Select Committee on the Effectiveness of the Australian Government's Northern Australia Agenda
ANSWERS TO QUESTIONS ON NOTICE
Australian Institute of Marine Science
PUBLIC HEARING Wednesday 9 October 2019

AGENCY: Australian Institute of Marine Science (AIMS)

TOPIC: Climate Change

REFERENCE: Question on Notice – Senator Roberts

HANSARD RECORD (PROOF, 18 OCTOBER 2019)

Senator Roberts:

- *In the last bullet point in your submission you mentioned consideration of the significant negative impacts of climate change. I have asked this question of NASA's Goddard Institute of Space Study, the CSIRO and the Bureau of Meteorology, and I've checked the UN and it doesn't have it; no-one can provide me with the empirical evidence that proves that human carbon dioxide output is affecting the climate and needs to be cut. No-one. Could you provide me—I don't expect you to do it on the spot—with the empirical evidence in a structured and logical format that proves human carbon dioxide is impacting the reef?*
- *Can you also provide me with your science that says ocean acidification is occurring? It's alkali; it's around 8.3 on a pH scale and it varies, according to what I've seen, on a pretty natural variation. I haven't seen any trends of ocean acidification. It is alkaline and remains alkaline. So if you could send me that, it would be great.*
- *I'd like to see what you rely upon for the statement that we are enduring climate change.*
- *I look forward to it—data in a framework that proves human CO2 causes climate change and needs to be cut.*
- *Could you tell me on notice, Dr Hardisty, the factual basis, the data that underpins your statement that most scientists agree that humans are causing climate change?*
- *You said, 'most scientists agree'. I want to know who 'most scientists' are, and the factual data that underpins that*

ANSWER

Human causes of carbon dioxide output are affecting the climate, and this is a risk to coral reefs

There is a strong scientific basis and consensus amongst climate scientists and the wider scientific community that rising atmospheric carbon dioxide (CO_2) and other greenhouse gas levels due to human activities is the primary cause of the current rapid rise in global temperatures (https://climate.nasa.gov/scientific-consensus/) (IPCC; https://www.ipcc.ch/).

Our scientists at AIMS fully recognise that human-induced global warming is a real and immediate threat to tropical coral reefs, such as the Great Barrier Reef (GBR). This position is based on rigorous scientific assessment of the evidence through peer-reviewed scientific publications (a literature to which our scientists have made significant contributions).

Our global climate system varies on a range of time scales and has clearly varied and changed in the past (e.g. the Ice Age cycles resulting from changes in radiative forcing as the Earth's position in space relative to the sun periodically changes). We have, however, entered a new era. It is now clear from numerous peer-reviewed scientific publications over many decades and the periodic assessments of available evidence of the Intergovernmental Panel on Climate Change (IPCC; https://www.ipcc.ch/) [1]that a) human activities since the start of the Industrial Revolution are increasing the concentration of greenhouse gases in the atmosphere, b) that this increase has changed the planetary energy balance with more heat being trapped in the climate system by greenhouse gasses including CO_2, and c) that this is leading to human-caused 'global warming'.

These conclusions are reached through multiple lines of evidence. These include thermodynamic theory (dating back to the 19th century, e.g. Fourier, Tyndall, Arrhenius), observations (e.g. Mauna Loa CO_2 measurements, weather station temperature measurements on land; ships' observations of sea surface temperatures; and more recently satellite observations), paleoclimatic reconstructions (which extend the observational records backwards in time), our improved understanding of the global climate system and global climate models. The latter, by necessity, have to parameterise processes in the complex, multi-dimensional climate system but are verified and refined against their performance for current day climate and periods in the past when boundary conditions were different from today. These models are constantly being improved and their projections closely agree with observed climate and paleoclimate records, giving us more confidence in their future projections.

Also, now emerging is evidence from the natural world that the global climate system is rapidly warming. This includes physical changes such as rising sea levels due to thermal expansion of the oceans with accelerating inputs from melting of land-based ice, thinning and shrinkage of Arctic sea ice extent, retreat of land-based glaciers, and thawing of permafrost; and for biological systems, shifts in species ranges, migration patterns – many of these responses and impacts are documented in the IPCC-AR5 WGII report (IPCC 2014), which is based on multiple peer-reviewed scientific publications and extensive and rigorous peer review.

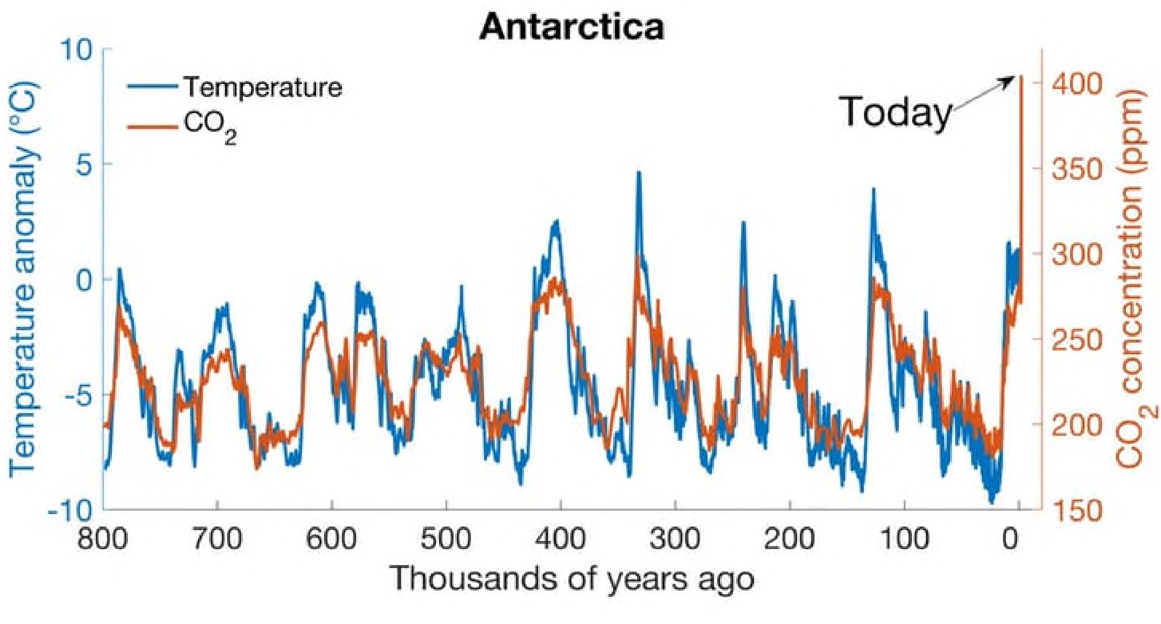
Critically, tropical coral reefs, such as the Great Barrier Reef (GBR), are already demonstrating their sensitivity and vulnerability to rapid warming of the tropical oceans. At the heart of healthy tropical coral reef ecosystems is a mutually beneficial symbiosis between the host coral animals and single-celled, photosynthetic plants (*Symbiodinium*) – the extra energy that the coral host obtains from their symbionts allows corals to calcify faster than the natural biological and physical forces of erosion and thus build the complex reef structures that provide habitat and food for the many thousands of reef-associated organisms (see van

[1] Note that the IPCC is a conservative body of international experts (and reviewers) who base their assessments on available peer-reviewed scientific literature. In their first assessment (AR-1, 1990) they concluded that it was 'not yet possible' to discern human influence on the climate system. It is only with their latest assessment (AR-5, 2013) that they were able to conclude from the available evidence that the 'human influence on the climate system is clear'.

Oppen and Lough 2018). Under stress, the corals lose their symbionts and associated energy source, in a process termed coral bleaching. Scientists have long been aware of this stress response of corals which can be due to unusually warm or cold water temperatures, lowered salinity and localised pollution. What is new is widespread coral bleaching affecting wide tracts of reef and even whole reefs which has been occurring with increasing frequency since the early 1980s. These mass coral bleaching events, which have now affected almost every reef system globally, are a demonstrated stress response to unusually warm sea surface temperatures, which, in turn, is a consequence of rapid global warming. The GBR, for example, has been affected by mass coral bleaching events in 1998, 2002, 2016 and 2017 – the most recent back-to-back events have had significant and ongoing impacts on the health of the Reef (e.g. Hughes et al 2017a, 2017b, 2018, 2019).

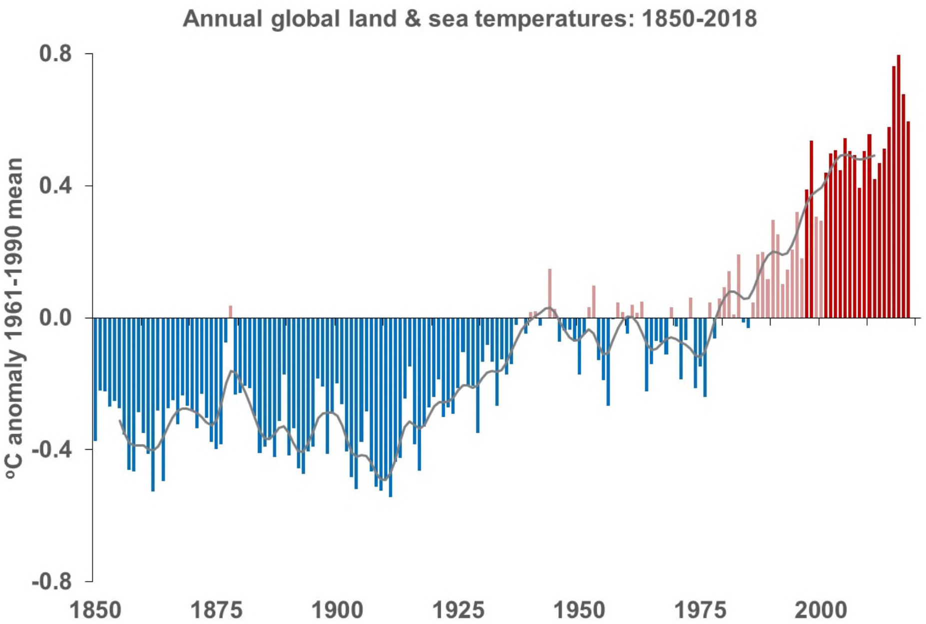
The frequency of thermal stress events that result in coral bleaching has also significantly increased globally since the late 19th century observational record period (e.g. Lough et al 2018). This is at the root of our and GBRMPA's concern for the future of the GBR (e.g. Great Barrier Reef Marine Park Authority 2019). The seriousness of the real threat to the maintenance of the GBR into the future is why AIMS and partners are exploring all possible avenues to protect, restore and help this invaluable ecosystem to deal with future environmental conditions (e.g. Reef Restoration and Adaptation Program https://www.gbrrestoration.org/).

As an example of the type of evidence scientists use to reach consensus on the reality of current rapid climate change and its human causes the below figure (based on analysis of Antartic ice cores) clearly shows that current atmospheric CO_2 levels have not been experienced over at least the past 800,000 years. The associated article by Ben Henley and Nerilie Abram (both established climatic and paleoclimatic scientists at the University of Melbourne and Australian National University, respectively) provides a comprehensive explanation of the linkages between past CO_2 levels and global temperatures and highlights the unprecedented nature of current conditions. It is also demonstrable that the recent increase in atmospheric CO_2 comes largely from the burning of fossil fuels which produce a characteristic carbon isoptopic signature in the atmosphere (the 'Suess effect' which is also evident in paleoclimatic archives such as corals and tree rings).



(Source B. Henley and N. Abram, The Conversation, June 13 2017; https://theconversation.com/the-three-minute-story-of-800-000-years-of-climate-change-with-a-sting-in-the-tail-73368).

As another example, the below figure (based on instrumental observations of temperature on land and at sea) clearly shows global warming since the late 19th century and that there is no evidence for global temperatures having remained 'relatively stable' in recent decades. Indeed, the past 5 years, 2014-2018, have been the warmest years on record.



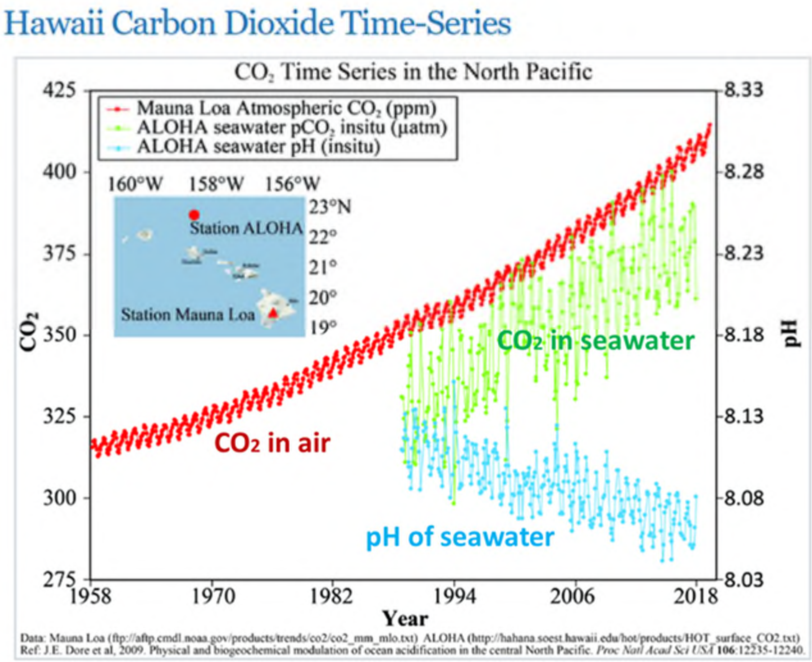
(Source HadCRUT4 global land and sea temperatures; https://crudata.uea.ac.uk/cru/data/temperature/).

The evidence base for a rapidly changing climate system and observed and projected consequences for natural and human systems is continuously being rigorously assessed by scientists internationally. Recent examples include the IPCC's (2019) *Special Report on Climate Change and Land* (https://www.ipcc.ch/report/srccl/) and the IPCC's (2019) *Special Report on The Ocean and Cryosphere in a Changing Climate* (https://www.ipcc.ch/srocc/home/).

In summary, the many lines of evidence, which have been mounting for decades convince our scientists at AIMS and the wider scientific community, that global warming due to human activities changing the composition of the atmosphere (and hence the planetary energy balance), is the major challenge of our times. We base our conclusions on the rigorous scientific process as documented in the international, peer-reviewed scientific literature.

Ocean acidification is occurring

The Great Barrier Reef has lost half its coral cover in the past thirty years. Most of that loss is due to storms, crown-of-thorns starfish, and bleaching due to extended periods of increased summer sea temperature. However other factors are also contributing to the ability of the Reef to respond to and recover from these impacts. Ocean acidification is a direct and measurable effect of carbon emissions. In the world's open oceans, the pH (and the calcium carbonate saturation states) of surface waters track the CO2 concentration in the atmosphere. This is because between 20% and 30% of the carbon dioxide (CO_2) that humankind is injecting into the atmosphere is being absorbed by the oceans (Sabine et al., 2004). In effect, without ocean acidification, atmospheric CO_2 (and consequently the global average temperature) would have been higher today (Doney et al, 2009). The term 'acidification' does not mean seawater will become acidic, it simply means ocean pH will decline.[2] If carbon emissions would follow an unmitigated path this century, average surface pH of open ocean waters would be projected to decline about 0.3 pH units (IPCC, 2019). Given that pH is on a log scale, such predicted changes in the concentration of hydrogen ions could be physiologically devastating for many species.



Source: https://www.pmel.noaa.gov/co2/file/Hawaii+Carbon+Dioxide+Time-Series

One of the clearest set of observations that ocean acidification is already progressing is from the study by Byrne et al. 2010. They observed a pH decline in the top 500 m of the North Pacific Ocean of around 0.06 between the years 1991 and 2006.

Ocean acidification is predicted (based on tens of high-quality experimental studies) to lead to multiple effects on coral reefs (reviewed by Anthony, 2016). One of the most critical functions affected by ocean acidification is marine calcification. Recent experimental work by AIMS colleagues on One Tree Island on the southern Great Barrier Reef has demonstrated that ocean acidification has already slowed reef calcification by around 7% (Albright et al., 2016). The shift in the seawater carbonate system under ocean acidification lowers the capacity of calcifying organisms, including corals, to build skeletons. Reduced coral calcification under acidification means slower coral growth, more fragile structures, and potentially a shift from net accretion to net dissolution. This implies greater susceptibility to

[2] The term 'acidification' is somewhat misleading because the pH of seawater will remain alkaline (above pH 7) even under the highest atmospheric CO_2 concentrations predicted this century. Acidification simply refers to the decline in pH and associated changes in the seawater chemistry. Model simulations by Stanford University colleagues investigating how the ocean's carbon chemical system will respond to anthropogenic CO_2 emissions indicate that ocean surface pH could fall as low as 7.6, that is around 0.7 units below today's level (Caldeira & Wickett, 2003). Interestingly, their geochemical model analyses, along with the geochemical record of atmospheric CO_2 levels over the past 300 million years, sees no evidence that ocean pH was more than 0.6 units lower than today.

storm damage, slower recovery rates between disturbances, less habitat-forming structures, and overall reduced reef resilience. Other biological and ecological functions affected by ocean acidification are reduced abundance of crustose coralline algae, which play a key role as substrates for invertebrate larval recruitment; shifts in competitive hierarchies between corals and algae; and potentially increased bleaching susceptibility of corals to warming. Further, in experiments reduced pH of reef water show behavioural changes in fishes including reduced ability to recognise and avoid predators (Munday et al., 2009).

While seawater pH (and calcium carbonate saturation states affected by pH) vary in the waters of the Great Barrier Reef (Mongin et al., 2016), driven by reef metabolism and coastal influences, ocean acidification will likely be superimposed on this variation (NASEM, 2019), leading to a net downward trend in pH.

AIMS scientists are continuing to research the effects of ocean acidification on coral reef organisms and ecosystems, using four complementary approaches: field research at unique carbon dioxide seeps in Papua New Guinea; studies of the carbonate chemistry in the GBR; controlled carbon dioxide enrichment experiments in AIMS research aquarium - SeaSim; and Computer models. Work by AIMS on specific coral reefs in Papua New Guinea where underground CO_2 have seeped naturally into the seawater for decades in the range expected under unmitigated carbon emissions this century (around pH 7.8), provide a look into how coral reefs are likely to respond to ocean acidification (Fabricius et al., 2011). The team's findings are an absence of the branching and structurally complex coral species that form critical fish habitat. Only a few hardy coral species are left standing. Reefs nearby in the area not exposed to CO_2 seepage have high characteristic abundance of structurally complex corals and have high coral biodiversity. Importantly, these studies examined impacts of ocean acidification without the warming effect, so results are likely to represent an optimistic look at the future for reefs under a high-emission path.

Most climate scientists believe in climate change and that humans are the main cause

Apart from the evidence provided above, there are many consensus statements from learned science organisations - representing the views of their members - that climate warming trends over the past century are extremely likely due to human activities. For your further reference I recommend a short selection of these:

- https://climate.nasa.gov/scientific-consensus/
- https://www.ametsoc.org/index.cfm/ams/about-ams/ams-statements/statements-of-the-ams-in-force/climate-change1/
- https://whatweknow.aaas.org/wp-content/uploads/2014/07/whatweknow_website.pdf
- https://www.amos.org.au/wp-content/uploads/2018/04/AMOS_Climate_Statement_20216.pdf
- https://public.wmo.int/en/resources/united_in_science
- https://www.climatechangecommunication.org/climate-change-in-the-american-mind/

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25 October, 2019

References

Albright R, Caldeira L, Hosfelt J, Kwiatkowski L, Maclaren JK, Mason BM, Nebuchina Y, Ninokawa A, Pongratz J, Ricke KL, Rivlin T, Schneider K, Sesboüé M, Shamberger K, Silverman J, Wolfe K, Zhu K, Caldeira K (2016) Reversal of ocean acidification enhances net coral reef calcification. *Nature* 531:362–365.

Anthony KRN (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.

Byrne RH, Mecking S, Feely RA, Liu X (2010) Direct observations of basin-wide acidification of the North Pacific Ocean. *Geophysical Research Letters* 37:1–5.

Caldeira K, Wickett ME (2003) Anthropogenic carbon and ocean pH. *Nature* 425:365.

Doney SC, Fabry VJ, Feely RA, Kleypas JA (2009) Ocean Acidification: The Other CO2 Problem. *Annual Review of Marine Science* 1:169–192.

Fabricius KE, Langdon C, Uthicke S, Humphrey C, Noonan S, De'ath G, Okazaki R, Muehllehner N, Glas MS, Lough JM (2011) Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations. *Nature Climate Change* 1:165–169.

Great Barrier Reef Marine Park Authority (2019) *Great Barrier Reef Outlook Report 2019*, GBRMPA, Townsville, 374pp.

Hughes TP, et al (2017a) Coral reefs in the Anthropocene. *Nature* 546: 82-90, doi:10.1038/nature22901

Hughes TP, et al (2017b) Global warming and recurrent mass bleaching of corals. *Nature* 543: 373-378, doi:10.1038/nature21707

Hughes TP, et al (2018) Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science* 359:80-83, doi:10.1126/science.aan8048

Hughes TP, et al (2019) Global warming impairs stock-recruitment dynamics of coral reefs. *Nature*, doi:10.1038/s41586-019-1081-y

IPCC (2014) Summary for policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability.Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

IPCC (2019) *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)]. In press.Lough JM, KD Anderson & TP Hughes (2018). Increasing thermal stress for tropical coral reefs: 1871-2017 *Scientific Reports*, 8:6079, doi:10.1038/s41598-018-24530-9

Mongin M, Baird ME, Tilbrook B, Matear RJ, Lenton A, Herzfeld M, Wild-allen K, Skerratt J, Margvelashvili N, Robson BJ, Duarte CM, Gustafsson MSM, Ralph PJ, Steven ADL (2016) The exposure of the Great Barrier Reef to ocean acidification. *Nature Communications* 7:1–8.

Munday PL, Dixson DL, Donelson JM, Jones GP, Pratchett MS, Devitsina G V, Døving KB (2009) Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. *Proceedings of the National Academy of Sciences of the United States of America* 106:1848–1852.

NASEM (2019) *A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs*. Washington DC.

Sabine CL, A. FR, Gruber N, Key RM, Lee K, Bullister JL, Wanninkhof R, Wong CS, Wallace DWR, Tilbrook B, Millero FJ, Peng T-H, Kozyr A, Ono T, Rios AF (2004) The oceanic sink for anthropogenic CO2. *Science* 305:367–371.

van Oppen MJH & JM Lough (2018, eds, 2nd edition) *Coral Bleaching. Patterns, Processes, Causes and Consequences*. Ecological Studies, Vol 233, Springer-Verlag, 356pp.