesticides) in priority areas
	Minimum 70 per cent late dry season groundcover on **grazing lands**	Minimum 70 per cent late dry season groundcover on **grazing lands**
	The extent of **riparian vegetation** is increased	The extent of **riparian vegetation** is increased
	There is no net loss of the extent, and an improvement in the ecological processes and environmental values, of **natural wetlands**.	There is no net loss of the extent, and an improvement in the ecological processes and environmental values, of **natural wetlands**.

What has happened since Reef 2050 Plan and gaps identified

Since the release of the Reef 2050 Plan in March 2015, the main foundational programs and activities have progressed as follows:

1. Reef Water Quality Protection Plan

To protect the GBR from diffuse source pollution from agricultural land uses, the first Reef WQ Plan was released in 2003 (The State of Queensland and Commonwealth of Australia, 2003), and subsequently revised and updated in 2009 (Reef Water Quality Protection Plan Secretariat, 2009), in 2013 (Reef Water

Quality Protection Plan Secretariat, 2013c), and in 2017 (The State of Queensland, 2017). Overall, the Reef WQ Plan aims to provide a coordinated and collaborative approach to improve water quality through industry-led best management practice (BMP) programs (Queensland Government, 2015b) that describe steps farmers can take to improve water quality, and through programs such as Reef Trust (Department of the Environment, 2015) that provide incentives and extension activities to support voluntary adoption of BMPs.

Reef WQ Plan 2013: The long term goal of the Reef WQ Plan (2013) is '*To ensure that by 2020 the quality of water entering the reef from broadscale land use has no detrimental impact on the health and resilience of the Great Barrier Reef*' (Reef Water Quality Protection Plan Secretariat, 2013c). Targets for both water quality and land and catchment management (Table 1, 2) have been set to achieve this goal. Progress towards meeting the goal and targets is evaluated by the Paddock to Reef Monitoring, Modelling and Reporting Program (Carroll et al., 2012), and reported via annual Reef Report Cards (Queensland Government, 2015a; Reef Water Quality Protection Plan Secretariat, 2011, 2013a, b, 2014, 2016). The latest Reef Report Card for 2015 reported GBR-wide trends from a 2009 baseline, including (i) poor to moderate uptake of BMPs, (ii) very good late dry season ground cover, (iii) very poor to moderate reductions in pollutant loads, and (iv) continued poor condition of the inshore marine environment (Reef Water Quality Protection Plan Secretariat, 2016). No information on progress towards targets for riparian vegetation or natural wetland was presented. Except for the target for late dry season groundcover on grazing lands, none of the other Reef WQ Plan targets set for water quality and land and catchment management (Table 1, 2) have yet been achieved (Reef Water Quality Protection Plan Secretariat, 2016), and will not be achieved by 2018 (Waterhouse et al., 2017c). Given that the water quality targets in the Reef 2050 Plan require even larger reductions in nutrients and sediment by 2025 (Table 1).

Although the principles of BMPs, Reef WQ Plan's main instrument to reduce diffuse source pollution from existing agricultural land uses, are well understood in the GBR catchments (Thorburn and Wilkinson, 2013), achieving the widespread or complete adoption of established or potential BMPs (e.g. as described by (Thorburn and Wilkinson, 2013) is a substantial socio-economic challenge (Rolfe and Gregg, 2015; Thorburn et al., 2013; van Grieken et al., 2013). Recent research shows that conflicting messages about reef health and social barriers to participating in BMP programs are some of the social dimensions affecting agricultural practice change in the GBR catchment (Eberhard et al., 2017). Cost-abatement analyses indicate progress towards achieving Reef Plan targets and goals can be accelerated through spatial prioritization of investment in water quality initiatives (Department of Environment and Heritage Protection, 2016; Star et al., 2015). Indeed, recent analyses on the costs of achieving the water quality targets for the GBR supports spatial prioritisation (Alluvium, 2016). However, current progress indicates that complete uptake of BMPs is unlikely, and a range of policy solutions is required to achieve Reef WQ Plan's sediment and nutrient targets in most GBR catchments (Alluvium, 2016; Department of Environment and Heritage Protection, 2016; Thorburn and Wilkinson, 2013; Waters et al., 2014).

The Reef WQIP (2017-2022): The Reef WQ Plan 2013 has recently been updated into the Reef 2050 Water Quality Improvement Plan (2017-2022), and is currently with the Ministers for approval and release for public consultation. The Plan has been restructured to link directly with the overall Reef 2050 Plan, and has been informed by regional WQIPs (see below). This updated Plan has a new outcome stating that '**Reef water quality supports the outstanding universal value of the Great Barrier Reef, builds resilience, improves ecosystem health and benefits communities**'. The development of the Reef WQIP has been informed by (i) the 2017 Scientific Consensus Statement Update, comprising four supporting chapters (Bartley et al., 2017; Eberhard et al., 2017; Schaffelke et al., 2017; Waterhouse et al., 2017a), a fifth synthesis chapter (Waterhouse et al., 2017b), and a summary statement (Waterhouse et al., 2017c), and (ii) the basin specific water quality targets for the 35 basins of the Great Barrier Reef (Brodie et al., 2017). The overarching consensus from the 2017 Scientific Consensus Statement Update is that:

Key Great Barrier Reef ecosystems continue to be in poor condition. This is largely due to the collective impact of land run-off associated with past and ongoing catchment development, coastal development activities, extreme weather events and climate change impacts such as the recent coral bleaching events.

Current initiatives will not meet water quality targets. To accelerate the change in on-ground management, improvements to governance, program design, delivery and evaluation systems are urgently needed. This will require greater incorporation of social and economic factors, better targeting and prioritisation, exploration of alternative management options and increased support and resources.

2. Water quality improvement planning

Regional water quality improvement plans have been finalised for the Wet Tropics (Terrain Natural Resource Management, 2015), Burdekin (NQ Dry Tropics, 2016), Whitsundays (Folkers et al., 2014), and Burnett-Mary (Burnett Mary Regional Group, 2015) Natural Resource Management (NRM) regions, and are being developed and finalised for the Cape York and Fitzroy NRM regions (Cape York Natural Resource Management, In preparation; O'Brien and Waterhouse, In preparation).

3. Sewage treatment plants upgrade to tertiary grade treatment

The Queensland Government has not met its own target of upgrading all coastal Sewage Treatment Plants that discharge into the marine environment to the most stringent treatment standards (i.e. tertiary treatment) by 2010 (Great Barrier Reef Marine Park Authority, 2014b). This target is currently not mentioned in either relevant regulation (Department of Environment and Heritage Protection, 2015) or guidelines (Department of Environment and Heritage Protection, 2012) despite projected annual population growth of ≥1.6% up to 2036 (Great Barrier Reef Marine Park Authority, 2014b).

4. Regulatory standards for stormwater run-off, dredging, sewage outfalls, mine discharges and industrial contaminants

The GBR is protected directly and indirectly by many other Federal, State and local government laws and policies in Australia's federal system of government that regulate activities affecting the reef (Jacobs Group (Australia) Pty Limited, 2014; McGrath, 2010). The Reef 2050 Plan refers specifically to four Commonwealth and six Queensland Acts, namely:

Federal Acts: *Environment Protection and Biodiversity Conservation Act* 1999, *Environment Protection (Sea Dumping) Act* 1981, *Protection of the Sea (Prevention of Pollution from Ships) Act* 1983, *Great Barrier Reef Marine Park Act* 1975;

Queensland Acts: *Environmental Protection Act* 1994, *Sustainable Planning Act* 2009, *Marine Parks Act* 2004, *Coastal Protection and Management Act* 1995, *State Development and Public Works Organisation Act* 1971, *Transport Operations (Marine Pollution) Act* 1995.

Many of these Acts regulate point sources of pollution such as sewage treatment plants, and industrial, mining and vessel waste discharges. It is currently unclear whether these acts are effective in improving the quality of water entering the Reef, due to lack of (publicly available) monitoring data for these point sources (Kroon et al., 2015).

Since the release of the Reef 2050 Plan, the main change in regulation has been the ban on dumping capital dredge spoil in the GBR Marine Park under the *Great Barrier Reef Marine Park Act* 1975. Spoil from maintenance dredging can still be dumped in the GBR Marine Park and in the GBR World Heritage Area (WHA) following the regulatory framework outlined in the 'Maintenance Dredging Strategy for the GBR WHA Ports' (Department of Transport and Main Roads, 2016).

Since the release of the Reef 2050 Plan in March 2015, the following additional activities as related to Reef water quality have occurred:

- The Australian Government reported on progress against the Reef 2050 Plan to UNESCO in December 2016 (Commonwealth of Australia, 2016b). The response by UNESCO, to be considered at the July 2017 meeting in Krakow, Poland (UNESCO, 2017), noted that '*progress towards achieving water quality targets has been slow, and the most immediate water quality targets set out in the 2050 LTSP are not expected to be achieved within the foreseen timeframe. The World Heritage Centre and IUCN consider that the implementation of the Plan will need to accelerate to ensure that the intermediate and long-term targets of 2050 LTSP are being met, in particular regarding water quality. It is also noted that important legislation regulating land clearing has not been passed yet, and that increased efforts are needed to ensure that all important legislation necessary to deliver the 2050 LTSP outcomes is put in place*'. Furthermore, the UNESCO report recommends that '*the Committee request the State Party to accelerate its efforts to reach the water quality targets set out in the 2050 LTSP and to ensure that all measures which are necessary to achieve them are taken*.'
- The Great Barrier Reef Water Science Taskforce released its final report in May 2016 (The Great Barrier Reef Water Science Taskforce, 2016). Several of their recommendations have progressed to further development, such as the Major Integrated Projects for the Wet Tropics and the Burdekin (https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef-major-projects/), and the release of the 'Enhancing reef regulation discussion paper' (https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef-regulations/).
- The potential risk of emerging contaminants to the Reef, namely heavy/trace metals and metalloids, alternate pesticides, petroleum hydrocarbons, coal particles, pharmaceuticals, personal care products, nanomaterials, antifouling paints, and marine debris including microplastics, was evaluated in a recent desk top study (Kroon et al., 2015). Several large monitoring datasets were examined for heavy/trace metals and metalloids, and for marine debris; additional datasets were identified but not made available by the respective custodians for this study. For most emerging contaminants, however, little to no monitoring data exists. The study concluded that the relative risk of marine plastic pollution, chronic contamination by antifouling paints, and certain PCPs to the Reef's marine ecosystems is of concern, and requires further research to improve our understanding of their presence, distribution and ecological impacts, including relative to current contaminants of concern (i.e. sediment, nutrients, pesticides).

Finally, the following additional gaps have been identified:

- No comprehensive regulatory and compliance regime to improve water quality in the GBR has been enacted for diffuse sources of pollution (i.e. agricultural land uses), the main source of sediment, nutrients and pesticides entering the Reef (Kroon et al., 2016; Tarte et al., 2017). This is particularly pertinent as internationally, management approaches that have resulted in measurable reductions in agricultural pollution to coastal ecosystems have all been non-voluntary (Boesch, 2002; Chu et al., 2009; Cloern, 2001; GEF-UNDP, 2006; Pastuszak et al., 2012; Stålnacke et al., 2003; Windolf et al., 2012), indicating that voluntary approaches alone may not be sufficient to achieve measurable improvements in Reef waters (Kroon et al., 2014). Several studies have emphasized the lack of effective legislative and regulatory instruments governing agricultural land uses and management in catchments discharging into the GBR WHA (Jacobs Group (Australia) Pty Limited, 2014; McGrath, 2010; Wulf, 2004). According to Wulf (2004), the Australian Government has the power under two of the Acts listed in Reef 2050 Plan, namely the *Great Barrier Reef Marine Park Act* 1975 and the *Environment Protection and Biodiversity Conservation Act* 1999, to control land-based pollution into the GBR Marine Park and WHA, but has to date not applied this provision.
- A number of the current government Acts, regulations and policies that affect land-based pollution and GBR water quality are inconsistent and do not align with the objective and targets of the Reef 2050 Plan. Three examples of this mis-alignment follow (from (Kroon et al., 2016). First, the Federal Government is proposing the development of water resources to support increased agricultural production in northern Queensland (Commonwealth of Australia, 2015a), including in one of the

catchments discharging into the GBR lagoon (the Burdekin). Such increases would likely work against the recently reported reductions in land-based pollution to the GBR lagoon (Queensland Government, 2015a), and are counter to recent marginal abatement analyses that imply some reduction in the production of current agricultural commodities is required to achieve larger reductions in pollutant export (Department of Environment and Heritage Protection, 2016). Second, recent amendments to Queensland's *Vegetation Management Act* 1999 (Department of Natural Resources and Mines, 2015a, b) to support agricultural development coincided with an almost 4-fold increase in woody vegetation clearing rates in the GBR catchments (Queensland Audit Office, 2015), likely promoting soil erosion and sediment run-off to the GBR lagoon (Department of Science Information Technology Innovation and the Arts, 2014). Proposed amendments under the *Vegetation Management (Reinstatement) and Other Legislation Amendment Bill* 2016 (Reinstatement Bill) were not agreed to by the Queensland Parliament in 2016. Finally, the provision of some forms of drought assistance to graziers by the Australian and Queensland Governments can generate incentives to manage properties in ways that may result in overgrazing and consequently increase the likelihood of sediment erosion (McColl and Young, 2010; Productivity Commission, 2009). For example, fodder subsidies may increase stock retention, and other financial subsidies may reduce the incentives for enterprise restructuring to better manage drought impacts on pasture and natural resources generally (Productivity Commission, 2009). Addressing these and other inconsistencies amongst Federal and State Acts, regulations and policies provide a considerable opportunity to improve the protection of GBR ecosystems from land-based pollution by assessing their effectiveness in protecting the Outstanding Universal Value of the GBR WHA.

Emerging implications for Reef 2050 Plan and opportunities to improve

From the above gap analysis, there are several significant emerging implications for Reef 2050 Plan. For the main foundational programs and activities these comprise:

Reef Water Quality Protection Plan

The Reef WQ Plan 2013 has recently been updated into the Reef 2050 WQIP (2017-2022), and is currently with the Ministers for approval and release for public consultation. The updated Plan contains (i) revised water quality targets for each of the 35 major GBR catchments; (ii) a basic program logic that link actions to outcomes, and (iii) an investment strategy (still to be released, and not available at the time of writing). The Plan is nested within the Reef 2050 Plan and the regional WQIPs.

We see three main opportunities to improve the Reef 2050 WQIP:

1. Better reflect the urgency of, and scale of change required to achieve the water quality targets, as recommended by the GBR Taskforce and others (Tarte et al., 2017);

2. Specifically link and quantify the actions and outcomes with progress towards, and achieving the water quality targets; and

3. Specifically link the proposed 'minimum practice standards everywhere' with the best management practise programs in agricultural land uses.

Water quality improvement planning

Targets, actions and investment strategies, outlined in the water quality improvement plans for the six NRM regions in the GBR catchments, need to be clearly nested within the Reef 2050 WQIP specifically, and the Reef 2050 Plan in general. This will ensure consistent messaging and increased effectiveness in investment.

Sewage treatment plants upgrade to tertiary grade treatment

The target to upgrade all coastal Sewage Treatment Plants that discharge into the marine environment to the most stringent treatment standards (i.e. tertiary treatment) needs to be reinstated in relevant Queensland regulation or guidelines for implementation. This is particularly pertinent given the projected annual population growth of ≥1.6% up to 2036 (Great Barrier Reef Marine Park Authority, 2014b).

Regulatory standards for stormwater run-off, dredging, sewage outfalls, mine discharges and industrial contaminants

The regulatory standards relate to point sources of pollution such as sewage treatment plants, and industrial, mining and vessel waste discharges. To ensure these regulatory standards are effective in protection the quality of water entering the Reef, information on contaminants of concern needs to collected using robust monitoring programs, and existing environmental data needs to be made available in the public domain for building marine baselines and risk assessments on contaminants present in Reef waters (Kroon et al., 2015).

Emerging implications derived from additional activities and gaps are:

- Given that complete uptake of BMPs is unlikely to achieve Reef WQ Plan's sediment and nutrient targets in most GBR catchments, additional approches to improve the quality of water from agricultural land uses entering the Reef are required (Kroon et al., 2014; Kroon et al., 2016; Tarte et al., 2017; The Great Barrier Reef Water Science Taskforce, 2016). This includes potential improvements to current policies and incentives, as well as potential changes to current agricultural land use, based on overseas experiences and Australia's unique potential:
    - Addressing inconsistencies amongst Federal and State Acts, regulations and policies provide a considerable opportunity to improve the protection of GBR ecosystems from land-based pollution by assessing their effectiveness in protecting the Outstanding Universal Value of the GBR WHA.
    - Several studies have emphasized the lack of effective legislative and regulatory instruments governing agricultural land uses and management in catchments discharging into the GBR WHA (Jacobs Group (Australia) Pty Limited, 2014; Kroon et al., 2016; McGrath, 2010; Tarte et al., 2017; Wulf, 2004), highlighting the opportunity to address land-based pollution using such instruments. The Queensland Government is currently working on the '*Enhancing reef regulation discussion paper*' (https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef-regulations/) to address agricultural land management. Amendments to Queensland's *Vegetation Management Act 1999* to reduce land clearing were not passed by Parliament. The Australian Government has the power under two of the Acts listed in Reef 2050 Plan, namely the *Great Barrier Reef Marine Park Act* 1975 and the *Environment Protection and Biodiversity Conservation Act* 1999, to control land-based pollution into the GBR Marine Park and WHA (Wulf, 2004), but has to date not applied this provision.
    - Experience both globally (Kroon et al., 2014) and in the GBR (Department of Environment and Heritage Protection, 2016; Thorburn and Wilkinson, 2013; Waters et al., 2014) suggests that a move beyond traditional agricultural systems is needed to achieve sufficient improvements in water quality to protect the condition of GBR coastal and marine ecosystems. This could include new agricultural products or land uses that are compatible with societal expectations and will be environmentally sustainable. Additional options to deliver large reductions in land-based pollution involve comprehensive programs of hydrological restoration of landscapes (Chu et al., 2009; McLellan et al., 2015; Walling and Fang, 2003). This is unlikely to be achieved without the retirement of at least some agricultural land (McLellan et al., 2015), for example by discontinuing production on land areas with highly erodible soils or those requiring high fertilizer input in environmentally sensitive (i.e. high risk) areas (Frisvold, 2004; Bennett, 2008; Stokstad, 2008; Windolf et al., 2012).

- The potential risk of certain emerging contaminants, in particular marine plastic pollution, chronic contamination of water and sediments with antifouling paints, and exposure to certain personal care products, to the Reef's marine ecosystems is of concern (Kroon et al., 2015). These contaminants are currently not specifically considered in the 24 water quality actions of the Reef 2050 Plan.

Implications for the midterm and 2020 review processes

Key implications for the Reef 2050 Plan Mid Term Review include the need to:

- Specifically link the water quality targets with ecological consequences (i.e. Ecosystem Health and Biodiversity). The Review should assess more specifically the biodiversity consequences of exceeding thresholds for water quality tolerance, versus what actions would be required to stay on the safe side of those thresholds given their dynamics in time and space.
- Consider whether the four main foundational programs and activities, as currently listed in the Reef 2050 Plan, are sufficient to address the main sources of land-based pollution to the Reef (i.e. diffuse pollution from agricultural land uses), in order to achieve targets for water quality and land and catchment management.
- Strengthen the program logic for water quality improvement in the Reef 2050 Plan, the Reef WQIP and the regional WQIPs, linking the outcome and targets with measurable actions needed to achieve these targets, including a properly costed investment strategy to deliver these actions. This includes a better balance between the main pollutant source of concern to the Reef (i.e. agricultural land uses) and the actions outlined for pollutant sources in the Reef 2050 Plan.
- Consider additional approaches to accelerate improvements in water quality towards targets, including potential improvements to current policies and incentives, as well as potential changes to current agricultural land use. Based on international experience and Australia's unique potential, this includes:
    - Harmonisation of Federal and State Acts, regulations and policies to improve the protection of GBR ecosystems from land-based pollution;
    - Implementation of effective legislative and regulatory instruments governing agricultural land uses and management in GBR catchments; and
    - Retirement of agricultural land in high-risk areas.
- Specifically consider point sources and associated contaminants other than those related to dredging (e.g. industrial, mining and vessel waste discharges).
- Consider the development of actions to determine and reduce the potential risk of emerging contaminants such as marine plastic pollution, chronic contamination by antifouling paints, and certain personal care products to the Reef's marine ecosystems.

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2.4 Community and Economic Benefits[4]

Context

The Reef 2050 Plan was a unique step forward in that it, for the first time, considered the wider concept of the human dimensions of the GBR as part of a more integrated "socio-ecological" asset. This step meant setting goals, targets and actions focussed on improving the health of the human asset (particularly comprising reef dependent and reef associated communities of interest) as it relates to the GBR. This approach was underpinned by the view that maximising the ecosystem services (benefits) that communities receive from the GBR, including cultural services, will increase the likelihood that people and groups using it will be more focussed on its long term stewardship.

In considering the GBR as a wider socio-ecological systems the **human dimensions** of the GBR, as articulated in the Reef 2050 Plan, could be seen as encompassing: (i) heritage; (ii) human aspirations, capacities and stewardship (ii) community benefits; (iii) economic benefits; and (iv) governance affecting the GBR. Heritage and governance issues are dealt with in their own right in other parts if this review scope, so with respect to guiding and implementing the Reef 2050 Plan, we concentrate attention here on community and economic benefits.

In respect to community, the Reef 2050 Plan recognised that the GBR plays an important role in community life. Local residents and visitors from within Australia and around the world are drawn to the Reef for its exceptional natural beauty, and many people have strong connections with it through culture, occupation or familiarity. Human wellbeing (happiness, good health and prosperity) is inextricably linked to environmental health. Through fishing, the Reef is also a healthy food source for people in Queensland and around the world. Traditional Owners, (dealt with in their own right in later sections) have long highlighted the benefits their communities derive from the Reef environment, including via cultural connections to sea country, access to the Reef 's resources, employment and improved health outcomes.

Equally, the Reef could be considered a critical economic asset, providing income and jobs for the community. For example, as a socioeconomic asset worth $56 billion. Deloittes also found that the GBR supports 64,000 jobs and contributes $6.4 billion to the wider Australian economy. Reef-dependent industries and Reef-associated industries support diverse communities. The Plan considered that these industries and communities need to be able to continue to prosper, while ensuring protection of the GBR's Outstanding Universal Value (OUV). The economic benefits theme, however, was more focussed on improving and maintaining the ecological asset rather than the social and economic sustainability of Reef-

[4] Allan Dale, Margaret Gooch and Diane Jarvis (JCU).

dependent and Reef-associated industries. This theme, however, recognised partnerships involving regional and Indigenous communities, government and industry are more likely to address development pressures than technical interventions alone.

The Deloitte report has been an important step in placing a clear economic value on the GBR asset, further encouraging action for economic *and* environmental purposes. Indeed, the estimation and application of non-market values for the environment is critically required if proper trade off analysis within the Reef 2050 Plan is to established in deciding the nature and size of policy response. This suggests that a significant gap in the plan is that it doesn't yet try to estimate the full use and non-use value of the GBR to the community (from international to local scales). There are a range of non-market valuation methods that could and have been used to value the Reef, and some recent reports/papers include:

- The Deloitte Access Economics (2017) report that took a non-market (contingent) valuation approach. As Deloitte's estimated a total value rather than an annual value they needed to estimate the useful life of the GBR, and then discount future years over that lifetime to estimate the current Net Present Value;
- Jacobs in their 2016 report 'Investing in the GBR as economic infrastructure', commissioned by Queensland Farmers' Federation, Queensland Tourism Industry Council, World Wide Fund for Nature Australia and Association of Marine Park Tourism Operators. This report applied a different valuation approach, not including non-use values or even all use values, and placing a value on the reef of $21bn; and
- A Life Satisfaction non-market valuation approach that allows the estimation of the value that people within the community actually place on the Reef. This is a holistic valuation technique, encompassing use and non-use values, so aggregating the value that people perceive from income earned and jobs created by industries in the region plus the value that people place on being able to visit the Reef and enjoy recreational activities. It also included the value that people place on just knowing the GBR exists and that it will continue to exist for future generations (see Jarvis et al. 2017). Jarvis et al. (2017) estimated that, should the GBR no longer provide these cultural ecosystem services, then residents would require an additional $8bn pa of income in compensation to maintain their life satisfaction.

At the time the Reef 2050 Plan was written, explicit consideration of the multitude of types of wider community and economic benefits in environmental decision making was not (and is still not) standard practice in the GBR context. As a result, the Reef 2050 Plan did aim to develop a shared understanding of community and economic benefits derived from the Reef. It set out a preliminary but not particularly deep set of individual and collective roles and responsibilities to ensure these benefits are maintained and transmitted to future generations. Consequently, the first step considered to be important was the further development of a long-term social and economic monitoring program to be implemented at local, regional and Reef-wide scales.

What has happened since Reef 2050 Plan and gaps identified

Before and since the release of the Reef 2050 Plan there has been a significant growth in international understanding of the concept of considering the human dimensions of Marine Protected Areas (MPAs). In short, intellectual thinking about these things has shifted from old models that simply saw the actions of humans as threats or impediments to core MPA values. This view, however, has only progressed towards a mixed approach, recognising human dimensions, but still thinking about them as potential threats to MPA values (or in this case OUVs) that need to be managed. Across the globe, new thinking around these issues is increasingly based on recognition that MPAs are socio-ecological systems, and that managers need to

identify and manage both biophysical and human values that are desired by society (e.g. De Groot et al. 2010; Jetzkowitz 2017). Consequently, these values need to be managed interchangeably; with investment and support in human development alongside conservation. Consider, for example, that a community that is less adaptive and resilient may be less likely to develop adopt and progressively improve stewardships practices to improve OUVs. This change of thinking sees MPA managers increasingly turning their attention to recognising important human dimensions (e.g. community or economic wellbeing), including the recognition that conflicts and trade-offs will arise from the different values of interest groups. This makes the setting of goals, targets and actions to improve these dimensions important. Such things could mean those involved in GBR management starting to focus on the creation of economic alternatives or significantly modified practices within those economic activities that might be posing a threat to the long term health of the GBR. This means that in the future, MPA managers increasingly and explicitly need to be moving towards managing a more complex socio-ecological system, rather than just seeking to fend off negative human influences to a biophysical asset.

While explicit inclusion of four (of five) key aspects of the human dimension of the GBR are now recognised within the Reef 2050 Plan, the goals sets can be predominantly be seen to revert back to focussed concern for the biophysical asset, rather than a shared concern for the human component or dimensions of the system. The two key goals related to community and economic benefits, for example, are:

- A community that plays a role in protecting the Reef for the benefits a healthy Reef provides for current and future generations; and
- Economic activities within the GBR World Heritage Area and its catchments sustain the Reef's Outstanding Universal Value (DoE 2015).

Both goals can be seen to consider the wider community and economic benefits of the GBR largely from the viewpoint of the health of the GBR, rather than from the viewpoint that human well-being is an inherently important part of the socio-ecological system (including a health set of OUVs). In the past, this has led MPA and World Heritage management agencies to be almost exclusively regulatory in their approach, and management institutions predominantly populated by people embedded in the biophysical sciences (see Dale *et al.* 2002). This "disciplinary bias" or rationalistic approach to problem solving has routinely resulted in significant tensions between the business of sustainable management and the economic and community wellbeing of (both directly related and associated) communities.

To address this problem, for the first time, there has been a practical and financial commitment to the development of a *Human Dimensions Working Group* and a benchmarking/monitoring product within the wider Reef Integrated Monitoring and Reporting Program (RIMReP) for monitoring the health of the GBR. Starting to monitor the health or resilience of both GBR associated and dependent communities is a critical first step in embracing the importance of the human dimensions of the GBR. The emerging Reef 2050 Plan human dimension indicator framework, comprised of indicator clusters and potential indicators for attributes within these clusters, is based on work by:

(a) the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES);
(b) Previously funded MTSRF and Queensland Centre for Social Science Innovation funded work on measuring community resilience in the wet Tropics region of the GBR catchment (Dale et al. 2016);
(c) The synthesis of other monitoring efforts and needs for Reef 2050 Plan implementation;
(d) The NESP-funded Social and Economic Long Term Monitoring Program (SELTMP); and
(e) Regional reporting in the catchment by Reef-based partnership groups (see Fitzroy Partnership for River Health 2015, Folkers et al. 2014; Gladstone Healthy Harbour Partnership 2016; Healthy Rivers to Reef Partnership: Mackay-Whitsunday 2016). .

The intention of this new monitoring approach is to review and to refine the indicator framework for understanding the human dimensions of the GBR as a basis for future strategy development for improving the health of these dimensions. This will be done through discussions and meetings with the program design expert panels and other similar groups of researchers, stakeholders, managers and partners. These meetings aim to stimulate discussions, compile relevant data sets against indicators, and refine specific components of the framework. The framework will be used to:

- Gather evidence regarding the state and trend of the human dimensions related to the GBR (published and unpublished sources of data, social surveys and other lines of evidence);
- Create narratives as they pertain to different components of the RIMReP's overall Drivers-Pressures-State-Impact-Response (DPSIR) framework;
- Develop a set of cohesive decision rules for creating an index from the lines of evidence used to inform benchmarking (scoring) of indicator clusters and sub-cluster attributes;
- Guide decision-making about index development by researchers and expert panels; and
- Deliver results to the RIMReP Program Design Working Group, the midterm and 2020 review processes and Outlook 2019.

This framework constitutes a significant progression in understanding the dynamicism of values related to the GBR. As such, it provides a useful first step in developing a Plan that is more explicitly cognisant of some of the drivers and impacts of environmental change within the social-ecological system. However, there are significant gaps in the human dimensions of the Reef Plan in relation potential actions that may create the social change required to meet key targets. Reaching pollutant reduction targets, for example, will require a rethink in how we engage with and incentivise land and sea managers, and consider the interactions between voluntary change, regulatory responses and strengthened governance.

Emerging implications for Reef 2050 Plan and opportunities to improve

The inclusion of human dimensions considerations in future planning, assessment and monitoring of the GBR is a new concept, even though GBR policy makers, managers and partners have long recognised that maintaining the health of the GBR, both now and into the future, will rely on mobilising the energy, motivation and aspirations of key individuals and sectors of society (particularly within GBR catchments) (GBRMPA, 2014). In particular, to improve GBR's health, policy makers and managers need to understand and monitor: (a) people's relationship with the GBR, including the values associated with different components of the GBR; (b) the range of factors influencing behaviours that affect the GBR (positively or negatively); (c) the role of GBR decision-makers, including users, managers, partners, communities and industry in affecting change; (d) equity and inclusion of multiple perspectives; and (e) the adaptive capacity of industries and communities who depend on the GBR for the economic, social, or cultural values it provides.

Several key regionally-scaled reports are now under development, produced as part of a 12 month National Environmental Science Program (NERP) project (*NESP Project 3.2.2: The IMS 2050 Human Dimensions Project: Cost-effective indicators and metrics for key GBRWHA human dimensions*). This new project is trialling a regionally-specific and robust framework to assess and monitor the human dimensions of the GBR and its catchment. The GBR catchment for this purpose lies wholly within six Natural Resource Management (NRM) regions and a human dimensions indicator report will be produced for each part of the GBR and catchment that falls within each region (i.e. the Wet Tropics; Eastern Cape York; Burdekin; Mackay-Whitsundays; Fitzroy; and Burnett- Mary).

The human dimensions of the GBR include the social, cultural, institutional, economic and governance factors that shape people's relationship with the GBR. These relationships are diverse and range from, for example, residents from outside the GBR who believe that the GBR is one of the world's most precious

natural assets even if they have not physically visited the area themselves, to the decisions and practices of individual land managers, GBR users and enterprises that have some association with the GBR. The relationships also include collective actions by industries, communities and governments, and how these influence GBR resilience. Marshall et al. (in review), for example, identified some nine cultural benefits (maybe also able to be considered and ecosystem-based cultural services) derived from the GBR.

Reviewed literature reveals that people's relationship with the GBR is also influenced by attitudes towards, and perceptions of the GBR and its management. These have changed considerably over time, and will no doubt change again in future. Attitudes and perceptions are shaped by culture, societal norms, context and circumstances, including personal experiences, word-of-mouth, and print media. Indigenous Traditional Owners have had the longest association with the GBR, and their attitudes and perceptions have been relatively constant over millennia as custodians and sustainable exploiters of the GBR and its resources. By contrast, non-Indigenous attitudes and perceptions are varied and can change relatively quickly, especially for those new to the GBR and its catchment.

The emerging new human dimensions indicator framework has been constructed to create evidence tables, based on the five themes or clusters presented in Table 3. These clusters are modified from the work by Vella et al. (2012) who describe four main groupings of indicators to describe the human dimensions of communities in north Queensland. These four groupings formed the basis of a framework for evaluating social resilience in the Wet Tropics region of the GBR catchment (Dale et al., 2016c, 2016a). To construct the framework the work of the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) has also been reviewed, recognising that healthy human systems depend (directly or indirectly) on a healthy ecosystem (Diaz et al., 2015). The IPBES and Dale et al. (2016c) frameworks were then aligned with values articulated in the GBR Strategic Assessment (GBRMPA, 2014a), the GBR Outlook Report (GMRMPA, 2014b) and previously published regional report cards for the GBR (Healthy Rivers to Reef Partnership: Mackay Whitsundays, 2016; Fitzroy Partnership for River Health, 2015; the Gladstone Healthy Harbour Partnership, 2016; and the Healthy Rivers to Reef Partnership: Mackay Whitsundays, 2016). A fifth cluster, culture and heritage, was added based on the cultural significance of the GBR, and its world heritage status.

Table 3: The five GBR human dimension clusters and their alignment with Reef 2050 Plan themes

Human Dimensions Cluster/Theme	Reef 2050 Plan Theme
Aspirations, capacities and stewardship represents the cohesive vision and aspirations for the future of the GBR together with awareness, skills, knowledge and capacities to turn aspirations into action. Personal and collective (including industry) efforts to: (a) minimise impacts on the GBR and catchment; (b) restore degraded marine, coastal and catchment ecosystems; (c) apply ESD principles; and (d) be actively involved in GBR and catchment management.	**All seven themes** – i.e. governance, community vitality, economic viability, heritage, water quality, ecosystem health and biodiversity
Community vitality is characterised by demographic stability, security, happiness and well-being. Community vitality associated with the GBR include services and infrastructure supporting the interface between the community and GBR as well as the social health derived from the GBR - e.g. nature appreciation, relaxation, recreation, physical health benefits, and other lifestyle benefits derived from the GBR. A healthy GBR community derives high levels of appreciation and enjoyment from the GBR and is highly satisfied with the GBR and its management.	**Community benefits** OUTCOME: An informed community that plays a role in protecting the GBR for the benefits a healthy GBR provides for current and future generations.
Culture and heritage represents the status of integrated and diverse culture and heritage associated with the GBR catchment. Cultural and heritage connections promote a sense of place associated with GBR coastal communities, and there is a strong sense of place attachment and identity associated with the community, because of its association with the GBR.	**Heritage** OUTCOME: Indigenous and non-Indigenous heritage values are identified, protected, conserved and managed such that the

This cluster also includes values of significance in accordance with Traditional Owner practices, observances, customs, traditions, beliefs or history. Historic Heritage is specifically concerned with the occupation and use of an area since the arrival of European and other migrants.	heritage values maintain their significance for current and future generations.
Economic viability. This includes the monetary advantages that people derive directly or indirectly from a healthy and well-managed Great Barrier Reef. Fundamental to this cluster is the premise that economic activities within the Great Barrier Reef World Heritage Area and its catchments are ecologically sustainable. GBR-dependent industries rely on a healthy GBR and include commercial fishing, marine tourism, GBR-based recreation, GBR-based research, Traditional Owner use. These industries generate income and employment for thousands of people in coastal communities near the Great Barrier Reef, and beyond. The marine tourism industry generates and collects the Environmental Management Charge which directly benefits GBR Marine Park management, which has flow on benefits to the broader community and society. GBR-associated industries include industries that may impact on the GBR, but are not economically dependent on GBR health e.g. shipping, catchment industries such as agriculture, urban development, port development.	**Economic benefits** OUTCOME: Economic activities within the Great Barrier Reef World Heritage Area and its catchments sustain the GBR's Outstanding Universal Value.
Governance Health of GBR-based decision-making systems (from local to international scales, including levels of connectivity between different parts of the governance system, effective use of diverse knowledge sets and system capacity for effective action. Also includes levels of satisfaction with GBR management among community, industry and partners; viability of institutional arrangements; community participation in GBR management; and use of ESD principles in planning and management.	**Governance** OUTCOME: The Outstanding Universal Value of the GBR is maintained and enhanced each successive decade through effective governance arrangements and coordinated management activities.

This indicator framework, based on five clusters and their constituent attributes, can also be visually represented as per Figure 1.

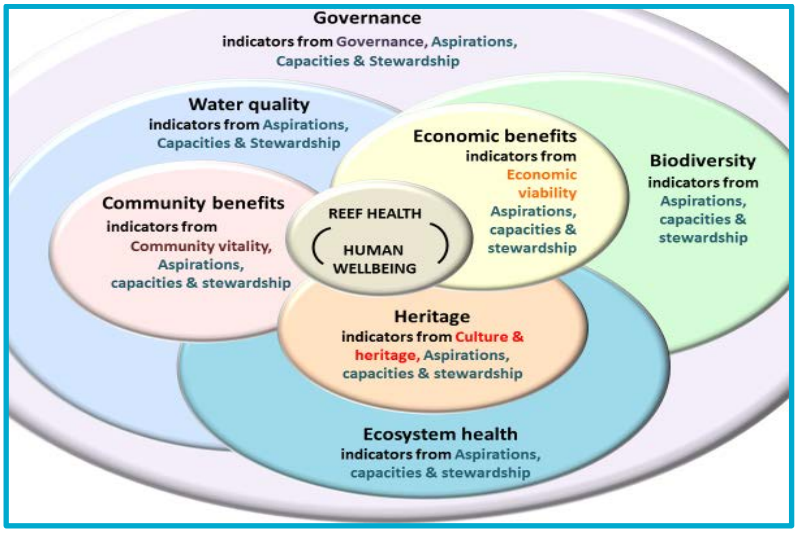

Figure 1: Human dimension values and their respective indices (as shown in Table 1) will contribute to a collective understanding of Reef 2050 Plan themes as shown here.

To support index development, each cluster is and can be further described by a set of attributes that can be allocated an indicator value based on available evidence (see Table 4). Evidence is gathered from peer-

reviewed literature, grey literature and other forms of knowledge such as Indigenous and local knowledge. This work draws upon both qualitative and quantitative data. Quantitative data sets used in analysis include the following:

- **ABS** (Australian Bureau of Statistics) *Data by Region* http://stat.abs.gov.au/itt/r.jsp?databyregion
- **ABS** (Australian Bureau of Statistics). (2015). *Information paper: An experimental ecosystem account for the Great Barrier Reef Region, 2015* (cat. no. 4680.0.55.001). Canberra: ABS. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/4680.0.55.001Main%20Features202015?opendocument&tabname=Summary&prodno=4680.0.55.001&issue=2015&num=&view=
- **ABARES** (Australian Bureau of Agricultural and Resource Economics and Sciences) *Catchment Scale Land Use of Australia* http://www.agriculture.gov.au/abares/display?url=http://143.188.17.20/anrdl/DAFFService/display.php%3Ffid%3Dpb_luausg9abll20160616_11a.xml
- **ABARES** (Australian Bureau of Agricultural and Resource Economics and Sciences) *Data sets*. http://www.agriculture.gov.au/abares/data

Table 4: Conceptual framework linking human dimension clusters and attributes to Reef 2050 Plan outcomes**.**

Reef 2050 Plan themed outcome	**Human dimension cluster**	**Attributes**	**Main sources of data for indicators**
All seven themes – i.e. economic benefits, community benefits, heritage, governance, water quality, biodiversity & ecosystem health. (Refer back to Figure 1).	Aspirations, capacities & stewardship represents the cohesive vision & aspirations for the future of the GBR together with awareness, skills, knowledge & capacities to turn aspirations into action. Personal & collective (including industry) efforts to: (a) minimise impacts on the GBR & catchment; (b) restore degraded marine, coastal & catchment ecosystems; (c) apply ESD principles; & (d) be actively involved in GBR & catchment management.	1.1 Effectiveness of community-based stewardship activities focussing on the GBR & catchment 1.2 Education/ knowledge/ skills levels & spread across the Region affecting GBR outcomes 1.3 Adoption of best practice systems – Ag. & land sector. 1.4 Adoption of best practice systems – Industry & urban. 1.5 Adoption of best practice systems – Marine sector.	Indicators for 1.1, 1.4, 1.5 derived from a stewardship framework based on based on nation-wide State of the Environment Report management effectiveness framework, where overall stewardship is rated as very effective through to not effective based on a range of criteria (Eco Logical Australia (2016a&b). Indicators for 1.3 derived from ABCD Agricultural Management Frameworks set out in regional Water Quality Improvement Plans (Folkers *et al.* 2014). Indicators for 1.2 derived from ABS & OESR data sets; regional NRM body documents.
Community benefits: An informed community that plays a role in protecting the GBR for the benefits a healthy GBR provides for current & future generations	**Community vitality** is characterised by demographic stability, security, happiness & well-being. Community vitality associated with the GBR include services & infrastructure supporting the interface between the community & GBR as well as the social health derived from the GBR - e.g. nature appreciation, relaxation, recreation, physical health benefits, & other lifestyle benefits derived from the GBR. A healthy GBR community derives high levels of appreciation & enjoyment from the GBR & is	2.1 Demographic characteristics across the catchment 2.2 Use patterns across the GBRMP 2.3 Security in the catchment including housing, safety & risk management. 2.4 Wellbeing/ happiness within the general community. 2.5 Community health/ wellbeing/ satisfaction associated with the GBR.	Indicators for 2.1, 2.3, 2.5, 2.6, derived from ABS & OESR data sets. Indicators for 2.2, 2.5 derived from SELTMP[5]; vessel registration data; work by Rolfe, Windle & Pascoe; & potentially from anaylsis of social media big data sets;

Reef 2050 Plan themed outcome	Human dimension cluster	Attributes	Main sources of data for indicators
	highly satisfied with the GBR & its management.	2.6 Regional services & service infrastructure supporting the interface between the community & GBR	
Heritage: Indigenous & non-Indigenous heritage values are identified, protected, conserved & managed such that the heritage values maintain their significance for current & future generations	Culture & heritage represents the status of integrated & diverse culture & heritage associated with the GBR catchment. Cultural & heritage connections promote a sense of place & place attachment associated with the GBR. This cluster also includes values of significance in accordance with Traditional Owner practices, observances, customs, traditions, beliefs or history. Historic heritage is specifically concerned with the occupation & use of an area since the arrival of European & other migrants.	3.1 Cultural integrity with respect to the GBR (i.e. attachment & identity, pride, place attachment links to World Heritage). 3.2 Traditional Owner cultural connections with GBR resources including identification, protection & management of Indigenous cultural heritage in sea country. 3.3 Identification, protection & management of historic heritage in GBR environments	Indicators for 3.1, 3.2, 3.3 are derived from SELTMP & other sources of information – published & unpublished reports, government documents.
Economic benefits: Economic activities within the Great Barrier Reef World Heritage Area & its catchments sustain the GBR's Outstanding Universal Value.	Economic viability includes the monetary advantages that people derive directly or indirectly from a healthy & well-managed GBR. Fundamental to this cluster is the premise that economic activities within the GBRWHA & its catchment/watershed are ecologically sustainable. GBR-dependent industries include commercial fishing, marine tourism, GBR-based recreation, GBR-based research, Traditional Owner use. These industries generate income & employment for thousands of people in coastal communities near the GBR & beyond. GBR-associated industries are those that may impact the GBR but are not economically dependent on GBR health e.g. shipping, catchment industries such as agriculture, urban development, port development.	4.1 Size & diversity of regional economic growth 4.2 Economic viability of Reef-associated industries & impacts on Reef-health 4.3 Economic viability of Reef-dependent industries & impacts on Reef-health 4.4 Inclusiveness & economic fairness/ equity 4.5 Workforce participation & employment 4.6 Economic confidence in GBR-dependent industries within the region	Indicators for 4.1, 4.4, 4.5, derived from ABS & OESR data sets. Indicators for 4.2 & 4.3 derived from SELTMP; ABARES Indicators for 4.6 derived from ABS & regional economic reports prepared by local economists.
Governance The Outstanding Universal Value of the GBR is maintained & enhanced each successive decade through effective governance arrangements & coordinated	Governance is the health of GBR-based decision-making systems (from local to international scales, including levels of connectivity between different parts of the governance system, effective use of diverse knowledge sets & system capacity for effective action. Also includes levels of satisfaction with GBR management among community,	5.1 Strategic focus of governance system. 5.2 Connectivity within & between key decision making institutions & sectors. 5.3 Adaptive governance capacity of key decision making institutions & sectors.	Indicators for 5.1, 5.2, 5.3, & 5.4 derived from government documents, & independent management effectiveness reports (e.g. Dale et al 2016d).

Reef 2050 Plan themed outcome	Human dimension cluster	Attributes	Main sources of data for indicators
management activities.	industry & partners; viability of institutional arrangements; community participation in GBR management; & use of ESD principles in planning & management.	5.4 Adaptive use & management of integrated knowledge sets.	

The indicator development process involves synthesising evidence from diverse sources, presenting the evidence as a series of easy to read tables, and allocating draft indicator scores to each attribute, and combined to form an index for each human dimension cluster. The tables and proposed scores (presented in each report) will be discussed and moderated in regional expert panel meetings using a consistent set of decision rules.

For this indicator work, 'community' includes residents in GBR regional towns and cities as well as national and international people who either have an interest in the GBR or who influence (directly or indirectly) the condition of the GBR, including industry sectors, Traditional Owners and government agencies (i.e. local government, state and Commonwealth governments). Based on strong theoretical considerations, the work considers that thriving, resilient communities can anticipate risks and limit impacts while still retaining the same function, structure, purpose, and identity. Sometimes a regional or local community may get trapped in a less resilience state, unable to change over time. Being able to understand which attributes of a community need attention to build resilience is a first step to overcome stagnation or decline (CARRI, 2013; Walker & Salt, 2006).

Within each region, expert panel members are involved to help determine regional resilience ratings. They are selected on the basis of: (a) their experience and knowledge of the GBR from a community, industry (GBR-dependent and GBR-associated industries), or governance perspective; and/or (b) their involvement in social, economic and/or environmental initiatives which contribute to regional community wellbeing. Specifically, panel members are invited to appraise the evidence about the GBR's human dimensions which are presented in the set of tables for their region; add additional knowledge to fill data gaps; and record data gaps and limitations. The scores, when considered will be used to make critical judgements on the state or condition of regional resilience as a way of representing the human dimensions of that part of the GBR. The process can help to plan for the future by paying specific attention to the state of the human dimension, and to alert GBR managers, partners and stakeholders to emerging issues and risks.

From the above gap analysis above, and strongly based on the emerging human dimensions monitoring process, there are several significant data gaps, summarised here:

- Understanding of how many people visit the Reef; where they go; what they do – particularly at scales useful to management;
- Lack of regionally specific data for GBR human dimensions;
- Lack of data on historic cultural values of the GBR;
- Lack of data on Indigenous cultural values of the GBR;
- Lack of sector specific data on the capacity (including willingness & interest) of Reef- dependent and Reef-associated communities and industries to respond to changes facing the GBR.

Based on this work, there are several emerging implications for Reef 2050 Plan:

1. *Considering Human Dimensions as an Asset Versus a Threat:* While there are some targets and actions in the Reef 2050 Plan that do seek to directly invest effort in building the health of the human dimension of the GBR socio-ecological system, there remains an over-arching logic that generally sees key aspects of the human dimension as a risk to OUV. While actions related to

physically doing something to improve biophysical OUV should be outlined in the Reef 2050 Plan (e.g. building more effective wetlands to improve water quality) specific policy or investment to improve the resilience of individuals, communities and regions (the primary feature of the human dimension) and resultant indicators should be logically embedded within the human dimensions sections of future Reef Plans (e.g. increasing economic diversity within all of the GBR catchments) and help drive adaptive management.

2. *Future Reef Plan Action Might Need to Explicitly Improve Human Dimensions:* Early evidence building around key clusters of indicators related to the human dimension (but specifically the community and economic benefit clusters) are already giving some pointers to significant issues/ future actions that might need to be included in the Review of the Reef 2050 Plan. These issues might previously have been un-represented in the current Plan.

Indeed, significant issues that human dimensions style thinking might mean for future review and redevelopment of the current Reef 2050 Plan might include:

- A significant improvement in investment and attention to understanding spatial use patterns across the GBR (i.e. how many people visit/use the GBR?; where do they go?; how do they get there?; how often do they visit?; how long do they stay?; why do they go?);
- More focus on monitoring and responding to international sentiment about the health of Reef (i.e. managing widespread international perceptions that the GBR is dead);
- A significant improvement in investment and attention to heritage related issues;
- A more cohesive, stable and integrated focus on lifting the capacity of stewardship and education across all sectors;
- The establishment of new stewardship capacities, institutions, R&D capacities and technologies for protecting and restoring high priority reef ecosystems;
- Building the social and community mandate for applying more defined triage-based approaches to spatial prioritisation of reef protection, restoration and management through social, economic and environmental trade-off analysis and purpose built decision support systems;
- Early consideration of major strategies to improve the economic resilience of communities seriously affected by the impacts of Coral Bleaching (e.g. Wet Tropics/ Cape York Peninsula);
- Early consideration of major strategies to improve the economic diversity of Queensland's GBR-based coal regions, including substantive offsetting of impacts or securing lower emission technologies, recognising that Coal will likely face increasing social licence issues;
- Significant reforms/continuous improvements in the wider GBR system of governance and particularly taking renewed action in dealing with the negative impactful policy subdomains and inefficiencies in Reef 2050 Plan delivery systems (see Governance Section).

Implications for the midterm and 2020 review process

Key consequent implications for the Reef 2050 Plan Mid Term Review include the need to:

- Further emphasise the non-market values of the GBR to better understand the trade-offs needed to manage different ecosystem services;
- Enable development, implementation and reporting of an annualized program (or work plan) underpinning the monitoring of human dimensions of the GBR;
- Integrate agreed issues emerging out of 1st benchmark (2017) in the Mid Term Review;
- Commence a process of regularised bilateral and stakeholder agreement about high priority strategies for improving the condition of the GBR human dimensions based on the benchmark and

monitoring of the health of key human dimension clusters (effectively Stewardship, Community Benefit, Economic Benefit, Heritage and Governance);

- Ensure there is specific consideration of the wider human dimension issues within any engagement associated with the Mid Term Review and a shift in emphasis from just seeing human dimensions as a threat to GBR OUV, enabling a much wider set of strategies and actions required to improve the overall health of the GBR socio-ecological system; and
- Include future benchmark results and emerging trends into the 2019 Outlook Report.
- As part of a foundational action in the lead up to the 2020 review of the Reef 2050 Plan, better understand the following:
    - How can we build the resilience of reef-dependent and reef-related enterprises and communities to expected/unexpected environmental change while improving environmental protection (e.g. though new practices, business models, risk management, adaptive capacity or technologies)?
    - How do we better engage and partner with place based communities and sectors to improve reef stewardship and enhance economic and social benefits?
    - What new policy instruments, models of collaboration and management are required to improve the effectiveness and adaptability of the wider system of governance affecting the reef in a changing environmental and socio-economic context?

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2.5 Governance and Implementation[6]

Context

The Reef 2050 Plan was made a schedule to the *GBR Intergovernmental Agreement 2009* between the Australian and Queensland governments (the highest level of agreement between a State and the national government in Australia and signed by the Prime Minister and the Premier). The GBR Ministerial Forum, which must meet at least annually, was then established to oversee implementation and monitoring of the

[6] Allan Dale (JCU)

Plan (DoE 2015). This arrangement has been supported by:

- a multi-sectoral **Reef Advisory Committee** (RAC) to facilitate engagement with industry and the broader community on implementation and review of the Plan (includes members from the Reef 2050 Long-Term Sustainability Plan Partnership Group, Traditional Owners and community representatives);
- an **Independent Expert Panel** (IEP) to provide expert advice on implementation and review, including objectives and targets, knowledge gaps and science priorities for delivery. The panel includes scientific (biophysical, heritage, social and economic) expertise; and
- an **Intergovernmental Operational Committee** (IOPP) of senior officials from the Australian and Queensland governments to oversee implementation of the Plan, facilitate coordination of Reef-related activities and report annually to the GBR Ministerial Forum.

These committees have been supported by a dedicated secretariat. As required, sub-committees have been supporting specific work streams (e.g. delivery of the *Reef Water Quality Protection Plan 2013*). Implementation of the Reef 2050 Plan*'s* actions has been reinforced as each agency builds responsible actions into their work programs. Building on the strong foundation of existing Reef programs, an overarching implementation strategy for the Plan was prepared by the IOC, in consultation with the RAC and IEP for consideration by the Ministerial Forum.

What has happened since Reef 2050 Plan and gaps identified

With these key overarching governance arrangements now in place, with respect to the business of governance related to the GBR, there have been several important developments that have progressed or analysed this agenda substantially. These have included:

- The Queensland Audit Office Report into Reef Water Quality (QAO 2015);
- The release of the Queensland' Reef Water Quality Science Taskforce (GBRWST 2016);
- The completion of the first "whole of system" benchmark analysis undertaken to analyse and establish the basis for monitoring the long term health of the system of governance affecting outcomes in the GBR relative to the Reef 2050 Plan (Dale et al. 2016);
- Consideration of governance issues for the first time in the emerging Reef Consensus Statement being overseen by the Queensland government (Waterhouse *et al.* 2017); and
- The current Craik Inquiry into the management of the Marine Park Authority.

The release of the QAO report (in June 2015 after the Reef 2050 Plan) is significant in that it hinted at the need for a major refocus of the programmatic effort related to Reef Water Quality programs in Queensland. In particular, the QAO found that, while there was a Reef 2050 Plan:

> … there was no cohesive state based reef program to support its achievement. The Qld Government's response to its *Reef (2050) Plan* commitments has lacked the programmatic rigour needed to address the serious issue of poor quality water entering the reef from catchments (QAO 2015: 2).

It was in this context, that the QAO felt that the Queensland government's response had lacked urgency and purpose, characterised by disparate projects with no central authority and no clear accountability for their delivery or for achievement. These findings lent impetus to the emerging establishment of the Queensland government's Office of the GBR (OGBR) and formation of the Reef Water Quality Science Taskforce. While the OGBR got on with the job of cross governmental coordination, the Taskforce, led by

Dr. Geoff Garrett, undertook an extensive review of the existing foundations for managing GBR water quality. The Taskforce process ran till mid-2016 and found that effective governance of water quality improvement in the GBR would require (GBRWST 2016):

- A mix of strategies and tools, including incentives, regulation and innovation;
- Everyone including farmers, graziers, developers, the resources sector, community members, Traditional Owners and tourism operators must be part of the solution; and
- Recognition that achieving water quality targets in the timescale proposed would be well beyond the funds currently allocated by the Queensland and Australian governments.

The Taskforce found that even full application of best management practices across all farms in the reef catchments would not achieve the Reef 2050 Plan targets, therefore, a strong focus on innovation, new technologies and different ways of thinking was required. While acknowledging the efforts of all player and the Queensland government to date, Taskforce considered that "it is abundantly clear that more widespread and rapid action is required". This suggested that there would need to be a fundamental shift in the way land is managed. Further arising from this work, a consortium of economic and water quality experts later finalised an assessment of the costs and effectiveness of various solutions to identify the total investment that may be required to meet the targets. As a result of these findings, the Queensland government allocated the balance of its $100 million commitment to improving Reef water quality, establishing a range of targeted programs including: (i) the development of two major integrated programs; (ii) extension; (iv) innovation; (v) governance improvement; (vi) monitoring and evaluation; and (vi) communication. These programs are now being rapidly designed and deployed by the OGBR, making it too early to evaluate success.

Finally, alongside these higher level evaluative considerations of governance associated with the GBR relative to Reef 2050 Plan objectives and targets, a significant NESP funded project has for the first time sought to define and then benchmark the health of the over-arching system of governance affecting social, economic and environmental outcomes relative to the GBR (Dale et al. 2016). This work, led by James Cook University, is now becoming formally integrated into the process of monitoring the human dimensions of the GBR under the RIMReP framework. This work could also be integrated into review processes and 5 yearly Outlook reporting, making it useful to both the current midterm review and the final reporting progress due by 2019. Prior to this, there has been no independent and integrated review of the key risks within the overall system of governance influencing GBR outcomes.

This GBR-focussed application of the new Governance System Analysis (GSA) technique identifies governance subdomains that present a high, medium, or low risk of failure to produce positive outcomes for GBR; and analysis system developed specifically for use in analysing the health of the system of governance affecting outcomes in the GBR. This approach importantly determined that three "whole of system" governance problems could undermine GBR outcomes. These included:

- While stressing the integrative importance of the *Reef 2050 Subdomain*, the work considered that, due to its embryonic state, it faces several internal governance challenges;
- The identification of a major risk of implementation failure in the achievement of GBR water quality actions due to a lack of system-wide focus on building strong, stable delivery systems at catchment scale through 10 other important governance subdomains subdomains **(catchment delivery challenges)**; and
- A finding that the *Reef 2050 Subdomain* currently has too limited a mandate/capacity to influence several other high-risk subdomains that must be more strongly aligned with Reef management such as the *Greenhouse Gas Emission Management* or *Northern Development Subdomains* (**competing policy challenges**).

This broader analysis enabled the inclusion of systemic governance considerations in the emerging Reef Consensus Statement (Waterhouse *et al.* 2017). Finally, as a subset of just one of these 40 subdomains, the Commonwealth has recently commissioned a Governance review of the GBR Marine Park Authority (GBRMPA), and has appointed Wendy Craik to undertake the review. The Terms of Reference for the review will focus its attention, among other things, on issues related to roles of the Chair, the Board and the CEO of the GBRMPA (Frydenberg 2017).

Emerging implications for Reef 2050 Plan and opportunities to improve

From the above gap analysis, there are several significant emerging implications for Reef 2050 Plan.

1. ***Competing Policy Challenges:*** In the future, the *Reef 2050 Plan* must concern itself with working positively and proactively with agencies responsible for those non-GBR policy areas that present the greatest risk to the achievement of Reef Plan outcomes. The priority subdomains requiring some level of urgent attention would include: (i) the *Greenhouse Gas Emission Management Subdomain*; (ii) the *Ecosystem Service Policy and Delivery Subdomain*; (iii) the *Northern Australian Development Subdomain*; (iv) the *Major Development Project Assessment Subdomain*; and (v) the *Vegetation Planning and Management Subdomain*.
2. ***Strengthening Policy Alignment Within the Long Term Sustainability Plan:*** The *Reef 2050 Plan Subdomain* is the one keystone arrangement with integrative potential to influence the entire GBR governance system. The subdomain did not exist in 2013 and has rapidly evolved from previous bilateral and partnership arrangements focussed initially on strategising and coordinating efforts to achieve GBR water-quality targets. The formation of these new arrangements, with strong coordinated government efforts, engagement systems and knowledge integration platforms, is a significant and bold governance innovation. Due to its infancy, however, the following characteristics need strengthening: (i) more cohesive target setting and strategy Development within *Reef 2050 Plan*; (ii) more cohesive trilateralism between the Commonwealth, State and Local governments; (iv) the strengthening of formal partnership arrangements associated with development and delivery of the Reef 2050 Plan; (v) the reduction of internal institutional overlaps; and (vi) improved science priority setting; (vii) Ongoing strengthening of monitoring and reporting arrangements via RimREP; and (viii) Revamping the purpose/focus of the Reef Trust concept.
3. ***Securing Reef Water Quality Catchment Delivery****:* There is a key cluster of 10 subdomains that are key to ensuring the delivery of planning and management actions for improving water quality and ecological health in GBR catchments (see Figure 2). These subdomains, however, are not being cohesively strengthened as critical *Reef 2050 Plan* delivery mechanisms. When looking across the wider GBR governance system, a consistent problem becomes clear in that there is poor integration between the policy intent of the Reef 2050 Plan and the delivery-oriented subdomains at regional or catchment scale (e.g. regional land use planning, river improvement, ports management). As in other governance systems, this lack of integration risks systemic implementation failure.

Implications for the midterm and 2020 review process

Key implications for the Reef 2050 Plan midterm and 2020 review processes include the need to:

- in the context of midterm review, commence a process of internal government and bilateral discussion about how to manage the highest risk competing policy issues emerging from the current benchmark of the health of the overall system of governance affecting the GBR;

- ensure there is specific consideration of wider policy alignment issues already identified through governance system benchmarking within any engagement associated with the midterm review;
- in the lead up to the 2020 review, complete a second independent benchmarking of the wider GBR policy environment by the end of 2018 followed by the Australian and Queensland governments jointly developing an adaptive work plan of priority Reef 2050 Plan policy alignment reforms;
- Inclusion of the priority outcomes of the current review of the GBRMPA into the midterm review of the Reef 2050 Plan; and
- Inclusion of future benchmark results and emerging trends into the 2019 Outlook Report and the 2020 review.

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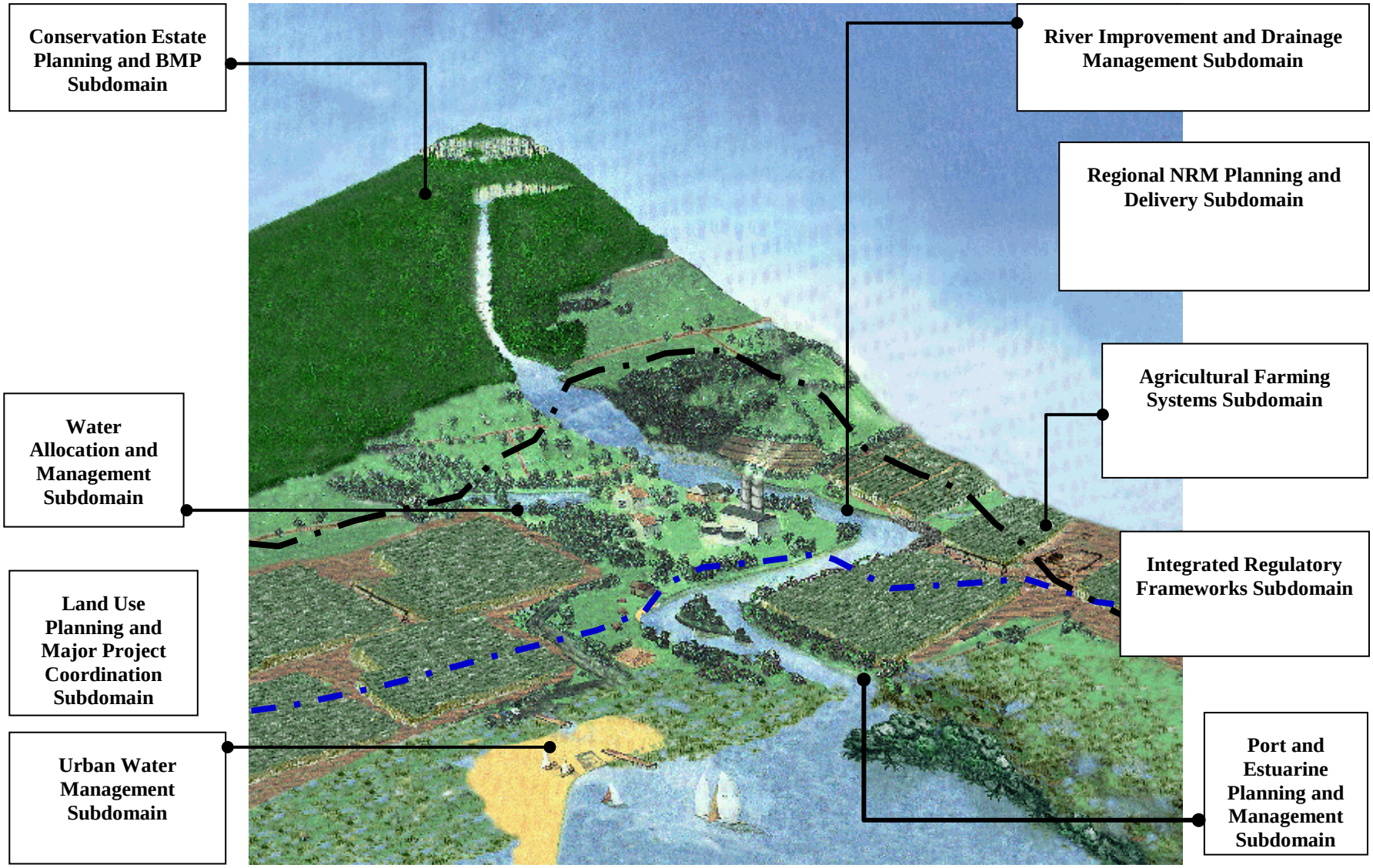

Figure 2: Different governance subdomains representing the key activities influencing the implementation in the GBR (adapted from Vella et al. 1999).

2.6 Traditional Owners and the Reef 2050 Plan[7]

Context

There are at least 44 Traditional Owner groupings with interests in sea country across the length of the GBR (GBRMPA n.d.), including some 28 in the Cape York context (Cape York Institute). Dale et al. (2016a) outline how all of these groups have been working hard towards increasing their ownership of and access to both land and sea country since the original formation of the Marine Park in 1975. In that time, there have been significant and ongoing claim activities in respect to rights to sea country. Indeed, in the Cape York region alone, Traditional Owners now have rights and interests to some 90% of the coastline associated with the GBR (see Figure 3). Following the success of sea country claims in the Torres Strait, the future of Indigenous claims across the GBR will increasingly turn to the sea country estate. This unfolding rights-based context substantively shifts the balance of power with respect to managing the Reef towards the need to meet prior and informed consent before governments can progress and implement substantive policy and planning activities. Additional, in places like Cape York Peninsula, Aboriginal and Torres Strait Islander people will continue to be the primary and most stable population dealing with future GBR issues.

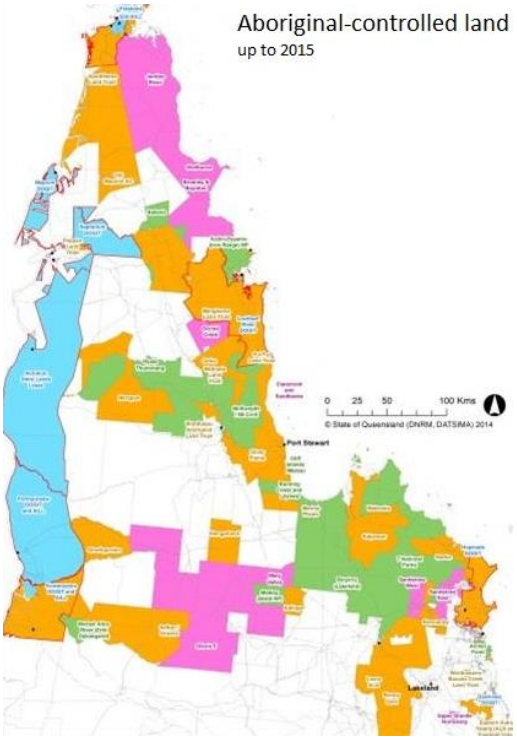

Figure 3: The 2015 extent of Indigenous rights/interests in the Cape York GBR coastline in 2015.
Source: Cape York Institute.

[7] Allan Dale and Jane Addison (JCU)

Indeed, since the mid-1990s, Traditional Owners have been coming together in attempts to reach broad frameworks with the Australian and Queensland Governments for genuine partnership in managing GBR catchments and sea country. People have been seeking government recognition of their authority with respect to land and sea country management. In the view of Traditional Owners, securing real Commonwealth and State commitment to such an approach, however, has been extremely difficult to achieve at all levels (from GBR to regional, sub-regional, tribal and clan levels). There remains a strong view that, despite the increasing level or rights and interest, Indigenous equity in key governance arrangements and decision making structures and processes remain a long way from any form of rights-based recognition and co-management (see Table 5).

Table 5: Indigenous representation on some key GBR-related decision making bodies.

Key reef stakeholders and associated governing body	Non-Indigenous members	Indigenous members
Great Barrier Reef Marine Park Authority – Board	4	1
Australian Institute of Marine Science - Council	7	0
Reef Foundation – Board	15	0
- Scientific Advisory Committee	7	0
- Tech Advisory Group	6	0
- Chairman's Panel	49	0
- Reef Champions (companies)	20	0
- Portfolio Committee	6	0
Reef Trust- Joint Steering Committee (government representatives)	?	0
- Reef 2050 Advisory Committee (interest groups)	17	1
- Independent Expert Panel	16	0
Australian Museum Foundation (Lizard Island)- Trustees	10	0

Source: Cape York Institute.

Given international recognition of the need to more deeply engage Traditional Owners in World Heritage management and given progressively increasing native title rights across the sea country estate, collectively, Traditional Owners have stated a strong desire for two layers of genuine recognition and partnership in GBR management since the late 1990s. These two layers include:

1. Foundation level partnerships and support in building the capacity of Indigenous Land and Sea institutions (at the scales considered most appropriate to Traditional Owners) that lead a self-determining approach that: (i) respects, preserves and increases recognised rights over sea country and associated coastal catchments; (ii) increases access to, management, business and research opportunities for the sustainable use of sea country resources; (iii) builds on the desire of Traditional Owners to work within their sea country and to be more involved than they currently are; and (iv) enables greater influence and involvement in the planning, decision making and management of sea country and associated catchments; and
2. To have a strong collective voice and respectfully negotiated partnership framework with State and Federal governments, GBRMPA and other sectors in achieving the above (building the strength of voice from the clan, tribal, sub-regional, regional and whole of GBR scales).

These aspirations were first cohesively articulated in the Sea Forum processes led by Traditional Owners in the 1990s. Over the years, people have also made real progress in securing improved recognition of their rights and in developing local capacities to govern and manage their sea country. Indeed, a detailed timetable of significant Traditional Owner driven events that progressed these interests up to 2012 is outlined in Figure 4. Recent developments also include the formation of the Cape York Turtle and Dugong Taskforce (2011). Despite these progressive wins, and good engagement by Commonwealth and State Governments on occasions, there has been no lasting, continuously improving GBR-wide approach to engaging Traditional Owners (Dale et al. 2016a).

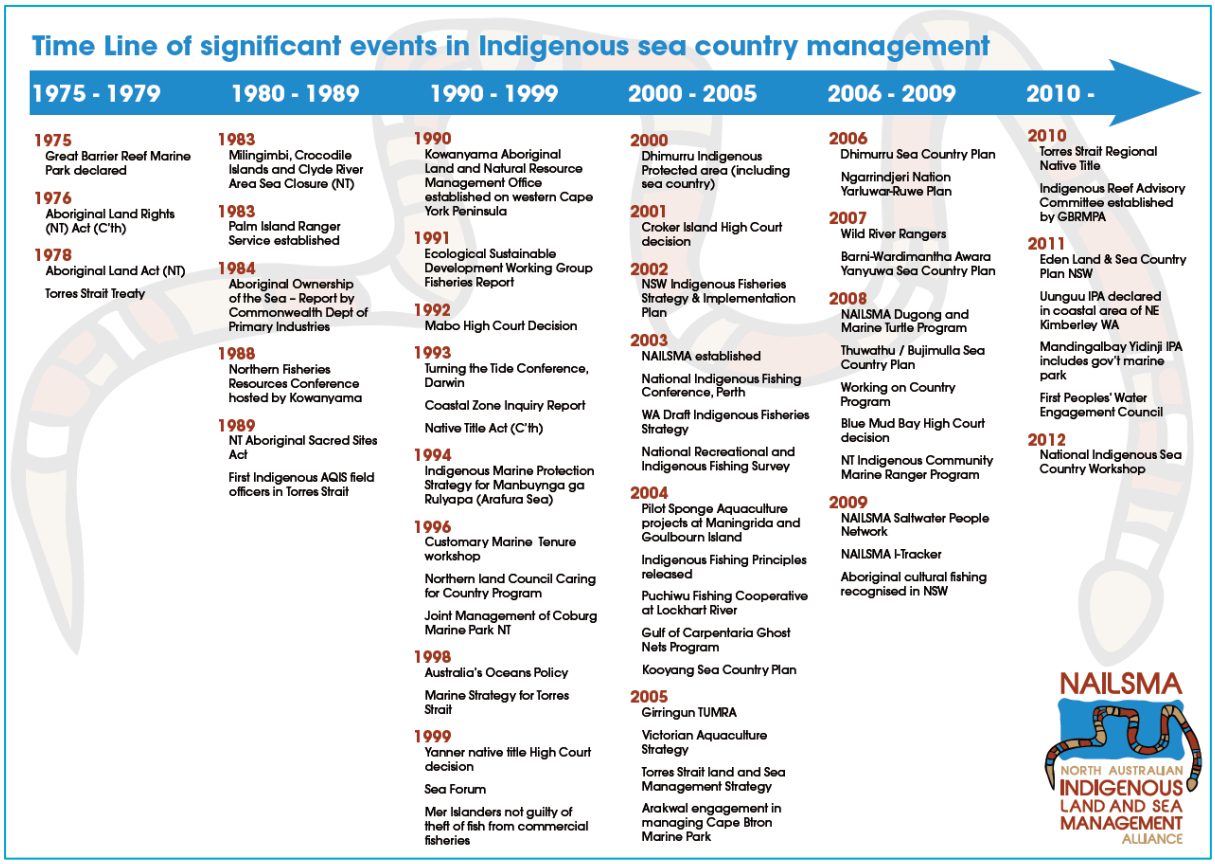

Figure 4: Timeline of significant events in Indigenous sea country management

With the commencement of development of the Reef 2050 Plan, there was no strong, whole of GBR mechanism for significant partnership building with Traditional Owners. The Reef 2050 Plan sets out the long-term focus for protecting and enhancing the key values of the GBR. As a foundation for doing so, however, Reef 2050 Plan does explicitly recognise that Aboriginal and Torres Strait Islander peoples are the GBR's Traditional Owners and that they have continuing connection to country. *Reef 2050* also sets a series of objectives, targets and actions (management guidance, on ground effort, stewardship, community participation, research and information management). Those that relate to the interests of GBR Traditional Owners are outlined in Appendix 1 of Dale *et al.* (2016).

Traditional Owners were broadly engaged in the development of these outcomes, objectives, targets and actions. Specific Traditional Owner advice also remains structured into the Reef 2050 Plan national advisory arrangements. As a result, for the first time, Indigenous actions are embedded right across the Plan's scope, and Traditional Owners recognise this as a noteworthy Reef 2050 Plan achievement. The range of different strategies finally included, however, were relatively weak and fragmented relative to Traditional Owners aspirations. Further, beyond this, there were no clear structures for the ongoing engagement of Traditional Owners to support implementation and monitoring of the Plan and to derive benefit from its implementation. In the view of Traditional Owners, the Reef 2050 Plan is generally not visionary about the role of Traditional Owners in the management of the GBR (see Dale *et al.* 2016; CYP 2017). Most objectives are set at a high level, are vague with respect to Traditional Owner roles, and may be difficult to measure. Accountabilities for implementation of these objectives, targets and actions are also weak.

At this point in the design of the processes for the review of the Reef 2050 Plan, it should also be noted that since completion of the *Plan* the international standards relating to Traditional Owner involvement in World Heritage management have changed. At the Bonn meeting of the WHC in July 2015, there was recognition of the need for securing the free, prior and informed consent Indigenous peoples in protected area management (UNESCO, 2015). As a consequence of this meeting, the World Heritage Committee's Operation Guidelines were updated to be more consistent with the UN Declaration on the Rights of Indigenous Peoples, although this is an ongoing process. Clause 123 of the Operational Guidelines now says "States Parties are encouraged to prepare nominations with the widest possible participation of stakeholders and to demonstrate, as appropriate, that the free, prior and informed consent of Indigenous peoples has been obtained" (UNESCO 2015). No such consent for the establishment of the GBRMPA or the World Heritage Area has yet been obtained, so this has implications for *Plan* review processes.

Dale *et al.* (2016) consider that this change and other UN-related developments may encourage:

- Pressure for the Australian and Queensland Governments to actively improve their foundations for the engagement of Traditional Owners in GBR governance; and
- Consideration of the value of supporting Traditional Owners as they consider the value of relisting the World Heritage Area for its cultural values.

It is also worth noting that UNESCO recently held a workshop on "How to ensure that the implementation of the World Heritage Convention is consistent with the UN Declaration on the Rights of Indigenous Peoples" (UNESCO 2012). The results may have implications for Traditional Owners in developing their policy positions on long-term approaches to co-governance of the GBR.

Importantly, without a clear partnership arrangement being in place during *Plan* development, there was no standing framework established to drive and oversee the implementation of the strategies. Indeed, the considered Traditional Owner view at the end of that process could be expressed as:

> *With the future health of the GBR under threat, the current Reef 2050 Long Term Sustainability Plan (Reef 2050) recognises the significance of Traditional Owner rights and interests in the management of sea country and the Marine Park. There are considered and significant Indigenous implementation actions embedded right across Reef 2050. Implementation,*

however, lies ahead. Given the long history of Traditional Owner attempts to influence sea country management across the GBR, they consider that, without strong partnerships, there could be a real risk of implementation failure. At this point, the mechanisms for cohesive and coordinated implementation of the Reef 2050 do not yet fundamentally engage Traditional Owners as real partners in the long-term management of sea country, consistent with international guidelines for their engagement in protected area management, which emphasise the required need for prior informed consent and ongoing equity (in Dale et al. 2016).

Gaps identified

With no clear mechanisms for implementing the fragmented actions outlined in the Reef 2050 Plan, Traditional Owner concern about Federal and State commitment to their interests began to emerge soon after its release. Based particularly through lobbying from Melissa George, the Chair of the Federal Environment Minister's Indigenous Advisory Committee, some preliminary funds were secured through the National Environment Research Program's GBR Water Quality Hub to explore Traditional Owner views and interests in implementation of the Indigenous actions in the *Plan*.

Given that the Reef 2050 Plan presented a new opportunity, and with the focus having turned to *Plan* actions and their implementation, the NESP Project gave Traditional Owners from across the GBR an opportunity to engage with the new governance arrangements going forward. Several workshops presented an opportunity for Traditional Owners in the southern GBR (but linked to efforts in Cape York and Torres Strait) to do this through response to the proposed Reef 2050 Plan implementation strategies and governance arrangements for *Plan* implementation. In short, the Project aimed to provide guidance to Australian Government agencies regarding the moves needed to implement some 24 Indigenous Actions in the Reef 2050 Plan effectively.

Linked to the processes associated with the NESP Project, the Commonwealth also funded a parallel (but staggered) investment direct through Gadarjil (based on advice from the Indigenous Reef Advisory Committee or IRAC) to commence development of an *Indigenous Sector Specific Implementation Plan* for the Reef 2050 Plan. The focus of this process was to also help build Indigenous capacity that would also support the delivery tasks identified in the *Plan*.

This *Indigenous Implementation Plan* was developed to support and guide implementation of the Traditional Owner led actions in the Reef 2050 Plan. Drawing on broad consultation with Traditional Owners, it highlights general findings and identified three focus areas as implementation priorities:

- Coordination;
- Cultural Heritage; and
- Business Capacity

These key areas were considered to intersect with the majority of the Traditional Owner actions in the Reef 2050 Plan, and for each of these three priorities, the *Implementation Plan* articulated the known challenges and opportunities, proposed a pathway to address those challenges and identified the results expected from implementation. The implementation of these priorities was considered by Traditional Owners to be important to progress meeting of the Indigenous targets and objectives in the Reef 2050 Plan. However, ongoing consultation and engagement was required (Gidarjil 2016).

On the back of the Gidarjil Report, the Commonwealth (though at this stage without full partnership input from the State) has now progressed towards the procurement of a (likely community-based) service organisation that could: (i) set the framework for, engaging, coordinating and reporting on the implementation of Traditional Owner-related actions from the Reef 2050 Plan; and (ii) provide an opportunity to engage Traditional Owners in the mid-term review of the Reef 2050 Plan. This approach

aims to test the best approach to policy framing around ongoing Reef management. There is currently no clear linkages between this approach and the existing IRAC framework, but explicit consideration of these linkages might well emerge from the processes being established.

Emerging implications for Reef 2050 Plan and opportunities to improve

Based on these developments since the completion of the Reef 2050 Plan, it would seem that key opportunities for improvement could build on the view of the Cape York Turtle and Dugong Taskforce, the findings of NESP Project and Gadarjl engagement with Traditional Owners regarding implementation of Reef 2050 Plan. Within a much stronger framework of Commonwealth and State recognition of the rights of Traditional Owners, key headline considerations include the following:

1. The core task ahead is to the **build strength and capacity of local, sub-regional and regional Indigenous land and sea management organisations** through Traditional Owner-driven:

- Sea-country planning and further development of rights, use and access agreements;
- Knowledge management systems, sharing of Traditional Owner technologies;
- Greater use of Rangers and Indigenous business units for on-ground delivery work;
- Business planning and development for Indigenous institutions;
- Science and knowledge building; and
- Network building across Indigenous organisations

2. **Higher level (and bilateral) partnership frameworks are required for recognising and partnering Traditional Owners** at the whole of GBR level (and associated regional, sub-regional and local scales) in the review, further development, implementation and review of the Reef 2050 Plan, including structured engagement that might include:

- Structured input of appropriate local, sub-regional and regional orgs;
- The formation and use of Local Indigenous Marine Advisory Committees (LIMACs), and in the case of Cape York, the Cape York Turtle and Dugong Taskforce framework;
- A Big-MAC that links LIMACs and the Taskforce together to create a GBR-wide forum;
- Continued support for the Indigenous Reef Advisory Committee (IRAC); and
- The development of a Reef 2050 Plan planning, implementation and compliance agreement.

3. **Support for open engagement with information and knowledge** generation is critical by:

- Continued improvement in information-provision to Traditional Owners and strategies that support Traditional Owners to build and better manage their required knowledge;
- Investment in Indigenous led research and improved Traditional Owner input into other research (monitoring, values of sea country management, impact assessment); and
- Ongoing implementation of TWQ Hub Indigenous Engagement Strategy.

Implications for the midterm and 2020 review processes

The main implication for the mid-term review at this point is:

1. The need for the Commonwealth and State to reach a stronger level of bilateralism in the progression of the proposed (open tender) procurement of services to determine the framework for engaging, coordinating and reporting on the implementation of Traditional Owner-related actions from the Reef 2050 Plan;
2. The potential splitting of this proposed tender into two stages: (i) a design phase; and (ii) a delivery, implementation and ongoing review phase.

3. The need for strong Traditional Owner partnership into the selection/management of and engagement during the design part of the tender, ensuring appropriate and quality input from tribal, sub-regional, regional and whole of GBR scale; and
4. The use of the resultant engagement structures to undertake detailed Traditional Owner partnership in the review of the Reef 2050 Plan and the progression of agreed actions.

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2.7 Monitoring, Evaluation and Reporting[8]

Context

The Reef 2050 Plan highlights that one key aspect to its implementation is integrated ecological, social and economic monitoring and reporting for the reef and its adjacent catchments, or the Reef Integrated Monitoring and Reporting Program (RIMReP). RIMReP is intended to provide a comprehensive and up-to-date understanding of the reef including its condition. This is seen to be critical for maximising the effectiveness of the Plan. The key objective of this comprehensive monitoring and reporting program is to measure and report progress towards achieving the Plan's outcomes, objectives and targets, as well as guide adaptive management.

The *Plan* sets out what needs be included in the RIMReP. It states that three types of monitoring need to be incorporated: (1) compliance monitoring (i.e. monitoring of the impacts of individual development actions and guided by the conditions specified in a permit, licence or approval), (2) short to medium-term, issue-specific monitoring (e.g. assessments of the condition of, extent of impact on and recovery rates of species, habitats or community benefits), and (3) long-term monitoring (i.e. monitoring that enables the assessment of the condition and trend of the Reef 's values and broad-scale impacts over many years). One of the key purposes of RIMReP is to integrate, and resolve duplications, across existing monitoring programs in the GBR space. Integration is seen as being developed through (1) the standardisation of protocols for information collection, collation, modelling, analysis and reporting (seen as key to improving scalability from point-source/local to regional and Reef-wide scales and for synthesis of information from different sources), (2) making explicit the links to management actions, targets, objectives and outcomes, (3) the use of a common framework (the DPSIR or Driver, Pressure, State, Impact, Response framework), and (4) incorporation of new information and knowledge as it becomes available into the monitoring program. As consistency of monitoring and information is increased over time, the program will develop appropriate indicators to help better target management activities.

The *Plan* envisions RIMReP to be developed and established via a network of collaborators and partnerships, and coordinated by the Great Barrier Reef Marine Park Authority.

The main reporting identified is through annual report cards that assesses progress in delivering the *Plan's* actions. Annual reporting is to be supplemented by a 5-yearly Outlook Report which collectively are intended to provide an assessment on progress achieved towards achieving the *Plan's* outcomes. These reports are to serve as the principal guides to reviewing the *Plan*.

What has happened since Reef 2050 Plan and gaps identified

RIMReP, as a cohesive program, remains to be fully implemented. Since the release of the Reef 2050 Plan in March 2015, working groups have been established to help design a program that effectively coordinates, aligns and integrates existing programs.

Some of the challenges and gaps identified are summarised below:

Lack of a coherent program logic linking actions, targets, objectives and outcomes. For monitoring, evaluation and reporting programs to be effective and efficient they must be underpinned and guided by an overarching framework that explicitly articulates how actions being implemented/planned are

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anticipated to deliver on targets, objectives and outcomes. The Reef 2050 Plan presents a significant advancement from previous plans related to the Reef in that it collates under one Plan and document all existing strategies and actions, and high-level desired changes, across a range of domains that go beyond water quality and agriculture. Nonetheless, it is missing a comprehensive explanation of how the foundational programs and activities, and actions, are understood to contribute to the objectives and outcomes and, ultimately, to achieving the vision for the GBR. This handicaps the Reef 2050 Plan from being able to inform the design of realistic, achievable goals and from establishing a common, shared understanding of the strategies and actions required to protect and improve the Reef's condition and to drive adaptive management. It also impedes the development and implementation of Reef monitoring, evaluation and reporting programs. The additional gaps identified below all stem from the absence of this overarching program logic.

Weak coordination and integration of existing monitoring, evaluation and reporting programs. There are over 90 monitoring programs operating in the GBR; the RIMReP Program was set up to coordinate and integrate these to minimise duplication and provide alignment with management objectives towards progressing the implementation of Reef 2050 Plan. Without an overarching program logic that provides guidance for why, what, and how the various monitoring programs are collecting data and associated data management and reporting mechanisms, RIMReP's capacity to identify key points of synergy, coordination and integration; measure, evaluate, and report on progress (Reef Report Cards and Outlook Reports); and inform management questions, is severely hampered. In the current arrangements, monitoring programs have disparate sets of indicators for different themes of the Reef Plan; and as a collective they do not provide a cohesive monitoring, evaluation and reporting system for RIMReP to effectively guide and build on and to enable any of the monitoring programs to achieve their intended objectives under the Plan. Because of a lack of clear program logic, the monitoring of human dimensions related to the GBR is historically weak.

Unclear alignment between DPSIR framework and Reef 2050 Plan. The DPSIR framework is being used as an overarching framework to bring together the various monitoring programs in the GBR. Two critical issues relate to the use of DPSIR. The first, most significant one, is a lack of clarity on how this framework is linked to the Plan (actions, targets, objectives and outcomes): if monitoring programs are using DPSIR to frame what they are monitoring, how does this inform how the Plan is tracking? Additionally, monitoring of the health of the governance response has been traditionally weak within this framework. The second is associated with challenges using DPSIR to inform adaptive management: DPSIR is good at capturing specific components of a system (e.g. drivers, pressures, state) but is poor at capturing and enhancing understanding about the relationships and dynamics between management responses and desired changes and impacts (e.g. 'avoid impacts', etc.). As such, used as an overarching framework (as opposed to a framework based on a program logic directly linked to and underpinning the Reef Plan), DPSIR has little capacity to inform how management responses need to change and adapt to effectively trigger the outcomes and impacts needed to protect and improve the Reef, particularly in such a complex and dynamic setting as the GBR where there are emerging issues and decisions require multi-stakeholder consultation.

Reporting primarily focused on actions and conditions. Given that there is no overarching program logic, current reporting being done to inform how the Reef 2050 Plan is tracking is primarily focused on reporting on actions (whether they have been implemented or not) and updates on the condition and (early) trends of broad scale impacts on the Reef. Because there is no framework to measure and collect evidence of links between actions and changes (social, economic, cultural, biophysical outcomes) needed to protect/improve the condition of the Reef, these are currently absent in reporting.

Implications for the midterm and 2020 review process

Current reporting is in weak position to inform review. The narrow scope of most of the progress reports produced under the Reef 2050 Plan means they are limited in their ability to inform the review on how well the Plan is tracking towards protecting the Reef. As such rigorous, engagement processes will need to be considered for the review to fill-in information gaps and inform the next iteration of the Plan.

Scope of what is reviewed needs to be expanded. This includes:

- Extending beyond an evaluation of actions and conditions of the Reef (values and biophysical dimensions): The assumed links in the current Plan between the 2050 outcomes, 2020 targets, 2035 objectives and 2015-2020 actions will need to be revisited. An assessment of the missing links and weak points would serve as a foundation for informing a process to develop a comprehensive program logic, or impact pathways, required for strengthening the design and implementation of the monitoring, evaluation and reporting of the Plan.
- Assessment of progress reporting: All reporting carried out prior to the review should be assessed for their effectiveness in tracking progress beyond actions and Reef conditions. This would serve to inform recommendations for improving reporting processes and structures and resources required to transform them into relevant, rigorous foundational sources for future Plan reviews.
- Enabling environment for RIMReP and associated monitoring programs: A greater understanding of the broader context (institutional, political, etc.) in which RIMReP and other monitoring programs have been embedded and how these have shaped, positively and negatively, these programs' ability to achieve their intended objectives is required. Such an assessment would provide insights into building an 'enabling environment' for better tracking and adaptive management of Reef 2050 Plan.

Process for undertaking the review of the monitoring, evaluation and reporting program of Reef 2050 Plan

- Reviewing and improving the monitoring, evaluation and reporting program of the Reef necessitates a close collaboration/engagement with the groups that have been directly involved (e.g. RIMReP Steering Committee and Working Groups). There is a lot to be learned from the challenges, bottlenecks, and successes experienced by those directly engaged in the various Reef monitoring programs. Building on the programs' participants' and other key stakeholders' perspectives and recommendations, as well as on lessons learned from similar efforts in other regions, is critical to building a monitoring, evaluation and reporting system in the Reef that enables appropriate and fit-for-purpose tracking whilst supporting adaptive management.

Prioritisation of what to monitor, evaluate and report on. The comprehensiveness of the Plan – that it cuts across a wide range of themes and scales – presents a significant challenge. Given existing and likely future funding constraints, the review needs to consider a process that enables identification of priority areas for M&E and reporting, with an adaptive mechanism incorporated that enables regular revision as new areas of concern and/or promising pathways to impact emerge.

3 Change Trajectories for the Great Barrier Reef[9]

3.1 Introduction

Recent warming events and cyclones on the Great Barrier Reef have severely impacted reef ecosystems and dependent livelihoods and industries. These events have been superimposed on impacts from regional and local stressors driven by land-use, coastal developments, fishing and starfish outbreaks. The extent of continued global change is uncertain and depends on mitigation commitments by countries worldwide. If countries meet the Paris Agreement's highest aspiration (< 1.5°C warming above preindustrial levels), then continued climate change will be limited, but not insignificant. This possible future would provide scope for the Reef 2050 Plan to support the natural resilience of GBR ecosystems and thereby to sustain their values. In the longer term it could provide scope for a sustained GBR in perpetuity (Heron et al. 2017). In a future without global carbon mitigation however, runaway climate change in a world that warms > 2°C will likely erode the capacity of the Plan to deliver outcomes despite investments and efforts. Nested within these possible climate futures are regional and local social and economic behaviours influencing the capacity of the Plan to meet targets and objectives. Importantly, these behaviours and their drivers are also uncertain, but they are under Australian management and policy influence. At one extreme, best land-management practices, innovative restoration efforts, effective starfish control and enhanced fisheries management could under strong global carbon mitigation allow opportunities to support the Reef's resilience maintain values to 2050. At the other extreme, socio-economic developments at odds with ambitions to manage regional and cumulative impacts, combined with runaway climate change, could mean very limited scope to sustain the outstanding values of the GBR ecosystem.

The purpose of this paper is to help the scoping of options for the midterm review of the Reef 2050 Plan. The paper explores different likely futures and informs the scope for the Plan to deliver desired outcomes under each of four scenarios. The paper thus prompts discussion around what management and policy decisions might best maintain the GBR values to 2050 and beyond. We first synthesise existing scientific knowledge around likely change scenarios and place these in the context of the GBR. The change scenarios we develop can be regarded as pessimistic and optimistic bookends along two dimensions of change: (i) global climate and (ii) regional and local socio-economic drivers. These bookends can serve as logical bounds for the scope of the Reef 2050 Plan midterm review process as they can help triangulate the management and policy strategies that might be most relevant and effective given each scenario. We do not commit to a specific scenario or trajectory here, but instead adopt a language of likelihood, consequence, risk and opportunities associated with each possible future.

3.2 Development of change trajectories

The Great Barrier Reef (GBR) is a multi-use area influenced by a suite of natural and anthropogenic pressures operating at multiple scales and with global, regional and local drivers. Integration across those drivers is needed to construct trajectories that are likely to play out for the GBR and dependent people and industries over the coming decades. This will help explore the plausible scenarios within which the Reef 2050 Plan will operate. To provide background for those change scenarios, recent trends in drivers and pressures and critical responses by key GBR ecosystems are reviewed and used to guide Reef 2050 Plan

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review options. All impacts on the Reef and their sources, local and regional drivers and activities occurring outside of the GBR Region (e.g. land-use) are included in our analysis. Lastly, the scientific knowledge has been canvassed to construct qualitative change trajectories based on storyline methods used by IPCC working groups (Pachauri and Meyer 2014) and other authors (Bohensky et al. 2011, Evans et al. 2011). The GBR region considered for these change scenarios includes the entire management region covered by the Great Barrier Reef Act and the GBR World Heritage Area (Commonwealth of Australia 2014). This area thus includes the offshore deep reefs at the edge of the Continental shelf, through to the coastal mangroves, and within the reef proper, both coral and non-coral habitats, including seagrasses and mangroves.

Four trajectories of change have emerged from the analysis. These are combinations of fast and slow projected rates of global climate change and contrasting changes in regional and local drivers and pressures. This set of scenarios thus provide possible corners on the environmental and socio-economic landscape by 2050. They are summarised as follows:

- Trajectory 1 represents global carbon mitigation coupled with effective regional and local action. Globally, the trajectory follows the Representative Concentration Pathway (RCP) 2.6 aspired to by the Paris Climate Agreement (UNFCCC 2016) to keep global warming < 2°C above preindustrial levels, and possibly to ~ 1.5°C. Regionally and locally, Trajectory 1 reflects efforts to effectively reduce cumulative impact from land-use, transport and coastal and urban developments. It offers opportunities to sustain ecosystem values that produce goods and services, support reef-dependent livelihoods, and to maintain the GBR's Outstanding Universal Value.
- Trajectory 2 represents global mitigation (as under Trajectory 1) but regional and local status quo. Here, economic and social drivers stimulating suboptimal land-use management and practices, combined with an escalation of ship traffic, coastal development and fishing pressures, will lead to continued cumulative impacts from regional/local sources on GBR values.
- Trajectory 3 follows an unmitigated global carbon emission path (RCP 8.5), but with effective regional and local action. Run-away climate change under this scenario is predicted to compromise ecosystem resilience as pressures from ocean warming, acidification and storms are projected to intensify (Anthony 2016). As GBR waters warm at around 70% of the global warming rate (Lough 2012), GBR surface waters could warm another 1.0 - 1.5°C by 2050. The capacity for regional and local management effort to sustain GBR values will deteriorate decade by decade, driving a shift towards strategies for human adaptation as well attempts to support ecosystem resilience.
- Trajectory 4 is characterised by global run-away coupled with regional and local status quo. This is an outlook to a deteriorated GBR. Global run-away climate change and local/regional economic and social behaviours will lead to escalated cumulative impacts on the system. The environmental tolerance of species that support key ecosystem functions (e.g. reef, seagrass mangrove foundations and habitats) and ecosystem services (tourism and fisheries) risk being lost despite attempts at regional environmental management and policy (Anthony 2016, Hughes et al. 2017b). Actions to support Reef values and livelihoods become constrained to smaller scales and using adaptation measures to manage altered or new ecosystems.

Climate change is predicted to be (and already shows signs of being) the strongest driver of change on the GBR (GBRMPA 2014a). Therefore, Trajectories 3 and 4 represent pathways to increasingly compromised GBR values despite investments regional and local management and policy (Trajectory 3). In contrast, reduced climate change under Trajectories 1 and 2 represent opportunities to support GBR resilience. However, an additional 0.5°C of global warming is locked in under the most optimistic carbon emissions path (RCP 2.6), and realisation of this pathway will depend on global commitments to meet emission targets (Rogelj et al. 2016). Therefore, regional and local management and policy have strong roles to play to sustain GBR values under Trajectory 1 and 2.

3.3 Cumulative impacts – context

Why take an integrated approach?

Impacts from climate change occur in addition to other local and regional pressures. To manage the GBR for resilience in a changing environment (see sections 2.2 and 2.3) will require insight into the cumulative impacts from different drivers and pressures and knowledge of where management and policy decisions can alleviate those impacts effectively. By taking an integrated approach to analysing these impact pathways we hope to provide transparency around options for the mid—term review.

The Great Barrier Reef is influenced by a suite of pressures with multiple natural and anthropogenic drivers (Figure 4). The growing influence from climate change - a global driver that exerts a set of pressures outside of direct GBR management and policy control - occurs in addition to pressures driven by regional and local activities that do have management and policy levers. In Figure 4, these are separated into Global and Regional & Local drivers to be able to discuss how different drivers may change the state of the Reef and impact on key values including Outstanding Universal Value (OUV, bottom of Fig. 1). Also it helps identify sets of interventions that can influence drivers, pressures and perhaps state changes directly (response pathway in Fig. 1). Such partitioning of drivers will support the discussion of how different future scenarios (trajectories) will likely influence the Reef in the near- and medium-term future and help a mid-term review identify policy options that might represent solutions.

Integration framework

To facilitate integration across environmental, ecological and socio-economic dimensions, we use a Drivers-Pressures-State-Impact-Response (DPSIR) framework (e.g. Omann et al. 2009, Atkins et al. 2011) that considers the GBR as a linked social-ecological system (Fig. 1). Here pathways from one or many drivers to impacts on one or more ecosystem goods and services can be explored and unpacked. This facilitates comparisons of avenues for management and policy that consider interventions in isolation (e.g. carbon mitigation as a global action or water quality management or Crown-of-Thorns Starfish (CoTS) control as regional/local actions, or as a portfolio of options that identify multiple decision points for a suite of drivers and pressures. Later in this review we explore such portfolio options as a combination of Representative Concentration Pathways (RCPs, van Vuuren et al. 2011) and regional-change scenarios. Clarity around the effectiveness of such different strategy alternatives can inform decisions that deliver against Reef 2050 mid-term goals and objectives as well as guide environmental policy in the long term. Coral reefs are used as an example in Figure 4, but the framework applies to any ecosystem in the GBR including seagrasses, inter-reef areas, mangroves and other coastal systems and their associated fauna and flora.

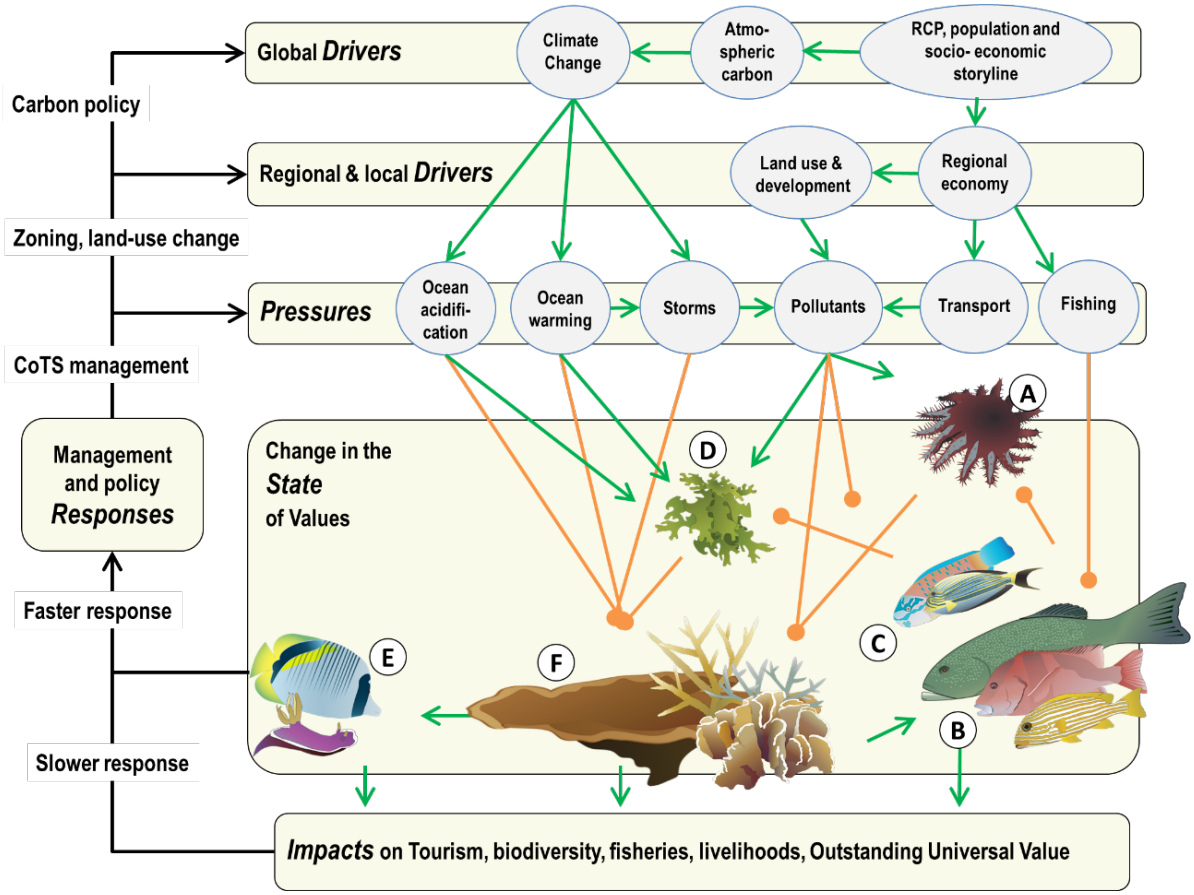

Figure 4. Simplified conceptual model of global, regional and local environmental influences on key functional groups on coral reefs. The model is structured within a drivers-pressures-state-impacts-responses framework. Sharp (*green*) and blunt (*orange*) arrows indicate positive and negative influences, respectively. Management and policy responses are a subset of examples only to guide review options under varying trajectories (scenarios). Organisms shown: (A) Crown-of-thorns-starfish, (B) predatory fish, (C) herbivorous fish, (D) macroalgae, (E) coral-associated fish and invertebrates, and (F) reef-building, habitat-forming corals. Modified from Anthony (2016).

3.4 Recent drivers of change on the GBR

When the GBRWHA was enlisted as a World Heritage Area in 1981, key drivers and activities leading to pressures on the Reef were land use and fishing. The re-zoning of the marine park in 2004 (Fernandes et al. 2005) and the introduction of the Reef Water Quality Protection Plan in 2003 addressed two key impact pathways. While the establishment of 33% of the park as no-take area has demonstrated benefits for fish stocks (Emslie et al. 2015) and enhanced resilience of both coral and fish communities (Mellin et al. 2016), substantial benefits to the Reef of addressing land-use drivers of water quality still need to be demonstrated (Kroon et al. 2014). The potentially clearest pathway to impact of addressing land-use as a driver is a reduced likelihood of CoTS primary outbreaks, due to increased larval survival under elevated chlorophyll concentrations in the water column (Fabricius et al. 2010, Wooldridge and Brodie 2015) (Fig. 1), although this connection is disputed by some researchers.

Since 1981, the set of drivers of change on the GBR has changed from primarily regional and local to increasingly global. Conservatively, mean sea surface temperatures of coral reef waters have warmed 0.2 - 0.3^{o}C over the past three decades (Lough 2012). The implications of such seemingly minor warming for the temperature dynamics and consequent stress on the Reef has been demonstrated by severe bleaching

events in 1998, 2002 and recently in 2016 and 2017 (Hughes et al. 2017b). In the 2012 study of decadal coral decline, coral bleaching accounted on average for 10% of the observed coral loss, while cyclones and CoTS accounted for the rest in near equal proportions (De'ath et al. 2012, see also Osborne et al. 2011). A similar analysis for the past 2-3 years on the GBR would attribute most of the severe coral loss in the northern and central regions to coral bleaching as the key proximal factor (Australian Institute of Marine Science 2017), and to a combination of a prolonged ENSO event and global warming as distal factors (NOAA 2017).

3.5 Recent impacts on GBR values

The observed status and trend of key habitats, including coral reefs and seagrasses, and environmental conditions indicate that the GBR is vulnerable to cumulative impacts from climate change and local and regional pressures, but show varying resilience (GBRMPA 2014a, McKenzie et al. 2016, Thompson et al. 2016). Near- to medium-term projections of environmental conditions and impacts on key GBR habitats of relevance for Reef 2050 Plan rely on analyses of monitoring data combined with experiments, models simulating future environmental conditions, and models predicting ecosystem responses. Here we briefly review the recent trends in important habitats including coral and seagrass and important environmental variables. To place in the context of the Plan we explain the relevant time scales of environmental drivers.

Trends in coral cover – declines in recent decades

From 1985 to 2012, the GBR lost around half of its coral cover, attributed primarily to cyclones (~50%) and CoTS (~40%), and less so to bleaching (~10%, De'ath 2012). Impacts occurred predominantly in the central and southern sections (Figure 5). Two severe cyclones and a CoTS outbreak then started a trajectory of coral decline in the north. In the summer of 2016, the GBR was hit by the third and worst bleaching episode in history – driven partly by a severe El Nino event. The north was the epicentre, and more than 90% of reefs in that region were affected by bleaching (Hughes et al. 2017b), leading to widespread coral mortality (Figure 5). Continued warming into 2017 led to bleaching in the central region, and consequently to significant coral mortality (not shown in Figure 5). Further, a trajectory of strong coral recovery in the south, which escaped the 2016 and 2017 bleaching, was stunted by TC Debbie in March 2017, likely resulting in recent coral decline (not shown in Figure 5, Australian Institute of Marine Science 2017).

These results indicate that the impact attribution from different pressures has changed in recent years. The relative importance of bleaching, with the 2016 and 2017 events being the first back-to back episodes in history, as a driver of coral mortality has exceeded that of CoTS. If bleaching becomes an annual event on the GBR, then warming and subsequent bleaching could become the most important overall driver of coral decline.

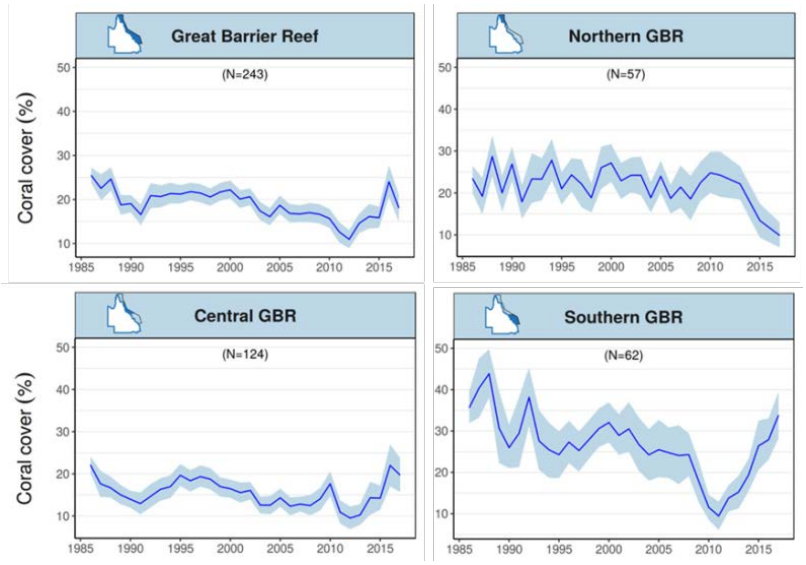

Figure 5. Trends in mean hard coral cover for the GBR over the past three decades. N indicates the number of reefs contributing to the analyses; blue shading represents 95% certainty. Note that the summary does not include most recent census of the impacts of 2017 bleaching in the central GBR or impacts of TC Debbie in the southern region. Data source: AIMS (Australian Institute of Marine Science 2017).

Threats to seagrasses and mangroves

GBR seagrasses have been in decline in most areas of the central and southern GBRWHA (Grech et al., 2011). The decline has been driven by a series of severe tropical cyclones (TC), in particular TC Larry in 2006, TC Hamish in 2009 and TC Yasi in 2011 (GBRMPA, 2011) and major river floods in the southern GBR in 2011 associated with intense rainfall following TC Tasha and in 2013 following TC Oswald. More generally, seagrass meadows are threatened by sedimentation, habitat erosion and herbicides, and in the longer-term, sea level rise and ocean warming (Waycott et al., 2007; Waycott et al., 2009). A projected regime of warming that causes physiological stress, drives stronger storms and consequent sediment erosion and resuspension will constitute increased risks to GBR seagrasses (Cullen-Unsworth and Unsworth 2016).

Mangrove forests adjacent to the Great Barrier Reef have been generally stable, except in areas of coastal development (GBRMPA 2014b). A large-scale mangrove die-off in the Gulf of Carpentaria in 2016 was attributed to a combination of a low water level and heat stress (Duke et al. 2016). In the long term, sea-level rise constitutes the main threat to mangroves (Lovelock et al. 2015).
These patterns suggest that impacts on seagrasses in particular are episodic with large changes in space, superimposed on a slow trend of declining area. The change in mangroves is uncertain but the recent large-scale die-off in northern Australia may indicate growing stress and risk under regional warming events.

Implications for species diversity and ecosystem services

Hard corals are the key framework and habitat builders of coral reefs, analogous to trees in rainforests (Knowlton 2001). Risks to reef corals thus represent risks to the approximately 1 million reef-dependent species that constitute reef ecosystems such as the GBR (Fisher et al. 2015). Analyses by AIMS' long- term monitoring team indicate that major disturbances to coral habitat lead to dramatic loss of fishes, including coral trout, and shifts in the reef fish community (Emslie et al. 2014). Figure 2 and 3 in combination illustrate the consequences of severe disturbances for reef habitats (corals) and the associated fish communities that make up a substantial part of the biodiversity, fisheries and aesthetic values of the Reef. For example, a major decline in coral cover caused by a cyclone or a severe bleaching event may lead to a

50% loss of fish species and around 50% loss of fisheries species including coral trout. Many species that rely on structural coral cover for both habitat and food such as butterfly fishes, can suffer up to 80% loss with consequent impacts on biodiversity (Figure 6).

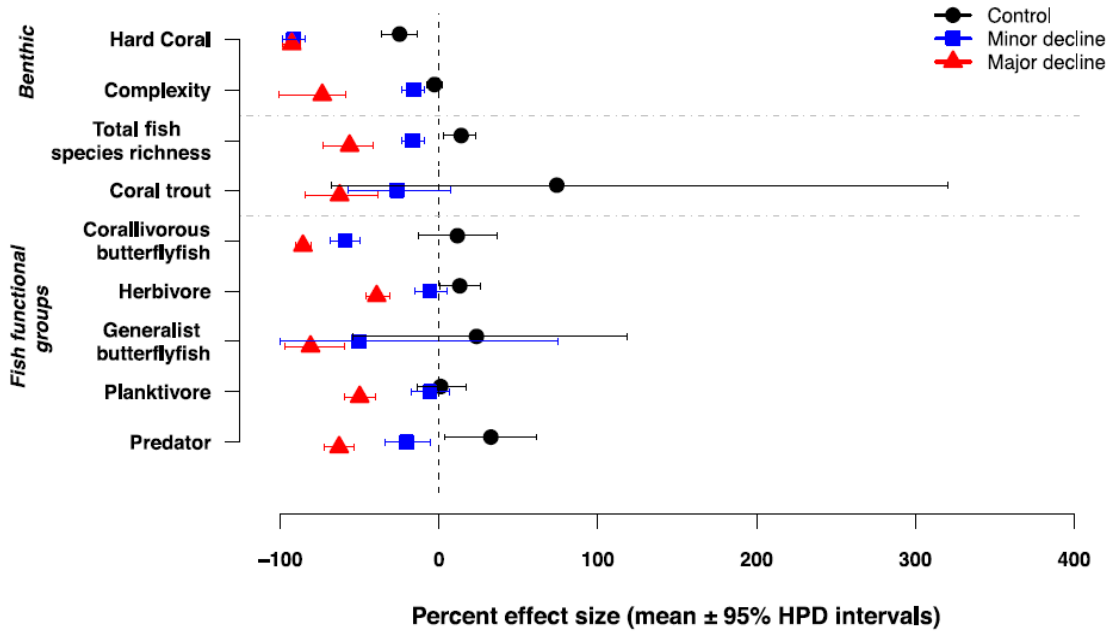

Figure 6. Impacts of disturbances on changes in hard coral cover, habitat complexity, and reef fish communities. Data are average effect sizes from generalized linear mixed effects model expressed as a per cent change from the time of greatest to least coral cover. Inferences about temporal changes were based on 95% Bayesian Highest Posterior Density (HPD) intervals of cell means predicted from posterior distributions of model parameters derived via Markov-chain Monte Carlo (MCMC) sampling. Effects are considered significant if the HPD intervals do not intersect zero. Modified from Emslie et al. 2014.

Seagrasses are also key ecosystem engineers, supporting myriad dependent species (Beck et al. 2001). On the GBR these include EPBC listed vulnerable (sea turtles) and endangered (Dugong) species (Grech et al. 2011). They also include critical fisheries species (Cullen-Unsworth et al. 2014). Similar to coral reefs and seagrass meadows, mangrove forests also provide habitat for a rich biodiversity (Ellison 2008). For example, they provide nursery grounds for fish in both pelagic and coastal environments (Mumby and Hastings 2008), protect coastlines from erosion (Beck and Shepard 2016) and serve as key carbon sink (Donato et al. 2011).

In summary, species composition of GBR habitats are likely to shift under climate change, as recently proposed as the long-term outlook for coral reefs in general (Hughes et al. 2017b). A challenge in the near term for guiding the focus of Reef 2050 Plan will be to identify what ecosystem functions, dependent species and ecosystem services are most at risk and, consequently, what actions can build resilience in priority functions and species in priority areas.

Rapidly changing environmental conditions

The rapid increase in the importance of environmental events is illustrated by the increase in warm water records for the GBR region. Since 1985 (just after a major El Nino), the GBR region has seen most warm events in recent years, with 50% of the region experiencing the warmest monthly temperatures since 2005, particularly in the northern portion of the GBR (Figure 7).

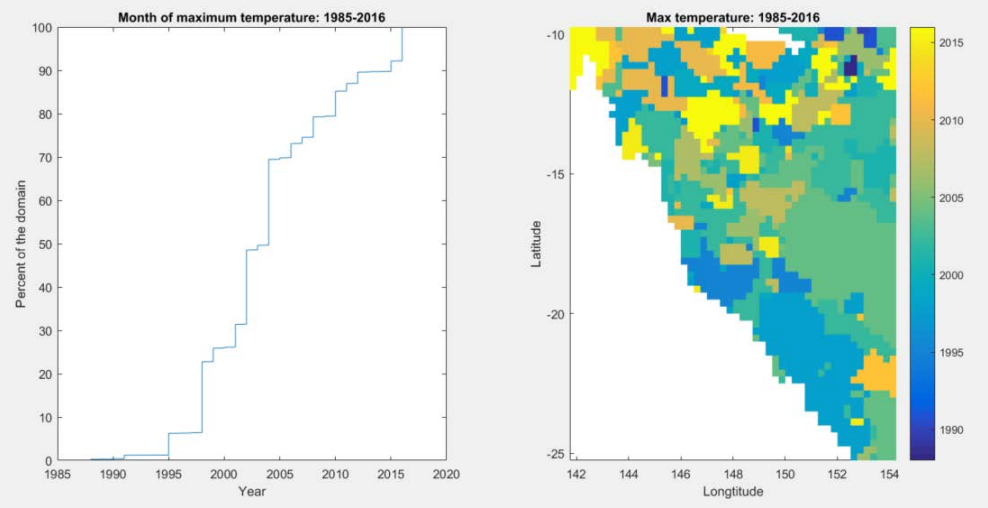

Figure 7. Temporal (a) and spatial distribution (b) of warm water records in the GBR region based on NOAA's Optimal Interpolation Sea Surface Temperature analysis (https://www.ncdc.noaa.gov/oisst).

These patterns show that even with rapid warming since 2005 over the whole region, there is spatial variation. This variation in environmental change means that some regions have not warmed as rapidly or as recently as others. This spatial variation is also evident (although limited by model resolution) in projections. A key implication is that there are strong spatial signals that need to be take into account when considering approaches to prioritise future reef management interventions and reef restoration measures. Understanding the cause of this spatial variation could allow decision-makers to allocate different interventions to different parts of the reef, based on relative expected differences in warming (see also Game et al 2008).

Extreme events influence the GBR environment

In addition to long-term environmental change, short-term events, known as extreme events, also influence the GBR. Climate change is likely to shift the world into a new risk environment earlier than slow, long-term change might suggest (Fischer and Knutti 2015). This means that GBR ecosystems could be exposed to stressful conditions earlier and more often, potentially exceeding the critical tolerance thresholds of key species and habitats (Anthony 2016) (Figure 8).

In the context of GBR management and policy for Ecosystem Health and Biodiversity (see also Anthony et al. 2015), understanding when and where extreme events are most likely to occur can inform decision-making around climate adaptation. In other words, such understanding can inform when and where to implement actions that can support reef recovery and underpin the resilience of both ecosystems and dependent communities and industries. The recent development of cyclone models for the GBR suggests that some areas (central and norther regions) have relatively elevated cyclone risks and that cyclones are likely to be clustered in time (Wolff et al. 2016). Attempts to downscale climate models also suggest that the southern section of the GBR might be a temporary climate refugium (van Hooidonk et al. 2013). However, a recent review of limits to the downscaling of global climate models suggest such refugia might be artefacts (Kwiatkowski et al. 2014).

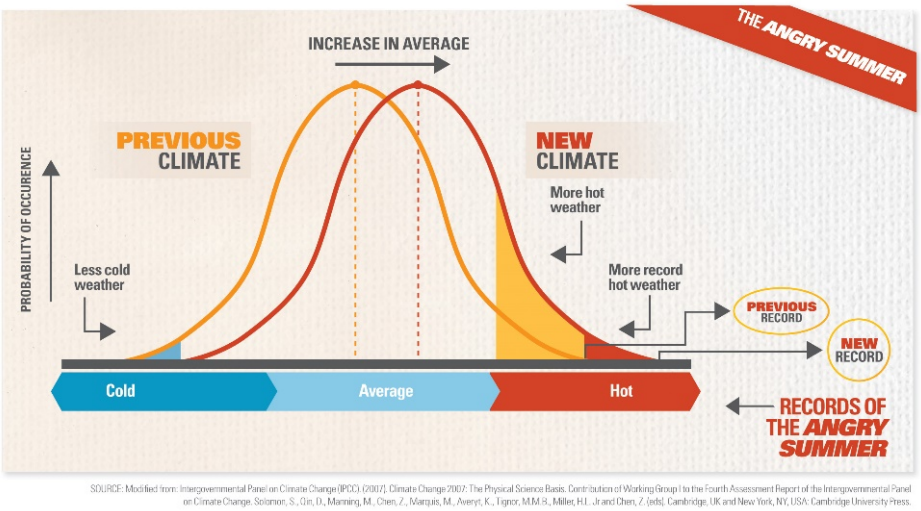

Figure 8. Illustration of the increase in extreme events with a shift in risk environment under climate change. Source: IPCC

Patterns of environmental and ecological change – timescales and thresholds

Managing for future change on the GBR requires consideration of the time scales of the different processes that incur change at the level of drivers, pressures, system state and which potentially cause impacts on Reef values (Figure 4). Importantly, all those processes are subject to variation, which means outcomes are a function of likelihood and consequence. The management and policy challenge for Reef 2050 Plan therefore becomes one of understanding and managing risk under uncertainty.

Environmental change typically involves time periods with favourable and unfavourable conditions, each of which can occur on a range of time scales that will influence the GBR (Figure 9). Here, Inter-annual environmental variability operates typically at time scales of 1-5 years. Inter-annual variability can manifest itself either as unpredictable noise, or relatively predictable episodic or periodic cycles (Figure 9a). Long-term sustained environmental change occurs, or is projected to occur, over many decades (Figure 9b). This may be due to anthropogenic climate change, resulting in long-term warming and acidification of the ocean.

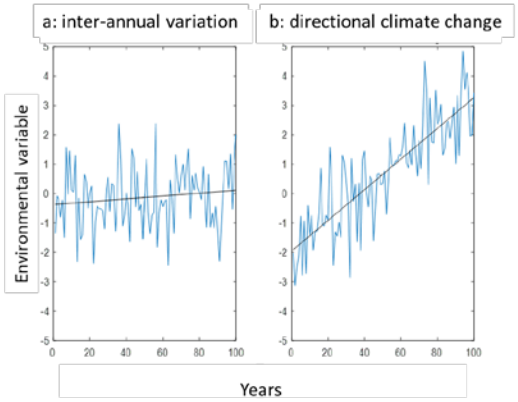

Figure 9: Illustration of environmental variability (a) without climate change and (b) with climate change. Note in each case the occurrence of extreme events, indicated by spikes in the environmental variable. Ocean temperature is an example of an environmental variable.

The implications of such time scales of change for the GBR are several-fold. Firstly, inter-annual variability in summer heat waves superimposed on a warming trend (Figure 9a) is likely to drive an increase in thermal stress events for corals (bleaching), seagrasses, mangroves and other sensitive systems. This is consistent with recent observations on the GBR (Duke et al. 2016, McKenzie et al. 2016, Hughes et al. 2017a). If the predicted warming trend is strong (Figure 9b), such as under an unmitigated carbon emissions scenario, then the expectation is an increased risk of more frequent and severe events. Note here that "risk" is an aggregate of event probability and event severity (consequence).

Under environmental change, natural ecosystems can become subject to sudden, dramatic, and potentially long-lasting changes in ecosystem structure and function (Scheffer et al. 2001, Walker et al. 2004). Such regime shifts can operate at small and large spatial scales (e.g., reef, meadow, region or basin) and can be characterized and potentially forewarned by temporal variability signalling a regime change (Scheffer et al. 2012, Anthony et al. 2015a). Regime shifts are also classically referred to as phase shifts (Bellwood et al. 2004) whereby dominant taxa such as reef-building corals give way to weedy macro algae, potentially driven by reduced water quality and/or reducing herbivore grazing (Mumby et al. 2007). While phase shifts are historically a Caribbean phenomenon (Roff and Mumby 2012), recent work indicates that phase shifts now also occur on some inshore coral reefs in the GBR (Cheal et al. 2010). Here, the combination of a severe pulse-type (acute) stressor (e.g. a cyclone or a bleaching event) and reduced tolerance to press-type (chronic) stress such as reduced water quality leads to reduced resilience and potential loss of sensitive and dominant taxa (Figure 10; Anthony et al. 2015a, Anthony 2016b). In effect, the lowered resilience and threshold exceedance is the manifestation of cumulative impacts under climate change and regional/local stressors.

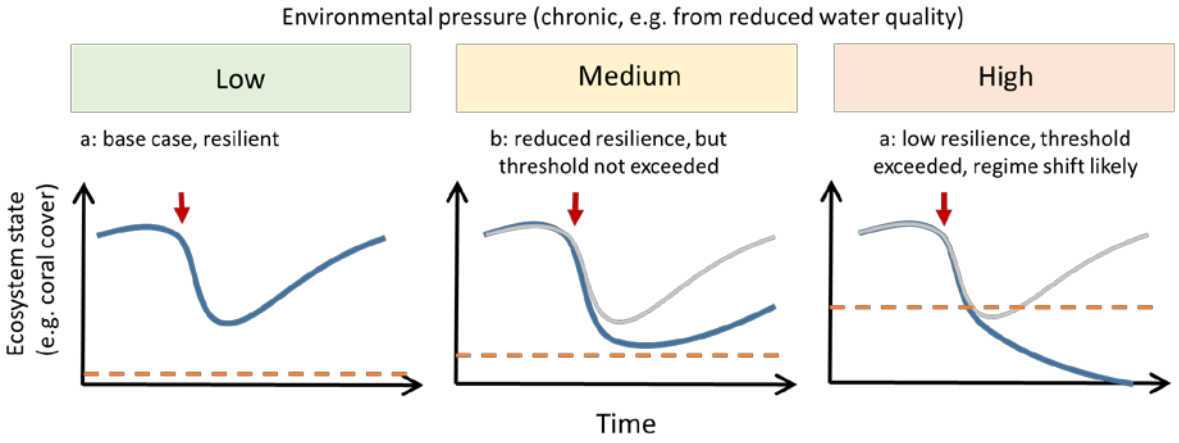

Figure 10. Schematic overview of how combinations of a pulse-type (acute) stressors such as a bleaching event (red arrow) and an increase in press-type (chronic) stress such as reduced water quality (panels left to right) can drive a loss of resilience, leading to a regime or phase shift. Here the dashed horizontal line represents a shifting tolerance threshold as chronic stress is increased. The loss of resilience and the potential loss of desired ecosystem state (e.g. coral cover) is a manifestation of the cumulative impacts of climate change and regional/local pressures. Note: the dashed line signifies the minimal ecosystem state that triggers a regime shift. Thus, an elevated dashed line indicates a narrowing distance from state to threshold.

In the context of the Reef 2050 Plan, understanding the risks of regime (phase) shifts under multiple stress scenarios of climate and local change will be critical for setting and adjusting targets for water quality and for regulating drivers that flow on to cause cumulative impacts (see also Figure 4). To manage the GBR for resilience would involve identifying the regional and local drivers that effective action would have the

greatest chance of alleviating. This would reduce risks of subsequent impacts under the anticipated climate future. In addition to changes in land use and continued fisheries management, actions could include innovative interventions to climate-harden key habitat-building species (Anthony et al. 2017a), targeted and effective CoTS control to promote local reef resilience (GBRMPA 2016) and restoration programs to enhance ecosystem recovery in high-value locations. Importantly, and as discussed below, the expected future change trajectory should guide the management strategy as different local and regional actions will have varying effectiveness and expected outcomes under different climate change scenarios.

3.6 Future impacts on the GBR – likely trajectories for drivers and associated pressures

To inform a near to medium-term outlook for key GBR species and ecosystems relevant for the Reef 2050 review we here produce a synthesis of model projections for key environmental drivers and pressures combined with current understanding of biological and ecological responses. Below is a summary outline of projections of key drivers and pressures is provided, which are then integrated into the future storylines.

Drivers of climate change and associated pressures

The key driver of global climate change is an increase in the atmospheric concentration of greenhouse gasses, most importantly carbon dioxide (IPCC 2014). For the purpose of this review we partition climate change into a package of three pressures: (1) global warming, (2) stronger storms and (3) ocean acidification (Fig. 1). Global warming and storms are physical consequences of more heat trapped in the atmosphere by increased carbon concentrations (Anthony 2016), and ocean acidification is a direct chemical consequence of more atmospheric CO_2 being dissolved in the ocean (Sabine et al. 2004, Doney et al. 2009, Orr 2011). On the GBR, storms impose a set of secondary pressures: (1) increased resuspension of sediment in the GBR lagoon leading to periods of high turbidity and (2) precipitation events increasing the risk of floods, and consequent run-off of pollutants and freshwater (Fig. 1). In addition to direct water quality stress on downstream ecosystems, nutrient enrichment in the northern region can fuel chlorophyll blooms and potentially increase the risk of CoTS outbreaks (Fabricius et al. 2010, Wooldridge and Brodie 2015).

For change scenarios to be helpful for the review of management and policy options under Reef 2050 Plan, they must take account of the interplay between global, regional and local drivers and their consequent cumulative impact pathways. Figure 4 shows only a subset of the suite of environmental, social and economic drivers of change and their pathways to impact. However it illustrates an important example of a key interaction between global and regional drivers: that of climate change driving storms which interact with land-use as they drive the run-off of pollutants (as a combination of run-off and resuspension). At the root of those pathways are the global socio-economic scenarios or storylines that drive climate change (as IPCC scenarios or Representative Concentration Pathways -RCPs) as well as regional markets and socio-political settings that drive urban developments, land-use changes, industries and fishing. In the following we first review the sets of pressures that result from these combinations of drivers. We then discuss how different combinations of global and regional drivers produce alternative future trajectories for the GBR and what the management and policy opportunities are for sustaining the Reef.

Temperature

The long-term trend in surface warming is expected to continue. Under all IPCC scenarios, the world is expected to warm (Figure 11). Regional historical warming has not been the same everywhere, and in future some areas will warm faster than others. About 75% of the moderate daily hot extremes over land

are attributable to global warming. The largest fraction of extreme temperature events is anthropogenic, and this contribution increases nonlinearly with further warming (Fischer and Knutti 2015).

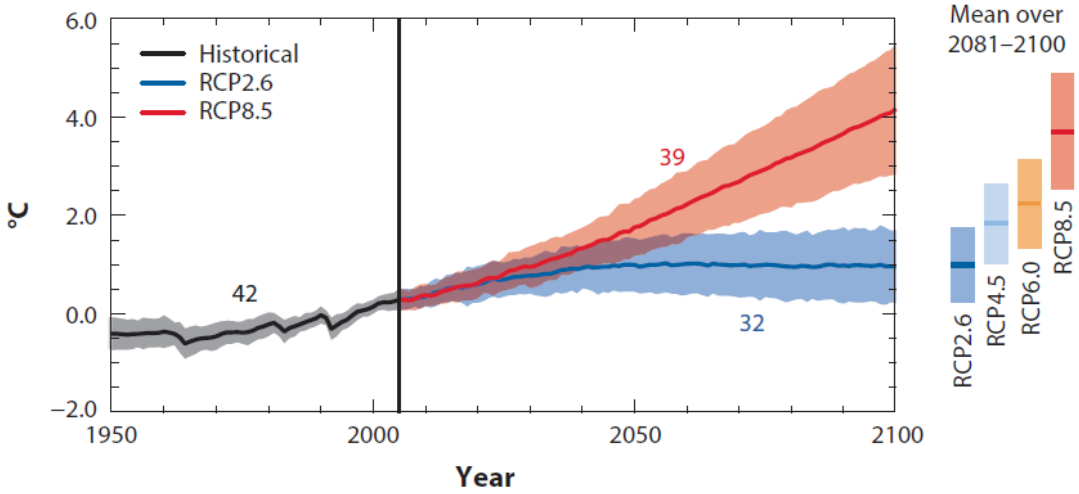

Figure 11. Projected change in global (air) surface temperature based on IPCC scenarios (Representative Concentration Pathways, RCP). Note that GBR surface waters warm at 70% of the global warming rate (Lough 2012). Changes here are relative to a 1986–2005 baseline (Source: IPCC 2014).

Extremes, such as marine heatwaves (MHWs) also impact the GBR, with recent bleaching events in 2016 and 2017 associated with MHWs. Like cyclones, extreme event frequency and intensity is more difficult to project, but limited modelling to date suggests more frequent and intense heatwaves will occur (Oliver et al, in prep).

Slower pathway of global warming

Under the most aggressive carbon mitigation scenario (Representative Concentration Pathway, RCP, 2.6) which corresponds to the 1.5°C target, the world is set to warm another 0.5 degree Celsius in the coming decades (**Figure 8).** As GBR surface waters warm at around 70% of global surface air warming (Lough 2012), this translates into a projected 0.4°C continued warming. Recent studies indicate that this could mean exceedance of critical bleaching thresholds (Ainsworth et al. 2016). Unfortunately, current Intended Nationally Determined Contributions to mitigation will not achieve the 1.5°C target (Sanderson et al. 2016). Even if the Paris Agreement delivers on this aspirational target, atmospheric carbon will continue to increase in coming decades (Schleussner et al. 2016), driving more frequent and severe coral bleaching events (Frieler et al. 2012), stronger storms (Knutson et al. 2010) and continued ocean acidification (Gattuso et al. 2015).

High scenario for global warming

Under an unmitigated emissions scenario (RCP 8.5; **Figure 8**), climate change could add >1.0°C to the current average temperature of tropical ocean surface waters already by 2050, thereby exceeding the threshold for annual mass coral bleaching under non-El Niño conditions (van Hooidonk et al. 2016).

In addition to the long term trend, climate modes, such as the phases of ENSO (El Nino and La Nina) can lead to warmer or cooler than expected environmental conditions (different regimes). Global temperature is rapidly approaching the warming above pre-industrial conditions of 1.5°C – i.e. the Paris target (Pachauri and Meyer 2014, van Hooidonk et al. 2016). In the absence of external cooling influences, such as volcanic

eruptions, surface temperature projections will exceed this 1.5°C target, relative to 1850–1900, before 2029. The phase of the Interdecadal Pacific Oscillation (IPO) will regulate the rate at which mean temperature approaches the 1.5°C level. A transition to the positive phase of the IPO would lead to a projected exceedance of the target around 2026, but it could be five to seven years later in a more favourable IPO phase (Figure 12).

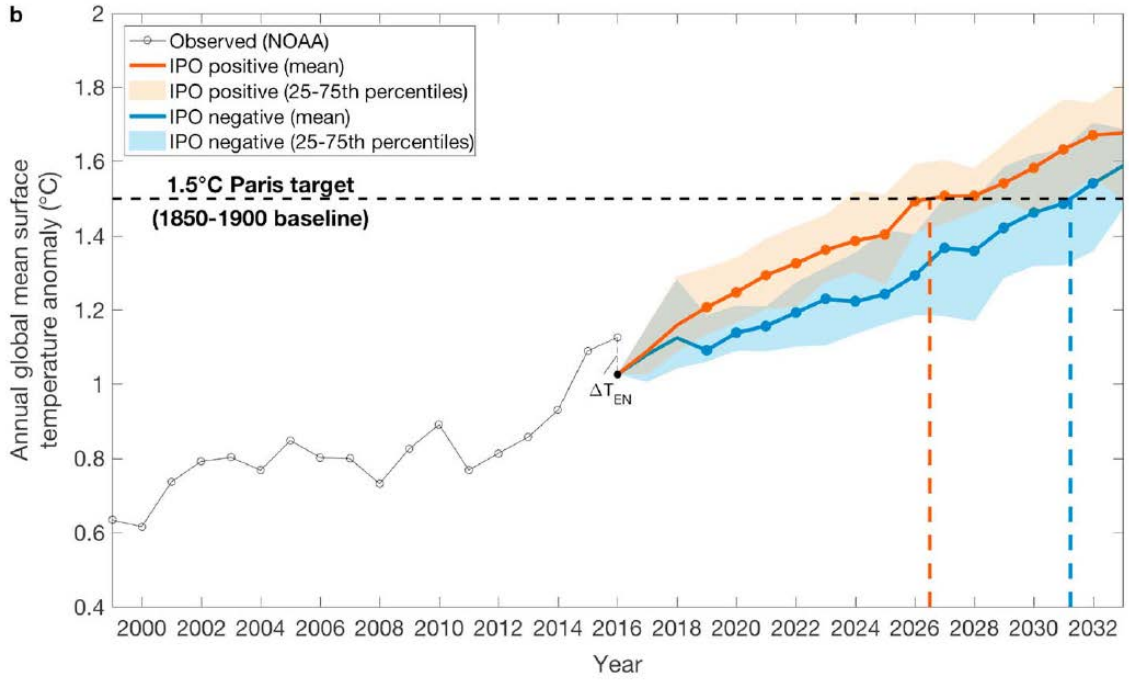

Figure 12. Observed and projected global temperature trajectories towards the 1.5 degrees C aspiration for the Paris Agreement. Source: Henley and King (2017)

Even with a warming trend there will continue to be inter-annual variation, with some years hot, some years cooler (Figure 13, right panels**).** Such inter-annual variation, coupled with spatial variation in warm and cold events, represent both increased risks and opportunities. The former in terms of increased likelihood of bleaching or cyclones, and the latter in terms of interludes for recovery. Understanding when and where these periods/areas of high vs low risk occur can guide decision-making around adaptation measures or intervention options that can support recovery or resilience (see also section 2.3).

Figure 10 shows monthly sea surface temperature projections, based on the CSIRO 10km downscaled climate model (and approximating a business as usual global warming scenario ~RCP 6.5), for the four regions of the GBR. If for example, we are interested in when a warm threshold (e.g. 30°C) is exceeded, this analysis can show the year in which the threshold SST would be first (left end of bar) and then always exceeded for each of the four zones (right end of bar). According to this model, the thresholds will be exceeded in the north before the south. Temporary exceedance, the period of time when some years months are above the threshold might allow some recovery in subsequent cooler years. This represents an adaptation window. Beyond this time, after permanent exceedance – there will be no respite.

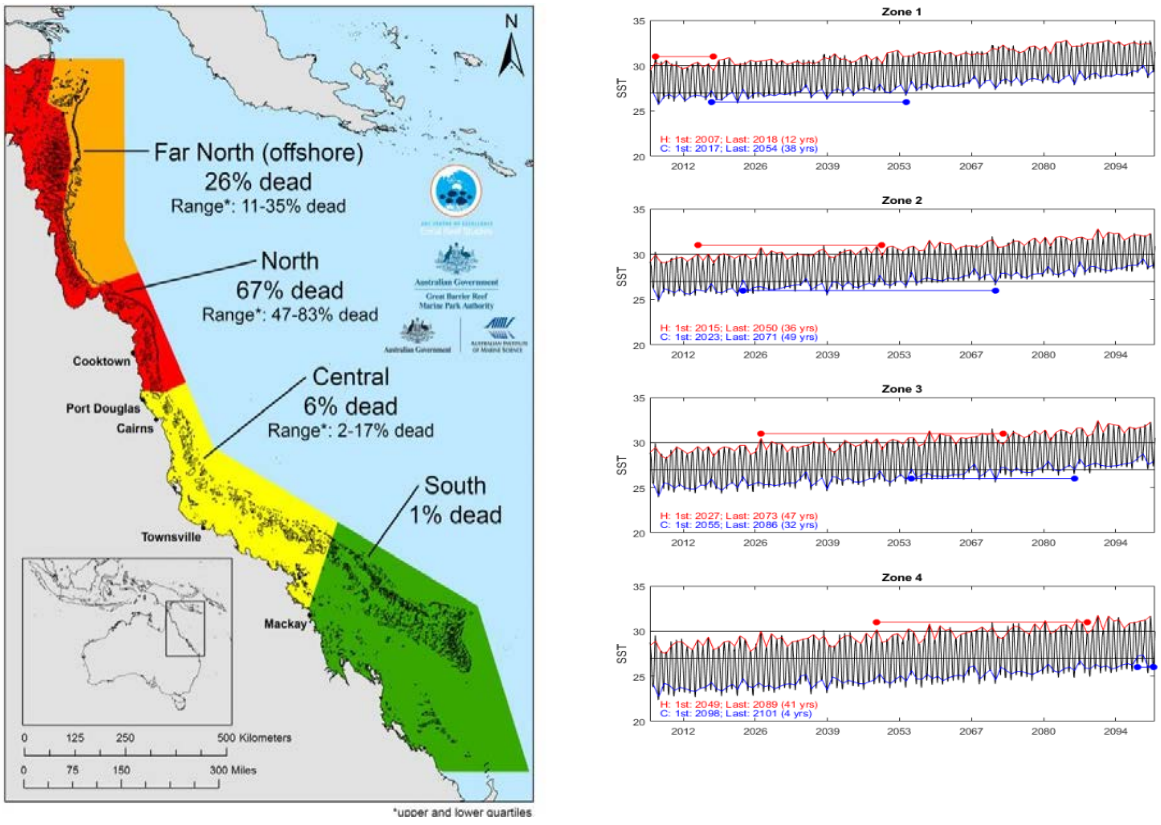

Figure 13. Extent and distribution of bleaching and coral mortality in 2016 (left panel) and projected monthly SST in each of four GBR regions (right panel) showing projected summer temperatures (red) and winter temperatures (blue). The numbers shown under each zone in the right panel show the year of the first and last exceedance (thereafter exceeded every year) (Source: Left: GBR map - http://www.abc.net.au/news/image/8073002-3x4-700x933.jpg ; right; Zhang and Hobday – unpublished).

Figure 13 also shows that, based on this model and a critical threshold of 30 C, the time window for adaptation may already be closing in the northern GBR, whereas there is still a reasonable adaptation opportunity before threshold temperatures are exceeded in the southern zones (right panels).

Ocean acidification

Ocean acidification is the chemical consequence of increasing CO_2 in the atmosphere (Figure 14). The ocean surface takes up CO_2 as a function of its partial pressure, and because dissolved CO_2 is a weak acid it lowers ocean pH and changes the carbon chemistry in the system (Raven et al. 2005). Ocean acidification lowers marine calcification (Kleypas et al. 2006), a critical process for all calcifying marine organisms including reef corals, molluscs and crustaceans. Ocean acidification slows reef growth, and reduces the capacity for population replenishment of a suite of species including corals and fish (Munday et al. 2010, Albright and Langdon 2011, Albright et al. 2016a). In addition to these impacts, ocean acidification also puts pressure on a group of species that provide substrate for the recruitment of invertebrates including corals: crustose coralline algae (Harrington et al. 2004). Further, ocean acidification promotes the growth of macroalgae (Fabricius et al. 2011) and shifts the competitive balance between corals and macroalgae in favour of macroalgae (Diaz-Pulido et al. 2011). Recent field studies on the southern GBR suggest that ocean acidification has already lowered reef calcification by around 7% (Albright et al. 2016b). Models of changing carbon chemistry (aragonite saturation state, which is correlated with pH) of the entire GBR indicate a high

level of spatial and temporal heterogeneity driven by calcification and dissolution in the GBR lagoon, exchange with the Coral Sea and the atmosphere and run-off from land (Mongin et al. 2016). These analyses indicate that ocean acidification effects will become greater in some places on the GBR (e.g. inner central lagoon) than predicted by IPCC forecasts (Figure 13). By impacting on reef growth, population replenishment and competitive interactions, ocean acidification may in places erode coral reef resilience significantly – in particularly under global scenarios of low carbon mitigation (Anthony et al. 2011, see also Silverman et al. 2009). Pollutants and freshwater run-off can exacerbate ocean acidification effects (Uthicke et al. 2014, Albright et al. 2016a, Mongin et al. 2016). Nonetheless, it is likely that the impact of rising sea temperatures will affect corals before ocean acidification reaches levels that significantly impair calcification (Hughes et al., 2017b).

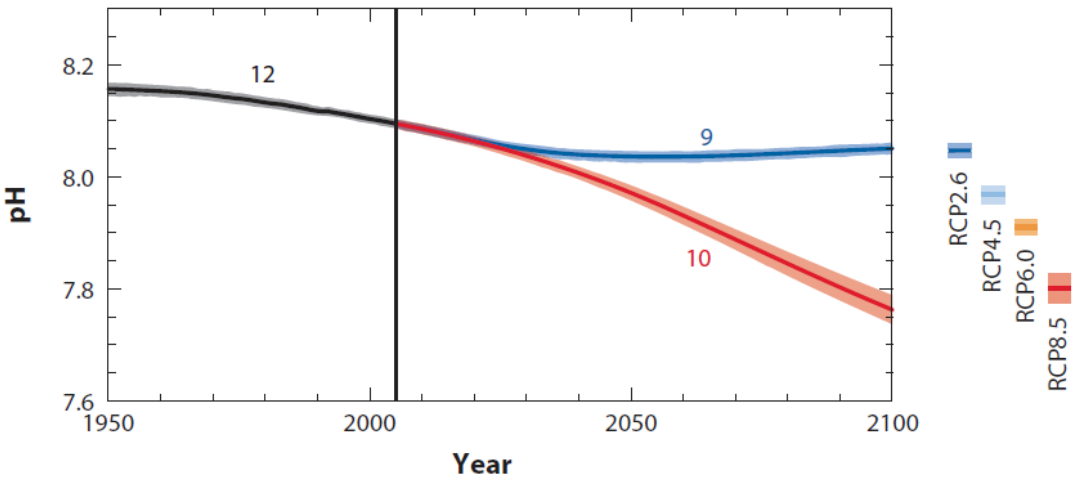

Figure 14. Projected change in ocean pH based on IPCC scenarios (Representative Concentration Pathways, RCP). Note that GBR surface waters warm at 70% of the global warming rate (Lough 2012). Note that changes here are relative to a 1986–2005 baseline (Source: IPCC 2014).

Cyclones

Storms are a natural part of tropical environments and have historically been the primary acute disturbance agent on coral reefs (Rogers 1993). A key question is whether storms will increase in intensity and/or frequency in a warmer climate. Recent analyses using downscaled global simulation models predict an increase in tropical storm frequency and intensity in most locations (Emanuel 2013). Since 2005, nine severe cyclones (category 3 or above) have affected the GBR, suggesting a shift to a stronger storm regime has already occurred (Cheal et al. 2017). Stronger storms will lead to greater risk of coral damage, further increasing the demand for faster reef recovery and enhanced resilience (Anthony 2016). Importantly, a consequence of ocean acidification is increased fragility of coral structures (Madin et al. 2008). This could result in greater damage from cyclones in the future, even under a conservative assumption that their intensity and frequency remain unchanged.

Not all parts of the GBR are equally prone to cyclone damage (Figure 15). Recent cyclone risk maps based on historical cyclone data integrated with modelled (synthetic) cyclone tracks indicate that the central part of the GBR is cyclone hot spot and that the far north and south are relative cyclone refugia (Wolff et al. 2016). In the context of the Reef 2050 Plan review this potentially means that management strategies for such cyclone refugia, especially if coinciding with reduced bleaching risk (van Hooidonk et al. 2013), means less acute stress and improved opportunities to support resilience. The type of patterns shown in Figure 12

can also be seen as an initial base from which to spatially target and prioritise future interventions. Such mapping could also be attempted for the other pressures, such as CoTS and sediment load. Collectively, such maps could identify locations on the reef (both impacted and not impacted) to attempt interventions. Interventions could be tested in areas currently impacted that may be analogues for currently more pristine sites in the future. Thus, rapid learning could result from careful selection of sites to test interventions and examine how biodiversity assets respond.

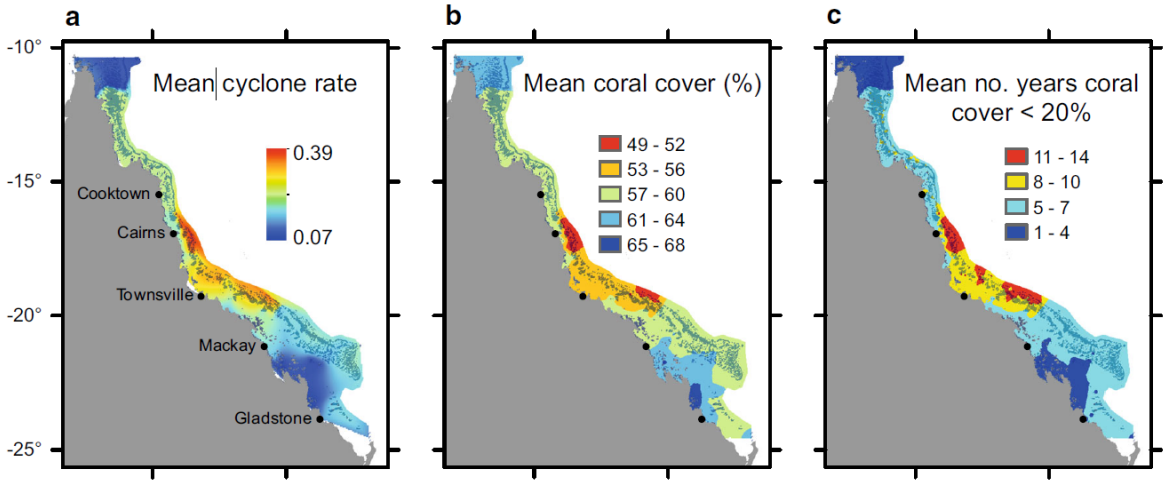

Figure 15. Estimated distribution of risks from cyclone damage on the GBR. Risk maps are produced by combining 1970–2011 regional cyclone statistics with synthetic cyclone tracks (simulations with physical forcing). Left panel: Mean annual cyclone rate; Centre: mean coral cover (*Acropora* assemblages) if cyclones were the only disturbance, and Right: predicted time window where *Acropora* cover was less than 20%. Source: (Wolff et al. 2016).

The results in Figure 15 can also be seen as an initial base from which to spatially target and prioritise future interventions.

Sea level rise

Sea level rise is a function of thermal expansion and the melting of polar ice caps (IPCC 2014). Modern coral reefs are keeping up with current sea level rise and may continue to do so under mitigated carbon scenarios (Woesik et al. 2015). However, under severe climate change, rapid sea level rise in combination with reduced net rates of reef growth due to warming and acidification might lead to decline in some coral reefs. This is most likely in coastal environments where increased sediment resuspension (turbidity) due to altered flows combine with reduced light in deeper turbid water (Field et al. 2011). Existing seagrass meadows will be at risk under sea level rise for the same reasons, but new seagrass habitats will likely form from a reconfigurations of coastlines and the creation of new shallow habitats. Mangroves are at direct risk of drowning under rapid sea level rise (Lovelock et al. 2015).

Crown-of-Thorns Starfish

Over the past 30 years, outbreaks of coral-eating Crown-of-Thorns Starfish (CoTS) have until recently accounted for more than 40% of the decline in coral cover on the GBR (De'ath et al. 2012). Strictly speaking, CoTS are both a pressure (as a pest Pratchett et al. 2014) and a system state indicator (Fig. 1) as CoTS are a natural part of the GBR fauna. Contrary to climate-driven pressures, such as coral bleaching and storms, CoTS are amenable to management interventions (GBRMPA 2016). However, numerous processes drive CoTS outbreaks and their relative influence remain uncertain (Pratchett et al. 2014). Nutrient run-off into the northern GBR (Fabricius et al. 2010, Wooldridge and Brodie 2015) and removal of key predators of CoTS

(Sweatman 2008, Cowan et al. 2017) are implicated as key drivers (Figure 4). Current management efforts to protect the GBR from CoTS impacts have had some but limited impact, in part due to low starfish detectability, high fecundity and high larval connectivity between reefs (Figure 16). However, increased cull efforts and opportunities around the development of new and proactive surveillance and cull technologies integrated with water quality management offer opportunities for more effective control (Anthony et al. 2017b). As CoTS are highly amenable to management and control whereas climate change is not, improved strategies to reduce reef damage from CoTS could be among the most critical opportunities to support coral reef resilience now and in the future.

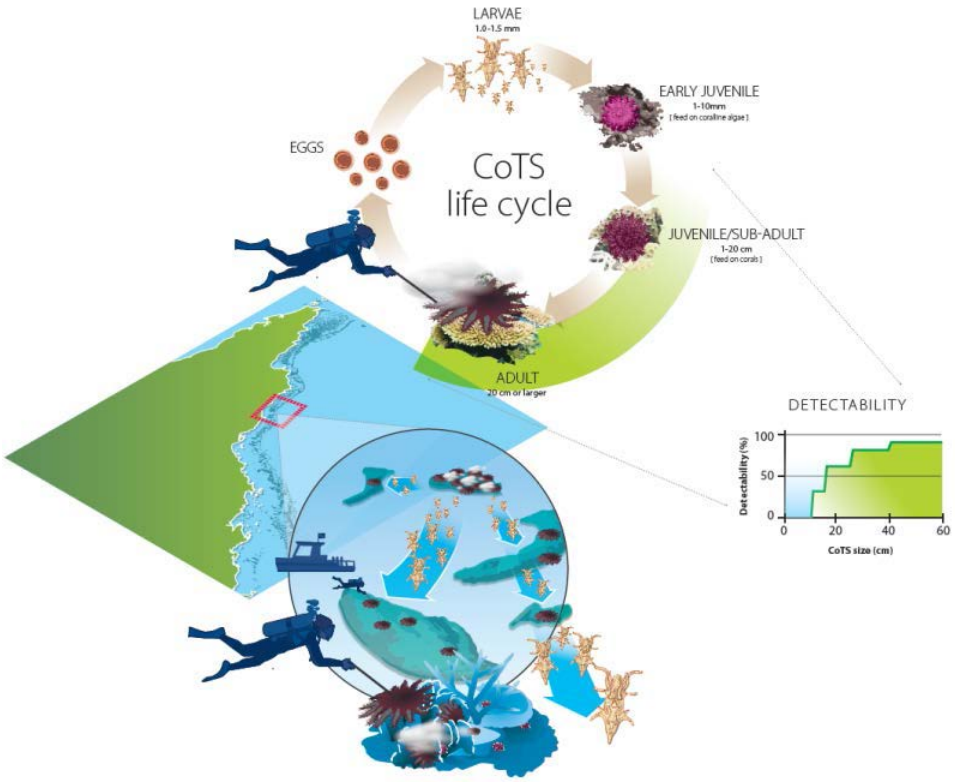

Figure 16. Crown-of-Thorns Starfish challenge in a nutshell. Management and control challenges include reducing nutrient inputs into the outbreak initiation zone (red box), enhancing starfish detectability (especially of juveniles), and proactive containment of outbreaks at source reefs. Source: Walshe and Anthony (2017).

Fishing

In recent years, commercial fishing effort on the GBR has been declining, particularly in a number of commercial fisheries, such as gillnet, trawl and line (Fletcher et al. 2015, Pascoe et al. 2016). The live aquarium fishery is considered sustainable, and is seeking eco-certification. The recreational fishing effort and spatial footprint is increasing, as is the size of vessels (hence range increasing) (Taylor et al. 2012). This increase in larger vessels has been linked to mining (and higher disposable income, so may have peaked, but boats still last a long time). Indigenous fishing and take of fish and large megafauna such as turtle and dugong is recognised under the Native Title Act. Harvests in Torres Strait and the northern Great Barrier Reef are considered sustainable (Flood et al. 2014).

Recreational and commercial reef fisheries are generally limited to predatory fish (Fig. 1), but spearfishers also target herbivores such as parrotfish (Frisch et al. 2012). This is significant as healthy populations of

herbivores are critical for the control of weedy algae (which grow faster under nutrient enrichment, are the first to establish after disturbances and compete with corals) and thereby supporting reef resilience (Mumby et al. 2007). Turbidity has a negative effect on herbivorous fishes (Wolanski et al. 2004, Cheal et al. 2012), making the resilience of inshore reefs particularly sensitive to further loss of herbivores.

A recent analysis indicate that warming above 1.5°C will lead to reduced catch from global fisheries including coral reefs (Cheung et al. 2016), in part due to changes in trophic structures. As coral bleaching (Munday et al. 2008) and storms (Emslie et al. 2014) affect fish habitats, climate change is likely to drive fisheries yields on the GBR.

Transport

Transport including shipping is driven by regional and global markets (Figure 4). The GBR is subject to moderate levels of shipping traffic crossing within the GBRMPA (Figure 17). More than 9,600 ship voyages were recorded in the Reef between 2012 and 2013, and 3,947 individual ships called in at Reef ports in 2012. At the current growth rate of 4.8% per annum, the projected increase in ship numbers calling into these ports will exceed 10,000 by 2032 (Grech and McCook 2015; http://theconversation.com/shipping-in-the-great-barrier-reef-the-miners-highway-39251). The global demand for coal, gas and minerals has driven the development and expansion of major ports along the Queensland coast, such as Gladstone Harbour. The projected increase in shipping may lead to an increase in spills and collisions, which can be managed to some degree (Grech et al. 2013). In Figure 4 only pollutants are included as a pressures (via spills, waste or sediment resuspension), but ship groundings and anchoring may also lead to direct damage to reefs and seagrass beds.

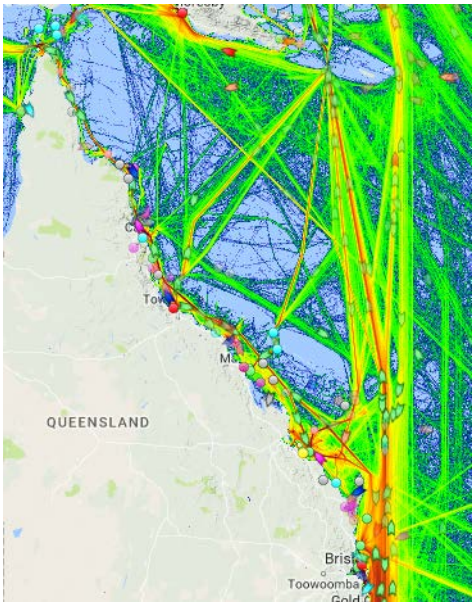

Figure 17: Example of shipping routes for the year 2016 with colour indicating density. Source: http://www.marinetraffic.com/en/ais/home/centerx:152.6/centery:-22.3/zoom:5

Water quality from terrestrial sources

Broad-scale land use in catchments adjacent to the GBR is a key driver of coastal and marine water quality in the GBR lagoon (Kroon et al. 2016). Several lines of evidence indicate that water quality in the GBR

lagoon along the developed central and southern sections has declined, following large-scale land clearing and associated agricultural development in the adjacent catchments since European settlement in the 1850s, and the subsequent modification of terrestrial pollutant fluxes (Kroon et al. 2016). River loads to the GBR lagoon are estimated to have increased substantially for suspended sediment (~5 fold), nitrogen (~2.1 fold), phosphorus (~2.9 fold) and pesticides (~12 000 kg/yr) (Bartley et al. 2017). Most of the GBR catchment area is used for agricultural production, namely rangeland cattle grazing (75% of the area), forestry (5%), dryland cropping (~2%) and sugarcane (~1%), with irrigated cropping, horticulture, dairy and bananas each covering less than <1% (Waters et al., 2014). Excess river sediment, nutrient and pesticide loads to the GBR lagoon are derived from (i) surface and subsurface erosion, predominantly in rangeland cattle grazing settings; (ii) fertilizer applications in sugarcane and broad-acre cropping; and (iii) pesticides (particularly photosystem II inhibiting herbicides) primarily applied during sugarcane cultivation (Bartley et al. 2017).

Despite over 15 years of efforts to improve GBR water quality through the various Reef WQ Plans, the 2017 Consensus Statement (Waterhouse et al. 2017) concluded two key points:

- Key Great Barrier Reef ecosystems continue to be in poor condition. This is largely due to the collective impact of land run-off associated with past and ongoing catchment development, coastal development activities, extreme weather events and climate change impacts such as the recent coral bleaching events.
- Current initiatives will not meet water quality targets. To accelerate the change in on-ground management, improvements to governance, program design, delivery and evaluation systems are urgently needed. This will require greater incorporation of social and economic factors, better targeting and prioritisation, exploration of alternative management options and increased support and resources.

Achieving substantial improvement in GBR water quality from the key drivers of land use will be a socio-economic challenge. Tarte et al. 2017 recommends that the updated Reef WQ Plan should contain (following (i) revised load targets for each of the 35 major GBR catchments; (ii) measurable actions needed to achieve these catchment targets; (iii) properly costed investment strategy to deliver actions; and (iv) that its implementation is given high priority. Furthermore, additional approaches to accelerate improvements in water quality towards targets have been proposed, including (i) harmonisation of Federal and State Acts, regulations and policies, (ii) implementation of effective legislative and regulatory instruments governing agricultural land uses and management, and (iii) potential changes to current agricultural land use including land retirement in high-risk areas (Kroon et al., 2014; Kroon et al., 2016; Tarte et al., 2017; The Great Barrier Reef Water Science Taskforce, 2016). Importantly, effects of land-use and practice changes will interact with climate change in driving water quality on the GBR (**Fig. 1**). For example, climate change is predicted to lead to reduced precipitation across Australia (Hobday and Lough 2011). A likely consequence is that longer droughts will make catchments more prone to erosion and export of nutrients and toxicants into GBR waters when floods do come (Bohensky et al. 2011).

The Great Barrier Reef Water Science Taskforce released its final report in May 2016 (The Great Barrier Reef Water Science Taskforce, 2016). Several of their recommendations have progressed to further development, such as the Major Integrated Projects for the Wet Tropics and the Burdekin (MIPS; https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef-major-projects/), and the release of the 'Enhancing reef regulation discussion paper' (https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef-regulations/).

The MIPs will explore and test the efficacy of a more integrated and comprehensive engagement and behavioural change process. As part of this, the MIPs will evaluate and communicate the environmental, economic and social benefits and corresponding costs (in terms of investment required) so that the

approaches can be appropriately applied across GBR catchments if successful. Producers and local communities in hot spot areas will be engaged closely in designing, delivering and evaluating the projects.

3.7 Integrated change trajectories (storylines, scenarios)

Scenarios provide a mechanism for consideration of the opportunities and risks that may be associated with particular decisions and have been developed at global (e.g. IPCC SSPs - Riahi et al. 2017) and local scales (e.g. GBR - Bohensky et al. 2011). Trajectories typically describe pathways to each of these futures, and while multiple trajectories may lead to the same end point, we here develop just one trajectory of change to represent each scenario. Scenarios have been widely used to illuminate the enabling conditions for and constraints on current and future management approaches and strategies identify possible adaptations and ultimately assist decision-makers to move from a position of "taking" to "making" desirable future change (Bohensky et al 2011).

In this section we use the information from the preceding sections to develop the change trajectories for the GBR. These scenarios are integrated and thus somewhat general, rather than absolute, and provide bounds to consider the future needs for the GBR. Previous literature has developed a range of plausible futures for the GBR (e.g. Bohensky et al. 2011, Evans et al. 2011) and we draw on that work here. Previous scenario work has been at a longer time scale (Bohensky et al 2011), or been focused on the adaptation options (Evans et al 2011). Here we consider four possible scenarios/trajectories (Figure 18) based on the rate of climate change by 2050 and projected changes in other drivers and associated pressures as described in earlier sections.

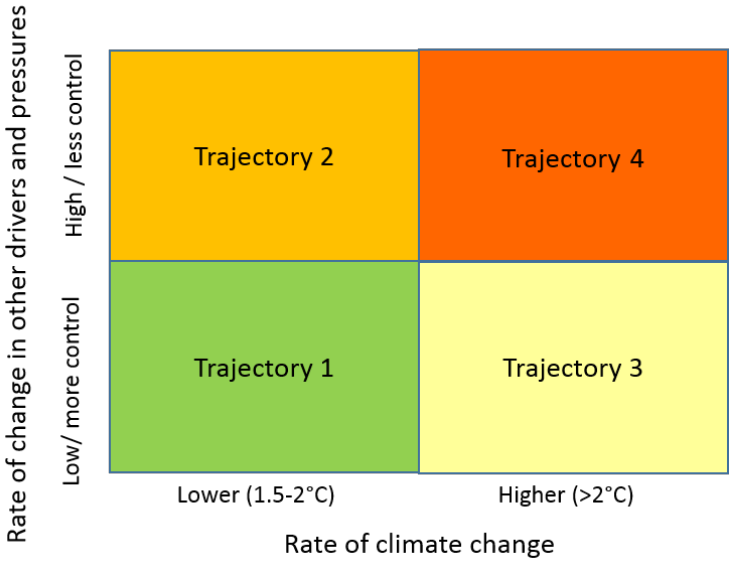

Figure 18. Generalised GBR change trajectories. The trajectories considered are based on the rate of climate change and the rate of change in the other regional and local driver and associated pressures. The rate of climate change is not under direct control of GBR decision makers, however, the rates of change in the other regional and local drivers and consequent pressures are more responsive to governance and management decisions.

These storyline for each of these trajectories and the management or policy responses used to address them are derived from the Drivers-Pressures-State-Impacts Response framework (Figure 4). Here, Figure 19 shows the pathways from global and regional drivers to pressures and through to impacts on ecosystem

services. Management and policy responses can be guided by observed and predicted state changes and impacts, and partitioned into global, regional and local actions. Direct action on pressures and states are possible via CoTS control and restoration measures but are not shown here.

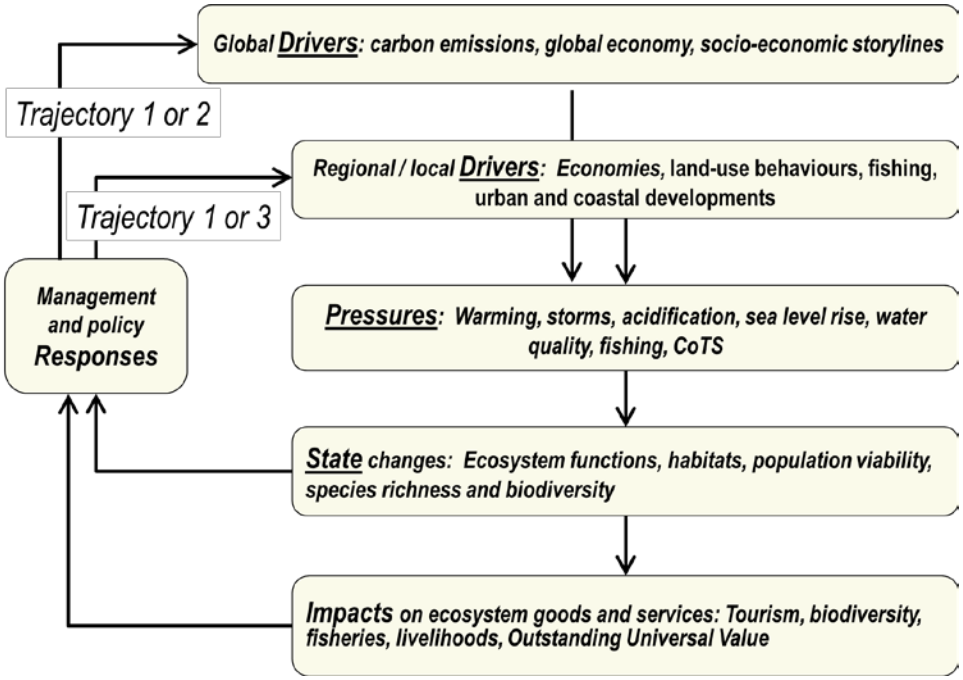

Figure 19. Figure 4 modified to illustrate how the four Trajectories are derived from the Drivers-Pressures-State-Impact-Response framework.

Trajectory 1 – Global mitigation, local action

This trajectory corresponds to RCP 2.6, which sees surface warming <2°C and slow decline in ocean pH by 2050, coupled with slow change or reduction in the other stressors through good management or declining economic activity.

- Climate trajectory
  - Air temperatures (surface warming) is kept below the global aspirational warming target of 2°C – ideally below 1.5°C above preindustrial levels. Consequently, continued warming of GBR waters are less than an additional 0.5°C.
  - Sea level rises slowly (~0.13 m – Evans et al 2011).
  - Ocean pH declines by less than 0.15 units (IPCC 2014).
  - Extreme events such as cyclones, floods, and marine heatwaves continue to challenge the reef.
- Other drivers and pressures
  - Water quality continues to improve, and terrestrial runoff is less damaging (less sediment, pollutants) than in present day.
  - Fishing effort remains at sustainable levels, with spatial management (zoning, special management areas) alleviating pressures in areas impacted by extreme events.

    - Transport does not increase substantially, and is managed throughout the Reef, with governance and oversight of shipping, along with improved navigation leading to reduced number of incidents within the GBR.
    - Population and urban development within and adjacent to the reef is managed for regional biodiversity values and public value and stewardship of the reef increases.
    - Indigenous stewardship increases and results in improved management of sensitive areas. Local businesses take advantage of reef conditions to provide local economic benefits.
    - CoTS outbreaks continue at historical frequency, but intervention options are developed and major reef-wide outbreaks are suppressed.
- Implications for the major habitats **(section 3)**
    - Coral cover declines somewhat, bleaching events increase in frequency, but remain spatially restricted.
    - Mangroves and seagrasses do not decline in coverage, and recover between disturbance events.
    - Species diversity – changes in habitat structure lead to declines in reef-associated species, but no major losses as recolonization between GBR areas is possible between disturbance events.

Trajectory 2 – Global mitigation, local status quo

This trajectory corresponds to RCP 2.6, which sees surface warming <2°C and lower declines in pH by 2050, however, faster change occurs in the other more local stressors, through poor management or increasing economic activity.

- Climate trajectory
    - Air temperatures (surface warming) is kept below the aspirational warming target of 2°C (1.5°C) above pre-industrial. Sea surface warming less than 0.5°C in the GBR.
    - Sea level rises slowly (~0.13 m – Evans et al 2011)
    - Ocean pH declines by < 0.15 units
    - Extreme events such as cyclones, floods, and marine heatwaves continue to challenge the reef
- Other stressors
    - Water quality declines and terrestrial runoff continues to damage reef habitats with increased sediment and pollutants compared to current levels.
    - Fishing effort increases, particularly from recreational fishers who reach all unprotected habitats, and areas impacted by extreme events continue to be fished following these events.
    - Transport from new developments on land increases substantially, and new shipping channels occur within the GBR, leading to an increased number of incidents within the GBR, including regional oil spills.
    - Population and urban development within and adjacent to the reef increases, leading to loss of coastal habitat for mangroves and seagrasses. Increased and unregulated recreational use of the coastal environment occurs.
    - Indigenous stewardship is not recognised and conflict arises in sensitive areas.
    - CoTS outbreaks occur more frequency, and intervention options are not able to halt regional outbreaks.
- Implications for the major habitats **(section 3)**
    - Coral cover declines somewhat, bleaching events increase in frequency, but remain spatially restricted.

    - Mangroves and seagrasses decline in coverage, and do not recover between disturbance events, as habitat quality is locally degraded due to increased regional stressors.
    - Species diversity – changes in habitat structure lead to declines in reef-associated species, and there are regional losses resulting from local activities that prevent connectivity between habitats following disturbance from extreme events.

Trajectory 3 – Local action, global runaway

This trajectory corresponds to RCP 8.5, unmitigated carbon emissions, which sees surface warming >2°C and larger declines in pH by 2050, however, there is slow change in the other more local stressors, through good management or declining economic activity.

- Climate trajectory
    - Surface air and water temperatures exceed the aspirational warming target of 2°C.
    - Sea level rises rapidly (~0.68 m – Evans et al 2011)
    - pH declines by 0.25 units
    - Extreme events such as cyclones, floods, and marine heatwaves continue to challenge the reef, more frequently and with greater intensity
- Other stressors
    - Water quality continues to improve, and terrestrial runoff is less damaging (less sediment, pollutants) than in present day.
    - Fishing effort remains at sustainable levels, with spatial management used to take pressure off areas impacted by extreme events.
    - Transport does not increase substantially, and is managed though the reef, with governance and oversight of shipping, along with improved navigation leading to reduced number of incidents within the GBR.
    - Population and urban development with and adjacent to the reef decreasing or constant
    - Indigenous stewardship increases and results in improved management of sensitive areas. Local businesses take advantage of reef conditions to provide local economic benefits.
    - CoTS outbreaks continue at historical frequency, but intervention options are developed and major reef-wide outbreaks are averted.
- Implications for the major habitats **(section 3)**
    - Coral cover declines dramatically, CoTS outbreaks increase, bleaching events increase in frequency and begin to impact the entire reef area.
    - Mangroves and seagrasses do not decline in coverage, and recover between disturbance events (cyclones and flooding), and more efforts in restoration offset environmental impacts from extreme events and sea level rise.
    - Species diversity – changes in habitat structure lead to large declines in reef-associated species, and there are regional losses resulting from local activities that prevent connectivity between habitats following disturbance from extreme events.

Trajectory 4 – Global runaway, local status quo

This trajectory corresponds to RCP 8.5, which sees surface warming >2°C and larger declines in pH by 2050, and is coupled with fast change in the local stressors, through poor management or increasing economic activity.

- Climate trajectory
    - Surface air and water temperatures exceed the aspirational warming target of 2°C.
    - Sea levels rise rapidly (~0.68 m – Evans et al 2011)
    - pH declines by 0.25 units
    - Extreme events such as cyclones, floods, and marine heatwaves continue to challenge the reef, more frequently and with greater intensity
- Other stressors
    - Water quality declines and terrestrial runoff continues to damage reef habitats with increased sediment and pollutants compared to current levels.
    - Fishing effort increases, particularly from recreational fishers who reach all unprotected habitats, and areas impacted by extreme events continue to be fished following these events.
    - Transport from new developments on land increases substantially, and new shipping channels occur within the GBR, leading to an increased number of incidents within the GBR, including regional oil spills.
    - Population and urban development within and adjacent to the reef increases, leading to loss of coastal habitat for mangroves and seagrasses. Increased and unregulated recreational use of the coastal environment occurs.
    - Indigenous stewardship is not recognised and conflict arises in sensitive areas.
    - CoTS outbreaks occur more frequently, and intervention options are not able to halt regional outbreaks.
- Implications for the major habitats **(section 3)**
    - Coral cover declines dramatically due to CoTS outbreaks and bleaching events, both of which increase in frequency and begin to impact the entire reef area.
    - Mangroves and seagrasses decline in coverage, and do not recover between disturbance events, and regional loss from extreme events and sea level rise occurs.
    - Species diversity – changes in habitat structure lead to large declines in reef-associated species, and there are regional losses resulting from local activities that prevent connectivity between habitats following disturbance from extreme events.

3.8 Conclusions

A number of guiding principles for the scope of the midterm and 2020 review stages of the Reef 2050 Plan can be drawn from the synthesis of trajectories, building on the conclusions provided at the end of section 2.2.

Firstly, the contrasting climate futures used here will be the strongest determinants of change on the GBR. This is consistent with the conclusion of the recent Outlook Report for the Reef (GBRMPA 2014c). The basis for this conclusion is recognizing scope for opportunity versus reducing risk. A future with less than 0.5°C additional warming (i.e. achieving the 1.5°C aspirational target) will mean opportunities to support ecosystem resilience through multiple impact pathways, including intensified strategies of conventional management approaches already in place (Fig. 1) as well as new innovative interventions to safeguard key species and ecosystem functions (Anthony et al. 2017a). Conversely, run-away climate change will mean high risks to ecosystems and people, and with few opportunities so sustain the Reef as it is today and produce future ecosystem services. The reason for the latter is that the package of stressors that come with an unmitigated carbon path such as RCP 8.5 presents two sets of risks: (1) ***increased demand for resilience*** by causing more severe and frequent acute disturbances (bleaching, storms) and (2) ***accelerated erosion of resilience*** by compromising the processes that normally ensure recovery between disturbances. From a Reef 2050 Plan perspective, a strongly mitigated carbon future represents opportunities for a sustained

GBR and dependent economies. Conversely, an unmitigated carbon future will be characterised by high risk and a need for intensified human adaptation. It is important to note that, while contrasts between carbon futures used here (RCP 2.6 vs 8.5) will differ by only 1-2 degrees Celsius by 2050, they are set to diverge dramatically during the second half of this century (Pachauri and Meyer 2014) and beyond (Meinshausen et al. 2011).

Within these alternative carbon futures, socio-economic drivers, management strategies and regional environmental policies have different scope for delivering outcomes under Reef 2050 Plan and beyond. Here, Trajectory 1 represents a future where opportunities for sustained GBR values can be realised through a combination of socio-economic behaviours that represent low risk of cumulative impacts and well-designed policies/strategies that further reduce or manage those risks (Fig. 16). In this context, Trajectory 2 represents loss of opportunity compared to Trajectory 1. By driving an economy of future taking as opposed to future making (Bohensky et al. 2011), the resilience support needed from, for example, improved water quality and reduced fishing pressures, will be missing under Trajectory 2, and thereby its ability to be an insurance policy for retaining the values of the GBR.

A future under Trajectory 3 will be one of local and regional uphill battles attempting to preside over systemic decline (Anthony 2016). There will be a high likelihood that the environmental tolerances of key species that make up the GBR will be increasingly exceeded, eventually resulting in an altered GBR (Graham et al. 2014, Hughes et al. 2017b). Environmental policy and management strategies here could be forced to shift away from resilience support in the traditional sense, and instead to embrace interventions that support a few climate-hardy species of importance for fisheries and tourism, and at increasingly smaller scales. Lastly, Trajectory 4 is both globally and locally pessimistic. For the GBR it represents the future with the fewest opportunities for the GBR and dependent people and industries, and the most risks to all. In the context of the Reef 2050 Plan it should serve two purposes: (1) as a worst-case scenario to be avoided, and (2) as a possible trajectory if global carbon mitigation is out of scope and if regional economies favour short-term opportunities over long-term sustainability.

The evidence presented here reinforce the conclusion in Section 2.2 that the meaningful inclusion of climate change adaptation and a recognition of the irreversible changes to the GBR will require a staged review process. The midterm review would need to focus on initially embedding climate change into the Reef 2050 Plan as well as triggering a range of additional actions, mainly aimed at building resilience (e.g. water quality improvement, additional emphasis on preventing CoTs outbreaks), as a means of 'buying time'. The foundation in the lead up to the 2020 review is laid to revise the overarching architecture of the plan, encompassing a thorough revision of targets and outcomes reflecting the likely changes to the overarching goal statement.

The analysis presented in this chapter provides some initial directions as to what actions might have to be undertaken in the period between both reviews. In particular, the results shown in Figures 7, 13 and 15 point to the opportunity of using spatial and temporal differentiation of processes and climate impacts in the GBR to inform the targeting and prioritising of interventions in a way that maximises adaption outcomes. This information will also support the planned development of a new reef restoration programme, which will also have to contend with the problem of where to target what future restoration interventions.

3.9 References

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