Senate Standing Committee on Environment and Communications
Legislation Committee
Answers to questions on notice
Environment and Energy portfolio

Question No: 243

Hearing: Budget Estimates

Outcome: Agency

Program: Great Barrier Reef Marine Park Authority (GBRMPA)

Topic: Submission to the 2017 Climate Policy Review

Hansard Page: 29

Question Date: 22 May 2017

Question Type: Spoken

Senator Waters asked:

Senator WATERS: Has GBRMPA been asked to contribute, and have you contributed, to the 2017 climate policy review that the government has long spruiked?
Dr Reichelt: We are sending in a submission on that.
Senator WATERS: Has that happened yet?
Dr Reichelt: Yes, it has.
Senator WATERS: Is that publicly available? Are you able to provide us with a copy of that?
Dr de Brouwer: I think we are just all receiving them, and it depends on whether people have asked for their submissions to be confidential. But we can come back maybe in the climate change discussion around the exact number.
Senator WATERS: Did you ask for it to be confidential?
Dr Reichelt: No, we send it to the review team. I am just not sure of what conditions they have around it. We could check that.

Answer:

A copy of the submission made by the Great Barrier Reef Marine Park Authority on the 2017 Government Climate Policy Review is attached.

Australian Government
Great Barrier Reef
Marine Park Authority

Climate Change Policies Review – Discussion Paper submissions
2017 Review Branch
Department of the Environment and Energy
GPO Box 787
CANBERRA ACT 2601

REF - 2017-0077

Dear Review Team

Australia's review of climate change policies: discussion paper, March 2017

The Great Barrier Reef Marine Park Authority ("GBRMPA" or the Authority) provides this submission for your consideration.

Climate change is a national and global issue and the most serious threat to the long-term health of coral reefs worldwide, including one of the world's greatest natural treasures—the Great Barrier Reef.

For over 40 years, the Australian Government's Great Barrier Reef Marine Park Authority has managed and protected the world heritage-listed Great Barrier Reef using the best available scientific information and input from marine managers, researchers, experts and Traditional Owners. In 2015 the Australian and Queensland governments' Reef 2050 Long-Term Sustainability Plan was released. This plan is mentioned on page 26 of the Discussion Paper. The Plan sets clear actions, targets, objectives and outcomes to guide management of the globally-valuable Great Barrier Reef in the face of significant pressures; the most serious being climate change.

The Great Barrier Reef Outlook Report 2014[1] found the overall outlook for the Reef ecosystem is poor and worsening. This assessment was reached after taking into account 150 years of past and accumulating human-caused impacts such as poor water quality and crown of thorns starfish outbreaks, and then secondly taking into account the very poor forward outlook for the reef under the present and increasing levels of Greenhouse Gases in the atmosphere.

Since 2014 unprecedented mass coral bleaching occurring in successive years, in 2016 and 2017, have hastened the decline.[2] As an agency tasked with managing and protecting the Reef for current and future generations, the Authority remains extremely concerned about the current and future very destructive impacts of climate change on the Great Barrier Reef Marine Park and World Heritage Area. We are keenly aware that mitigating global climate change remains the most difficult policy challenge to secure the long-term future of the Great Barrier Reef.

Our submission focuses on the importance of Australia playing a lead role in global efforts to meet the 1.5 degree Celsius goal of the Paris Climate Change Agreement — from a coral reef perspective.

2 - 68 Flinders Street
PO Box 1379
Townsville Qld 4810
Australia

Phone + 61 74750 0700
Fax + 61 7 4772 6093

info@gbrmpa.gov.au
www.gbrmpa.gov.au

Document number: 100323 v1
Date approved: 12-Oct-2015

Question: Australia has committed to considering a potential long-term emissions reduction goal for Australia beyond 2030. What factors should be considered in this process?

Answer: Minimising climate change-related threats to ocean ecosystems (including coral reefs) and their services is critically important, and necessitates immediate and substantial reduction of greenhouse gas emissions which are already causing air and ocean warming that in the past two years has caused the onset of oceanic heat-waves leading to sudden death of thousands of square kilometres of corals on the Great Barrier Reef.

The first widespread loss of coral from heat-stress bleaching occurred on the Great Barrier Reef in successive summers (2016 and 2017). Further loss of coral is inevitable and can be minimised rather than prevented if the aspirational goal of the Paris 2015 Agreement is reached.

Until 2016 the Great Barrier Reef had not seen such large scale loss of coral from heatwaves – however for many other coral reef regions across the Indian, Pacific and Caribbean seas coral loss began on a massive scale in 1998.

Climate change impacts on coral reefs are predicted to worsen and critically affect the survival of coral reefs globally without the strongest possible climate change mitigation.*3*

Human-caused emissions of carbon dioxide and other greenhouses gases) in our industrialised world directly affect atmospheric chemistry but also have a strong influence on the physics[4] and chemistry[5] of the oceans[6]. In particular, the warming ocean trends have already led to huge ecological impacts on the ocean, including for Australia's Great Barrier Reef and other coral reef ecosystems.

An example of such impacts is the unfolding mass coral die-off from bleaching on the Great Barrier Reef in 2016 and 2017, driven in large part by ocean warming. This is part of the longest-running global coral bleaching event, and shows the potential of climate change to cause harm that cannot be remediated through management or adaptation.

Although only one of many ecosystems vulnerable to climate change, coral reefs are particularly sensitive to this threat as their existence hinges on the health of reef-building corals, which have narrow thermal and chemical tolerance limits.[7]

Many coral reef fishes and invertebrates rely on live, healthy coral for their survival, making them vulnerable to changes in coral reef habitats. These reef-associated species, as well as many other species and habitats that occur within the Great Barrier Reef World Heritage Area, are also directly vulnerable to various impacts from climate change.[8]

Of particular concern for GBRMPA are the predictions that the Reef could experience temperature-induced bleaching events twice per decade by about 2020 and annual bleaching events could occur within three decades.[9] As bleaching becomes more frequent and more intense, recovery processes are unlikely to be sufficient for reefs to persist as coral-dominated systems.[10] This threatens the future of coral reefs world-wide.

As stewards of the Great Barrier Reef, it is important that Australian and Queensland government policies across different portfolios are consistent with commitments under the Reef 2050 Plan for the sustainable management of the Reef.

Other human activities also have impacts on the Reef — compounding the risks from climate change and potentially lengthening recovery timeframes.[11] For example, chronic stress due to poor water quality can affect the recovery potential of reef communities because reproduction and larval recruitment in corals are particularly sensitive to environmental conditions.[12] Considerable efforts are being made under the Reef 2050 Plan to reduce the impacts of other pressures to help reefs cope with or recover from disturbances. In turn these will help build the resilience of reefs to future climate-related disturbances.

While these actions to reduce pressures and build resilience remain crucial, environmental management efforts can only compensate for reduced coral reef resilience in the face of climate change to a limited extent and over a limited timeframe.[13] Modelling shows that preserving 10 per cent of coral reefs worldwide would require limiting global warming to below 1.5 degrees Celsius relative to pre-industrial levels.[14]

Among other consequences of greenhouse emissions in the years and decades to come, there are likely to be more intense weather events and gradual ocean acidification will increasingly restrict coral growth and survival. Although there are some uncertainties in the predictions for cyclone frequency under climate change, cyclone intensity is predicted to increase globally. This will cause more frequent occurrences of the most destructive cyclones with potentially severe consequences for coral reef ecosystems.[15] Prior to the 2016 bleaching event it is estimated that cyclones were responsible for about half (50 per cent) of the total coral loss on the Great Barrier Reef since 1986.[16]

Across Australia heavy rainfall events and associated flooding are likely to become more frequent as global warming continues.[17] There will be a tendency for more large-scale flood events to contribute significant volumes of freshwater to the marine environment[18], bringing additional sediment and nutrients to the Reef.

Even relatively small decreases in ocean pH reduce the capacity of corals to build skeletons, which in turn reduces their capacity to create habitat for reef biodiversity.[19] Further, if coral skeletons are weakened they may have reduced capacity to resist and recover from physical damage caused by cyclones.[20]

The combined effects of ocean acidification and increasing ocean warming are likely to have contributed to reducing calcification rates of coral throughout the Great Barrier Reef. Skeletal records of massive corals from the inshore Great Barrier Reef indicate that between 1990 and 2005 there was an 11 per cent decline in calcification. This is the fastest and most severe decline in at least 400 years.[21]

It is predicted that ocean acidification could ultimately affect most marine life through habitat destruction or modification, food web deterioration and disruption of physiological processes.[22] In addition, the effects of global warming and ocean acidification may magnify each other[23], and will be amplified by the accumulation of other impacts such as those caused by excess nutrient run-off.

The Reef 2050 Plan Independent Expert Panel has also expressed serious concerns about the future of the Great Barrier Reef, and their Communiqué from 5th May 2017[24] includes:

Quote from the Independent Expert Panel:

> ***'The Panel members were united in their concern about the seriousness of the impacts facing the Reef and concluded that coral bleaching since early 2016 has changed the Reef fundamentally. There is great concern about the future of the Reef, and the communities and businesses that depend on it, but hope still remains for maintaining ecological function over the coming decades.***

> ***Members agreed that in our lifetime and on our watch, substantial areas of the Great Barrier Reef and the surrounding ecosystems are experiencing major long-term damage which may be irreversible unless action is taken now. The planet has changed in a way that science informs us is unprecedented in human history. While that in itself may be cause for action, the extraordinary rapidity of the change we now observe makes action even more urgent.***
>
> ***The Panel considers that action to reduce emissions of greenhouse gases must be central to the response.***
>
> ***This needs to be coupled with increased efforts to improve the resilience of the coral and other ecosystems that form the Great Barrier Reef. The focus of efforts should be on managing the Reef to maintain the benefits that the Reef provides.'***

In addition to considering these environmental risks and implications in decisions about reducing emissions, there are also economic, social and cultural risks that should be considered in the process.

> ***Coral reefs not only provide critical habitat and support exceptional biodiversity, but they also provide livelihoods and food and tourism opportunities. At a global-level, loss of coral reefs has been estimated to put nearly a $1 trillion at risk.25***
>
> ***Within the Great Barrier Reef Region, reef-dependent activities, including tourism, fishing, recreation and traditional use, are vulnerable to the negative effects that warming sea temperatures, sea level rise, more frequent extreme weather and ocean acidification may have on the condition of the Great Barrier Reef. We outline below some of the associated concerns for the social, cultural and economic values derived from the Great Barrier Reef.***
>
> ***Strong and rapid global climate change mitigation would minimise these far-reaching impacts for the environment and dependent industries and communities.***

GBRMPA promotes strong and effective management of local pressures (such as pollution and pest outbreaks) because such management builds the resilience of the system in the face of the externally driven risks posed by Climate Change.

> ***There remains hope for a better outlook for the Reef. The future of the Reef can be dramatically improved with action on both greenhouse gas emissions and relieving the reef ecosystem from local pressures.***
>
> ***A study has shown that a better future for the Reef could be secured if emissions are reduced drastically now and there is continued investment in reef management, with visible benefits within 20 years.26 The study indicates that the benefits for coral reefs of concerted action to reduce greenhouse gas emissions would be realised within our lifetime.***

GBRMPA strongly welcomes the increased ambition contained in the Paris 2015 Agreement: 'holding the increase in the global average temperature to well below two degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.'

Modelling shows even the two degree Celsius goal in the Paris Agreement would be a very dangerous level of warming for the world's coral reef ecosystems. To ensure a future for the Great Barrier Reef (i.e. as a functioning reef ecosystem), the latest science indicates the stronger position in the Paris Agreement to restrict the increase to 1.5 degrees Celsius (or ideally less) above pre-industrial is essential.

We say "ideally less" than 1.5 degrees Celsius since climate change impacts are already seriously affecting the Reef at the current level of global warming[27], and predictions indicate even 1.5 degrees Celsius of warming above pre-industrial poses substantial risks to coral reef ecosystems.[28]

> ***This advice*** *(to remain within 1.5 C deg increase)* ***is consistent with GBRMPA's reports[29], which clearly highlight climate change is threatening the Great Barrier Reef. We found there is a critical need to halt increasing concentrations of global greenhouse gases and restore them to levels that will support growth, recruitment and recovery processes of the Great Barrier Reef ecosystem. The science of carbon dioxide concentrations and coral reefs indicates optimum limits for coral reef ecosystems are at or below a concentration of 350 ppm[30] [31] This requires a lowering of current global greenhouse gas concentrations.***

For heat-related extremes, the difference between 1.5 degree Celsius and 2 degree Celsius marks the transition between the upper limit of present-day natural climate variability and a whole new climate regime, particularly in tropical regions.[32]

Very ambitious long-term emissions reduction goals for Australia beyond 2030 would set a leading example of climate change action globally. It has been argued stronger national efforts and leadership on this issue by Australia would make effective global mitigation outcomes more likely. In turn, this will help avoid the massive and mostly irreversible impacts of climate change on coral reefs, and associated loss of environmental, economic and social values.

Mangrove forests, tidal marshes, and seagrass ecosystems provide economic, environmental and social benefits for Australia with additional climate-related benefits being possible through their ability to capture and store carbon (known as blue carbon). The carbon stored in and flowing through these ecosystems has considerable potential to contribute to both emission reductions and the National Greenhouse Gas Inventory.[33]

The remainder of our submission addresses aspects of all the following questions:

Are there particular concerns or opportunities with respect to jobs, investment, trade competitiveness, households and regional Australia that should be considered

- *when reducing emissions in the electricity sector?*
- *for households, SMEs and the built environment?*
- *when reducing emissions in the industrial sector?*
- *in relation to research, development, innovation and technology?*

Or associated with policies to reduce emissions

- *in the transport sector?*
- *in the land and agriculture sectors?*

> ***Answer: From a Great Barrier Reef perspective, there are far-reaching economic, social and cultural climate change-related impacts driving the need***

for effective policies on mitigation across all these sectors. There are also major positive opportunities to consider across each of these topics.

Mitigation of greenhouse gases must occur across all of the major sources and sectors, especially the direct and indirect emissions arising from the combustion of fossil carbon to create energy for electricity and other uses.

Notwithstanding the significant innovation and changes required, all policies that promote an increase in the proportion of renewable energy (non-fossil carbon based) will assist in the reduction of greenhouse gas emissions.

Keeping within the 1.5 degrees Celsius goal of the Paris 2015 Agreement would help maximise future environmental, economic, social and cultural values of coral reefs.

Coral reefs are incredibly valuable economic and environmental assets.

The Great Barrier Reef is a world-renown natural icon that is home to unique plants, animals and habitats. It is valued by Australians and people around the world, and many communities and industries depend on a healthy Reef for recreation and their livelihoods.

The Reef attracts about 2 million tourism visitors each year and many more recreational visitors. According to the Social and Economic Long-Term Monitoring Program, more than 90 per cent of residents in the Region felt the Great Barrier Reef had outstanding beauty, were satisfied with their experience of the Reef and proud of its World Heritage status and 95 per cent of tourists felt the Reef has outstanding beauty.

Great Barrier Reef-dependent industries are estimated to contribute $5.6 billion per year to the Australian economy; however the total economic value of the ecosystem and community benefits from the Reef is much greater at an estimated A$15-$25 billion each year. The Reef also supports the livelihoods of 69,000 Australians employed in sectors such as tourism.[34]

The Great Barrier Reef's world and national heritage values are underpinned by the ecosystem and directly affected by changes to it. Climate change is likely to affect the way people interact with the Great Barrier Reef and the economic, social and cultural benefits they derive from it.

Climate change poses one of the greatest risks to the future economic value of Reef-dependent industries such as tourism, fishing and recreation. While the implications of climate change for the economic value of Reef-dependent industries are numerous and there is an improved understanding of these[35], they remain difficult to accurately quantify.[36]

Concerns for the tourism industry include degradation of reef sites, poor recovery of bleached sites as a result of other stresses, and a loss of marketing appeal as a high-quality reef destination.[37] A healthy and resilient Reef is fundamental to the success of many tourism operations and deteriorating Reef conditions may reduce tourism opportunities and visitor satisfaction, with significant economic repercussions for regional Australia.

Commercial fishing and aquaculture in and adjacent to the Reef generate about $160 million per year, and recreational fishing continues to be one of the most popular pastimes of Reef users. Fishing activities are likely to be highly sensitive to climate change, including as a result of projected changes in fish abundance, survivorship[38], size and distribution, disruptions to shallow-water nurseries and loss of coral reef habitats, as well as changes in

cyclone and storm activity.[39] Vulnerability assessments have identified high risks from climate change for Queensland fishery species and their habitats,[40] and several documents provide insights into the associated concerns relating to Queensland's fisheries and regional Australia.[41] As an example, studies suggest ongoing ocean warming may jeopardise the catchability of coral trout and the sustainability of Australia's reef-based fisheries.[42]

Indigenous heritage values are likely already being affected and also particularly vulnerable to climate change because the natural environment is fundamental to Traditional Owner connections to their land and sea country.[43] Many aspects of Indigenous heritage such as cultural practices, sacred sites, sites of particular significance, stories, songlines, totems, language, technology, tools and archaeology will be affected by global warming and ocean acidification. Some impacts will come as a result of ecosystem effects, while others will occur directly. Historic heritage places and artefacts are at risk too, along with social, aesthetic and scientific values.

Foreshores and coastal infrastructure such as ports[44], and the benefits communities derive from them, will also be influenced by climate change impacts on the catchment and the Great Barrier Reef Region.

Another important value of coral reefs is the physical protection they provide against natural hazards from coastal storms, flooding and rising sea level. In this sense the Great Barrier Reef can be thought of as a living, self-repairing "breakwater" that protects Queensland coastal communities and industries. Combined results across studies show that coral reefs dissipate 97 per cent of the wave energy that would otherwise impact shorelines.[45] This valuable coastal protection could be lost if reefs become heavily degraded and unable to keep up with rising sea levels.

We wish you every success in pursuing opportunities for enhancing Australia's Climate Change Policies.

Yours sincerely

Russell Reichelt
Chairman

12 May 2017

References and notes

[1] Great Barrier Reef Marine Park Authority 2014, *Great Barrier Reef Outlook Report 2014*, GBRMPA, Townsville.
[2] Great Barrier Reef Marine Park Authority 2016, *Interim report: 2016 coral bleaching event on the Great Barrier Reef*, GBRMPA, Townsville link to report. Hughes, T.P., et al. 2017, Global warming and recurrent mass bleaching of corals, *Nature 543* : 373-377. See also http://www.gbrmpa.gov.au/media-room/reef-health
[3] Baker, A.C., Glynn, P.W. and Riegl, B. 2008, Climate change and coral reef bleaching: an ecological assessment of long-term impacts, recovery trends and future outlook, *Estuarine, Coastal and Shelf Science* 80(4): 435-471. Hughes, T.P., et al. 2017, Global warming and recurrent mass bleaching of corals, *Nature 543* : 373-377.
[4] The oceans absorb much of the excess heat caused by global warming, and tropical ocean surface waters are warming on average at 70 per cent of the global warming rate. According to the Bureau of Meteorology, in 2016 the Great Barrier Reef recorded its hottest-ever average sea surface temperatures for February, March, April, May and June since records began in 1900. Each month was 1.0 to 1.3 degrees Celsius higher than the 1961–1990 average and even higher above the pre-industrial baseline to which reefs are adapted. Ocean warming under climate change threatens coral reefs directly, through mass coral bleaching and die-off from heat stress, and degradation of reef structures and indirectly, by boosting the energy of cyclones that cause coral destruction and loss of associated organisms. Future increases in sea temperature of as little as 0.5 degrees Celsius from present are expected to lead to significant degradation of the Great Barrier Reef (Ainsworth et al. 2016). Climate change also has other impacts such as sea level rise and changes to ocean circulation, and leads to species-level shifts in distribution, abundance, life-history timings (migration, reproductive). Ainsworth, T.D., et al. (2016) Climate change disables coral bleaching protection on the Great Barrier Reef. *Science,* 352: 338-342.
[5] Approximately 26 per cent of the carbon dioxide released from human activities since industrialisation has been absorbed by the oceans, resulting in a reduction in pH and carbonate ion concentration, termed ocean acidification. Global ocean pH has decrease by 0.1 units since the start of the Industrial Revolution, corresponding to a more than 25 per cent increase in the concentration of hydrogen ions.
[6] Gattuso, J.P. et al., 2015, Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios, *Science* 349: Issue 6243, DOI: 10.1126/science.aac4722. The Oceans 2015 Initiative, Part I An updated synthesis of the observed and projected impacts of climate change on physical and biological processes in the oceans
[7] Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Gomez E, Sale PF, et al. 2007. Coral reefs under rapid climate change and ocean acidification. *Science* 318:1737–42 Hoegh-Guldberg, O. 1999, Climate change, coral bleaching and the future of the world's coral reefs, *Marine and Freshwater Research* 50(8): 839-866.
[8] Johnson, J.E. and Marshall, P.A. (eds) 2007, *Climate change and the Great Barrier Reef: a vulnerability assessment*, Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Townsville.
[9] van Hooidonk, R., Maynard, J.A. and Planes, S. 2013, Temporary refugia for coral reefs in a warming world, *Nature Climate Change* 3(4): 508-511.
[10] Hughes, T.P., et al. 2017, Global warming and recurrent mass bleaching of corals, *Nature 543* : 373-377.
[11] Great Barrier Reef Marine Park Authority 2014, *Great Barrier Reef Outlook Report 2014*, GBRMPA, Townsville. Hughes, T.P. and Connell, J.H. 1999, Multiple stressors on coral reefs: a long-term perspective, *Limnology and Oceanography* 44(3): 932-940.
[12] De'ath, G. and Fabricius, K.E. 2008, *Water quality of the Great Barrier Reef: Distributions, effects on reef biota and trigger values for the protection of ecosystem health*, Great Barrier Reef Marine Park Authority, Townsville. Wooldridge, S.A. 2009, Water quality and coral bleaching thresholds: formalising the linkage for the inshore reefs of the Great Barrier Reef, Australia, *Marine Pollution Bulletin* 58(5): 745-751.
[13] Anthony K.R.N., 2016, Coral reefs under climate change and ocean acidification: challenges and opportunities for management and policy. *Annual Review of Environment and Resources* 41: 59-81
[14] Frieler K., Meinshausen M., Golly A., Mengel M., Lebek K., Donner S. D. & Hoegh-Guldberg O., 2013. Limiting global warming to 2 °C is unlikely to save most coral reefs. *Nature Climate Change*. doi: 10.1038/nclimate1674. http://www.nature.com/nclimate/journal/v3/n2/abs/nclimate1674.html. Schleussner, C.F., et al. 2016, Differential climate impacts for policy-relevant limits to global warming: the case of 1.5 °C and 2 °C, *Earth System Dynamics* 7(2): 327-351.
[15] Cheal A.J., MacNeil M.A., Emslie M.J., Sweatman H., 2017, The threat to coral reefs from more intense cyclones under climate change. *Global Change Biology* 23(4): 1511-1524

[16] De'ath, G., Fabricius, K.E., Sweatman, H. and Puotinen, M. 2012, The 27–year decline of coral cover on the Great Barrier Reef and its causes, *Proceedings of the National Academy of Sciences* 109(44): 17995-17999.
[17] Steffen, W., Hughes, L. and Karoly, D. 2013, *The critical decade: Extreme weather*, Climate Commission Secretariat, Canberra.
[18] Great Barrier Reef Marine Park Authority 2014, *Great Barrier Reef Outlook Report 2014*, GBRMPA, Townsville.
[19] Anthony, K.R.N., Kline, D.I., Diaz-Pulido, G., Dove, S. and Hoegh-Guldberg, O. 2008, Ocean acidification causes bleaching and productivity loss in coral reef builders, *Proceedings of the National Academy of Sciences* 105(45): 17442-17446. Anthony, K.R.N. and Marshall, P. 2012, Coral Reefs, in *A marine climate change impacts and adapation report card Australia 2012*, ed. E.S. Poloczanska*, et al.*, CSIRO, Canberra, pp. 259-280.
[20] van Hooidonk, R., Maynard, J.A., Manzello, D. and Planes, S. 2014, Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs, *Global Change Biology* 20(1): 103-112.
[21] De'ath, G., Lough, J.M. and Fabricius, K.E. 2009, Declining coral calcification on the Great Barrier Reef, Science 323(5910): 116-119. Cooper, T.F., De'ath, G., Fabricius, K.E. and Lough, J.M. 2008, Declining coral calcification in massive *Porites* in two nearshore regions of the northern Great Barrier Reef, *Global Change Biology* 14(3): 529-538. De'ath, G., Fabricius, K. and Lough, J. 2013, Yes: Coral calcification rates have decreased in the last twenty-five years! *Marine Geology* 346: 400-402. Pandolfi, J.M., Connolly, S.R., Marshall, D.J. and Cohen, A.L. 2011, Projecting coral reef futures under global warming and ocean acidification, *Science* 333(6041): 418-422.
[22] Doney, S.C., Fabry, V.J., Feely, R.A. and Kleypas, J.A. 2009, Ocean acidification: the other CO_2 problem, *Annual Review of Marine Science* 1: 169-192.
[23] Anthony, K.R.N., Kline, D.I., Diaz-Pulido, G., Dove, S. and Hoegh-Guldberg, O. 2008, Ocean acidification causes bleaching and productivity loss in coral reef builders, *Proceedings of the National Academy of Sciences* 105(45): 17442-17446.
[24] The communique from 5 May 2017 Reef 2050 Independent Expert Panel meeting is available here: http://www.environment.gov.au/system/files/pages/abff0d5e-b94d-4495-b79b-90dc52274f69/files/expert-panel-communique-5may2017.pdf
[25] Worldwide, coral reefs provide livelihoods, food and tourism estimated to be worth nearly a trillion dollars each year. Hoegh-Guldberg O et al. (2015) BBG Economic Valuation: Methodology and Sources. *Reviving the Economy: The case for action - 2015*.
[26] Ortiz, J.C., Bozec, Y., Wolff, N.H., Doropoulos, C. and Mumby, P.J. 2014, Global disparity in the ecological benefits of reducing carbon emissions for coral reefs, *Nature Climate Change* 4(12): 1090-1094.
[27] By 2016, Great Barrier Reef waters had warmed by approximately 0.80 degree Celsius since 1871, with most of the warmest years occurring in the past two decades (J Lough, pers. comm [data from HadISST, HadCRUTv4]). Sea surface temperatures in northern Australia have warmed on average by 0.12 degree Celsius per decade since 1950. Reisinger, A., et al. L. Chapter 25. Australasia, in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. B. Fitzharris and D. Karoly, pp. 1-101.
[28] Great Barrier Reef Marine Park Authority 2014, *Great Barrier Reef Outlook Report 2014*, GBRMPA, Townsville.
[29] e.g. Great Barrier Reef Marine Park Authority 2014, *Great Barrier Reef Outlook Report 2014*, GBRMPA, Townsville. Great Barrier Reef Marine Park Authority 2013, *Great Barrier Reef Region strategic assessment: Strategic Assessment Report.* GBRMPA, Townsville.
[30] Veron, J.E.N., Hoegh-Guldberg, O., Lenton, T.M., Lough, J.M., Obura, D.O., Pearce-Kelly, P., Sheppard, C.R., Spalding, M., Stafford-Smith, M.G. and Rogers, A.D. 2009, The coral reef crisis: The critical importance of <350 ppm CO_2, *Marine Pollution Bulletin* 58(10): 1428-1436
[31] It is not straightforward to compare this with targets expressed in degrees Celsius. However, a guardrail of about 1.2 to 1.5 degrees Celsius would be needed.
[32] Schleussner, C.F., et al. 2016, Differential climate impacts for policy-relevant limits to global warming: the case of 1.5 °C and 2 °C, *Earth System Dynamics* 7(2): 327-351.
[33] Cannard, T. et al., 2016, Coastal Blue Carbon Emissions Reduction Opportunities, Workshop Report Prepared for the Department of the Environment and Energy, CSIRO

[34] Jobs data are as measured in full-time equivalent workers. Economic data are currently being updated. Deloitte Access Economics 2013, Economic contribution of the Great Barrier Reef, Great Barrier Reef Marine Park Authority, Townsville.

[35] Poloczanska, E.S., Hobday, A.J. and Richardson, A.J. 2012, *Marine climate change in Australia, impacts and adaptation responses. 2012 report card*, CSIRO, Canberra.

[36] Miles, R.L., Kinnear, S., Marshal, C., O'Dea, G. and Greer, L. 2009, *Assessing the socio-economic implications of climate change (coral bleaching) in the Great Barrier Reef catchment. Synthesis report prepared for the Marine and Tropical Sciences Research Facility*, Reef and Rainforest Research Centre Limited, Cairns.

[37] Tourism Industry Council 2008, *Climate change response manual for Great Barrier Reef Marine Park operators*, TIC, Brisbane.

[38] Kikkawa, T., Kita, J. and Ishimatsu, A. 2004, Comparison of the lethal effect of carbon dioxide and acidification on red sea bream (*Pagrus major*) during the early developmental stages, *Marine Pollution Bulletin* 48(1-2): 108-110. Ishimatsu, A., Kikkawa, T., Hayashi, M., Lee, K. and Kita, J. 2004, Effects of carbon dioxide on marine fish: larvae and adults, *Journal of Oceanography* 60(4): 731-741. Guinotte, J.M. and Fabry, V.J. 2008, Ocean acidification and its potential effects on marine ecosystems, *Annals of the New York Academy of Sciences* 1134(1): 320-342.

[39] Johnson, J.E. and Marshall, P.A. (eds) 2007, *Climate change and the Great Barrier Reef: a vulnerability assessment,* Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Townsville. Fenton, M., Kelly, G., Vella, K. and Innes, J. 2007, Climate change and the Great Barrier Reef: industries and communities, in *Climate change and the Great Barrier Reef: a vulnerability assessment*, eds. J.E. Johnson and P.A. Marshall, Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Townsville, pp. 745-771. Tobin, A.J., Schlaff, R., Tobin, R., Penny, A., Ayling, T., Ayling, A., Krause, B., Welch, D., Sutton, S., Sawynok, B., Marshall, N.A., Marshall, P.A. and Maynard, J.A. 2010, *Adapting to change: minimising uncertainty about the effects of rapidly-changing environmental conditions on the Queensland Coral Reef Fin Fish Fishery, Final Report to the Fisheries Research and Development Corporation, Project 2008/103*, James Cook University, Townsville.

[40] Morison and Pears (2012) Assessment of the Ecological Vulnerability of the East Coast Otter Trawl Fishery to Climate Change: A brief Synthesis of Information and Results of an Expert Workshop. Great Barrier Reef Marine Park Authority, Townsville. <http://hdl.handle.net/11017/522> Munday et al. (2012) Tropical Coastal Fish. In: A Marine Climate Change Impacts and Adaptation Report Card for Australia 2012 (Eds. E.S. Poloczanska, A.J. Hobday and A.J. Richardson). <http://www.oceanclimatechange.org.au/content/images/uploads/2012_Tropical_fish_MarineReportCard_2.pdf> Welch et al. (2014) Implications of Climate Change Impacts on Fisheries Resources of Northern Australia. Fisheries Research and Development Corporation, 2010/565 (2014). <http://frdc.com.au/research/Documents/Final_reports/2010-565-DLD%20Part%201.pdf>

[41] Great Barrier Reef Marine Park Authority (2011) Extreme Weather on the Great Barrier Reef. Great Barrier Reef Marine Park Authority, Townsville. <http://hdl.handle.net/11017/645> Great Barrier Reef Marine Park Authority (2012) Climate Change Adaptation: Outcomes from the Great Barrier Reef Climate Change Action Plan 2007-2012. Great Barrier Reef Marine Park Authority, Townsville. <http://hdl.handle.net/11017/1139> (Particularly pages 42 – 55) Donnelly, R. (2011) Climate change vulnerability assessment: Queensland marine aquarium supply industry, 2010. Great Barrier Reef Marine Park Authority, Townsville.<http://hdl.handle.net/11017/476> Donnelly, R. (2013) Stewardship Action Plan: Mitigating Ecological Risk in a Changing Climate. Pro-vision Reef Inc., Cairns. <http://www.provisionreef.org.au/stewardship-action-plan/stewardship-action-plan-2013/> Creighton et al. (2013) Climate Change and Recreational Fishing, Fisheries Research and Development Corporation, Brisbane. <http://frdc.com.au/research/Final_Reports/2011-037-DLD.pdf>

[42] Pratchett, M.S., et al., 2016, Effects of climate change on coral grouper (Plectropomus spp.) and possible adaptation options, *Reviews in Fish Biology and Fisheries* doi: 10.1007/s11160-016-9455-9.

[43] Great Barrier Reef Marine Park Authority 2014, *Great Barrier Reef Outlook Report 2014*, GBRMPA, Townsville.

[44] McEvoy, D. and Mullett, J. 2013, *Enhancing the resilience of seaports to a changing climate: Research synthesis and implications for policy and practice. Work Package 4 of Enhancing the resilience of seaports to a changing climate report series*, National Climate Change Adaptation Research Facility, Gold Coast.

[45] Ferrario, F.,et a. 2014, The effectiveness of coral reefs for coastal hazard risk reduction and adaptation, *Nature Communications* 5: 3794 Available at https://www.nature.com/articles/ncomms4794