Case No. 18-36082

IN THE UNITED STATES COURT OF APPEALS FOR THE NINTH CIRCUIT

KELSEY CASCADIA ROSE JULIANA, *et al.*,
Plaintiffs-Appellees,
v.
UNITED STATES OF AMERICA, *et al.*,
Defendants-Appellants.

On Interlocutory Appeal Pursuant to 28 U.S.C. § 1292(b)

DECLARATION OF OVE HOEGH-GULDBERG IN SUPPORT OF PLAINTIFFS' URGENT MOTION UNDER CIRCUIT RULE 27-3(b) FOR PRELIMINARY INJUNCTION

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I, Ove Hoegh-Guldberg, hereby declare and if called upon would testify as follows:

1. I am a Professor of Marine Studies and the Director of the Global Change Institute at The University of Queensland and Deputy Director of the Australian Research Council (ARC) Centre for Excellence for Coral Reef Studies. My office is located in Saint Lucia, Queensland, Australia.
2. I have been retained as an expert on behalf of Plaintiffs in this litigation before the United States District Court for the District of Oregon ("District Court").
3. I have prepared an expert report for this litigation ("Expert Report"), which forms part of the record in the District Court (D. Ct. Doc. 260-1). On August 2, 2018, Plaintiffs' counsel served on counsel for Defendants a supplemental version of my Expert Report. A true and correct copy of my Supplemental Expert Report is attached hereto as **Exhibit 1**. Additional information regarding my professional and educational background can be found in my curriculum vitae, attached to this declaration as **Exhibit A** to **Exhibit 1**. The Supplemental Expert Report does not include the visual, video and spreadsheet attachments that are titled Exhibits E-BB, which were served on Defendants via portable hard drive.
4. My work for this litigation is pro bono.

Expert Qualifications and Experience

5. I am one of the world's leading experts on coral reefs. I have worked on the impacts of ocean warming and acidification from the burning of fossil fuels for over 30 years. I was a Coordinating Lead Author of the chapter titled "The Ocean" for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("IPCC"). I was also a Coordinating Lead Author of the chapter titled "Impacts of 1.5ºC global warming on natural and human systems" for the IPCC's recent Special Report on Global Warming of 1.5°C ("SR1.5").

6. I have been diving and snorkeling on coral reefs since I was 10, and have spent thousands of hours underwater studying and photographing marine life. My fields of research and professional interests include:

   a. coral reefs and marine science;

   b. effects of climate change (particularly ocean warming and acidification) on reef-building corals, *Symbiodinium*, tropical coral reefs and related marine ecosystems;

   c. coral bleaching and mortality, and their connection to global warming and ocean acidification; and

   d. biology of symbiotic associations in reef-building corals and the impacts of stresses such as global warming upon these associations.

7. I have produced over 310 peer-reviewed publications as part of my contribution to the fields of physiology, ecology, environmental sciences, and climate change, and am amongst the most highly-cited authors in my fields.[1]

Current Atmospheric CO_2 Levels Are Harming Our Oceans

8. The ocean is the world's largest "carbon sink." The ocean has absorbed approximately 30% of human-caused CO_2 emissions as well as 93% of the excess heat in our climate system caused by fossil fuels and other sources of greenhouse gas ("GHG") pollution.[2] This absolute amount of excess heat absorbed by our oceans is tremendous: the equivalent of energy from approximately 1.5 Hiroshima-sized atomic bombs per second over the past 150 years, at-present the equivalent of approximately 3-6 Hiroshima-sized bombs every second.[3] That excess energy has created a precipitously dangerous condition in our oceans. While other experts focus on ice melt and sea level rise, I will discuss below the dangers to life in our oceans, on which

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[1] Ex. 1, at 10.

[2] Ex. 1, at 3, 11; *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2013).

[3] Damian Carrington, Global warming of oceans equivalent to an atomic bomb per second, *The Guardian*, Jan. 7, 2019, https://www.theguardian.com/environment/2019/jan/07/global-warming-of-oceans-equivalent-to-an-atomic-bomb-per-second; Zanna, L., et al., *Global reconstruction of historical ocean heat storage and transport*, 116(4) *Proceedings of the National Academy of Sciences* 1126 (2019).

hundreds of millions of people depend for sustenance, prosperity, and recreation.

9. The ocean's "carrying capacity" to absorb more anthropogenic CO_2 emissions is decreasing as the ocean warms and acidifies. This is because many of the processes by which the ocean currently absorbs CO_2 are sensitive to climate change, such that the ocean is projected to absorb a decreasing fraction of anthropogenic CO_2 emissions as the emissions of these GHGs increase.[4] This creates a vicious circle: the less CO_2 absorbed by the ocean, the more CO_2 is retained in the atmosphere and, thus, the more and more rapidly the Earth warms. Alarmingly, a recent study has found that the oceans are warming at a rate 40% faster than estimated in the IPCC's Fifth Assessment Report in 2014.[5] This rate of warming has increased rapidly since 1991.[6]

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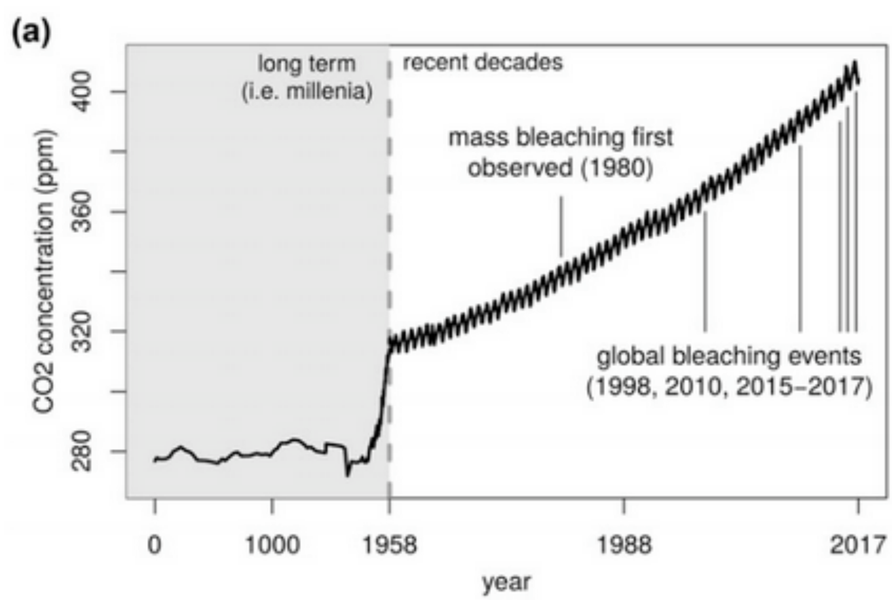
[4] Ex. 1, at 17; Gattuso, J.-P., et al., *Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios*, 349 Science aac4722, aac4722-5 (2015).

[5] Kendra Pierre-Louis, Ocean Warming Is Accelerating Faster Than Thought, New Research Finds, *The New York Times*, Jan. 10, 2019, https://www.nytimes.com/2019/01/10/climate/ocean-warming-climate-change.html; Cheng, L. et al., *How fast are the oceans warming?*, 363 Science 128 (2019).

[6] Cheng, L. et al., *How fast are the oceans warming?*, 363 Science 128, 129 (2019); Tony Barboza, Oceans had their hottest year on record in 2018 as global warming accelerates, *The Los Angeles Times*, Jan. 16, 2019, https://www.latimes.com/science/sciencenow/la-sci-sn-oceans-temperature-record-20190116-story.html ("The rate of warming in the ocean's upper 6,500 feet has been up to five times faster since 1991 than it was in the 1970s and '80s, scientists found.").

10. The Ocean's vital role in absorbing excess anthropogenic CO_2 and heat has and will continue to come at a significant cost to oceanic life and ecosystems and the hundreds of millions of people that rely upon them. There is broad scientific agreement that ocean warming, acidification and hypoxia (reduced ocean oxygen levels and a consequence of warming) have generally synergistic effects on the growth, survival, fitness, calcification, and development of marine organisms and ecosystems.

11. Mass coral bleaching is a key example of this phenomenon. Mass coral bleaching is a signature harm of rising CO_2 emissions, a fact illustrated by the following figure:[7]



[7] Beyer, H., et al., *Risk-sensitive planning for conserving coral reefs under rapid climate change*, 11(6) Conservation Letters e12587, 3.

12. Although some coral reefs are able to recover from minimal, short-term warming, reefs are unlikely to recover from the sustained, severe warming and acidification associated with present and continued levels of anthropogenic CO_2 emissions.[8] The Hawai'ian Islands, for instance, where Plaintiff Journey Z. lives, experienced record levels of bleaching in 2014.[9] The mass coral bleaching event of 2015-2016 affected ~75% of coral reef ecosystems globally,[10] and resulted in a 50% loss of coral cover in shallow water areas of the Great Barrier Reef.[11] At current levels of warming, we face "a scenario in which every hot summer, with or without an El Niño event, has the potential to cause bleaching and mortality at a regional scale."[12]

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[8] Gattuso, J.-P., et al., *Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios*, 349 (6243) Science aac4722, aac4722-5 (2015).

[9] U.S. National Oceanic and Atmospheric Administration, *Coral Bleaching During & Since the 2014-2017 Global Coral Bleaching Event: Status and an Appeal for Observations* (2018), https://coralreefwatch.noaa.gov/satellite/analyses_guidance/global_coral_bleaching_2014-17_status.php.

[10] Hughes, T., et al. 2018. *Spatial and temporal patterns of mass bleaching of corals in the Anthropocene*, 359 Science 80 (2018).

[11] Ex. 1 at 6, 14; Commonwealth of Australia Great Barrier Reef Marine Park Authority, *Final report: 2016 coral bleaching event on the Great Barrier Reef* (2017), http://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/3206/1/Final-report-2016-coral-bleaching-GBR.pdf; Hughes, T., et al., *Global warming transforms coral reef assemblages*, 556 Nature 492 (2018).

[12] Hughes, T., et al. 2018. *Spatial and temporal patterns of mass bleaching of corals in the Anthropocene*, 359 Science 80, 82, Supplementary Materials Table S1 (2018).

13. This scenario has already arrived in Florida. According to the United States Global Change Research Program's *Fourth National Climate Assessment*:

> Coral elevation and volume in the Florida Keys have been declining in recent decades, and present-day temperatures in the region are already close to bleaching thresholds; hence it is likely that many of the remaining coral reefs in the Southeast region will be lost in the coming decades.[13]

14. Additionally, the United States National Oceanic and Atmospheric Administration's ("NOAA") Coral Reef Outlook website currently projects a significant likelihood of another mass bleaching event on the Great Barrier Reef this coming February or March of 2019.[14] This would be the third mass bleaching event in the last four years, and could devastate much of the remaining living coral. The serious implications of these changes are emphasized by the fact that mass coral bleaching did not occur prior to 1979, and the first global scale mass coral bleaching event occurred in 1998.[15]

15. The IPCC's recent SR1.5 report acknowledged that previous risk assessments of coral reef degradation from ocean warming have been overly-conservative. That is, real-world impacts and observations such as the global mass

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[13] U.S. Global Change Research Program, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* 776 (2018) (hereafter "Fourth National Climate Assessment").
[14] U.S. National Oceanic and Atmospheric Administration, *Coral Reef Watch Satellite Monitoring and Modeled Outlooks* (2019), https://coralreefwatch.noaa.gov (last visited Jan. 11, 2019).
[15] Hoegh-Guldberg, O., *Coral bleaching, climate change and the future of the world's coral reefs* 50 Mar. Freshw. Res 839 (1999).

bleaching event of 2015-2016 and the back-to-back bleaching events on the Great Barrier Reef in 2016-2017 are outpacing even the least-conservative IPCC projections.[16] Plainly, this means that the IPCC's assessments have underestimated how quickly and profoundly climate change would harm our oceans and marine life. It is now generally-accepted that, even if global temperatures and CO_2 levels were stabilized at current levels (which would mean that all anthropogenic GHG emissions would immediately cease), coral reefs are committed to a very significant degree of irreversible decline.[17]

16. This does not mean that nothing can be done to slow or mitigate the harm that is currently happening. Rather, current atmospheric CO_2 concentrations are so far beyond safe levels for ocean ecosystems that the extent to which these ecosystems can recover from the harm done to them depends more on what happens in the next few years than over the next century.

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[16] Hoegh-Guldberg, O., et al., *Impacts of 1.5℃ global warming on natural and human systems*. In: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (World Meteorological Organization, 2018) 3-83 (hereafter "IPCC 1.5°C Special Report"); Hoegh-Guldberg, O., *Coral bleaching, climate change and the future of the world's coral reefs* 50 Mar. Freshw. Res 839 (1999); Hughes, T., et al., *Global warming and recurrent mass bleaching of corals*, 543 Nature 373 (2017); Hughes, T., et al., *Spatial and temporal patterns of mass bleaching of corals in the Anthropocene*, 359 Science 80 (2018).

[17] Ex. 1 at 8; IPCC 1.5°C Special Report, 3-83–3-84.

17. For some viable remnants of coral reef ecosystems to survive in the short-term and have any chance of re-propagation and eventual recovery in the long-term, CO_2 emissions must be reduced as rapidly as humanly possible[18]. Any increase in emissions risks pushing coral reefs and other marine ecosystems over the ecological 'precipice' (i.e. near complete loss) by further reducing the return time of mass bleaching events and further driving ocean temperatures beyond tolerable limits for many species.[19] I cannot emphasize enough the urgent and dire necessity of bringing CO_2 emissions swiftly down from every major emitting nation, this year in 2019 and beyond.

18. The ocean is changing, and its critical ecosystems degrading, at rates not seen in tens of millions of years. Critically-important ocean ecosystems are already severely threatened by present day carbon dioxide levels (~ 407 ppm), such that – from a scientific standpoint – any increase above current levels is nothing short of reckless. If emissions are not rapidly reduced, the damage we are doing now may not be completely undone for generations if not

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[18] Ex. 1 at 8-9, 18; Veron, J., et al., *The coral reef crisis: The critical importance of< 350ppm CO_2*, 58 Marine Pollution Bulletin 1428 (2009); Frieler, K., et al., *Limiting global warming to 2°C is unlikely to save most coral reefs*, 3 Nature Climate Change 165 (2013); Hansen, J., et al., *Assessing "dangerous climate change": required reduction of carbon emissions to protect young people, future generations and nature*, 8 PLoS ONE e81648 (2013).

[19] Hughes, T., et al. 2018. *Spatial and temporal patterns of mass bleaching of corals in the Anthropocene*, 359 Science 80, 82 (2018).

millennia.[20] It is crucial that atmospheric CO_2 levels do not increase in the short term in order to give our oceans a chance at beginning the gradual process of repair and regeneration.[21]

<u>Plaintiffs' Are Being Irreparably Harmed By Ocean Warming and Acidification</u>

19. In order to prepare my opinions for this Declaration, I reviewed the District Court's orders denying Defendants' Motion to Dismiss, Motion for Judgment on the Pleadings and Motion for Summary Judgment (D. Ct. Docs. 68, 369), the Declarations filed by Plaintiffs Journey Z. and Levi D. in support of Plaintiffs' response to Defendants' Motion for Summary Judgment (D. Ct. Docs. 284, 287), and the Declarations filed by Journey and Levi in support of this Motion. I have also spoken with Journey via telephone. In light of these documents and my discussions with these Plaintiffs, I now wish to briefly

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[20] Ex. 1 at 3, 17; Hoegh-Guldberg, O., et al., *The Ocean*, in Barros, V., et al. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2014) 1675, https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap30_FINAL.pdf; Hoegh-Guldberg, O., et al., *Reviving the Ocean Economy: the case for action*, (World Wildlife Fund, 2015) 8, http://assets.worldwildlife.org/publications/790/files/original/Reviving_Ocean_Economy_REPORT_low_res.pdf?1429717323&_ga=1.187.

[21] Hoegh-Guldberg, O., et al., *The Ocean*, in Barros, V., et al. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2014) 1675, https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap30_FINAL.pdf.

address how the youth Plaintiffs are being irreparably harmed by the scientific phenomena and changes described above.

20.***Hawai'i.*** Plaintiff Journey Z., resides on the island of Kaua'i, Hawai'i. Coral reefs on Hawai'i's main island continue to be impacted from the back-to-back mass bleaching events such as seen in 2014-2015.[22] Ongoing GHG emissions at current levels will virtually ensure that Hawaii's coral reef ecosystems will be unable to provide the food security of many Pacific island communities including those of Hawai'i. NOAA has acknowledged that "failure to reduce carbon dioxide and other heat-trapping gases that cause ocean acidification and rising temperatures may make management efforts [in Hawai'ian coral reefs] futile."[23] The devastating impacts of the current decline of the Hawaiian reef system is significantly impairing Journey's interests in fishing and snorkelling, as well as his wellbeing, future job prospects, and ongoing outlook (D. Ct. Doc. 284 at ¶¶19-20; Journey Z. Decl., ¶¶9-13, 25-26).[24]

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[22] U.S. National Oceanic and Atmospheric Administration Coral Reef Conservation Program, *Coral reef condition: a status report for the Hawaiian Archipelago* (2018) 6; Hughes, T., et al. 2018. *Spatial and temporal patterns of mass bleaching of corals in the Anthropocene*, 359 Science 80, 82, Supplementary Materials Table S1 (2018).

[23] U.S. National Oceanic and Atmospheric Administration Coral Reef Conservation Program, *Coral reef condition: a status report for the Hawaiian Archipelago* (2018) 3.

[24] See also Lawler, J., and M. Patel. *Exploring children's vulnerability to climate change and their role in advancing climate change adaptation in East Asia and the Pacific*, 3 Environ. Dev 123 (2012).

21. Journey has already witnessed the loss of coral reefs to heat stress-related coral bleaching in areas where he recreates and snorkels. Journey Z. Decl., ¶¶9-13. These losses will only increase with further increases in GHG emissions and heating. To give Hawai'ian reefs any chance of survival, CO_2 concentrations must rapidly decline, and the warming of the oceans must be stabilized as quickly as is possible. Such a turnaround will not occur if the U.S. continues to grow its emissions and lock in more fossil fuel use.

22. ***Florida.*** As I noted in my Expert Report, Plaintiff Levi's observations of apparent species shifts and die-offs in the coastal ecosystems of his homes in Satellite Beach and Indiatlantic, Florida are in my opinion consistent with those documented and expected in Florida's coastal ecosystems.[25] Levi D. Decl., ¶¶10-14. Similarly, the frequency and intensity of the "red tide" algal blooms that Levi has observed in the coastal and estuarine waters near his

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[25] Ex. 1 at 14; Moser, S., et al., *Coastal Zone Development and Ecosystems*, in: *Climate Change Impacts in the United States: The Third National Climate Assessment* (Melillo, J., et al. eds., U.S. Global Change Research Program, 2014) 579; Hoegh-Guldberg, O., et al., *The Ocean*, in Barros, V., et al. (eds.) C*limate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2014) 1675, https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap30_FINAL.pdf; Wong, P., et al., *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change* (Cambridge University Press, 2014).

home are, according to the scientific literature, exacerbated by climate change and associated ocean warming.[26] Levi D. Decl., ¶11.

23. Additionally, as noted above, U.S. government agencies have acknowledged that there is virtually no chance that the coral reefs of Florida, which Levi enjoys visiting, will continue to exist in a few decades if warming and emissions trends continue. As the U.S. Environmental Protection Agency recently stated, "Unlike other sectors of this Technical Report where the climate change signal emerges from natural variability over the course of the next 25 years, the most severe impacts to coral reefs are occurring now."[27] These impacts, as well as those described above, have adversely impacted Levi's emotional and psychological wellbeing, and hopes for the future. Levi D. Decl., ¶¶5-8, 23-25.

The Imperative of Halting Further CO_2 Emissions

24. In light of the existing harms described above and the fact that continued emissions of GHG such as CO_2 will only worsen existing harms to oceanic

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[26] Havens, K., and H. Paerl, *Climate Change at a Crossroad for Control of Harmful Algal Blooms*, 49 Environmental Science and Technology 12605; Chapra, S., et al., *Climate Change Impacts on Harmful Algal Blooms in U.S. Freshwaters: A Screening-Level Assessment*, 51 (16) Environmental Science and Technology 8933.

[27] U.S. EPA, Multi-Modal Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment (May 2017) at 175. Available at: https://cfpub.epa.gov/si/sipublic_record_Repoftcfm?Lab=OAP&dirEntryld=335095.

ecosystems, a rapid reduction in CO_2 emissions is not only necessary but would have massive net benefits to the broader public.

25. First, mitigating anthropogenic CO_2 emissions is the *only* action that will stop *both* further ocean warming and further acidification, and ensure that these Plaintiffs and future generations will live in a world that will include coral reefs like those of today.[28] Speculative technological interventions that seek to reduce warming without reducing CO_2 emissions will not provide relief from ocean acidification (i.e., ocean acidity will continue to rise even as temperature decreases), and thus will only delay the inevitable, necessary deep cuts in CO_2 and other greenhouse gases.[29] But that delay may result in the loss of coral reefs for the foreseeable future. Reducing CO_2 emissions and preventing any further sources of, or increases in, CO_2 emissions is therefore an immediate imperative for the safety of our oceans and marine ecosystems and the Plaintiffs and other members of society who depend upon these ecosystems.

[28] Fourth National Climate Assessment, at 361, 367.
[29] Gattuso, J.-P., et al., *Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios*, 349 (6243) Science aac4722, aac4722-7 (2015).

26. Second, rapid reductions in CO_2 emissions will have massive economic benefits to the "ocean economy" and wider society.[30] The economic value of the ocean is at least US$2.5 trillion annually, and as much as 70 percent of this annual value depends on the ocean remaining healthy.[31] Given that many marine ecosystems are already impaired from the effects of global warming and other forms of environmental degradation, reducing CO_2 emissions would have a strong stimulus effect on the ocean economy.[32] To do otherwise will squander the ocean's wealth for future generations,[33] and lead to a host of broader, cascading detriments to the welfare and security of wider society.[34]

27. The United States government has acknowledged that massive economic losses will be incurred as a result of damage to oceanic ecosystems from ongoing GHG emissions. United States government reports found that more than 90% of the recreational value of Florida reefs is likely to be lost across

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[30] See Hoegh-Guldberg, O., et al., *Reviving the Ocean Economy: the case for action*, (World Wildlife Fund, 2015); Hoegh-Guldberg, O., et al., *Reviving Melanesia's Ocean Economy: The Case for Action*, (World Wildlife Fund, 2015).

[31] Hoegh-Guldberg, O., et al., *Reviving the Ocean Economy: the case for action*, 7 (World Wildlife Fund, 2015).

[32] *Id.*, 8.

[33] *Id.*, 29.

[34] U.S. Environmental Protection Agency, *Multi-Modal Frameworkfor Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment* 173-174 (2017), https://cfpub.epa.gov/si/sipublic_record_Repoftcfm?Lab=OAP&dirEntryld=335095 (hereafter "EPA Technical Report"); Fourth National Climate Assessment, at 355.

most modelled scenarios, which by 2100 could be more than US $140 billion nationally and more than US $70 billion in Florida alone.[35] Consumer welfare losses within the United States due to declining shellfish numbers and rising prices are also projected to be in the hundreds of millions of dollars each year. Preventing any increases in and rapidly reducing CO_2 emissions within the United States is therefore also an economic and security imperative.

28. Finally, current and potential future economic losses stemming from climate change degradation of marine ecosystems have significant flow-on effects on the wellbeing of young people like Plaintiffs Journey and Levi. Coral-reef dependent economies are highly vulnerable to even minor impacts to these ecosystems.[36] The present accelerating changes to these ecosystems inevitably will cause many young people to chronically worry and become depressed about their own future livelihood and that of their communities.

29. These concerns are compounded by the incredible scale and visual effect of the recent catastrophic mass coral bleaching events, which are both emblematic of the impacts of present climate change and a harbinger of even more profound changes to come. In contrast, reducing emissions and thereby

[35] EPA Technical Report, at 173-174; Fourth National Climate Assessment, at 355.
[36] Hoegh-Guldberg, O., et al., *Reviving the Ocean Economy: the case for action* 27-28 (World Wildlife Fund, 2015).

commencing the long process of reversing these changes is likely to inspire optimism and hope in these young people, and in society more broadly.

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct. Executed on February 6, 2019.

Respectfully submitted,

Ove Hoegh-Guldberg

Exhibit 1

EXPERT REPORT
OF
OVE HOEGH-GULDBERG, Ph.D.

Director, Global Change Institute
Australian Research Council Laureate Fellow
The University of Queensland

Kelsey Cascadia Rose Juliana; Xiuhtezcatl Tonatiuh M.,
through his Guardian Tamara Roske-Martinez; et al.,
Plaintiffs,

v.

The United States of America; Donald Trump,
in his official capacity as President of the United States; et al.,
Defendants.

IN THE UNITED STATES DISTRICT COURT
DISTRICT OF OREGON

(Case No.: 6:15-cv-01517-TC)

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TABLE OF ACRONYMS AND ABBREVIATIONS

ARC:	Australian Research Council
CEQ:	United States Council on Environmental Quality
CLA:	Coordinating Lead Author
CO_2:	carbon dioxide
FAC:	First Amended Complaint
GAO:	United States Government Accountability Office
GBRMPA:	Great Barrier Reef Marine Park Authority
GHG:	greenhouse gas
IPCC:	Intergovernmental Panel on Climate Change
IPCC AR4:	IPCC Fourth Assessment Report
IPCC AR5:	IPCC Fifth Assessment Report
$\mu mol\ kg^{-1}$	micromole per kilogram
NCAR:	United States National Center for Atmospheric Research
NOAA:	National Oceanic and Atmospheric Administration
NRC:	United States National Research Council
ppm:	parts per million
PDO:	Pacific Decadal Oscillation
SLR:	sea level rise
WMO:	World Meteorological Organization

INTRODUCTION

I, Ove Hoegh-Guldberg, have been retained by Plaintiffs in the above-captioned matter to provide expert testimony regarding how human-caused CO_2 emissions are affecting the chemistry and temperature of the oceans and life within them, including specifically the impacts to coral reefs and organisms that rely upon calcification processes to create their shells, skeletons, and sometimes reefs. The devastating harm we are already (and have been for decades) witnessing, recording, and studying is causing some of the injuries and constitutional violations alleged in the First Amended Complaint in this case, and those harms are only worsening as greenhouse gas pollution, primarily from burning fossil fuels, continues to be emitted at high levels into the atmosphere.

Coral reefs are one of the most spectacular places on the planet, and occupy tropical and subtropical coastal and oceanic regions throughout the planet. While they only represent less than 0.1% of the ocean floor, they are the most biologically-diverse marine ecosystem on the planet. Estimates of the biological diversity of coral reefs range from 1-9 million species, many of which are unknown to science (Reaka-Kudla 1997).

In addition to being beautiful and inspiring, these magnificent reefs also play a critical role in supporting around 500 million people with food, livelihoods, cultural context, recreational activities, new medicines, and coastal protection, among many other benefits (Burke et al. 2011). A recent study by Boston Consulting Group estimated that the asset value of coral reefs is at least $0.9 trillion, with measurable benefits of several hundred billion dollars each year from activities such as fisheries and tourism (Hoegh-Guldberg et al. 2015). These estimates are probably at the lower end of the scale given that many benefits, such as those of cultural and biological significance, are difficult to quantify.

Despite their importance, coral reefs are degrading at the rate of 1-2% per year, with periodic increases in mortality, as a consequence of human activities that include local impacts from poorly-managed coastal development, overfishing, pollution, and climate change (Gardner et al. 2003, Bruno and Selig 2007, Burke et al. 2011, De'ath et al. 2012). While impacts from non-climate change sources are significant, rapid increases in ocean temperature are now the principal drivers of the degradation and mortality of coral reefs (Hoegh-Guldberg et al. 2007, IPCC 2014b, Hughes et al. 2017, 2018a,b). While impacts from development and overfishing can be remedied in shorter relative time frames, the consequences of ocean heating and acidification will last for millennia (Hönisch et al. 2012, IPCC 2013a,b, Webster et al. 2018).

Increased carbon dioxide (CO_2) emissions from the burning of fossil fuels are the primary cause of ocean warming and acidification (IPCC 2013b). Scientific consensus reveals that continuing emissions of CO_2 and other greenhouse gases will result in more frequent mass coral bleaching and mortality events (responses by corals to stress) that will become an annual occurrence within 30-40 years (Hoegh-Guldberg 1999, Hoegh-Guldberg et al. 2014). Indeed, bleaching events are becoming more frequent on coral reefs (Baker et al. 2008), and we have seen damaging back-to-back bleaching events (Hughes et al. 2017, 2018a,b) in many places worldwide just in the last three years (e.g. Hawaii, Great Barrier Reef). The continuation of current levels of greenhouse gas emissions will commit the planet to conditions in which coral reefs will disappear for thousands of years. Action taken today, however, to rapidly reduce emissions to close to zero by mid-century will stabilize ocean conditions and will ensure that the children of today and their children will be able to enjoy the multiple and unique benefits of living coral reefs.

This report contains my opinions, conclusions, and the reasons therefore. The opinions expressed in this report are my own and are based on the data and facts available to me at the time of writing. All opinions expressed herein are to a reasonable degree of scientific certainty, unless otherwise specifically stated. Should additional relevant or pertinent information become available, I reserve the right to supplement the discussion and findings in this expert report in this action.

My curriculum vitae, which provides a summary of my professional and educational qualifications and experience, is contained in **Exhibit A** to my expert report in this action. A list of publications I authored within the last ten years is shown in **Exhibit B** to my expert report in this action. A statement of my previous testimony within the preceding four years as an expert at trial or by deposition is contained in **Exhibit C** to my expert report in this action. My report contains citations to the principal documents that I have used or considered in forming my opinions, listed in **Exhibit D**. I also attach, as **Exhibits E-AA**, visual and video exhibits to be used in summary of, or in support for, my opinions within this report. **Exhibit BB** is a spreadsheet providing the precise location, GPS coordinates, timecode of the clip, metadata, and dates for **Exhibits E-AA**.

In preparing my expert report and testifying at trial, I am deferring my expert witness fees to the charged Plaintiffs given the financial circumstances of these young Plaintiffs. If a party seeks discovery under Federal Rule 26(b), I will charge my reasonable fee of $200 per hour for the time spent in addressing that party's discovery.

EXECUTIVE SUMMARY

Human-caused CO_2 and Other GHG Emissions are Harming Our Oceans

1. The ocean is a dominant component of the earth's climate system. While the earth is huge, the volume of the atmosphere (light blue sphere on the left) and the volume of water on and surrounding the globe (darker sphere) are relatively small (**Figure 1**). We see the Earth as a blue planet, but in reality, it has only a thin skin of air and water - and therefore Earth's climate and oceans are easier to impact than many might first assume.

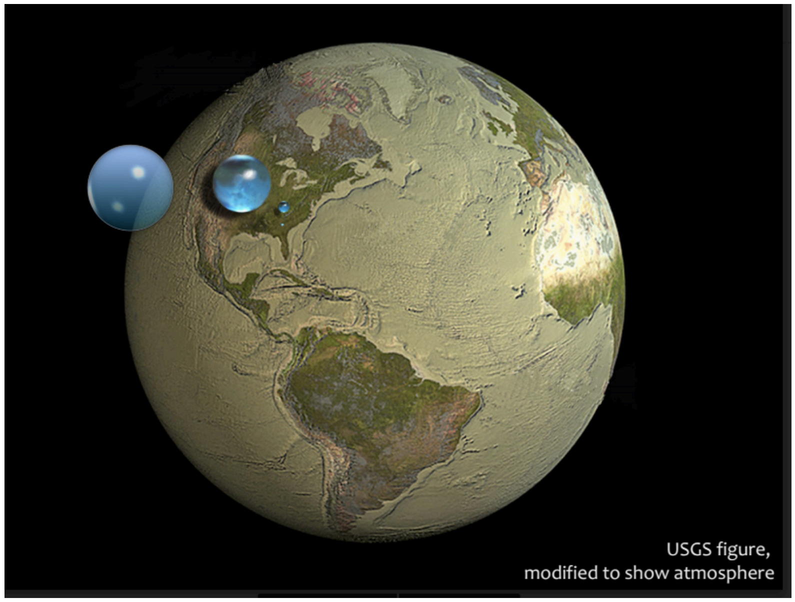

Figure 1. Comparative volume of Earth's atmosphere and water (Reprinted courtesy of Dr. Joanie Kleypas, NCAR).

2. Climate change and ocean acidification are placing coral reefs in conditions that they have not experienced over the past 740,000 years, if not the last 65 million years (Raven et al. 2005, Hoegh-Guldberg et al. 2007, Pelejero et al. 2010, Hönisch et al. 2012). Even the relatively rapid changes during the ice age transitions, which resulted in major changes to the biological systems of the planet, occurred at rates of change in CO_2 and temperature which were at least two orders of magnitude (i.e. one hundred times) slower than the rate of change that has occurred over the past 150 years (Hoegh-Guldberg et al. 2007), primarily due to the rapid rise in fossil fuel emissions.

3. The scientific consensus is that these changes are occurring at rates that dwarf even the most rapid changes seen over the past 65 million years, if not 300 million years (Hönisch et al. 2012; IPCC 2014a; Hoegh-Guldberg et al. 2014, Webster et al. 2018). Most evidence suggests that this rate of change will increase and that it already exceeds the biological capacity of coral reefs to respond via genetic change (i.e. evolution). As a result, there is a high degree of consensus within the scientific community that coral reefs, like a large number of other ecosystems, are set to degrade rapidly over the coming decades (Donner et al. 2005, Hoegh-Guldberg et al. 2007, IPCC 2007, 2014a, c).

4. Approximately 93% of the extra energy trapped by the enhanced greenhouse effect is absorbed by the ocean (Gattuso et al. 2015, Jewett and Romanou 2017). The extra energy is absorbed by the upper layers of the ocean (mostly the layer from 0-700 m) where it increases the temperature of ocean waters. The effect of this extra energy on the temperature of the water column decreases with depth. In addition to adversely impacting marine life and ecosystem processes, the added heat to the upper layers of the ocean has a number of distinct effects. Just like the human body with a fever, a small change in temperature results in increased stress due to different processes interacting and responding

at different rates. Without the oceans absorbing a major amount of the extra energy absorbed from human driven climate change, scientists estimate that the average temperature of Earth's surface would be very much higher than recent Earth's average annual temperature (in 2013), which was around 58.3 degrees Fahrenheit (14.6ºC; NASA).

5. The following graphic summarizes the various effects of increasing atmospheric CO_2 (**Figure 2**). Increased global CO_2 concentrations result in multiple impacts on the world's oceans, not just progressive warming. Rising CO_2 results in warmer oceans, ocean acidification, sea level rise, changes in nutrient recycling, more intense storms, ocean stratification and reduced mixing, and oxygen depletion. All of these changes have impacts on marine life and represent an even greater challenge when taken together.

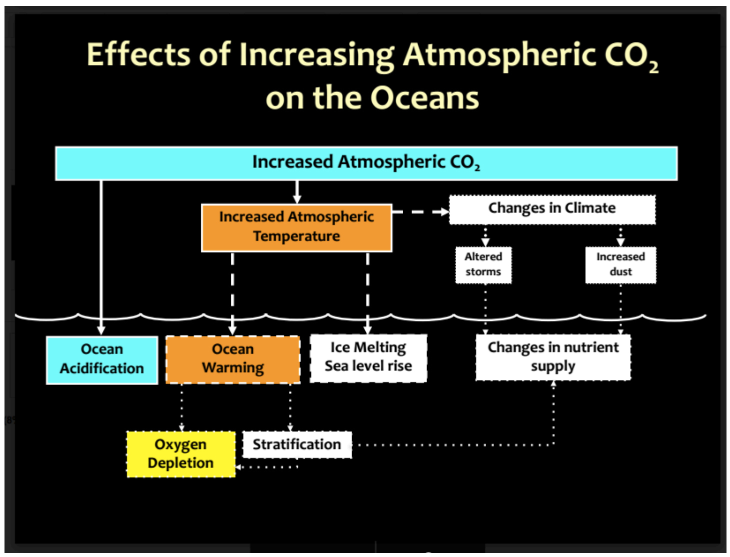

Figure 2. Multiple pathways to ocean damage from climate change: acidification, warming, stratification, sea level rise, and oxygen depletion (Reprinted courtesy of Dr. Joanie Kleypas, NCAR).

6. These changes affect marine organisms and ecosystems in a variety of ways. Each change has a different timeline and each type impacts marine life differently. Some are easier for marine life to recover from. The general categories (and examples) are:

i. Pulse (i.e. storms)
ii. Press (i.e. climate shift)
iii. Ramp (i.e. acidification, warming, deoxygenation) (**Figure 3**)

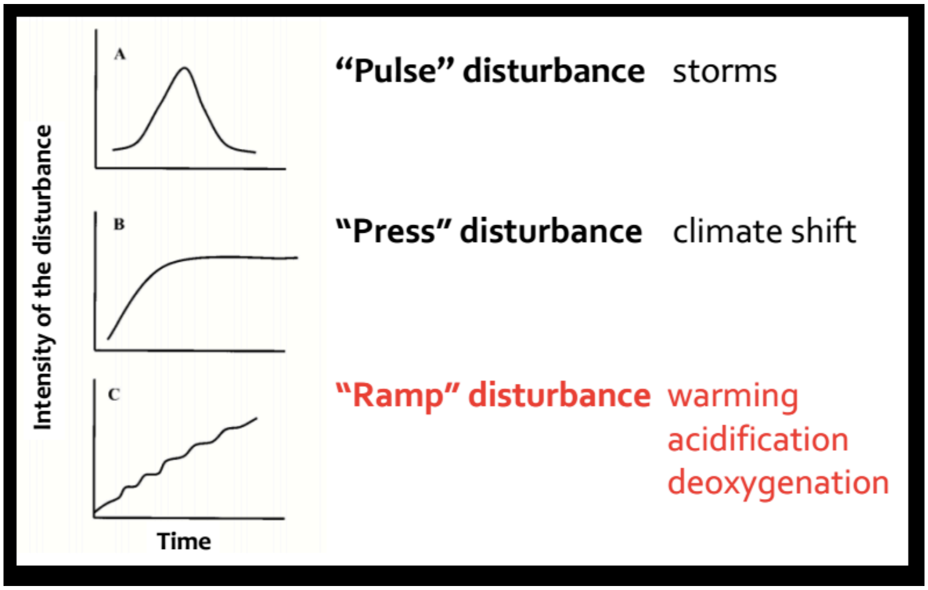

Figure 3. Pulse, press, and ramp disturbances (Reprinted courtesy of Dr. Joanie Kleypas, NCAR).

7. The specifics of the effect of the ocean trapping extra heat involve several phenomena. Firstly, adding heat increases the volume of the ocean (due to the thermal expansion of water and the melting of land-based ice), which manifests itself as sea level rise. The average increase in sea level has recently been around 3.2 mm per year, higher and lower in some regions due to local influences and interactions between landmass and phenomena such as currents (IPCC 2013a). Increases in sea level are causing the increasing inundation of coastal areas, and are projected to have serious impacts on coastal communities worldwide. Not restraining sea level rise will increase the impacts of storms, waves, and the seepage of saltwater into freshwater aquifers (vitally important for drinking and aquaculture). Given that hundreds of millions of people live close to sea level, impacts of rising seas on the well-being of coastal communities is an important factor influencing the opportunities and safety and hence well-being of children (Nicholls et al. 1999, Nicholls et al. 2008, Nicholls and Cazenave 2010, Nicholls et al. 2011a, Nicholls et al. 2011b, IPCC 2013a).

8. Secondly, increasing the amounts of energy absorbed by the upper layers of the ocean also leads to the reduced mixing of the water column from increased stratification. Together with the temperature- and pollution-driven increases in metabolic rate (e.g. bacteria) with depth, plus decreasing levels of mixing between the water column and the atmosphere, decreasing oxygen levels have been observed in ocean waters. These changes can trigger the mass death of oxygen dependent organisms such as fish due to low oxygen, representing an additional and growing risk to the health of ecosystems and coastal communities. Reduced mixing may also lead to less nutrient recycling in some areas where upwelling has been reduced, which is very likely to reduce fisheries productivity of the upper layers of the ocean in these areas (Pörtner et al. 2014).

9. Finally, changes to the temperature of the surface layers of the ocean have been observed to influence the distribution of organisms such as fish, which has implications for production in fisheries and the well-being of people who require access to these fisheries for food and income (Cheung et al. 2009, Cheung et al. 2010, Burrows et al. 2011, Burrows et al. 2014). This change in the distribution of fisheries has been identified as a key risk to coastal communities and people who do not have other options (Cheung et al. 2016).

Climate Change is Harming Coral Reefs

10. Coral reefs are an exceptional part of the Earth's biosphere that provides multiple benefits (e.g. food, livelihoods, cultural inspiration, recreational activities, and new medicines) to at least 500 million people in the world's tropical and subtropical regions, including millions of people from the United States and its territories.

11. To the extent an economic value can be placed on an otherwise invaluable group of organisms and ecosystems, the asset value of coral reefs has been estimated to be at least hundreds of billions of U.S. dollars, which contributes an annual dividend of many billion dollars each year (Hoegh-Guldberg 2015). The estimated total economic value of ecological services from coral reefs in U.S. coral jurisdictions alone ranges from $2.4 to 3.4 billion per year (Brander and van Beukering 2013, Edwards 2013). In the minds of many experts, including myself, these estimates are a significant under-estimate of the value of coral reefs due to the many other contributions and services of coral reefs that are difficult to assign a financial value to.

12. Coral reefs or similar ecosystems have been a prominent part of tropical marine ecosystems over the last several hundred million years. At various points in time, however, catastrophic events (such as an asteroid impact 65 million years ago) have resulted in their disappearance for millions of years at a time (Veron 2008). Coral reefs have recovered but only after extremely long periods of time (also millions of years).

13. There is substantial evidence that coral reefs are disappearing at the rate of 1-2% per year in terms of coral cover, as a direct result of ocean warming and other human factors since the early 1980s (Gardner et al. 2003, Bruno and Selig 2007, De'ath et al. 2012). Coral cover (percent of a reef covered by the reef-building corals) is a measure of the health of coral reefs. While non-climate factors have historically played a key role in degrading coral reefs, in the last two decades, coral reefs have been severely impacted by the increasing frequency and intensity of climate events (i.e. mass coral bleaching and mortality). In the past 15 years, large-scale and largely irreversible impacts have occurred on almost every coral reef worldwide. This includes the large-scale devastation of Caribbean reefs in 2005 (Eakin et al. 2010) and the loss of 50% of the Great Barrier Reef in 2016-2017 (Hughes et al. 2017, 2018b, GBRMPA 2017). In the case of the Great Barrier Reef, the loss of coral in 2016 and 2017 was greater than the losses that occurred over the previous 30 years combined (De'ath et al. 2012, Hughes et al. 2017, 2018b). As marine heatwaves and bleaching events become more frequent and intense (Hughes et al. 2018a, Oliver et al. 2018), the time between mortality events has become shorter and shorter, resulting in a rapid decline in coral communities across the world.

14. The loss of corals results in habitat loss for coral reef fish and other organisms, and reduced ecological benefits, which in turn impact humans by reducing fishing and tourism opportunities (i.e. income and livelihoods). The loss of these benefits from coral reefs have particularly devastating impacts on tropical coastal societies, very often increasing levels of poverty and disadvantage, exacerbating impacts such as sea level rise and related coastal erosion and inundation, and consequently harming children (Cinner et al. 2009, Bell et al. 2011, Burke et al. 2011, Harris et al. 2018).

15. While non-climate factors, such as pollution, unsustainable coastal development, and overfishing, have caused a decline in coral cover, climate change is now the number one driver of change in coral health (measured by % cover lost), and would cause significant mortality of coral reefs, even if all other non-climate factors were eliminated. As noted above, the loss of corals in the past two years on the Great Barrier Reef is more than the loss seen in the past 30 years, which was around 50% (De'ath et al. 2012).

16. The first impacts of climate change were measured on reefs in the early 1980s and consisted of mass coral bleaching in the eastern Pacific and Caribbean regions (Glynn 1990, Glynn 1991, Baker et al. 2008). Since that time, mass coral bleaching and mortality has increased in frequency and scale, and has adversely impacted most if not all coral reefs across the world's tropical and subtropical regions, including in U.S. territorial waters (Hoegh-Guldberg 1999, Eakin et al. 2008, Wilkinson 2008).

17. The scientific consensus is that ocean warming driven by unrestrained increases in atmospheric greenhouse gases such as CO_2 is producing conditions that are becoming more and more hostile to biological systems such as coral reefs (Hoegh-Guldberg et al. 2007, Eakin et al. 2008, GCRMN 2008, Wilkinson 2008, Hoegh-Guldberg et al. 2014, IPCC 2014 a,b, Gordon et al. 2018).

18. A lack of deep action on climate change (i.e. significant, rapid reduction of fossil fuel emissions) will eliminate coral reefs from the world's oceans. By doing so, we will eliminate opportunities for children living today and future generations to enjoy coral reefs, as well as drive many coastal societies and their children into increasing levels of poverty and disadvantage.

Ocean Acidification is Harming Marine Life

19. In addition to warming the planet, rising levels of atmospheric CO_2 are also resulting in increased amounts of CO_2 entering the ocean (Caldeira and Wickett 2003; Jewett and Romanou 2017). On entering the ocean, CO_2 reacts with water to produce a dilute acid that subsequently dissociates, producing protons that interact with carbonate ions, turning them into bicarbonate ions (Doney et al. 2009). These chemical reactions reduce the alkalinity of seawater and change its chemistry (i.e. reduce the concentration of carbonate ions). The overall impact of CO_2 on the chemistry of seawater is referred to as ocean acidification (i.e. a set of processes that reduce the alkalinity of the ocean (Hönisch et al. 2012)).

20. Ocean acidification has been shown to have different effects on different organisms. In the case of corals, which produce a calcium carbonate skeleton, ocean acidification leads to reduced rates of calcium carbonate precipitation and hence skeletons that are more vulnerable to breakage from waves and storms. Ocean acidification also negatively affects a wide range of physiological processes including the behavior of many organisms, leading to disrupted navigation abilities in fish and larval development in a wide range of invertebrates (Kroeker et al. 2013, Gatusso et al. 2014, Gattuso et al. 2015, Albright et al. 2016).

21. While we have only recently discovered many of the ways that ocean acidification affects marine life (Kleypas et al. 1999), there is a growing literature on the impacts of ocean acidification on a very wide variety of affected organisms and ecological processes, including those that are important to building and maintaining coral reefs (Kroeker et al. 2013, Gatusso et al. 2014, Gattuso et al. 2015, Albright et al. 2016; Eyre et al. 2018), and those important for the base of the food chain such as pteropods (Bednaršek 2014, 2016). While the scientific consensus is building that ocean acidification has important and mostly negative effects on ocean ecosystems, these influences may well be with us for a very long time. For example, to reverse the ocean acidification that has occurred over the last 100 years, it will take at least 10,000 years of weathering of the earth's continents to produce the alkali that is needed to counter the increased acidity of ocean waters. Consequently, it becomes extremely important to understand and avoid potentially negative impacts of ocean acidification that will be with us for an extremely long period of time (Hönisch et al. 2012).

Safe Levels of CO_2 and Temperature to Protect Our Oceans

22. In my expert opinion, present levels of atmospheric CO_2, as with any level above 350 parts per million (ppm), presents a serious and ongoing threat through dangerous acidification of the world's oceans.

23. Given the extremely damaging conditions that coral reefs currently face, there is no safe further increase in the concentration of greenhouse gases such as CO_2. In fact, even achieving the goals of the Paris Climate Agreement (Dec 2015) and restraining warming to "well below" 2°C (equivalent to approximately 450 ppm of CO_2) will still result in the loss of 90% of today's corals (Frieler et al. 2013, Donner et al. 2005).

24. At today's level of ~410 ppm, most reefs worldwide are committed to a considerable irreversible decline (Veron et al. 2009, Frieler et al. 2012). The rate, extent, and nature of this decline will become increasingly severe if atmospheric CO_2 concentrations continue to increase above current levels. Returning the atmosphere to a safe level of CO_2 for coral reefs requires atmospheric CO_2 concentrations below 350 ppm (Veron et al. 2009, Frieler et al. 2012) and achieving long-term targets of a maximum temperature peak of 1.3°C above the Pre-Industrial Period with a gradual cooling below those levels through the end of this century and beyond (Hansen et al. 2013).

25. Given the growing evidence that relatively small increases in the concentration of atmospheric CO_2 will trigger a wide array of irreversible changes to critically important marine ecosystems, avoiding any further increases and aiming to reduce the atmospheric concentration of CO_2 below 350 ppm in the long term is seen by many experts as an international and urgent imperative (Veron et al. 2009, Frieler et al. 2012, IPCC 2014a,b). Reducing the atmospheric concentration of CO_2 to below 350 ppm is critical for preserving a safe climate system (Hansen et al. 2008, Rockström et al. 2009). These findings are consistent with the findings of the IPCC, including the IPCC Assessment Report 5 of which I was the Coordinating Lead Author for the chapter on "The Ocean" (Hoegh-Guldberg et al. 2014). In addition to harming ocean life, not reducing atmospheric concentration of CO_2 below 350 ppm in the long term will escalate growing losses from a range of failing ecosystems, fisheries, and aquaculture, flooding coastal regions, increasing numbers of extreme events (storms, inundation events), and other health and societal impacts.

26. These observations of a warming and acidifying ocean indicate that current levels of atmospheric CO_2 and other greenhouse gases are already eliminating opportunities for, and negatively impacting, coastal people and communities in the tropics. Further increases in atmospheric CO_2 will exacerbate the adverse impacts already being experienced. Without concerted science-based action to decrease CO_2 emissions, impacts from a warming and acidifying ocean will threaten future opportunities as well as the well-being of children and subsequent generations.

27. Only by quickly eliminating fossil fuel emissions, returning atmospheric CO_2 levels to 350 ppm by 2100, limiting mean earth surface temperatures to a maximum peak of 1.3°C, and reducing long-term warming to no more than 1°C will we be able to reduce and eventually stabilize ocean temperatures such that the total loss of coral reefs will be averted (Donner et al. 2005, Frieler et al. 2013, Hansen et al. 2013). While we will still lose substantial amounts of today's coral reefs, coral reefs are likely to begin to recover by midcentury as conditions stabilize.

28. Failing to stop and ultimately reverse climate change will result in the loss of coral reefs for hundreds if not thousands of years, which will directly impact the livelihoods of hundreds of millions of people, particularly children who will live with the consequences far longer than adults, and reduce the opportunities for, and threaten the well-being of, future generations.

QUALIFICATIONS

I am a Professor of Marine Studies and the Director of the Global Change Institute at The University of Queensland and Deputy Director of the Australian Research Council (ARC) Centre for Excellence for Reef Studies. I am also a Fellow of the Australian Academy of Science, and I hold a prestigious Australian Research Council Laureate Fellowship. I have been a Coordinating Lead Author (CLA) on the Fifth Assessment Report of the IPCC and am presently a CLA on the IPCC Special Report on 1.5°C. My fields of research and professional interest include:

(a) coral reefs and marine science;
(b) the effects of climate change (particularly ocean warming and acidification) on reef-building corals, *Symbiodinium*, tropical coral reefs and related marine ecosystems;
(c) coral bleaching and mortality, and their connection to global warming and ocean acidification;
(d) biology of symbiotic associations in reef-building corals and the impacts of stresses such as global warming upon these associations.

I have produced over 310 peer-reviewed publications (e.g. peer-reviewed publications, book chapters) as part of contributions to physiology, ecology, environmental sciences, and climate change. My research publications have been cited over 25,000 times (Thompson-Reuters) and I have an H-index of 72 (Thomson Reuters 2018) or 91 (Google Scholar). An H-index of over 60 is deemed exceptional. In this regard, I have received several awards from Thomson-Reuters ISI Web of Science for papers that are among ISI's hottest papers (most cited over the previous two years) in both the area of "climate change" and "ocean acidification" (sciencewatch.com/ana/fea/09novdecFea/). In 2011, I was the most cited Australian author (and 3rd internationally out of 53,136 authors) on the subject of "climate change" according to the Thomson-Reuter's ISI Web of Science (2011, sciencewatch.com/ana/st/climate/authors). This represents a group of less than 0.5% of all published researchers in the world. I received a major award from Thomson Reuters in 2012 (Citation Award Winner in Ecology Thomson Reuters Citation & Innovation Award).

I have been diving and snorkeling on coral reefs since I was 10, and have spent thousands of hours underwater studying and photographing marine life. My formal studies in marine science began in 1980, with my undergraduate BSc Hons degree in marine biology, and my PhD focusing on the physiology and ecology of coral reefs (starting in 1984). During my PhD at UCLA in California, I published some of the first experimental evidence that small increases in ocean temperature (above summer temperatures) were causing reef-scale mass coral bleaching in the 1980s. In the 1990s, I continued to study coral bleaching, and by the end of the decade was convinced that increasing sea temperatures from global climate change were driving increasingly severe mass coral bleaching and mortality events. In 1999, I published the first study to show that even mild increases in atmospheric CO_2 would lead to future conditions that would exceed the heat tolerance of corals. This particular paper (Hoegh-Guldberg 1999) stimulated widespread discussion about the importance of the climate change threat to coral reefs, and predicted that future sea temperatures would become too warm for corals within the next 30-40 years. The extraordinary conditions of 2016-2017 drove the worst coral bleaching seen across the planet (including the Great Barrier Reef) and sadly confirmed the projections I made in 1999.

My expertise and interest in the influence of climate change on coral reefs led to my involvement as Contributing Author (IPCC AR4 2007) and eventually Coordinating Lead Author (IPCC AR5 2014) with the Intergovernmental Panel on Climate Change (IPCC). I am currently a Coordinating Lead Author on the special report on the implications of a climate target of a 1.5°C temperature rise above the pre-industrial period. I have been nominated by my government (and accepted by the international community) for these volunteer positions. I have not received any income for my involvement in these IPCC activities.

The robust and carefully reviewed assessment reports (and other outputs) associated with the IPCC have provided accurate and important information on recent rapid climate change, as well as its impacts on the atmosphere and energy balance of the planet, plus impacts on physical, biological and human systems, as well as mitigation and adaptation options. One of the important roles of the IPCC is to provide a consensus from the scientific community on crucial evidence, proof and adaptation options. It is extensively reviewed and there is no other process that comes as close in terms of reviewing and building scientific consensus on climate change. It is also important to point out, however, that the current projections of the IPCC are considerably conservative in nature, due to the multiple levels of cautious review, and the need to have an agreed consensus on the major issues and knowledge. This tends to slow the process and has been criticized in terms of its overly conservative nature. That is, action on many of the challenges associated with rapid human caused climate change is well overdue in the majority of cases. Coral reefs are a case in point. It was very clear from the scientific literature in the late 1990s that unrestrained ocean warming was most likely pushing coral reefs to a point from which they will not recover. On the other hand, this did not appear in the IPCC's output as a strong scientific consensus until the assessment report in 2007 (IPCC AR4).

EXPERT OPINION

1. Climate Change/Ocean Warming and Ocean Acidification

The emissions of CO_2 that result from burning fossil fuels and land management practices are adversely affecting our oceans in several ways: by increasing ocean temperatures (ocean warming), by increasing acidification of ocean waters (ocean acidification), by changing sea level (SLR), and by reducing the oxygen content of some parts of the ocean (deoxygenation). Climate change is often discussed in terms of impacts to Earth's surface temperatures, but in fact, our oceans have absorbed approximately 30% of human caused CO_2 emissions and 93% of the excess heat in our climate system caused by fossil fuels and other sources of greenhouse gas pollution (IPCC 2013a, b). This scientific understanding is not new. In fact, the U.S. government has known that emissions of CO_2 that result from burning fossil fuels would melt polar ice, raise sea level, warm and acidify the oceans, since at least 1965 (Fed. Answer ¶ 134, citing FAC ¶ 134; Fed. Answer ¶¶ 259, 260) (White House 1965).

The ocean, the land, and the atmosphere are intimately connected. Local weather is a consequence of the interaction between these three elements. Oceans, however, play a dominant role in stabilizing planetary temperature given the large thermal inertia of water. They also play key roles in driving local weather patterns, primarily as a result of temperature gradients across land and sea. In addition to being physically connected, the three elements are connected through gas exchange, with both land and sea contributing roughly equal shares in terms of primary productivity and hence global oxygen production. The entry of CO_2 into the ocean also leads to chemical interactions and the phenomenon of ocean acidification - where the entry of CO_2 into the ocean is increasing.

While acting as a significant sink for human pollution, our oceans are suffering enormous consequences, which have harmful and long-lasting ramifications for people, especially young people and future generations who stand to lose entire ecosystems, ways of life, and sources of food and opportunity.

A. The Rate of Ocean Warming is a Signature Harm of Anthropogenic CO2 Emissions

In my expert opinion, ocean warming is a signature harm of anthropogenic CO_2 emissions. This is based on the consensus of the scientific community that rising levels of greenhouse gases such as CO_2 are causing increasing planetary and hence ocean temperatures, and that rising ocean temperatures are directly linked to the incidence of negative impacts such as mass coral bleaching and mortality from heat stress. This linkage between the rise of greenhouse gases such as CO_2 and mass coral bleaching and mortality has been heavily reviewed and is a consensus accepted by the International Panel on Climate Change (IPCC) at very high confidence (>99%, IPCC 2013a, Hoegh-Guldberg et al. 2014).

Increasing levels of greenhouse gases have increased the amount of heat absorbed by the Earth. This has resulted in rising surface temperatures on both land and sea, with huge consequences for organisms and ecosystems, and the derived benefits for humans (very high confidence, >99%, IPCC 2013a; Hoegh-Guldberg et al. 2014). The U.S. Defendants admit that scientific evidence shows that elevated CO_2 levels have caused adverse effects to coral reefs and other marine life (Fed. Answer ¶ 260).

Approximately 93% of the excess heat from the Earth's energy imbalance, caused by human pollution, has been absorbed by the upper layers of the ocean. Sea temperatures in tropical and subtropical locations have increased significantly over the past 50-100 years (IPCC 2013a; Jewett and Romanou 2017). During the past 60 years the rates of increase in sea surface temperatures in the waters around Alaska, the U.S. Northeast and the U.S. Southwest have exceeded the global average rate (Jewett and Romanou 2017). The year, 2017, was the warmest on record for the global mean temperatures in the upper-level (0-2000 meters) of the ocean (Cheng and Zhu 2018), and the third warmest after the years 2015 and 2016 for global sea-surface temperatures (WMO 2018).

Reef-building corals have millions of tiny single-celled dinoflagellates within their tissues. These simple organisms live inside the cells of corals and are able to trap the energy of sunlight and produce food for the coral host. In response, corals provide the dinoflagellates with inorganic nitrogen and phosphorus (i.e. fertilizer), which are often in short supply in tropical oceans. As a result of the inherent physiological and energy efficiencies, corals are able to precipitate large amounts of calcium carbonate from seawater and build their skeletons, which can build up over time to create coral reefs and islands (Hoegh-Guldberg 1999).

One response of corals to stress is the breakdown of their symbiosis with dinoflagellates. By removing the brown dinoflagellates, corals go from a brown to a stark white color. This is referred to as coral bleaching. Corals may bleach in response to a range of stresses such as low salinity, toxins, as well as too little or too much light and temperature.

If stress levels are low enough, corals may regain their dinoflagellate symbionts and their brown color and health may return over time. While corals may have lost ground in terms of growth and reproduction, the effects of such mild bleaching may be quite minimal.

Beginning in the early 1980s, coral bleaching and mortality began to affect large areas of the world's coral reefs (Glynn 1993, Wilkinson 1998). Corals not only bleached but also died in great numbers in places like the Caribbean and the eastern Pacific. Hence, these events are referred to as *mass* coral bleaching and *mortality* events.

After the 1980s bleaching events, scientific experiments and fieldwork soon identified that mass coral bleaching and mortality events were being driven by short periods of elevated sea temperature of 1-2°C above the summer maximum sea temperature (Glynn et al. 1988, Hoegh-Guldberg and Smith 1989, Hoegh-Guldberg 1999, Dove et al. 2013). Between 1925 and 2016, the frequency and duration of marine heatwaves globally have increased by 34% and 17% respectively, and the annual number of marine heatwave days globally have increased by 54%. These trends are largely attributable to increases in mean ocean temperatures, induced by anthropogenic global warming. (Oliver et al. 2018).

Since the 1980s, the frequency and intensity of mass coral bleaching and mortality has increased substantially, as atmospheric CO_2 concentrations and global surface and ocean temperatures have continued to rise (Hoegh-Guldberg 1999, Baker et al. 2008). By 1997, the U.S. Council on Environmental Quality reported: "Coral reefs are the world's most biologically diverse marine ecosystems, home to one third of all marine fish species and as well as tens of thousands of other species. It is estimated that 10 percent of the world's coral reefs have already been degraded beyond recovery, and another 30 percent are likely to decline in the next 20 years" (CEQ 1997).

In 1998, mass coral bleaching and mortality affected coral reefs in almost every tropical and subtropical country that had coral reefs along its coast (Wilkinson 1998, Hoegh-Guldberg 1999) and earned the distinction of being the first *global* mass bleaching and mortality event. Similar conditions occurred in 2010, driving the second *global* mass bleaching and mortality event (Tun et al. 2010). By 2010, the U.S. Government's National Research Council confirmed: "Corals face death and eventual collapse from bleaching episodes that are the result of short periods of unusually high ocean temperatures in combination with other factors such as eutrophication and ocean acidification" (NRC 2010a).

Coral reefs may recover from mass coral bleaching and mortality if given enough time before the next mass bleaching and mortality event affects them. The amount of time required for coral communities to recover from previous bleaching events is about 15-20 years. However, if ocean temperatures remain elevated and continue to increase, the time between mass coral bleaching and mortality will become so short that coral reefs will not be able to recover and will progressively disappear. Already, in many parts of the world, reefs have failed to recover before the next mass coral bleaching and mortality event has occurred (Baker et al. 2008, Hughes et al. 2018). Temperature projections indicate that recovery periods will become shorter and shorter such that coral reefs will increasingly fail to recover over the coming decades (Hoegh-Guldberg 1999, Hughes et al. 2018). At this point, coral reefs will disappear from most, if not all, parts of the world.

In the past three years, planetary temperatures have hit all-time highs. At the same time, ocean temperatures have also hit record levels and have driven unprecedented mass coral bleaching and mortality events (Hughes et al. 2017, 2018). While several studies have yet to publish their results, these impacts have been seen in many parts of the world including Florida, Hawaii, Maldives, Chagos, Seychelles, and the Western Pacific over the past two years (Hughes et al 2018). These impacts on coral reefs over the past 3 years are seen as the third *global* mass bleaching and mortality event. Significantly, the interval between events appears to be shortening over time (1998 to 2010: 12 years; 2010 to 2016: 6 years). The third global mass bleaching and mortality event affected approximately 75% of global coral reefs from 2016-2017, and was comparable in scale to the then-unprecedented 1997-1998 mass bleaching event (Hughes et al. 2018). These changes in ocean temperature have been driven by changes to our atmosphere that have occurred since the pre-industrial period, and which have intensified over the past 50 years (IPCC 2013a). All further increases in ocean temperature increase the risk of catastrophic coral bleaching events (Hoegh-Guldberg 1999).

Hawaii's coral reefs have bleached at least three years in a row, which has severely impacted these important coral reefs with devastating mass coral bleaching and coral mortality in parts of the remote and well-protected Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands (Couch et al. 2017). Many parts of Hawaii are experiencing mass coral bleaching and mortality for the second time in recent history. Similarly, in American Samoa, and many other western Pacific nations, coral reefs have seen bleaching and mortality for two years in a row. The loss of corals in these areas is similar, ranging from 20-90% of reef-building corals.

In keeping with scientific projections (Hoegh-Guldberg 1999) of how corals are likely to respond to warming oceans, the last three years have seen the first incidents of annual back-to-back bleaching events in many parts of the world (Hughes et al. 2017).

In the case of Australia's Great Barrier Reef, 50% of its corals across an area the size of Italy have died over two record years of high temperatures and mass coral bleaching (2016-2017) that have occurred back to back during exceptionally warm planetary temperatures (Hughes et al. 2017, 2018b; GBRMPA 2017).

The loss of corals as a result of heat stress has significant impacts on the ecosystem goods and services provided. As coral communities die, the habitat for many species, including those important for fisheries and tourism, slowly degrade. Coral reef ecosystems that have been degraded by coral bleaching are less acoustically-attractive to larval and juvenile fish species, slowing overall ecosystem recovery (Gordon et al. 2018). As well, the loss of the calcium carbonate framework as corals disappear opens up coastal areas to increasing impacts from storms and waves as coastal protection degrades (Kennedy et al. 2013).

As fisheries and tourism opportunities decrease, opportunities for food and livelihood are also likely to decline. In addition to the loss of the reefs, there is the loss of aesthetic appeal and inspiration, as well as a reduction in opportunities for employment and livelihoods. This directly affects the well-being and opportunities for children and future generations (Hansen et al. 2013). For instance, plaintiff Levi's observations of apparent species shifts and die-offs in the coastal ecosystems of his homes in Satellite Beach and Indiatlantic, Florida—impacts that are consistent with studies of climate change impacts to coastal ecosystems (Moser et al. 2014, Wong et al. 2014)—have adversely impacted his emotional and psychological well-being (Levi D. 2017).

Plaintiff Jacob is similarly affected by the changing ecology, increased toxic algal blooms and declining crab and mussel stocks on the Oregon coast (Lebel 2017).

B. Ocean Acidification is also a Signature Harm from Anthropogenic CO_2 Emissions

In my expert opinion, ocean acidification is a signature harm from anthropogenic CO_2 emissions. This comes from the incontrovertible evidence that increasing amounts of CO_2 are going into the ocean from the burning of fossil fuels, and to a lesser extent land-use change, and that the additional absorption of CO_2 reduces the pH of the upper layer of the ocean (Kleypas et al. 1999, Caldeira and Wickett 2003). There is clear and growing evidence that species and ecosystems are being harmed by the consequences of ocean acidification (Kroeker et al. 2013, Gattuso et al. 2014, Gattuso et al. 2015; Pörtner et al. 2014).

Approximately 30% of the CO_2 associated with the burning of fossil fuels has been absorbed by the upper layers of the ocean (IPCC 2013a,b, Jewett and Romanou 2017). When CO_2 is absorbed by the ocean, it reacts with water to produce a dilute acid. This decreases the pH of the upper layers of the ocean, affecting the chemistry by changing the concentration of ions such as carbonate and bicarbonate. The impact of CO_2 on the upper layers of the ocean is referred to as ocean acidification (Caldeira and Wickett 2003).

While the ocean remains alkaline, the changes in pH make it relatively more acidic. Ocean surface waters have become 30% more acidic over the last 150 years (Jewett and Romanou 2017). This impacts a wide variety of organisms, including corals, fish, plankton, and invertebrates. The list of impacted species is rapidly increasing as more and more scientific studies pursue an understanding of the impacts of ocean acidification on ocean organisms and ecosystems (Kroeker et al. 2013, Gattuso et al. 2014, Gattuso et al. 2015).

Scientists have confirmed that ocean acidification reduces the ability of many organisms to build skeletons (e.g. corals) and shells (e.g. oysters), and to reproduce and grow (e.g. as seen in many invertebrates), and it also changes the behavior of marine organisms (e.g. fish). These impacts have ramifications up the food chain to many other species, such as salmon and marine mammals such as whales (Kroeker et al. 2013, Gattuso et al. 2014, Gattuso et al. 2015). Ocean acidification also adversely impacts the success, quality and taste of aquaculture-raised fish and seafood, with resulting impacts on coastal economies (WMO 2018).

The U.S. Government Accountability Office confirmed the dangers of ocean acidification in 2007: "Because carbonate ion is a substance that coral reefs need to build their skeletons, ocean acidification may reduce the calcification rate in corals (and other calcium carbonate-based species) and cause other changes in the oceanic food chain, plankton communities, and the distribution of certain species" (GAO 2007).

Many marine organisms create shells and skeletons from calcium and carbonate irons in the water surrounding them. The addition of CO_2 reduces the alkalinity of seawater, reducing the concentration of carbonate ions and making it more difficult for marine organisms to deposit shells and skeletons. If enough CO_2 is added to seawater surrounding organisms such as corals, then calcium carbonate will dissolve as opposed to precipitate. The latter is similar to the effect seen when one puts an egg shell (i.e. precipitated carbonate) into a high CO_2 environment such as vinegar, which results in dissolution and bubbles of CO_2.

Ocean acidification is already having a net dissolution effect on calcium carbonate sediments at a number of coral reef sites globally. Under current CO_2 emissions trends, reef sediments globally will transition from net carbonate ion precipitation to net dissolution circa 2050 (Dove et al. 2013, Eyre et al. 2018). The U.S. Defendants in this case admit, for instance, that increased acidity makes it more difficult for certain organisms to build and maintain their skeletons and shells (including corals, oysters, clams, scallops, mussels, abalone, crabs, geoducks, barnacles, sea urchins, sand dollars, sea stars, sea cucumbers, calcareous seaweeds, many common single-celled organisms, and protists such as coccolithophores), putting many of these organisms at risk, and thereby impacting larger ecosystem processes (Fed. Answer ¶ 231).

One group of mollusks that is significantly impacted by ocean acidification off the U.S. west coast are the pteropods, which are a small group of mollusks that have wing-like swimming organs, and which include the sea butterflies (*Thecosomata*) and the sea angels (*Gymnosomata*). The California Current Ecosystem is one of the most biologically-productive areas in the world due to upwelling of nutrients. However, the acidity of Pacific Northwest waters along the California Current Ecosystem has doubled since the Industrial Revolution and is on track to triple by 2050 (Bednaršek 2014). Pteropods live mostly near the sea surface, are less than 1 cm long, and are a key marine food source for salmon, herring, other fish, birds, and whales. Acidifying seas caused by CO_2 emissions are dissolving the shells of pteropods, as depicted below, with a healthy pteropod at the left, and dissolving pteropods, at the middle and right (**Figure 4**). The hardest hit pteropods are those off of the Washington and Oregon coasts, where NOAA scientists pinpoint the cause as atmospheric CO_2. Scientists predict that by 2050 at least 70% of pteropods in the U.S. west coastal waters near to shore will have severe shell damage (Bednaršek 2014). The cumulative effects of ocean warming and deoxygenation combined with acidification place even greater stressors on these animals at the base of the food chain (Bednaršek 2016). How this damage to pteropods will affect the larger marine food chain is a more complicated inquiry, but we know enough to know that the impacts are adverse and that pteropods are an indicator species of ocean acidification.

Figure 4. Healthy (left) and dissolving pteropods with holes and pits (middle and right) (Craig Welch and Steve Ringman (photographer), *Sea Change: Vital Part of Food Web Dissolving*, Seattle Times, April 30, 2014, http://apps.seattletimes.com/reports/sea-change/2014/apr/30/pteropod-shells-dissolving/).

These biological and ecological changes that are occurring in the world's oceans have significant implications for industry and people today, and into the future. The slowing of growth and the ability to produce skeletons has important implications for ecosystems such as coral reefs and plankton (Balch and Utgoff 2009), as well as many other ecosystems within the ocean (Hoegh-Guldberg et al. 2007, Hilmi et al. 2009, Kroeker et al. 2013, Gattuso et al. 2015, Albright et al. 2016; Hoegh-Guldberg et al. 2014). Processes like calcification are responsible for the establishment and maintenance of coral reefs, islands, beaches, and many coastal areas. Ocean acidification is likely to lead to these important features eroding, although the precise time frames are unclear. That said, the loss of corals in the Caribbean has led to the "flattening" of reef structures such that the habitat for key fisheries has been destroyed (Alvarez-Filip et al. 2009*).*

Ocean acidification has a different profile when compared to the effects of ocean warming in that its influence tends to be slow and gradual as compared to the rapid rates of change that are associated with ocean warming (e.g. mass coral bleaching and mortality) (Fabricius et al. 2011). Whereas mass coral bleaching and mortality would be akin to one's house catching fire and burning down, ocean acidification is more akin to the steady (and somewhat hidden) impact of the house being infested and consumed by termites (or to osteoporosis versus bone shattering trauma in a medical sense). The end result, however, is similar. There is much to learn about whether the ocean warming is synergistic with ocean acidification, although there are a growing number of studies that indicate that this may be so (Anthony et al. 2008, Fabricius et al. 2011; Dove et al. 2013; Chen et al. 2017).

There are two important issues associated with the rate of change and ocean acidification. The first issue is that the current rate of increase in ocean chemistry exceeds anything seen over the past 65 million years, if not 300 million years (Hönisch et al. 2012). The U.S. Defendants admit that ocean acidity is increasing at a rate 50 times faster than the past 100,000 years, and that the oceans have probably not experienced this rate of change in pH for 100 million years (Fed. Answer ¶¶ 231, 232). The U.S. National Research Council projects that ocean acidification could intensify by three to four times by the end of the century if current levels of CO_2 emissions continue, thereby reducing the oceans ability to absorb CO_2, creating another feedback loop of faster CO_2 accumulation in the atmosphere and more warming for the earth and its oceans (NRC 2010b). The second issue is that it takes 10,000 years to weather enough rocks from the world's continents to produce the alkali required to reverse the ocean acidification that has occurred over the past 100 years (Hönisch et al. 2012). Given this "commitment" time and the increasing evidence of fundamental and dangerous changes to important ocean ecosystems caused by ocean acidification, it appears irrational not to decrease emissions of CO_2 as rapidly as is possible.

The U.S. Defendants admit that coral reefs are threatened by increasing acidity and that climate change and ocean acidification threaten the survival of plants, fish, and wildlife, and also threaten biodiversity (Fed. Answer ¶¶ 233, 235, 241). The results of ocean acidification to marine ecosystems are potentially catastrophic according to the U.S. NRC (NRC 2010b). In my expert opinion, present levels of atmospheric CO_2, as with any level above 350 ppm, present serious and ongoing threats through dangerous acidification of the world's oceans.

C. Safe Levels of CO_2 and Global Temperatures for Oceans/Corals

Given the extremely damaging conditions that coral reefs currently face, there is no further increase in the concentration of greenhouse gases such as CO_2 that is safe. In fact, even achieving the goals of the Paris Climate Agreement and restraining warming to "well below" 2°C (and approximately 450 ppm of CO_2) will still result in the loss of up to 90% of today's corals (Frieler et al. 2013, Donner et al. 2005). Saving a fraction of existing coral reefs, however, will eventually support the regrowth of coral reefs once ocean temperature and chemistry have stabilized in the future.

Driving mean surface temperature of Earth above 2°C will almost certainly cause coral reefs to disappear for hundreds if not thousands of years, at least. Given the relatively short life span of a human, the loss of coral reefs over hundreds of years would be essentially permanent – a sad and unjust outcome for U.S. and other children, as well as future generations.

The first scientific reports of mass coral bleaching and mortality were received in the early 1980s. Given that there is a lag time between reaching a certain level of atmospheric CO_2 and the resultant warming (conservatively estimated here as 10-20 years), impacts on the first instances of mass coral bleaching began to occur as atmospheric CO_2 levels approached ~320 ppm. Curiously, this occurred around 1965 when President Lyndon B. Johnson's White House issued the report: 'Restoring the Quality of Our Environment, Report of the Environmental Pollution Panel President's Science Advisory Committee', one of the early publications discussing impacts of climate change on oceans (White House 1965). The ocean warming that was already in the pipeline by 1965 caused the coral bleaching events of the 1980s. When CO_2 levels reached ~340 ppm around 1980, sporadic but highly destructive mass coral bleaching and mortality occurred on most reefs worldwide, often associated with El Niño events that added to the background levels of warming from climate change. Recovery from these events was dependent on the vulnerability of individual reef areas and on their previous history and resilience. At today's level of ~410ppm, allowing a lag-time of 10 years for sea temperatures to respond, most coral reefs worldwide are committed (to some extent) to entering into a period of dramatic and potentially irreversible decline (Veron et al. 2009, Frieler et al. 2012). The rate, extent, and nature of coral reef decline will become increasingly severe if atmospheric CO_2 concentrations continue to increase above current levels. Returning the atmosphere to a safe level of CO_2 for coral reefs requires atmospheric CO_2 concentrations below 350 ppm (Veron et al. 2009, Frieler et al. 2012) and achieving long-term targets of no more than 1°C above the pre-industrial period.

Australia's top coral reef management body, the Great Barrier Reef Marine Park Authority (GBRMPA), concluded that the optimum limits for coral reef ecosystems of atmospheric CO_2 are at or below 350 ppm (GBRMPA 2014). It also found that there is already evidence of effects on the Great Barrier Reef at levels of ~400 ppm CO_2, such as declining calcification rates, that appear to be caused by temperature stress in addition to ocean acidification, and atmospheric concentrations of CO_2 above 450 ppm pose an extreme risk for coral reef ecosystems and tropical coastal habitats (GBRMPA 2014).

Given the growing evidence that relatively small increases in the concentration of atmospheric CO_2 will trigger a wide array of irreversible changes to critically important marine ecosystems, avoiding any further increases, and aiming to reduce the atmospheric concentration of CO_2 below 350 ppm in the long term, is seen by many experts as an international imperative (Veron et al. 2009, Frieler et al. 2012, IPCC 2014 a,b). A CO_2 target that is below 350 ppm is consistent with the findings of the Assessment Reports of the IPCC, which I note tend to be more conservative than individual peer-reviewed studies due to requirements for consensus, levels of confidence, and government approval built into the IPCC's processes. Reducing the atmospheric concentration of CO_2 to below 350 ppm is also critical for preserving a safe climate system (Hansen et al. 2008, Rockström et al. 2009). In addition to harming ocean life, not pursuing this objective will escalate growing losses from a range of failing ecosystems and agriculture, flooding coastal regions, increasing numbers of extreme events (storms, inundation events), and other health and societal impacts. Additionally, the IPCC's 5th Assessment Report of which I was the Coordinating Lead Author of the Ocean chapter, indicate that present levels of warming above preindustrial levels carry significant risks to natural and human systems (Hoegh-Guldberg et al. 2014), that there is a material risk of surpassing major climatological tipping points at 1°C of warming, and that, consequently, even a 1.5°C target cannot be considered "safe" (Seneviratne et al. 2018).

D. Global Impacts at Current Levels of CO_2

There is no longer any credible doubt that increasing levels of greenhouse gases such as CO_2 are driving higher land and ocean surface temperatures (IPCC 2013a, b). These increases in ocean temperatures have, in turn, increased the risk of mass coral bleaching and mortality, which is evidenced by the increasing frequency and intensity of mass coral bleaching and mortality events (Hoegh-Guldberg 1999, Baker et al. 2008, Eakin et al. 2010, Hughes et al. 2017, Hoegh-Guldberg et al. 2014).

The current level of impacts on coral communities and reef ecosystems is not sustainable, given that the rate at which corals are disappearing greatly exceeds the rate at which they are being regenerated (Bruno and Selig 2007, De'ath et al. 2012).

If we stabilize ocean temperature and chemistry within the next 30 years, we would still see approximately 90% of today's corals eliminated from the world's coral reefs. That said, protecting the reefs that survive the transition to stabilized ocean conditions by reducing non-climate threats has the potential to see coral reefs re-flourish in the world's oceans by mid to late century. If we act to reduce greenhouse gas emissions today, coral reefs have a real fighting chance of surviving, and along with them the vast marine diversity that they support.

E. Future Global Impacts Projected Under Temperature and CO_2 Scenarios

Climate change and ocean acidification are placing coral reefs in conditions that they have not experienced over the past 740,000 years, if not the last 65 million years (Raven et al. 2005, Hoegh-Guldberg et al. 2007, Pelejero et al. 2010, Hönisch et al. 2012). Even the relatively rapid changes during the ice age transitions, which resulted in major changes in the biota of the planet, occurred at rates of change in CO_2 and temperature that were at least two orders of magnitude (i.e. one hundred times) slower than the rate of change that has occurred over the past 150 years (Hoegh-Guldberg et al. 2007), primarily due to the rapid rise in fossil fuel emissions.

There is a scientific consensus that these changes are occurring at rates that dwarf even the most rapid changes seen over the past 65, if not 300, million years (IPCC 2014a; Hönisch et al. 2012). Most evidence suggests that this rate of change will increase and already exceeds the biological capacity of coral reefs to respond via genetic change (evolution). As a result, there is a high degree of consensus within the scientific community that coral reefs, like a large number of other ecosystems, are set to undergo transformative and rapid degradation over the coming decades (Donner et al. 2005, Hoegh-Guldberg et al. 2007, IPCC 2007, 2014a, c).

Consideration has recently been given to how reef systems will change in response to increased levels of atmospheric greenhouse gases. It is accepted that the environmental values of coral reef ecosystems will continue to decline as the average global temperature increases (Frieler et al. 2013, Hoegh-Guldberg 2015). In this regard, Hoegh-Guldberg et al. (2007) concluded that carbonate coral reefs such as those in Hawaii and the western Pacific (e.g. Western Samoa) are unlikely to maintain themselves beyond atmospheric CO_2 concentrations of 450 ppm. The evidence comes from a wide array of sources, including field, laboratory, and other sources (see references). Neither temperature (+2°C above pre-industrial global temperatures) nor ocean carbonate concentration (<200 µmol kg^{-1}, which arise when atmospheric CO_2 reaches approximately 450 ppm) in these scenarios are suitable for coral growth and survival, or the maintenance of calcium carbonate reef structures. These conclusions are based on the observation of how coral reefs behave today and how they have responded to the relatively mild changes in ocean temperature so far. Mass coral bleaching and mortality, for example, is triggered at temperatures that are just 1°C above the long-term summer maxima, which is the basis for highly successful satellite detection programs (Strong et al. 1997, Strong et al. 2000, Strong et al. 2004, Strong et al. 2006). Coral reefs also do not accrete calcium carbonate or form limestone-like coral reefs in water that has less than 200 µmol kg^{-1} carbonate ion concentrations (roughly equivalent to an aragonite saturation of 3.25) (Kleypas et al. 1999). These conditions will dominate tropical oceans if CO_2 concentrations are greater than 450 ppm (**Figure 5**).

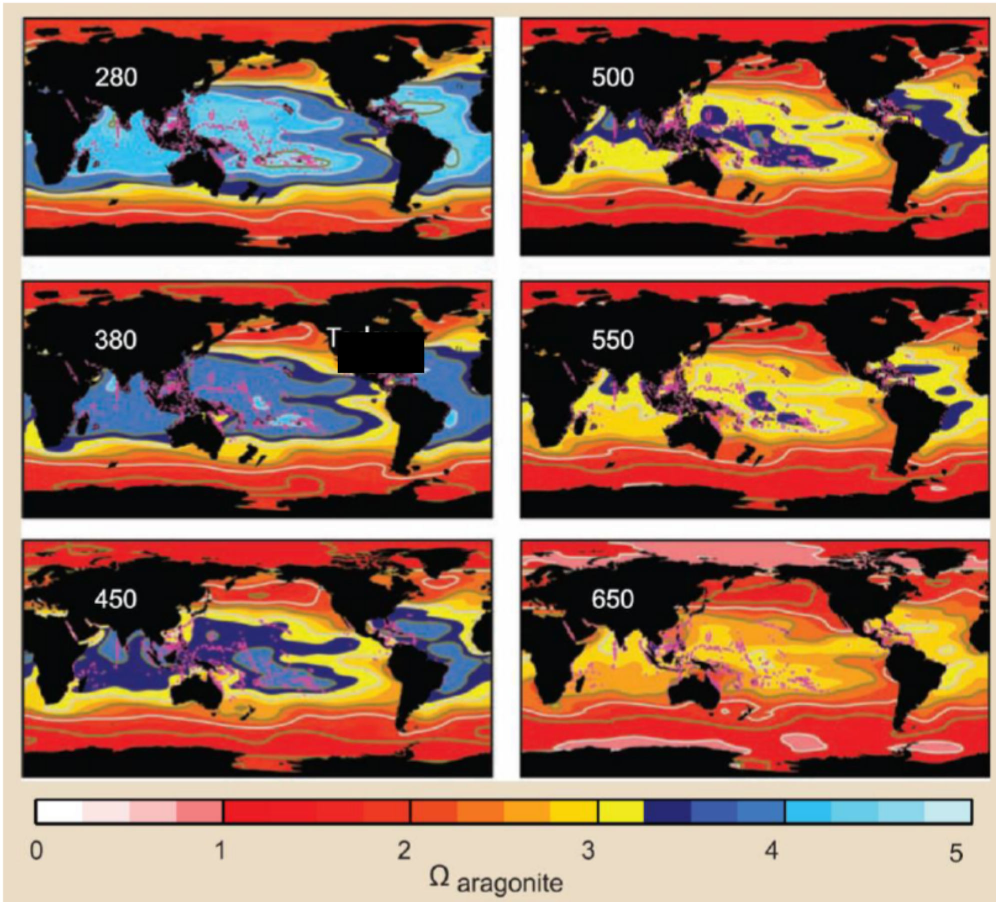

Figure 5. Calculated values for aragonite saturation, which is a measure of the ease with which calcium carbonate crystals (aragonite) form, as a function of geography. Coral reefs today only form where the aragonite saturation exceeds 3.25, which is illustrated by the blue colored areas (coral reefs found today are indicated in this panel by the pink dots). As the concentration of carbon dioxide in the atmosphere increases from 375 ppm in 2007, the extent of conditions that are suitable for the formation of carbon coral reefs dwindles until there are few areas with these conditions left at 550 ppm and above. Ocean acidification represents a serious threat to carbonate reef systems and may see the loss and decay of reef structures across the entire tropical region of the world (Reprinted courtesy of Science Magazine; Hoegh-Guldberg et al. 2007).

Taking the two drivers (warming and acidification) together allows the scientific community to project how carbonate coral reefs will change if atmospheric concentrations of CO_2 continue to increase. The critical point for losing carbonate coral reef systems arises when CO_2 concentrations exceed 450 ppm. At this point, the majority of evidence points to tropical reef systems that do not have the dominant coral populations. As coral reefs are the result of vibrant coral communities, many of the ecosystem services (e.g. fisheries, tourist use) are severely degraded at this point.

Using the evidence and conclusions of the scientific community, three basic scenarios for coral reefs can be assigned (**Figure 6**).

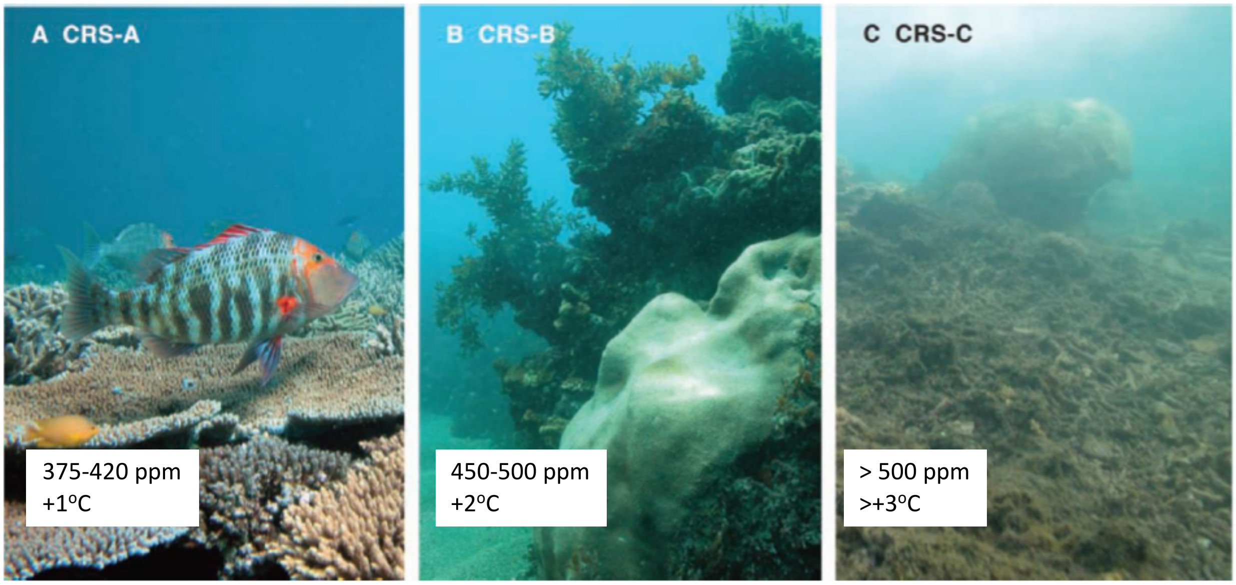

Figure 6. Expected conditions if (A) atmospheric CO_2 levels stabilize at current levels of 375 ppm to around 420 ppm (scenario CRS-A), (B) CO_2 levels increase to around 450-500 ppm (scenario CRS-B), and (C) CO_2 levels increase above 500 ppm (scenarios CRS-C) (Adapted from Hoegh-Guldberg et al. 2007, Science).

If atmospheric CO_2 levels had stabilized at levels between 375-420 ppm (CRS-A), conditions will be similar to today except that mass bleaching events will be approximately twice as common and will have more severe impacts on reefs like the Great Barrier Reef. If atmospheric CO_2 concentrations increase to around 450-500 ppm, together with a global temperature rise of 2°C above pre-industrial levels, back to back mass coral bleaching and mortality events would be annual – and a major decline in reef-building corals would be expected (CRS-B). Because carbonate ion concentrations will fall below that required by corals to calcify and keep up with the erosion of calcium carbonate reef frameworks, reef frameworks will increasingly erode and fall apart. Seaweeds, soft corals, and other benthic organisms will replace reef-building corals as the dominant organism on these much simpler reef systems. Levels of CO_2 in the atmosphere above 500 ppm and associated temperature change (CRS-C) will be catastrophic for coral reefs, which will no longer be dominated by corals or many of the organisms that we recognize today. Reef frameworks will actively deteriorate at this point as they dissolve and would be impacted by storms and "flattened" (Alvarez-Filip et al. 2009), with ramifications for marine biodiversity, coastal protection, and tourism.

It is important that the three scenarios in **Figure 6** be seen as representing a continuum of change and not a set of discrete thresholds or "tipping points." That said, it is also noteworthy that coral reefs regularly show non-linear behavior. For instance, corals will show minimal change for a period and then experience a sudden and catastrophic decline when they were a once-dominant species (Hughes 1994). While we do not know with 100% certainty where these "breakpoints" exist relative to particular concentrations of atmospheric CO_2, it is important to understand that there is a significant likelihood that most if not all coral reef ecosystems like the Great Barrier

Reef might experience phase-transitions such as those already seen in the Caribbean and other coral reef realms (Hughes 1994).

If CO_2 stabilizes at around current levels or up to 420 ppm (CRS-A in **Figure 6**), conditions surrounding coral reefs will differ from today's reefs in the following significant ways.

Firstly, mass coral bleaching events are likely to be more frequent and intense relative to those that have occurred over the past 25 years. Based on modeling studies (Hoegh-Guldberg 1999, Hoegh-Guldberg et al 2014; Donner et al 2003; IPCC 2014 a,b), mass coral bleaching events are likely to be twice as frequent as they are today if sea temperatures surrounding coral reefs such as the Great Barrier Reef will increase by another 0.5°C over and above today's temperatures. Changes in sea temperature of this magnitude will also increase the intensity of the thermal anomalies which, depending on the particular phase of the El Niño Southern Oscillation and longer-term changes in sea temperature such as the Pacific Decadal Oscillation (PDO), will result in large scale impacts on coral reefs like those that occurred in 2016-2017 to the Great Barrier Reef and other reefs around the world. This will result in a greater likelihood of mass mortalities among coral communities, and an overall downward adjustment of average coral cover on coral reefs. Some areas may lose coral permanently while others, such as those in well flushed and ecologically-resilient locations (e.g. with good water quality, intact fish populations), are likely to remain coral dominated.

Secondly, there is likely to be a shift towards more degraded three-dimensional reef frameworks as concentrations of carbonate ions decrease and become limiting for the calcifying activities of corals. At the same time, organisms that dissolve and remove calcium carbonate appear to be stimulated (Dove et al. 2013; Fang et al. 2017a,b). This may remove the habitat for some species (e.g. coral-dwelling fish and invertebrate species) while it may increase habitat for others (e.g. some herbivorous fish species). It is important to appreciate that reefs are likely to be populated by some form of marine life. Equally importantly, however, the replacement organisms (possibly seaweeds and cyanobacterial films) are unlikely to match (replace) the beautiful, charismatic, and biologically diverse coral reefs that we currently enjoy.

If atmospheric CO_2 increases beyond 450 ppm (CRS-B), large-scale changes to coral reefs would be inevitable. Under these conditions, reef-building corals would be unable to keep pace with the rate of physical and biological erosion, and competition with other organisms, and coral reefs would slowly shift towards non-carbonate reef ecosystems. As with non-carbonate reef systems today, primary productivity and biodiversity would be lower on these transformed systems. Reef ecosystems at this point would resemble a mixed assemblage of fleshy seaweed, soft corals, and other non-calcifying organisms, with reef-building corals being much less abundant (even rare). As a result, the three-dimensional structure of coral reefs would begin to crumble and disappear, leading to reef flattening (Alvarez-Filip et al. 2009), although the precise time frames for these changes to reef structure are uncertain. Other factors such as intensifying storms and sea level rise will add additional pressures on reef systems as a function of climate change (Ferrario et al. 2014).

The loss of the three-dimensional structure has significant implications for other coral reef dwelling species such as populations where at least 50% of the fish species are likely to disappear with the loss of the reef-building corals and the calcium carbonate framework of coral reefs

(Wilson et al. 2006, Graham et al. 2007, Pratchett et al. 2008). More recent work indicates that these changes also sigificantly and negatively affect fisheries (Graham et al. 2014).

Loss of the calcium carbonate framework of coral reefs would also have implications for the protection (from waves and storms) provided by coral reefs to other ecosystems (e.g. mangroves and sea grasses) and human infrastructure, as well as industries such as tourism which depends on highly biologically diverse and beautiful reef structures. While coral reefs under this scenario would retain considerable biodiversity, their attractiveness to tourists is likely to be significantly reduced (**Figure 6B**). Additionally, loss of the structural complexity of coral reefs will, in the short term, have a greater impact on the erosion and inundation of tropical coastal zones than sea level rise, and, in the long term, exacerbate sea level rise impacts (Harris et al. 2018).

The expected rapid reduction in coral cover will have major consequences for other organisms and reef services and functions. Many organisms that are coral dependent will become rare and may become locally or globally extinct (Carpenter et al. 2008). Other organisms, such as herbivores, may actually increase as reefs change from coral domination to domination by algal/cyanobacterial organisms. Increases in the abundance of cyanobacteria may have implications for the incidence of poisoning by the toxin ciguatera, a major problem in some areas of the world already (Llewellyn 2010). It is expected that harmful algal species are likely to become more common as coral dominated reefs systems disappear.

If the concentration of CO_2 in the atmosphere increases to higher levels and conditions approach those of CRS-C, conditions will exceed those required for the majority of coral reefs across the planet (**Figure 6C**). Under these conditions, the three-dimensional structure of coral reef ecosystems would be expected to deteriorate, with a massive loss of biodiversity, and ecological services and functions. Many of the concerns raised in a vulnerability assessment (Johnson and Marshall 2007) would become a reality, and most groups of coral reefs like the Great Barrier Reef would undergo major change. As argued by many coral reef scientists (e.g. Hoegh-Guldberg et al. 2007; IPCC 2007, 2014ab), an increase in atmospheric CO_2 to 500 ppm would result in scenarios where any semblance of reefs to the coral reefs of today would vanish.

These changes will also adversely impact the health and wellbeing of communities, including children, that depend on the ecosystem services that reefs provide (Lawler and Patel 2012, Hoegh-Guldberg et al. 2016). Malnutrition levels are already unusually high in the Pacific region (AusAID 2012). Projected climate change-driven declines in coral reef fish catches will exacerbate the existing gap between the fish needed for food security and actual fish catches in these regions (Bell et al. 2013), lower the monetary value of the region's ocean assets (Hoegh-Guldberg et al. 2016), and irreversibly harm the cognitive, physical and educational development of the region's children (AusAID 2012, Lawler and Patel 2012).

F. Long-term Sustainability of Global Coral Reefs

Even accounting for other impacts, climate change through ocean warming and acidification pose the greatest risks of irreversible impacts to oceans and marine life.

Since at least the early 1980s, marine heatwaves and climate change impacts have increased in frequency and intensity, with the first impacts of climate change on corals occurring in the early 1980s and consisting of mass coral bleaching in the eastern Pacific and Caribbean regions. Since this time, mass coral bleaching and mortality has increased and has had impacts on most if not all coral reefs across the world's tropical and subtropical regions. Shocking impacts like the loss of 50% of the world's largest continuous reef system, the Great Barrier Reef, have occurred over the past two years and look likely to increase given the rapidly rising trends in temperature. These impacts can only be reduced through a significant and rapid reduction in fossil fuel emissions.

Under current high greenhouse gas emission trajectories, conditions will become intolerable for coral reefs almost everywhere within the next 30 to 40 years, at which point coral reefs will be unrecognizable. This will increase the vulnerability of over 500 million people, and will significantly degrade the opportunities for young people, who will inherit the devastation as adults, as will many future generations, and who will be deprived of the spectacular glory as well as tangible benefits that coral reefs such as the Great Barrier Reef provide.

If we take immediate action to reduce and, by mid-century, largely eliminate human-caused greenhouse gas emissions, however, coral reefs will still have undergone a significant decline. Nevertheless, not all coral communities will have been eliminated, and there would be a significant chance that coral reefs will be able to regenerate in a stabilizing ocean.

G. Impacts on the Great Barrier Reef as a Harbinger for other Global Coral Reefs and Marine Ecosystem Health

Mass coral bleaching is one of the most visual impacts of climate change - given that corals turn a brilliant white when they are stressed. Other changes in the ocean may be more cryptic despite being as serious in nature (Hoegh-Guldberg and Bruno 2010, Hoegh-Guldberg et al. 2014). For this reason, coral reefs like the Great Barrier Reef (Hoegh-Guldberg 1999, Hughes et al. 2017) are important harbingers of future changes in other ecosystems – illustrating the impacts of climate change and the serious consequences of climate change for present and future generations – in a very visual way.

Exhibits E-K of my report show time lapses of the Great Barrier Reef bleaching events that occurred between March and May of 2016 at various locations on the Reef. These time lapse sequences accurately depict the process of coral bleaching and mortality, and reflect what has again happened in 2017 and what will continue to occur with increasing frequency as ocean temperatures warm. A professional team of filmmakers and camera people captured the video images of the coral dying due to ocean temperatures being too high, as part of their work to produce the film *Chasing Coral*. I worked with this team of filmmakers as a senior scientific advisor, and have reviewed the time lapses in **Exhibits E-K**, and have verified that these time lapses accurately depict the bleaching and mortality that occurred. A spreadsheet providing the precise location, GPS coordinates, timecode of the clip, metadata, and dates is attached hereto as **Exhibit BB**. As one watches the time lapses, it is noticeable that the coral begins to exhibit enhanced and vivid coral pigments, which are a sign of stress, and then, after the dinoflagellates are expelled, the coral turns white, which is just the transparent coral tissue remaining over the white reef skeleton. Eventually, the coral dies too and soon the impacted corals become covered with a brownish-greenish slime that is algae. Over time, the skeleton will erode and be broken down, removing habitat for fish and other organisms, and reducing the role of these reefs as sources of food and coastal protection, among other ecological services.

Exhibit E shows bleaching at Lizard Island, Picnic Beach RED Macro Site, Great Barrier Reef, Australia.

Exhibit F shows bleaching at Lizard Island, Big Vicki's Site 2, Great Barrier Reef, Australia.

Exhibit G shows bleaching at Lizard Island, Loomis Site 2, Great Barrier Reef, Australia.

Exhibit H shows bleaching at Lizard Island, Loomis Site 5, Great Barrier Reef, Australia.

Exhibit I shows bleaching at Lizard Island, Loomis RED Site 01, Great Barrier Reef, Australia.

Exhibit J shows bleaching at Lizard Island, Loomis RED Site 01b, Great Barrier Reef, Australia.

Exhibit K shows bleaching at Lizard Island, Picnic Beach RED Site 03, Great Barrier Reef, Australia.

Exhibits L-Q are photo transects of healthy Great Barrier Reefs prior to bleaching and the same section of reef 4-9 weeks later after the bleaching occurred between March and May of 2016. As with **Exhibits E-K**, these photo-transects also accurately depict the process of coral bleaching. A professional team of filmmakers and camera people captured these photo-transects of the coral dying due to ocean temperatures being too high, as part of their work to produce the film *Chasing Coral*. I worked with this team of filmmakers, have reviewed the photo transects in **Exhibits L-Q**, and have verified that these photo-transects accurately depict the bleaching that occurred. A spreadsheet providing the precise location, GPS coordinates, timecode of the photos, metadata, and dates is attached hereto as **Exhibit BB**.

Exhibit L shows bleaching at Lizard Island, Loomis RED Site 6, Great Barrier Reef, Australia.

Exhibit M shows bleaching at Lizard Island, Loomis RED Site, Great Barrier Reef, Australia.

Exhibit N shows bleaching at Lizard Island, Loomis Cove and Palfrey Island, Great Barrier Reef, Australia.

Exhibit O shows bleaching at Lizard Island, RED Site at Big Vicki's, Great Barrier Reef, Australia.

Exhibit P shows bleaching at Lizard Island, Loomis Cove and Palfrey Island Site, Great Barrier Reef, Australia.

Exhibit Q shows bleaching at Lizard Island, Picnic Beach RED Site, Great Barrier Reef, Australia.

While the filmmakers had more luck being in the right place at the right time with working underwater camera equipment to capture the bleaching events on the Great Barrier Reef, the same thing happened on reefs around the globe, including in U.S. territorial waters. For instance, **Exhibits R-S** show time lapses of healthy to dead coral reefs in American Samoa waters and in the Florida Keys. These time lapses accurately depict healthy coral reefs before bleaching and dead coral reefs afterward. Professional camera people also captured these images. I have reviewed the time lapses in **Exhibits R-S** and have verified that these time lapses accurately depict the bleaching that occurred. A spreadsheet providing the precise location, GPS coordinates, timecode of the clip, metadata, and dates is attached hereto as **Exhibit BB**.

Exhibit R shows Airport Reef in American Samoa's reef.

Exhibit S shows Carysfort Reef in the Florida Keys, Florida.

Exhibit T shows Rib Reef on the Great Barrier Reef – an area that was affected minimally by the extraordinary thermal stress and bleaching on the Great Barrier Reef in 2016 (i.e. was south of major impacts). The exhibit shows the diversity and abundance of life on a healthy coral reef, contrasting the depressing site of reefs killed recently by climate change.

Exhibit U describes coral bleaching and mortality, as explained by international expert Dr. Ruth Gates, Director of the Hawaii Institute of Marine Biology.

Exhibit V describes recent trends in sea temperatures and how they drive coral bleaching.

Exhibit W describes the projections of ocean temperature using multiple climate models.

Exhibit X depicts the testimony from experts from all over the world who have been recording mass coral bleaching and mortality in the past 12-18 months.

Exhibit Y shows the bleaching over 35 days of the ubiquitous coral, *Stylophora damicornis* – in a laboratory experiment where temperatures were raised slightly above the long-term summer maxima for this species (with bleaching happening over days). If these corals were exposed to higher temperatures, the corals depicted would bleach far more quickly (e.g. over hours).

Exhibit Z shows the important coral *Acropora* sp bleaching and dying over 9 days. *Acropora* is an important habitat for thousands of organisms but is very sensitive to heat stress and mass coral bleaching and mortality.

Exhibit AA shows the vivid colors of corals (host pigments) when they get stressed. While beautiful, these colors are produced by the coral in a response to extreme stress. Despite their beauty, many of these depicted corals died in the days and weeks that followed.

H. Impacts to Coral Reefs in U.S. Territorial Waters and Effects on Biodiversity/Ecology/Economy

Within the U.S. territorial waters are coral reefs in Florida, Hawaii, American Samoa, Commonwealth of the Northern Mariana Islands, Guam, Puerto Rico, and the U.S. Virgin Islands, all of which are in a state of decline. The U.S. NOAA reports: "Coral reefs contribute significant economic value to the US public" (Edwards 2013). According to Hughes et al (2018): "widespread bleaching (affecting >50% of locations) has now occurred seven times since 1980 in the Western Atlantic, compared to three times for both Australasia and the Indian Ocean, and only twice in the Pacific. Over the entire period, the number of bleaching events has been highest in the Western Atlantic, with an average of 10 events per location, two to three times more than in other regions."

The Florida coral reef system is the third largest reef in the world. There are over 100 species of coral along the Florida Reef Tract, with the most prolific reefs in the waters of the Florida Keys and further south into the Caribbean. Many of the corals along this reef have declined upwards of 80% already and are experiencing bleaching events and disintegrating skeletons at levels that were not predicted to occur until mid-century, making recolonization even more difficult. Between 1996 and 2005, coral cover in the Florida Keys declined by 44%. However, in the last two years of bleaching events, some believe the majority of coral are now gone. Scientists believe that many of the Florida reefs have already hit a tipping point from which they will not recover this century. Plaintiff Levi, who resides on the eastern Florida coast, will therefore have fewer and fewer opportunities to visit and experience healthy coral reefs in Florida or the Caribbean. The Florida reef is estimated at a value of $7.6 billion from tourism and commercial fisheries revenue.

The grave danger to coral reefs around the world is also facing the reefs of Hawaii. In the most recent global bleaching event this spring of 2017, nearly 10% of Hanauma Bay's corals died, even though Hanauma Bay, as a nature preserve, is one of the most protected sites for coral. Similarly, reefs protected by one of the largest marine protected areas in the world, the Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands, have been badly damaged (especially in 2014, Couch et al. 2017). Coral reefs off of Kauai are also rapidly declining, where Plaintiff Journey and his family have traditionally recreated, including reefs in Hanalei Bay. Without applying a discount rate, NOAA has valued the Hawaiian coral reefs at $19 billion (Edwards 2013).

I. U.S. Contribution to CO_2 Levels Is a Significant Global Impact on Oceans and Coral Reefs Historically and Presently

Even just accounting for the United States' territorial emissions, and not its additional CO_2 contributions from consumption or extraction, it has contributed more to the warming and acidifying of our oceans than any other nation in the world (Hansen 2015). Eliminating U.S. emissions and keeping U.S. fossil fuels in the ground alone will have a significant impact in limiting CO_2 absorption by the oceans, and will slow the rate of ocean warming, even if other nations' emissions do not similarly decline in the same time frame. Global reductions in emissions are needed, of course, but the U.S. contribution is so significant globally, that it will make a measurable difference should the U.S. stop burning and extracting fossil fuels.

CONCLUSION AND RECOMMENDATIONS

As a coordinating lead author for the IPCC with over 300 peer reviewed publications, and based upon over 30 years of research and study on marine ecosystems and coral reefs, both in the field and in the lab, it is my expert opinion that young people today, including the youth Plaintiffs in this case, have already suffered tremendous harm to their oceans and the marine life therein, including coral, from human-caused greenhouse gas emissions, especially CO_2. The U.S. Defendants are responsible for a large share of those emissions. The ocean warming, acidification, and deoxygenation described herein has caused the death and diminishment of coral reefs worldwide, including the stark and visible death of coral in Hawaii, Florida, and in Caribbean U.S. territorial waters, which are important to Plaintiffs Journey and Levi specifically. Those losses are already impacting young people's experience of these waters, and the benefits they receive from them.

In the future, if current emission trajectories continue, young people will grow up with even greater loss of marine life and ocean waters that will no longer sustain the same biodiversity and access to food, beauty, recreation, and coastal safety for those who live near, recreate by, and utilize these waters and resources. The broader economic and food chain ramifications are substantial and also incalculable. For future generations not alive today, but alive by mid-century, their knowledge will be of a world without living coral reefs, and the biodiversity they support, if emissions continue unabated.

We have already consigned these young Plaintiffs and future generations to substantially degraded reefs and acidifying waters. If we transition swiftly off of the use of burning fossil fuel for energy and protect our carbon sinks (Hansen et al. 2013), we have an opportunity to protect at least some of our coral reefs so that they may lead the way to re-propagate and expand when the wrath of warming slows and our planet once again begins to cool and rebalance. It is my expert opinion that that is the only rational and safe course and the only way to protect these invaluable marine ecosystems for these children and their children's children.

I conclude with these key points:

1. Ocean warming and acidification will degrade many marine ecosystems beyond recognition within the next 30-40 years unless immediate and deep action reducing fossil fuel emissions is taken. This will change ecosystem services that support millions of people and industries across the planet. This will expose many of the world's children to dangerously eroding food security in many societies where children are already highly vulnerable.

2. Coral reefs are a primary example. Ocean warming is accelerating mass coral bleaching and mortality events at an alarming rate. The last three years have seen unprecedented warming across the tropics and has been accompanied by a mass coral bleaching and mortality event that has stretched across two to three years for the first time in places like the Great Barrier Reef and Hawaii.

3. If further actions are taken to perpetuate fossil fuel energy and swift action is not taken to eliminate fossil energy, then coral reefs will disappear or degrade beyond recognition. This will deprive children and future generations, including the Plaintiffs, of the splendor of coral reefs - with degraded coral reefs offering far fewer benefits in terms of food and income, further acerbating poverty and the opportunities for children and future generations.

4. The fact that the U.S. Government has known of this problem yet has not take proportionate steps to reduce greenhouse gas emissions from the fossil fuels that it exploits and promotes, is irrational and runs at odds with its constitutional responsibility to look after the security of its citizens, born and unborn.

Signed this 2nd day of August, 2018 in Brisbane, Australia.

Ove Hoegh-Guldberg, Ph.D.

EXHIBIT A: CURRICULUM VITAE

OVE HOEGH-GULDBERG
GLOBAL CHANGE INSTITUTE
UNIVERSITY OF QUEENSLAND

NATIONALITY

Australian (born: 26/9/59, Sydney)

EDUCATION

1989	Ph.D. University of California, Los Angeles
1982:	B.Sc. (Hons, 1st class) University of Sydney

CURRENT POSITIONS

Director and Founder, Global Change Institute, University of Queensland (2010 –present)
Deputy Director, ARC Centre for Excellence for Reef Studies (2006-present)
Professor of Marine Studies, University of Queensland (2000-present)
Affiliated Professor in Tropical Marine Biology, University of Copenhagen (2016-present)

SIGNIFICANT APPOINTMENTS

2017-2018	Coordinating Lead Author, UN IPCC Special Report on the Implications of the 1.5^{o}C (Paris long-term target).
2016	Australian Delegate, IPCC Scoping meeting: Special Report on 1.5^{o}C (Geneva)
2016	Australian Delegate, UN IPCC Scoping meeting: Special Report on Oceans/Cryosphere (Monaco)
2018-present	Commissioner, World Commission on the Ethics of Scientific Knowledge and Technology (COMEST); Appointed by the Director-General of UENSCO
2016-2017	Australian Representative, UNESCO, Preparation of a non-binding Declaration on the Ethical implications of climate change
2013-present	Fellow, Australian Academy of Science
2013-2014	Global Partnership for Oceans, Chair, Blue Ribbon Panel (World Bank)
2015-present	Independent Expert Panel (Chaired by Australian Chief Scientist Prof Ian Chubb)
2015-present	GBR Taskforce, water quality (Chair: QLD chief scientist, Prof Geoff Garret)
2010-2014	Coordinating Lead Author, "The Ocean" Chapter, 5th Assessment Report, Intergovernmental Panel on Climate Change (IPCC, Geneva)
2010 – 2014	Affiliated Researcher, Centre for Ocean Solutions, Stanford University
2014-present	Chair, Technical Advisory Group, Great Barrie Reef Foundation
2012-2017	Chief Scientist, Catlin Seaview Survey (www.globalreefrecord.org)
2001-2010	Visiting Professor, Stanford University
2001-2010	Director and Founder, Stanford Australia Marine Studies Program
2010-2013	Senior Executive Management Committee, University of Queensland
2006-2012	Member, Board of Reviewing Editors, Science Magazine
2000-2009	Director and Founder, Centre for Marine Studies, University of Queensland
2001-2009	Chair, Climate Change and Coral health working group within CRTR project, Global Environmental Facility -World Bank (www.gefcoral.org).
2006-2010	Member, Royal Society, London, Marine Advisory Network (MAN)

2004-2010	Founding Member, Australian Climate Group (now Climate Science Australia)
2000-present:	Member, International Scientific Advisory Committee, GBR Foundation
2004-2007	Member, Royal Society, London, Working Group on Ocean Acidification
2001-2005	Member, UNESCO-World Bank-IOC Synthesis Panel TRG Coral research.
2000-2009	Director, Heron Is, Low Isles and Morton Bay Research Stations

HONORS AND AWARDS

2016	Banksia Foundation International Award
2014	Prince Albert II of Monaco Climate Change Award
2014	American Society of Microbiologists, ASM Lecturer for 2014
2013	ARC Laureate Fellowship (2013-2018)
2008	Queensland 2008 Smart State Premier's Fellow (2008 - 2013)
2011-2014	Highly Cited Researcher (Thomson Reuters, 4 years in a row, 13 HiCi articles)
2010	Thomson Reuters' ISI Highly Cited Researchers (most cited Australian scientist in the area of Climate Change, 3rd most cited internationally; top cited Ecologist)
2009	Whitley Certificate of Commendation for book on Great Barrier Reef
2009	Thomson-Reuters' ISI Hot Paper Award.
2009	Wesley College Foundation (University of Sydney) Medal 2009
1999	The 1999 Eureka Prize for Scientific Research

INSTITUTE WEBSITE: WWW.GCI.UQ.EDU.AU

LAB WEBSITE: **WWW.**CORALREEFECOSYSTEMS.ORG**:**

STDUENTS/POSTDOCS: OVE 65 RESEARCH FELLOWS & HONS-PHD STUDENTS

PROFESSIONAL SOCIETIES AND BOARD MEMBERSHIP

Science Magazine (Board of Reviewing Editors, 2006-2012)
Technical Advisory Committee, Great Barrier Reef Foundation (Chair, 2014-present)
Great Barrier Reef Foundation (International Scientific Advisory Committee; 2000-present)
Biodiversity Research Centre Academia Sinica, Taipei (Advisory Board; 2010 - present)
Leibniz Center for Tropical Marine Ecology, Bremen (Advisory Board; 2010 - present)
International Symbiosis Society (Governing Councilor, 2004-2010)

BIOGRAPHICAL SKETCH

Ove Hoegh-Guldberg is the Director of the Global Change Institute (GCI: www.gci.uq.edu.au), Deputy Director of the Centre for Excellence in Coral reef Studies (www.coralcoe.org.au), Affiliated Professor in Tropical Marine Biology at the University of Copenhagen (2016-present), and Professor of Marine Science (www.coralreefecosystems.org) at the University of Queensland in Brisbane, Australia. Ove's research focuses on the impacts of global change on marine ecosystems, and is one of the most cited authors on climate change with more than 25,000 citations from > 310 papers, books, and patents). In addition to pursuing scientific discovery personally, Ove has had a 20-year history in leading research organisations such as the Centre for Marine Studies and the Global Change Institute, both at the University of Queensland. These roles have seen him raise more than $100 million in terms of funding for research and infrastructure. Ove is a great believer in the power of transdisciplinary approaches to problem solving and his long history of working across traditional boundaries between academic units and organisations, within the University of Queensland and across the national and international landscape. He has also been a dedicated communicator of the threat posed by ocean warming and acidification to marine ecosystems, one of the earliest to identify the serious threat posed by climate change for coral reefs in a landmark paper published in 1999. In addition to leading a research group at the University Queensland, he is the Coordinating Lead Author for the 'Oceans' chapter for the Fifth Assessment report of the Intergovernmental Panel on Climate Change (IPCC) and is currently the Coordinating Lead Author on the Impacts chapter of the IPCC Special report on 1.5^{o}C. He has been awarded a Eureka Prize for his scientific research and a QLD Premier's fellowship, and is currently an ARC Laureate Fellow and member of the Australian Academy of Science. He received the Prince Albert II 2014 Award for Climate Change, and the 2016 International Award from the Banksia Award.

SCHOLARSHIP:

Ove has produced over 310 peer-reviewed publications (34 in Science, Nature or PNAS), with 124 since the beginning of 2012 together with over 35 peer-reviewed book chapters, research reports and 2 international patents. Publications include major contributions to physiology, ecology, environmental politics, and climate change. Ove's most significant scientific contributions have been recognized recently through invited reviews by leading journals such as Science (Hoegh-Guldberg and Bruno 2010; Hoegh-Guldberg *et al.* 2007), major research and infrastructure funding (>$100 million since 2000; ARC Centre for Excellence, Queensland Smart State Premier's Fellowship; ARC Laureate Fellowship) and his appointment as Coordinating Lead Author of Chapter 30 ("The Oceans") for the 5th Assessment Report, as well as the special report on the implications of 1.5^{o}C (for the Intergovernmental Panel on Climate Change). He is currently the most cited Australian author (and 3rd internationally out of 53,136 authors) on the subject of "climate change" according to the Thomson-Reuter's ISI Web of Science (2011, sciencewatch.com/ana/st/climate/authors). This represents a group of less than 0.5% of all published researchers in the world. Ove received a major award from Thomson Reuters in 2012 (Citation Award Winner in Ecology Thomson Reuters Citation & Innovation Award). His research publications have been cited over 25,000 times (Thompson-Reuters) and is cited over 2,000 times per year. Ove's H-index is 72 (ISI 2011) or 91 (Google Scholar) and he have received several awards from Thomson-Reuters ISI Web of Science for papers that are among ISI's hottest paper (most cited over the previous two years) in the both the area of "climate change" and "ocean acidification" (sciencewatch.com/ana/fea/09novdecFea/). He has also produced the edited book (Hutching, Kingsford and Hoegh-Guldberg, "The Great Barrier Reef", Springer/CSIRO Publishing; winner of a Whitley Award commendation in 2009, soon in its second edition) and over 30 book chapters and refereed reports, and continue to hold 2 international patents (together A/Prof Sophie Dove) on a novel class of Green Fluorescent Pigments. He has received several major prizes, including the UCLA Distinguished Scholar Award and the 1999 Eureka Prize for discovering the molecular mechanism (see below) behind mass coral bleaching and mortality (Hoegh-Guldberg and Jones 1999; Hoegh-Guldberg and Smith 1989a; Hoegh-Guldberg and Smith 1989b) and impact of global climate change on the earth's coral reefs (Hoegh-Guldberg 1999). These early discoveries shaped his career which has increasingly focused on the impact of global climate change on the marine ecosystems and the implications for people and societies (Hoegh-Guldberg *et al.* 2009). As part of this, Ove has worked on numerous film projects with environmental film-makers such as Sir David Attenborough, Richard Smith, and Jeff Orlowski to communicate these key messages from science. Recent awards include being in The Conversation's top ten articles in 2011 (http://theconversation.edu.au/the-conversations-top-ten-articles-in-2011-4929), Thomson Reuters (Top 12 Australian Scientists), Prince Albert II 2014 Award for Climate Change, 2016 International Award from the Banksia Award, QLD Premier's fellowship, and ARC Laureate Fellow (which he currently holds).

RECENT ADMINISTRATIVE RESPONSIBILITIES

INSTITUTE DIRECTOR

Global Change Institute (GCI) began operation in January 2010. Ove was appointed inaugural Institute Director and has been responsible with his team for building a University Institute focused on providing solutions to the complex interactions and challenges that increasingly face our world. The Institute is currently focused on human impacts on biodiversity and natural ecosystems, climate change impacts on the ocean, renewable energy, sustainable business, as well as food and water security. In its first six years, the Institute attracted a community of 100 researchers and funding of over $70 million. Its operation works on a 'incubator' model, developing teams of academics around challenges from global change and eventually budding them off as entities in their own right. For example, the highly successful UQ Solar was developed by the GCI and developed one of the largest photovoltaic arrays globally, and a funding model (using electricity savings) that delivered >$600,000 each year into research associated with the array. This successful operation was recently moved out of the GCI and into the Faculty of Engineering and Information Technology. In October 2013, the Institute moved to a new building (funded by $15m in philanthropic funding attracted by Director Hoegh-Guldberg in partnership with UQ Advancement). This building is among Australia's most sustainable buildings, and has been listed as the world's 34th most sustainable building. On an average day, this building generates more energy than it consumes and has also won several awards (and us a six-star, green star listed building, Living Building Challenge). It is considered a centre-piece of the University and is strongly aligned to the University's philosophy of promoting and living sustainability. GCI also launched Australia's largest roof-top solar array and are currently constructing a 3.75 MW array at the Gatton campus of UQ. The Institute have also put forward plans to take the carbon footprint of this campus of the University of Queensland to zero over the next 10 years. Institute's vision is to become "an internationally respected source of knowledge for advocating and understanding, solving and addressing the problems of a changing world", and to inspire students, scholars and the general public to solve the global challenges that will face our societies in the coming decades. Our mission is 'to advance discovery, create solutions, and influence decision makers to position the University of Queensland as a global leader in addressing the challenges of a changing world".

CENTRE DIRECTOR

Ove began the Centre for Marine Studies with handful of staff in 2000, after being appointed its inaugural Director. By 2009, the Centre had grown to 60 staff members, and over 40 postgraduate and Honours students at its St Lucia hub (annual turn-over of $6.5 million). The Centre was also responsible Heron Island Research Station, the largest research station on the Great Barrier Reef; Moreton Bay Research Station, a modern facility on North Stradbroke Island in Moreton Bay; Low Isles Research Station, a small station on the inner, northern Great Barrier Reef; a suite of vessels of various capacities; and Pinjarra Aquatic Research Station, an aquaculture facility a few kilometres from the main University campus. As a result, the Centre grew from an annual budget of under $2 million to over $6.5million per year, from a staff and student body of 12 to over 90 people. During that time, Ove was responsible for attracting major funding for the infrastructure associated with the Centre (e.g. $6.5 million, systemic infrastructure, 2002) and have brought major research initiatives to the Centre (e.g. GEF-WB-IOC project; $28 million; 2004-2008, to be coordinated by UQ: www.gefcoral.org). In 2005, Ove was a founding partner (along with Prof Terry Hughes, JCU, and Prof Malcolm McCulloch, UWA) of the ARC Centre of Excellence bid (>$30 million, 2005-2018). The three research stations at the University of Queensland were completely refurbished under his period as director (funding attracted by Ove from the Federal government; $10.2 million), with the three stations experiencing rapid growth in research, teaching and engagement activities

DIRECTOR, STANFORD AUSTRALIA PROGRAM (STANFORD UNIVERSITY)

With an active interest in establishing new milestones for marine education, Ove conceived of and developed the Great Barrier Reef Study Program at Stanford University, which began in 2001 and is currently in its 15th year. Ove was the Program's Director up until 2010, responsible for five full-time courses that run out of the Centre – and directly taught and coordinated two of the courses involved (Coral Reef Ecosystems and Targeted Research Project). In addition to coordinating the Program, Ove gave lectures, run field exercises and perform assessment on the 48 students that enter the program each year – and was also responsible for the development of new subject areas and continued program development in association with the Overseas Study Program at Stanford University. The Australia Program continues to be one of the most popular programs run by Stanford University.

CHAIR, GEF CORAL BLEACHING TARGETED RESEARCH GROUP

The Intergovernmental Oceanographic Commission (IOC) and World Bank Coastal Program established the Global Coral Reef Targeted Research and Capacity Building Project in 2000. As part of this, Ove chaired one of six expert groups that focused on coral bleaching and related ecological factors – coordinating the input from 12 leading scientists, helping establish research plans and setup budgets. As part of his duties, he also represented this group on the Project Synthesis Panel. Details of the groups can be found at www.gefcoral.org. This project attracted over $40 million (USD) from the Global Environment Facility (GEF), World Bank, NOAA and other partners (e.g. NOAA, UQ). Professor Hoegh-Guldberg played a significant role in crafting the strategy behind this project, including writing the document "Four Oceans" and being lead author on the document that set out the management of the execution of the project. The latter led to the University of Queensland being selected to coordinate the first five-year phase of the project. Total funding for this project is $41 million (USD) plus an estimated $50 million (USD) in other funds during first phase. The second stage of this project (GEF/WB/UQ funded: Capturing Coral Reef Ecosystems Services) started in 2013 and has partnered with Indonesian and Filipino research communities (CCRES, www.ccres.net). It is coordinated by the Global Change Institute.

CORAL REEF ECOSYSTEMS LABORATORY (CORALREEF ECOSYSTEMS.ORG**)**

Ove has maintained an active research career in the area of marine symbiosis, coral reef ecology, and is responsible for a sizable marine laboratory at the University of Queensland. As part of this, Ove leads a large research group that and currently hold over $10 million in funding for the next 4 years, and has been responsible for the supervision to completion of over 60 PhD., M.Sc. and Honours students. Research activity within the Coral Reef Ecosystems group has generated over 300 peer-reviewed publications, 34 book chapters, 1 book and two international patents. See the laboratory website: www.coralreefecosystems.org for further detail.

RESEARCH FUNDING (FUNDING, INITIATIVES) SINCE 2000, > $110 MILLION

(This is direct research funding to OHG and research collaborators – funding attracted to GCI (e.g. UQ Solar) reported separately in Annual Reports from the GCI. As Director, funding raised for GCI (> $50 million)

2017-2019 ($1.8 million for '50 Reefs' program). Funded by Bloomberg, Tiffany and Paul G Allen family Foundations. Global strategy for conservation solutions to coral reefs under climate change.

2014-2020 ($2.3 million for Hoegh-Guldberg, $28 million, total refunding) ARC Centre for Excellence for Coral Reef Studies. Director: Terence Patrick Hughes, Deputy Directors: Ove Hoegh-Guldberg, and Malcolm Thomas McCulloch. Has been operating since 2004 and is now one of the longest running examples of an ARC Centre for Excellence.

2013-2018 ($3 million, ARC Laureate). Coral reef metabolism in a changing climate (Hoegh-Guldberg)

2015-2019 ($12 million) XL Catlin Seaview Survey. (Hoegh-Guldberg; Chief Scientist)

2014-2018 ($0.8 million) XL Catlin Global Reef Record. (Hoegh-Guldberg; Catlin Insurance)

2011-2014 (ARC Linkage, Industry partners: GBRMPA, NOAA USA: $10 million, cash; $10 million in-kind) Next generation satellite tools for understanding change in coral reef ecosystems due to multiple global and local stressors. Investigator: O. Hoegh-Guldberg and S. Dove. LP110200874

ARC Super Science project (FS100100024; $555,000, 2010-2013) Treading water in a changing climate: The vulnerability of Australia's tropical islands to sea level rise, led by Professor Hoegh-Guldberg in collaboration with colleagues at UQ and the University of Wollongong. This project will directly benefit the people and businesses associated with 1174 tropical islands found in Great Barrier Reef and Torres Strait waters. By bringing together a multi-disciplinary team and training young Australian researchers, this project will establish an integrated research program that will outline the challenges, and develop the solutions, that will be needed for Australians to cope with rising sea levels; and

ARC Super Science project (FS110200005; $834,000; 2011-2014) Adapting to the impacts of sea level rise as a result of rapid climate change, led by Professor Hugh Possingham. Professor Hoegh-Guldberg was responsible for coordinating and writing. Rapid sea level rise has been identified as a major threat to coastal Australia, where most of the Australian population lives. By building capacity and answering many urgent and difficult questions related to the legal, environmental and planning ramifications of sea level rise, this project will prepare communities and policymakers for the difficult times ahead.

ARC Super Science project (FS100100074; $834,000; 2011-2014) Led by Janice Lough. The Great Barrier Reef (GBR) is a national and international icon, recognized through its inscription as a World Heritage Area and economic and social value to Australians. Maintenance of the GBR as we know it is now compromised by a rapidly changing climate. Ocean acidification, warming water temperatures and increased freshwater will progressively be detrimental to the fundamental reef-building process of calcification. Informed policy and management strategies in a rapidly changing physical environment require determination, for short and long-time frames, of the regional consequences and impacts of changing reef-building capacity.

2009-2013 (Queensland Smart State Premier's Fellowship; $2.6 million; Great Barrier Reef Foundation $1.4 million) Ensuring a sustainable future for Queensland through the science-based solutions to climate change on the Great Barrier Reef. Investigator: Hoegh-Guldberg, O.

2009 LE0989608 Prof O Hoegh-Guldberg; Dr DI Kline; Dr KR Anthony; Dr SG Dove; Prof MT McCulloch; Dr BN Opdyke; Dr JM Lough; Dr PG Brewer; Mr WJ Kirkwood; The Heron Island Climate Change Observatory: An In-Situ Ocean Acidification and Carbonate Chemistry Monitoring Platform. 2009: $ 190,000ARC

ARC Linkage ($1.1 million ARC & $1.7 million industry, LP0775303 2005-2010) ARC Linkage grant. New tools for managing ecosystem responses to climate change on the southern Great Barrier Reef. Investigators: Prof Ove Hoegh-Guldberg, Dr Kenneth Roald Nies Anthony, Prof Andrew Bakun, Dr

Bradley Charles Congdon, Dr Michael Julian Caley, Dr Sophie Gwendoline Dove, Dr Gene Carl Feldman, Prof Malcolm Lewis Heron, Dr Ronald Johnstone, Dr Andrew K Krockenberger, Dr Laurence John McCook, Dr Alan E Strong, Dr Paul Marshall

2009-2013 ($4 million for Hoegh-Guldberg, $24 million, total) ARC Centre for Excellence. Prof Terence Patrick Hughes, Dr Kenneth Roald Nies Anthony, Dr Andrew Hamilton Baird, Prof David Roy Bellwood, Dr Sean Richard Connolly, Dr Sophie Gwendoline Dove, Dr Maoz Fine, Prof Carl Folke, Dr Michael Kevin Gagan, Prof Ove Hoegh-Guldberg, Dr Morgan Stuart Pratchett, Dr Geoffrey Paul Jones, Prof Ronald H Karlson, Prof Michael John Kingsford, Dr Janice Mary Lough, Dr Mark Ian McCormick, Prof Malcolm Thomas McCulloch, Dr Mark Meekan, Dr David John Miller, Dr Philip Laing Munday, Dr John Michael Pandolfi, Dr Serge Planes, A/Prof Garry R Russ, Prof Robert Steneck, Dr Roger Hudson Bradbury, Dr Madeleine Josephine van Oppen, Dr Laurence John McCook, A/Prof Bette Lynn Willis, Prof David Yellowlees, Dr Carles Pelejero

2005-2009 ($1.9 million, total) Pitman, A. Earth System Science ARC Network

2003-2006 (~$650,000 total): Tracing the origins of stress in the symbionts of reef-building corals. (ARC Large, DP0346647); Investigators: Prof Ove Hoegh-Guldberg, A/Prof David Yellowlees, Prof William K Fitt, Dr Ruth Deborah Gates, Dr Todd C LaJeunesse.

2004-2006 (~$500,000 total): Solar radiation, coral bleaching and climate change. (ARC Large, DP0453361); Investigators: Prof Ove Hoegh-Guldberg, A/Prof Manuel Nunez, Dr Maoz Fine, Mr Alan E Strong, Dr Kenneth Roald Nies Anthony, Dr Roberto Iglesias-Prieto

2004-2006 (~$300,000 total): Ecology, physiology and molecular microbiology of coral disease on the Great Barrier Reef. (ARC Linkage, LP0453609); Investigators: Prof Ove Hoegh-Guldberg, Dr Ross Jeremy Jones, A/Prof Linda Louise Blackall, Dr Maoz Fine, Dr John Bythell

2002-2006 (~$900,000 total): Vision and remote sensing: using nature's technology to examine the health of The Great Barrier Reef and Moreton Bay. (ARC Linkage, LP0214956); Investigators: Dr Justin Nicholas Marshall, Prof Ove Hoegh-Guldberg, Dr William Cullen Dennison, Dr Stuart Ross Phinn, Prof John Douglas Pettigrew, Dr David Ian Vaney, A/Prof Shaun Patrick Collin, Dr Kim Bryceson, Dr J Zeil, Dr Marilyn Ball

2005-2007 (~$450,000 total): Long-term changes in Mackay Whitsunday water quality and connectivity between coral reefs and mangrove ecosystems. (ARC Linkage, LP0560896); Investigators: **Prof Ove Hoegh-Guldberg**, Prof Malcolm Thomas McCulloch, Prof Robert B Dunbar, Dr Laurence John McCook, Dr David Bruce Haynes

2002-2004 ($80,000) Edmunds; P. J., Gates; R. D., Hoegh-Guldberg, O. Global climate change and coral recruitment: the interactive effects of temperature and ontogeny on the biology of *Porites astreoides* larvae NOAA/NURP/NURC, 10/1/2002-9/31/2004

2001-2003: (~$230,000 total): The structure and function of the host pigments of reef-building corals. (ARC Large, A00106021); Investigators: Dr Sophie Dove, Prof Ove Hoegh-Guldberg

2001-2003 (~$400,000 total): The development of Pulse Amplitude Modulated (PAM) chlorophyll fluorometry as a management tool for non-intrusive sublethal stress assessment in corals of the Great Barrier Reef. (ARC Linkage, C00002489); Investigators: Dr Ross Jeremy Jones, A/Prof Ove Hoegh-Guldberg, Mr David Haynes, Mr Ken Ronald Nies Anthony, Mr Raymond Wiebe Berkelmans, Dr Jamie Oliver, Mr Jon Edward Brodie, Mrs Angela Maria Hesse, Dr Graeme Edward Batley

2000-2002 (~$300,000 total): The role of physiological energetics in defining niche boundaries of corals on turbid reefs. (ARC large, A00105071); Investigators: Dr Kenneth Roald Anthony, A/Prof Terence Patrick Hughes, Dr Bette Lynn Willis, Prof Ove Hoegh-Guldberg

2000-2002 (~$180,000 total): Reef studies of larval settlement competency periods, dispersal potential, and survivorship of juvenile scleractinian reef corals. (ARC small; A00000950); Investigators: Dr Peter Lynton Harrison, Prof Ove Hoegh-Guldberg

2000-2002 (~$300,000 total): The diversity of symbiotic dinoflagellates from Australian reef-building corals. (ARC Large, A10009205); Investigators: Dr Ove Hoegh-Guldberg, Dr Diedre Anne Carter, Dr Robert K Trench, Dr Robert G Rowan

2000-2002 (~$330,000 total): The molecular mechanism of bleaching in reef-building corals. (ARC Large, A10009109); Investigators: Dr Ove Hoegh-Guldberg, Prof Anthony William Larkum, Prof Murray Ronald Badger, Dr Linda Ann Franklin, A/Prof David Yellowlees

Other major funding ($44 million directly)

2005 ($3.5 million): Smart State Research Facilities Funding for a Queensland Marine Science Centre; Hoegh-Guldberg authored this grant that led to funding for GEF project infrastructure at St Lucia ($2.55 million), Heron Island (0.5 million) and Orpheus Island ($0.45 million).

2004-2008 ($28.0 million): Global Coral Reef Targeted Research and Capacity Building Project. Global Environment Facility and World Bank. Administered directly by the University of Queensland. The involvement of the University in this project arose as follows. I was chosen to chair an international working group on coral bleaching that was funded by the Intergovernmental Oceanographic Commission of UNESCO project in 2000. Soon afterwards, a World Bank representative (Andrew Hooten) approached the IOC-UNESCO group with the idea of approaching the Global Environment Facility for a broader based project on coral reefs, environmental change and coastal management. Our group joined this project proposal as the first of six expert groups. Hoegh-Guldberg was the principal author of concept documents that drive the project ("Four Oceans" and "PEA at UQ concept"). He also evolved the concept of the University becoming the Project Executing Agency.

2002-2005 ($10.7 million; $6.5 million for research stations at UQ): Systemic infrastructure grant (DETYA). MARINE RESEARCH AND EDUCATION NETWORK. 2002-2005 – Hoegh-Guldberg was principal author and wrote the successful bid with some help from MJ Kingsford at JCU as co-author. Was submitted through JCU to enable the remote campus issue to be highlighted as much as possible.

2005 (ARC infrastructure: Total $990,000): ARC LEIF LE0453998 HF radar facility for oceanography in the Great Barrier Reef, Heron, Hoegh-Guldberg, Skirving and Willis. Successful bid to build High Frequency Radar Facility for understanding wave and current patterns in the Capricorn-Bunker group of islands.

2000 (ARC infrastructure: $561,132; Total $960,000): Advanced Bio-Imaging Capability for the Regional Facility for Microscopy and Microanalysis. (ARC large infrastructure, R00002784); Investigators: Prof Anthony Ronald Moon, Prof Colin Sheppard, Prof Robert Lindsay Raison, Dr Guy Christopher Cox, Dr Donald Keith Martin, Prof Max Bennett, Dr Matthew Ronald Phillips, A/Prof Robyn Lynette Overall, Prof Basil Don Roufogalis, Dr Nicholas Charles Smith, A/Prof Ove Hoegh-Guldberg, Dr Maria Byrne, A/Prof Robert Sowerby Armstrong, A/Prof Greg Goodman.

RESEARCH TEAM MEMBERS

The research pursued and supervised by Ove is powered by an exciting group of students and scholars with interests spanning the following topics: ocean warming and acidification, evolution, physiology, biochemistry and molecular biology of plant-animal symbioses, coevolution, biology of hermatypic corals, calcification, coral bleaching, climate change, invertebrate larvae, physiology/biochemistry of larval development. The following people are currently members of my research group.

Post-graduate students (current):

Ms Anjani Ganese (80%)
Ms Catherine Kim (50%)
Ms Kristen Brown (50%)
Mr Dominic Bryant (50%)
Ms Veronica Radice (50%)
Mr Norbert Englebert (50%)
Ms Michelle Achlatis (50%)
Mr Rene van der Zande (50%)

Post-doctoral and research fellows (current):

Dr Pim Bongaerts
Dr Manuel González-Rivero
Dr Alberto Rodriguez-Ramirez
Dr Julie Vercelloni
Dr Hawthorne Beyer
Dr Emma Kennedy

Post-doctoral fellows (last 10 years):

Dr William Leggat,
Dr Saki Harii,
Dr William Loh,
Dr Eugenia Sampayo
Dr Mauricio Rodriquez-Lannetty
Dr Tyrone Ridgway
Dr Nela Rosic
Dr Paulina Kaniewska
Dr Dan Franklin,
Dr Selina Ward
Dr Kenneth Anthony (Senior Research Fellow)

Dr David Kline

Dr Vanessa Hermanan

Dr Guillermo Pulido-Diaz
Dr. Maoz Fine
Dr Ben Neal
Dr. Christine Schoenberg
Dr Uli Siebeck
Dr Oren Levy
Dr Scarla Weeks (Senior Research Fellow)
Dr Mathieu Pernice
Dr Linda Tonk
Dr Olga Pantos
Dr Simon Dunn (Senior Research Fellow)
Dr Dorothea Bender
Dr Andreas Kubicek

EXAMPLES OF KEY COLLABORATORS AND AUTHOR WITH HOEGH-GULDBERG LAB (KEY EXAMPLES)

Eugenia Sampayo, University of Queensland

David Kline, Scripps Institution of Oceanography, UCSD

Paul A Marshall, Director, Reef Ecologic.

Mauricio Rodriguez-Lanetty, Assistant Professor of Biological Sciences, Florida International University

John Bruno, Professor, Department of Biology, UNC Chapel Hill

Tracy D Ainsworth, Associate Professor, Scientia Fellow, The University of New South Wales, Australia

Dr Ross Jones, Australian Institute of Marine Science (Perth)

John Pandolfi. Professor of Marine Science, University of Queensland

Dee Carter, University of Sydney

Prof. Alasdair Edwards, Newcastle University

Guillermo Diaz-Pulido, Griffith University, School of Environment

Morgan Pratchett, James Cook University

Dr Mark Prescott (La Trobe University, Australia)

Dr Todd LaJeunesse (University of Georgia, USA)

Dr Steve Palumbi (Stanford University)

Dr Bill Fitt (University of Georgia, USA)

Dr Rob van Woesik (Florida Institute of Technology, USA)

Dr Michael Kuhl (University of Copenhagen, Denmark)

Dr Ruth Gates (Hawaii Institute of Marine Biology, USA)

Dr Manuel Nunez (University of Tasmania, Australia)

Dr John Bythell (University of Newcastle, UK)

Dr Ken Caldiera (Stanford University, USA)

RESEARCH PUBLICATIONS

Thompson-Reuters:

Sum of the Times Cited	26,207
Sum of Times Cited without self-citations:	24,987
Citing Articles:	15,580
Citing Articles without self-citations:	15,618

Average Citations per Item:	85.48
H-index:	72

Google Scholar:

Sum of the Times Cited:	47,081
Average Citations per Item:	69.47
H-index:	91
i10-index	275
Citations per year	4,750

Thomson Reuters: 13 Hoegh-Guldberg articles are in the highly cited category.

2018 (TO DATE)

1. Achlatis, M., M. Pernice, K. Green, P. Guagliardo, M.R. Kilburn, O. Hoegh-Guldberg and S. Dove. Single-cell measurement of ammonium and bicarbonate uptake within a photosymbiotic bioeroding sponge. The ISME Journal. doi:10.1038/s41396-017-0044-2

2. Skirving, W., S. Enríquez, J.D. Hedley, S. Dove, C.M. Eakin, R.A.B. Mason, J.L. De La Cour, G. Liu, O. Hoegh-Guldberg, A.E. Strong, P.J. Mumby and R. Iglesias-Prieto. 2018. Remote Sensing of Coral Bleaching Using Temperature and Light: Progress towards an Operational Algorithm. Remote Sensing, 10(1): 18.

3. Fang, J. K. H., C. H. L. Schönberg, M. A. Mello-Athayde, M. Achlatis, O. Hoegh-Guldberg, and S. Dove. 2018. Bleaching and mortality of a photosymbiotic bioeroding sponge under future carbon dioxide emission scenarios. Oecologia, 187(1): 25.

4. Brown, K. T., D. Bender-Champ, A. Kubicek, R. van der Zande, M. Achlatis, O. Hoegh-Guldberg, and S. G. Dove. 2018. The dynamics of coral-algal interactions in space and time on the southern Great Barrier Reef. Frontiers in Marine Science 5.

5. Seneviratne, S. I., J. Rogelj, R. Séférian, R. Wartenburger, M. R. Allen, M. Cain, R. J. Millar, K. L. Ebi, N. Ellis, O. Hoegh-Guldberg, A. J. Payne, C. Schleussner, P. Tschakert, and R. F. Warren. 2018. The many possible climates from the Paris Agreement's aim of 1.5 °C warming. Nature 558(7708): 41.

2017

6. Achlatis, Michelle, van der Zande, Rene M., Schonberg, Christine H. L., Fang, James K. H., Hoegh-Guldberg, Ove and Dove, Sophie (2017) Sponge bioerosion on changing reefs: Ocean warming poses physiological constraints to the success of a photosymbiotic excavating sponge. Scientific Reports, 7 1: . doi:10.1038/s41598-017-10947-1

7. Albert, Simon, Saunders, Megan I., Roelfsema, Chris M., Leon, Javier X., Johnstone, Elizabeth, Mackenzie, Jock R., Hoegh-Guldberg, Ove, Grinham, Alistair R., Phinn, Stuart R., Duke, Norman C., Mumby, Peter J., Kovacs, Eva and Woodroffe, Colin D. (2017) Winners and losers as mangrove, coral and seagrass ecosystems respond to sea-level rise in Solomon Islands. Environmental Research Letters, 12 9: . doi:10.1088/1748-9326/aa7e68

8. Brown, Kristen T., Bender-Champ, Dorothea, Bryant, Dominic E. P., Dove, Sophie and Hoegh-Guldberg, Ove (2017) Human activities influence benthic community structure and the composition of the coral-algal interactions in the central Maldives. Journal of Experimental Marine Biology and Ecology, 497 33-40. doi:10.1016/j.jembe.2017.09.006

9. Bryant, D. E. P., Rodriguez-Ramirez, A., Phinn, S., Gonzalez-RIVERO, M., Brown, K. T., Neal, B. P., et al. (2017). Comparison of two photographic methodologies for collecting and analyzing the condition of coral reef ecosystems. Ecosphere 8. doi:10.1002/ecs2.1971.

10. Bongaerts P, Riginos C, Brunner R, Englebert N, Smith SR, Hoegh-Guldberg O. Deep reefs are not universal refuges: Reseeding potential varies among coral species. Science Advances. 2017;3:12.

11. Englebert N, Bongaerts P, Muir PR, Hay KB, Pichon M, Hoegh-Guldberg O. Lower Mesophotic Coral Communities (60-125mDepth) of the Northern Great Barrier Reef and Coral Sea. Plos One. 2017;12:16.

12. Enriquez S, Mendez ER, Hoegh-Guldberg O, Iglesias-Prieto R. Key functional role of the optical properties of coral skeletons in coral ecology and evolution. Proceedings of the Royal Society B-Biological Sciences. 2017;284:9.

13. Fang JKH, Mason RAB, Schonberg CHL, Hoegh-Guldberg O, Dove S. (2017) Studying interactions between excavating sponges and massive corals by the use of hybrid cores. Marine Ecology-an Evolutionary Perspective. 2017;38:8.

14. Fang JKH, Schonberg CHL, Hoegh-Guldberg O, Dove S. Symbiotic plasticity of Symbiodinium in a common excavating sponge. Marine Biology. 2017;164:11.

15. Glasl B, Bongaerts P, Elisabeth NH, Hoegh-Guldberg O, Herndl GJ, Frade PR. Microbiome variation in corals with distinct depth distribution ranges across a shallow-mesophotic gradient (15-85 m). Coral Reefs. 2017;36:447-52.

16. Gonzalez-Rivero, M., Harborne, A. R., Herrera-Reveles, A., Bozec, Y. M., Rogers, A., Friedman, A., Ganase, A. and Hoegh-Guldberg, O. (2017) Linking fishes to multiple metrics of coral reef structural complexity using three-dimensional technology. Scientific Reports, 7 1: . doi:10.1038/s41598-017-14272-5

17. Griffin KJ, Hedge LH, Gonzalez-Rivero M, Hoegh-Guldberg OI, Johnston EL. An evaluation of semi-automated methods for collecting ecosystem-level data in temperate marine systems. Ecology and Evolution. 2017;7:4640-50.

18. Hoegh-Guldberg, O., Poloczanska (2017) The Effect of Climate Change across Ocean Regions, Front. Mar. Sci., 17 November 2017 | https://doi.org/10.3389/fmars.2017.00361

19. Hoegh-Guldberg, O., Poloczanska, E. S., Skirving, W., and Dove, S. (2017). Coral Reef Ecosystems under Climate Change and Ocean Acidification. Front. Mar. Sci. 4. doi:10.3389/fmars.2017.00158.

20. Heron, Scott Fraser; Eakin, C. M. (Carlon Mark); Douvere, Fanny; Anderson, Kristen L., 1959-; Day, Jon C.; Geiger, Erick; Hoegh-Guldberg, Ove; Van Hooidonk, Ruven; Hughes, Terry; Marshall, Paul, 1969-; Obura, David O. (2017) Impacts of climate change on World Heritage coral reefs: a first global scientific assessment World Heritage Centre, UNESCO (CLT-2017/WS/12).

21. Skirving, W., Enríquez, S., Hedley, J., Dove, S., Eakin, C., Mason, R., et al. (2017). Remote Sensing of Coral Bleaching Using Temperature and Light: Progress towards an Operational Algorithm. Remote Sens. 10, 18. doi:10.3390/rs10010018.

22. Pontasch S, Fisher PL, Krueger T, Dove S, Hoegh-Guldberg O, Leggat W, et al. (2017) Photoacclimatory and photoprotective responses to cold versus heat in high latitude reef corals. Journal of Phycology. 2017;53:308-21.

23. Tonk L, Sampayo EM, Chai A, Schrameyer V, Hoegh-Guldberg O. Symbiodinium (DINOPHYCEAE, (2017) Community patterns and invertebrate hosts from ensure marginal reefs on southern Great Barrier Reef, Australia. Journal of Phycology. 53:589-600.

2016

24. Magnan AK, Colombier M, Bille R, Joos F, Hoegh-Guldberg O, Portner HO, et al. Implications of the Paris Agreement for the ocean. Nature Climate Change. 2016;6:732-5.

25. Mills M, Leon JX, Saunders MI, Bell J, Liu Y, O'Mara J, et al. Reconciling Development and Conservation under Coastal Squeeze from Rising Sea Level. Conserv Lett. 2016;9:361-8.

26. Sampayo EM, Ridgway T, Franceschinis L, Roff G, Hoegh-Guldberg O, Dove S. Coral symbioses under prolonged environmental change: living near tolerance range limits. Scientific Reports. 2016;6:12.

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patterns rather than host genetics in a key Caribbean reef-builder, Orbicella annularis. In Proc. R. Soc. B (Vol. 283, No. 1842, p. 20161938).

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33. Mills M, Leon JX, Saunders MI, Bell J, Liu Y, O'Mara J, Lovelock CE, Mumby PJ, Phinn S, Possingham HP, Tulloch VJ. Reconciling Development and Conservation under Coastal Squeeze from Rising Sea Level. Conservation Letters. 2015 Dec 1.

34. Sampayo, Eugenia M., Tyrone Ridgway, Lorenzo Franceschinis, George Roff, Ove Hoegh-Guldberg, and Sophie Dove. "Coral symbioses under prolonged environmental change: living near tolerance range limits." Scientific Reports 6 (2016): 36271.

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36. Poloczanska, Elvira S., Michael T. Burrows, Christopher J. Brown, Jorge Garcia Molinos, Benjamin S. Halpern, Ove Hoegh-Guldberg, Carrie Vanessa Kappel et al. "Responses of marine organisms to climate change across oceans." Frontiers in Marine Science 3 (2016): 62.

37. Glasl, Bettina, Pim Bongaerts, Nathalie H. Elisabeth, Ove Hoegh-Guldberg, Gerhard J. Herndl, and Pedro R. Frade. "Microbiome variation in corals with distinct depth distribution ranges across a shallow–mesophotic gradient (15–85 m)." Coral Reefs (2017): 1-6.

38. Fang, J.K.H., Schoenberg, C.H.L., Hoegh-Guldberg, O., Dove, S., 2016. Day-night ecophysiology of the photosymbiotic bioeroding sponge Cliona orientalis Thiele, 1900. Marine Biology 163.

39. Pontasch, Stefanie, Paul L. Fisher, Thomas Krueger, Sophie Dove, William Leggat, Ove Hoegh-Guldberg, and Simon K. Davy. "Photoacclimatory and photoprotective responses to cold versus heat stress in high latitude reef corals." Journal of Phycology (2016).

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45. Bell, J., M. I. Saunders, J. X. Leon, M. Mills, A. Kythreotis, S. Phinn, P. J. Mumby, C. E. Lovelock, O. Hoegh-Guldberg, and T. Morrison. 2014. Maps, laws and planning policy: Working with biophysical and spatial uncertainty in the case of sea level rise. Environmental Science & Policy 44:247-257.

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BOOK CHAPTERS

1. Bell, J., Ganachaud, A., Gehrke, P., Hobday, A., **Hoegh-Guldberg, O.,** Johnson, J., Le Borgne, R., Lehodey, P., Lough, J., Pickering, T., Pratchett, M., Sikivou, M. and Waycott, M. (2013). Vulnerability of fisheries and aquaculture to climate change in Pacific Island countries and territories. In: J. Johnson, J. Bell, and C. De Young (eds) Priority Adaptations to Climate Change for Pacific Fisheries and Aquaculture: Reducing Risks and Capitalizing on Opportunities. FAO Fisheries and Aquaculture Proceedings no. 28, pp. 25-109.

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3. **Hoegh-Guldberg**, O. (2012), Implications of climate change for Asian-Pacific coastal and oceanic environments, in Climate Change and the Oceans: Gauging the Legal and Policy Currents in the Asia Pacific and Beyond, edited by R. Warner and C. H. Schofield, p. 21, Edward Elgar publishing Inc, Cheltenham, United Kingdom.

4. **Hoegh-Guldberg**, O. Andréfouët, S, Fabricius, KE, Diaz-Pulido, G., Lough, JM, Marshall, PA, Pratchett, MS (2011) “Vulnerability of coral reefs in the tropical Pacific to climate change” In *Vulnerability of tropical Pacific fisheries and aquaculture to climate change*, Editors: Johann D. Bell, Johanna E. Johnson, Alistair J. Hobday, Secretariat of the Pacific community, press.

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6. **Hoegh-Guldberg**, O (2011). Coral reefs, climate change and mass extinction. In “Extinction Risk from Climate Change”, Editor Lee Hannah, Island Press

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13. **Hoegh-Guldberg**, O (2007). Impacts of Climate Change on Coral Reefs. pp 59-68. In IMPACTS OF CLIMATE CHANGE ON AUSTRALIAN MARINE LIFE. A. J. Hobday, T. A. Okey, E. S. Poloczanska, T. J. Kunz and A. J. Richardson (Eds.). CSIRO Marine and Atmospheric Research

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19. **Hoegh-Guldberg**, O. (2004) Marine ecosystems and climate change. Chapter 20, Lovejoy and Hannah, L. Yale University Press (34 pp)

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REVIEWED PROCEEDINGS

1. Cameron MCDONALD*, Robert DUNBAR, Jeffrey KOSEFF, Stephen MONISMITH, Ove **HOEGH-GULDBERG**, Matthew REIDENBACH (2008) Large-scale, In-situ Measurements of Coral Reef Community Metabolism Using an Integrated Control Volume. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).
2. Stacy JUPITER*, Guy MARION, George ROFF, Meegan HENDERSON, Verena SCHRAMEYER, Malcolm MCCULLOCH, Ove **HOEGH-GULDBERG** (2008) Linkages between coral assemblages and coral-based proxies of terrestrial exposure along a cross-shelf gradient of the Great Barrier Reef. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).
3. Baraka KUGURU*, Nanette E. Chadwick CHADWICK, Yair ACHITUV, Sophie DOVE, Ove **HOEGH-GULDBERG**, Dan TCHERNOV (2008) Mechanisms of microhabitat segregation among corallimorpharians: Evidence from physiological parameters related to photosynthesis and host cellular response to irradiance. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).
4. Nedeljka ROSIC, Mauricio RODRIGUEZ-LANETTY, William LEGGAT, Ove **HOEGH-GULDBERG*** (2008) Effect of irradiance and increased temperature on differential gene expression in dinoflagellate. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).
5. Paulina KANIEWSKA*, Paul CAMPBELL, Maoz FINE, Ove **HOEGH-GULDBERG** (2008) Phototropic growth and molecular basis for axial polyp differentiation in the branching coral Acropora aspera. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).
6. Susana ENRQUEZ*, Eugenio MENDEZ, Ove **HOEGH-GULDBERG**, Roberto IGLESIAS-PRIETO (2008) MORPHOLOGICAL DEPENDENCE OF THE VARIATION IN THE LIGHT AMPLIFICATION CAPACITY OF CORAL SKELETON. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).
7. Joshua MEISEL*, Ruth REEF, Mauricio RODRIGUEZ-LANETTY, Sophie DOVE, Ove **HOEGH-GULDBERG** (2008) The Role of Oxidative DNA Damage and Repair in Cnidarian-Dinoflagellate

Symbiosis Breakdown. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

8. Bill LEGGAT, David YELLOWLEES, Sophie DOVE, Ove **HOEGH-GULDBERG*** (2008) Gene Expression in Symbiodinium Under Stress. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

9. Mauricio RODRIGUEZ-LANETTY*, Saki HARII, Ove **HOEGH-GULDBERG** (2008) Thermal regulation in coral larvae: a microarray screening. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

10. Nachshon SIBONI*, Eitan BEN-DOV, Alex SIVAN, Ove **HOEGH-GULDBERG**, Ariel KUSHMARO (2008) Global diversity and distribution of coral associated Archaea and the possible role in coral nitrogen cycle. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

11. Tracy AINSWORTH*, Ove **HOEGH-GULDBERG** (2008) Coral-bacterial associations vary under environmental and experimental conditions. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

12. Oren LEVY*, Lior APPELBAUM, William LEGGAT, Yoav GOTHILF, David HAYWARD, David MILLER, Ove **HOEGH-GULDBERG** (2008) Light-Responsive Cryptochromes from a Simple Multicellular Animal, the Coral Acropora millepora. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

13. Pim BONGAERTS*, Norbert ENGLEBERT, Tyrone RIDGWAY, Cynthia RIGINOS, Ove **HOEGH-GULDBERG** (2008) Genetic connectivity of the shallow and deep reef: intra-reef genetic structure of Seriatopora hystrix on the northern Great Barrier Reef. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

14. Justin MARSHALL, Dave LOGAN*, Ulrike SIEBECK, Ove **HOEGH-GULDBERG**, Joanne MARSTON, Jenny Miller GARMENDIA, Ania BUDZIAK (2008). CoralWatch: A Flexible Coral Bleaching Monitoring Tool for You and Your Group. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

15. William SKIRVING*, Roberto IGLESIAS-PREITO, Susana ENRIQUEZ, Tyler CHRISTENSEN, John HEDLEY, Mark EAKIN, Ove **HOEGH-GULDBERG**, Sophie DOVE, Scott HERON, Peter MUMBY, Alan STRONG, Gang LIU, Jessica MORGAN, Dwight GLEDHILL (2008) A methodology for using satellite-based temperature and light measurements for predicting coral bleaching severity and mortality. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

16. Ove **HOEGH-GULDBERG*** (2008) Is 500 ppm CO2 and 2□C of warming the 'tipping point' for coral reefs? If so, how should we respond? Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

17. David I. KLINE*, Kenneth R. N. ANTHONY, Guillermo DIAZ-PULLIDO, Sophie DOVE, Selina WARD, Ove **HOEGH-GULDBERG** (2008) Impacts of Ocean Acidification and Warming on Calcifying Coral Reef Organisms. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

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20. Ruth REEF*, Sophie DOVE, Maya CARMI, Ann MOONEY, Paulina KANIEWSKA, Oren LEVY, Ove **HOEGH-GULDBERG** (2008) Climate change can supersensitise corals to natural levels of ultra violet radiation. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

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23. Pim BONGAERTS*, Thomas BRIDGE, Eugenia SAMPAYO, Norbert ENGLEBERT, Tyrone RIDGWAY, Mauricio RODRIGUEZ-LANETTY, Jody WEBSTER, Ove **HOEGH-GULDBERG** (2008) Diversity of Symbiodinium in mesophotic coral communities on the Great Barrier Reef. Proceedings of the International Coral Reef Symposium, Fort Lauderdale, July 2008 (abstracts).

24. Marion GS, **Hoegh-Guldberg** O, McCulloch MT (2006). “Nitrogen isotopes (δ15N) in coral skeleton: Assessing provenance in the Great Barrier Reef Lagoon.” Geochimica et Cosmochimica Acta 70:13 (From the Goldschmidt International Geochemistry conference, Melbourne).

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28. Hoegh Guldberg, O. (2002) Coral reefs, thermal limits and climate change. Biodiversity Advisory Council meeting, Canberra (reviewed proceedings in print and on-line: http://www.deh.gov.au/biodiversity/science/bdac/greenhouse/chapter3.html#3-2)

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33. **Hoegh-Guldberg** O, Berkelmans R, Oliver J. 1997. Coral bleaching: implications for the Great Barrier Reef Marine Park. Proceedings of the Great Barrier Reef: Science, Use and Management National Conference, Townsville, 25-29 November 1996. Great Barrier Reef Marine Park Authority. 1: 210-224.

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36. Salih, A., O. **Hoegh-Guldberg** and Cox, G (1997) Bleaching Responses of Symbiotic Dinoflagellates in Corals: The Effect of Light and Elevated Temperature on their Morphology and Physiology. Proceedings of Australian Coral Reef Society 75th yr conference: 194-199.

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40. **Hoegh-Guldberg**, O. (1992) Is Acanthaster planci able to utilise dissolved organic matter (DOM) to satisfy the energy requirements of larval development? Great Barrier Marine Park Authority Workshop Series 18: 37-54

MAJOR REVIEWED RESEARCH REPORTS

1. **Hoegh-Guldberg**, O., **Hoegh-Guldberg**, H., Veron, J.E.N., Green, A., Gomez, E. D., Lough, J., King, M., Ambariyanto, Hansen, L., Cinner, J., Dews, G., Russ, G., Schuttenberg, H. Z., Peñaflor, E.L., Eakin, C. M., Christensen, T. R. L., Abbey, M., Areki, F., Kosaka, R. A., Tewfik, A., Oliver, J. (2009). The Coral Triangle and Climate Change: Ecosystems, People and Societies at Risk. WWF Australia, Brisbane, 276 pp.

2. Raven, J.; Caldeira, K; Elderfield, H., **Hoegh-Guldberg**, O.; Liss, P; Riebesell, U.; Shepherd, J.; Turley, C., Watson, A. (2005) Ocean acidification due to increasing atmospheric carbon dioxide. Royal Society Special Report, pp 68; ISBN 0 85403 617 2

3. **Hoegh-Guldberg**, H and Hoegh-Guldberg, O. (2004) Biological, Economic and Social Impacts of Climate Change on the Great Barrier Reef. World Wide Fund for Nature; 318 pp.

4. **Hoegh-Guldberg**, O., Hoegh-Guldberg, H, Stout, DK, Cesar, H, Timmerman, A (2000). Peril in Pacific: Biological, Economic And Social Impacts of Climate Change On Pacific Coral Reefs. Study for Greenpeace International, Amsterdam, The Netherlands (ISBN 1 876 221 10 0; 72 pp).

5. **Hoegh-Guldberg**, O. (1999). Coral bleaching, climate change and the future of coral reefs. Greenpeace International, 200 pp

6. **Hoegh-Guldberg**, O. (1997) The effect of nutrient enrichment on the energetics and growth of clams and reef-building corals. Final project report (ENCORE) to the Great Barrier Reef Marine Park Authority, 101 pp.

7. **Hoegh-Guldberg**, O. (1997) Nutrient induced perturbations to the natural abundance of carbon and nitrogen isotopes in reef-building corals. Final project report (ENCORE) to the Great Barrier Reef Marine Park Authority, 25 pp.

8. **Hoegh-Guldberg**, O. (1996) Effect of elevated nitrogen and phosphorus on the dynamics of dissolved free amino acids (DFAA) on micro atolls. Final project report (ENCORE) to the Great Barrier Reef Marine Park Authority, 42 pp.

9. **Hoegh-Guldberg**, O. (1995) The mass bleaching of coral reefs in the Central Pacific in 1994. A follow up study and establishment of long-term monitoring sites. Climate Impacts Series, 2. Greenpeace International

10. **Hoegh-Guldberg**, O. (1994) Mass-bleaching of coral reefs in French Polynesia, April 1994. Report for Greenpeace International (36 pages).

11. Ayukai, T. and **Hoegh-Guldberg**, O. (1992) "The role of DOM, bacteria and phytoplankton in the diet of the larvae of the Crown-of-Thorns starfish" GBRMPA report (45 pages).

INVITED SYMPOSIA, ABSTRACTS AND PRESENTATIONS (SINCE 2000)

1. **Hoegh Guldberg, O. (2016)** Towards COP22: African Ministerial Conference on Ocean Economies and Climate Change, World Bank Group, Mauritius (Nov, 2016)

2. **Hoegh Guldberg, O. (2016)** Oceans and climate change: Crunch time for coral reefs? Kathryn Fuller Plenary Lecture. WWF, Washington DC (Oct 20, 2016)

3. **Hoegh Guldberg, O. (2016)** Climate change, Paris, coastal planning and what just happened last week. Keeble Lecture: Planning Institute of Australia, Brisbane (Nov 7, 2016)

4. **Hoegh Guldberg, O. (2016)** Meeting the challenges of change: The Great Barrier Reef Marine science and climate change: Australian-Indonesian Science Symposium, Australian Academy of Science, Canberra (Nov 29-30)

5. **Hoegh Guldberg, O. (2016)**) COP21+1: The Paris climate change agreement, one year on: transition to low carbon economy, where does Australia stand? French Australian Chamber of Commerce (Nov 11, 2016)

6. **Hoegh Guldberg, O. (2016)** Emptying the treasure chest: The Great Barrier Reef, Biomimetics and Climate Change. Invited plenary: International Mesostructured Materials Symposium, Brisbane Convention Centre Brisbane, August 20, 2016

7. **Hoegh Guldberg, O. (2016)** Rough seas ahead? Oceans, coasts and climate change Invited lecture: Australian Embassy, Jakarta (Aug 25, 2016)

8. **Hoegh Guldberg, O. (2016)** Restoring the ocean economy: meeting the challenge of global change. Invited lecture: Business School, University of Jakarta, Jakarta (Aug 26, 2016)

9. **Hoegh Guldberg, O. (2016)** Climate Change and the Great Barrier Reef. Qantas employee association, Brisbane, August 27, 2016

10. **Hoegh Guldberg, O. (2016)** Grappling with a changing ocean: Coral reefs, people and COP21 (Paris) agreement. Invited talk, Bremen Earth and Social Science (BEST) talks: Bremen, Oct 27, 2016.

11. **Hoegh Guldberg, O. (2016)** Opening plenary: The Ocean, People and Ecosystem Health: Challenges and solutions in a changing world. One Health Congress & The 6th Biennial Conference of the International Association for Ecology and Health. Dec 4, 2016

12. **Hoegh Guldberg, O. (2016)** Plenary at the Scoping Meeting for the IPCC Special Report on Climate Change and Oceans and the Cryosphere, Dec 5-9 2016. Monte Carlo, Monaco;

13. **Hoegh Guldberg, O. (2016)** Temporal patterns of coral cover on the far northern Great Barrier Reef in response to mass bleaching stress and strong cyclones. Presentation to Department of Energy and the Environment, Canberra, Nov 28, 2016

14. **Hoegh Guldberg, O. (2016)** Introduction to public forum: Marine science and climate change: an Indonesian and Australian perspective. Australian-Indonesian Science Symposium; Australian Academy of Science, Canberra (Nov 28, 2016)

15. **Hoegh-Guldberg, O. (2014)** "State of the Science: Impacts of Ocean Acidification"; invited by US Secretary of State John Kerry to address "Our Ocean" summit at State Department in Washington DC (June 17, 2014).

16. **Hoegh-Guldberg, O. (2014)** "Positioning the Ocean within the Global Action Landscape", Opening plenary at the Global Ocean Action Summit, The Hague (April 22, 2014)

17. **Hoegh-Guldberg, O. (2014)** "Climate Change and the Unravelling of Microbial Partnerships in the Ocean", opening Plenary (as ASM Lecturer for 2014) for the American Society of Microbiologists, Boston (May 17, 2014).

18. **Hoegh-Guldberg, O. (2013)** Climate change in the ocean: where, how much and at what consequence? Alfred Wagner Institute, (October, 2013)

19. **Hoegh-Guldberg, O. (2013)** The Global Climate Challenge: Design Specifications for the 21st Century, Sustainable Minerals Institute, (Nov 22, 2013)

20. **Hoegh-Guldberg, O. (2013)** The Catlin Seaview Survey: a race against time; Catlin CEO conference, Singapore (May 15 2013)

21. **Hoegh-Guldberg, O. (2013)** The Catlin Seaview Survey: a race against time; Catlin CEO conference, London (August 21 2013)

22. **Hoegh-Guldberg, O. (2013)** The Catlin Seaview Survey: a race against time; Catlin CEO conference, Bermuda (September 13 2013)

23. **Hoegh-Guldberg, O. (2013)** The Catlin Seaview Survey: A race against time; Catlin CEO conference, Turks and Caicos (November 13 2013)

24. **Hoegh-Guldberg, O. (2013)** Coral Reefs in a rapidly changing climate: Going, going, gone? ARC Centre for Excellence conference. Coral Reefs in the 21st Century – Townsville, 2013.

25. **Hoegh-Guldberg, O. (2013)** Saving the Planet one Ocean at a Time, BrisScience, Brisbane City Hall, 2013.

26. **Hoegh-Guldberg, O. (2013)** Why should we worry about the Ocean? Plenary: Northeastern University, May 23 2013: Sustaining Coastal Cities

27. **Hoegh-Guldberg, O. (2013)** Opening plenary: Ecology, coral reefs and the human heart: meeting the challenge of climate change. Aug 20: INTECOL 2013 Into the next 100 years, London

28. **Hoegh-Guldberg, O. (2012)** Thomson Reuters Citation & Innovation Awards, Canberra. One of two award winners to address Press Club, Canberra (May 30, 2012)

29. **Hoegh-Guldberg, O. (2012)** Coral reefs in the rapidly changing climate: going, going, gone? Nobel Conference, October 3, Gustavus Adolphos College, Minnesota USA

30. **Hoegh-Guldberg, O. (2012)** Coral reefs and global climate change: Where do the solutions lie? Key Note Address, International Coral Reef Symposium, Cairns, July 5 2012.

31. **Hoegh-Guldberg, O. (2012)** Coral reefs and climate change: adapt or mitigate, what is more expensive? Australian Rivers Institute, Oct 2012

32. **Hoegh-Guldberg, O. (2012)** Climate change, ocean acidification and the future of coral reefs: One Perspective: What's next in research? Great Barrier Reef Marine Park Authority, Public lectures, Aug 9, Reef HQ, Townsville

33. **Hoegh-Guldberg, O. (2012)** Virtual diving. Invited TEDx Sydney talk (May 27, 2012)

34. **Hoegh-Guldberg, O. (2011)** Understanding future impacts of rapid ocean warming and acidification on the carbonate balance of coral reefs. Invited key note: American Geophysical Union annual meeting, San Francisco

35. **Hoegh-Guldberg, O. (2011)** Coral reefs, anthropogenic stressors and climate change. Nov 1 Key note to"ZMT symposium: Ocean acidification: A problem in the tropics?. University of Bremen, Germany

36. **Hoegh-Guldberg, O. (2011)** Invited Keynote: In hot water: The future of Australia's marine resources in a warm and assertion. Conference: Four Degrees or More? Australia in a hot world. July 12, Sidney Myer Centre, Melbourne.

37. **Hoegh-Guldberg, O. (2011)** Invited talk, Asian-Pacific in the spotlight: climate change, coasts and people. Launch of Children Health and Environment Program, Aug 7, Royal Children's Hospital, Herston Campus.

38. **Hoegh-Guldberg, O. (2011)** Ocean planet: Understanding, living and meeting the challenges of a changing world, Peter Doherty Lecture, Indooroopilly State High School, Aug 12, 2011 (also filmed and made into an episode of ABC catalyst).

39. **Hoegh-Guldberg, O. (2011)** Climate change: The Conservation Challenge for Marine Resources and People in the Pacific Keynote address – Fijian Conservation Society Annual meeting. Sep 16, 2011

40. **Hoegh-Guldberg, O. (2011)** " Large-scale change in marine ecosystems" World Forum on the Environment and Enterprise, Oxford University, June 30, 2011. Invited by Sir David King

41. **Hoegh-Guldberg, O. (2011)** " The Global Ocean: Climate Change, blue economics, and essential ecological services. Can we live without them? The World Bank, June 23 2011.

42. **Hoegh-Guldberg, O. (2011)** "Climate change and the Coral Triangle" International Conference on Biodiversity and Climate Change, Manila, Philippines (Feb 1, 2011)

43. **Hoegh-Guldberg, O. (2011)** "Climate change and the future of the Great Barrier Reef." Invited keynote talk, Greenhouse 2011.

44. **Hoegh-Guldberg, O. (2011, by video)** "Climate change and coral reef ecosystems". I International Programme on the State of the Ocean, the Royal Society and the Zoological Society of London (July 6, 2011)

45. **Hoegh-Guldberg, O. (2011)** Climate change, coastal biodiversity, and people: The folly of false optimism. Invited keynote, Biodiversity Research Centre Academia Sinica, Taipei. (March 24, 2011)

46. **Hoegh-Guldberg, O. (2011)** "Scaling up from experimental responses" , Invited address, IPCC, 11-14 January WGII AR5 First Lead Authors Meeting – Okinawa, Japan

47. **Hoegh-Guldberg, O. (2011, by video)** "The Coral Reef Story". Workshop on ocean acidification for teachers; Committee on Education of the European Geosciences Union (EGU; June 24, 2011)

48. A. Redondo-Rodriguez, S.J. Weeks, R. Berkelmans, J.M. Lough, C. Steinberg, **O. Hoegh-Guldberg,** Implications of climate change for the oceanography of the Great Barrier Reef ecosystem [abstract]. In: Marine and Tropical Sciences Research Facility 2009 Annual Conference; 2009 Apr 28-30; Townsville, Queensland: MTRSF: 2009, P 50.

49. **Hoegh-Guldberg, O. (2010)** "The Coral Triangle Alliance." Senior Officials Meeting, CTI, Manado, Indonesia November 2011. Invited by Indonesian Minister Fadel Muhammad, Fisheries and Marine Affairs to address meeting.

50. **Hoegh-Guldberg, O. (2010)** "The impacts of climate change on world's marine ecosystems." NCCARF, Brisbane, September 2010

51. **Hoegh-Guldberg**, O. (2010) "Climate change and its impact on ocean ecosystem function." Potsdam, Germany September 10, 2010

52. **Hoegh-Guldberg**, O. (2010) "Climate change and marine ecosystems: have dangerous changes already begun?", Oxford University, September 6, 2010

53. **Hoegh-Guldberg, O. (2010)** "Climate change and the global ocean - have we gone too far?" ISME-13 STEWARDS OF A CHANGING PLANET, Seattle Washington, August 26, 2010

54. **Hoegh-Guldberg**, O. (2010) "Our Changing Oceans: evidence, implications and ramifications" Stanford University, August 18, 2010

55. **Hoegh-Guldberg**, O. (2010) "Ocean acidification: unraveling the complexities of its impacts on coral reefs", Shine Dome, Canberra, 7 Oct 2010

56. **Hoegh-Guldberg**, O. (2009) "Coral reefs, symbiosis and Koyaanisqatsi." June 27 Invited speaker, Archilife Research Foundation, Tapei, Taiwan

57. **Hoegh-Guldberg**, O. (2009) "Oceans of Change: Why we must achieve firm action on CO2 emissions in Copenhagen." June 23 Invited Speaker, Australian Education International, Tapei, Taiwan.

58. **Hoegh-Guldberg**, O. (2009) "Coral reefs, evolution and climate change." Workshop: Responses of Coral Holobionts under the Impact of Climate Change: Symbiont Diversity, Coral Bleaching, Diseases, and Ocean Acidification; June 23 Invited speaker. Tapei, Taiwan

59. **Hoegh-Guldberg**, O. (2009) "Coral reefs and climate change: Is there any hope for coral reef ecosystems?" Workshop: Responses of Coral Holobionts under the Impact of Climate Change: Symbiont Diversity, Coral Bleaching, Diseases, and Ocean Acidification. June 22, Plenary speaker. Tapei, Taiwan

60. **Hoegh-Guldberg**, O. (2009) Coral reefs in a rapidly heating and acidifying global ocean: reasons for hope and strategies for survival. World Ocean Congress, Manado, Indonesia (May 11-15, 2009)

61. **Hoegh-Guldberg**, O. (2009) "450 ppm or bust: Copenhagen, climate change and the future of the earth's biosphere." Invited speaker, Woods Institute, Stanford University.

62. **Hoegh-Guldberg**, O. (2009) “Climate change and our climate” Invited speaker, Blue Visions Summit, Washington DC, March 2009.

63. **Hoegh-Guldberg**, O. (2009) "The Coral Reef Crisis", Invited lecture to EarthStock Day at Stony Brook University, New York, USA.

64. **Hoegh-Guldberg**, O. (2009) "Coral reefs and Rapid Climate Change: Impacts, Risks and Implications for Tropical Societies.” International Scientific Congress on Climate Change, University of Copenhagen, March 12-14 2009.

65. **Hoegh-Guldberg** O (2008) Coral reef ecosystems, climate change and human societies. Key Note Address to the World Bank's Environment Sector Board, Washington DC, USA.

66. **Hoegh-Guldberg** O (2008) Keynote address “Coral reefs and global change”. AAAS Annual Meeting in Boston on "Global Interactions between Climate Change and Microbial Activity." Boston MA, USA

67. **Hoegh-Guldberg** O (2008) “Coral reefs and ocean acidification.” Invited lecture given as part of the public symposium “What's Killing the Coral Reefs?” at the Marian Koshland Science Museum Coral Reefs Program Washington DC, USA

68. Hoegh-Gulderg O (2008) Invited keynote address. “Climate change, coral bleaching and the future of the world's coral reefs.” International Symposium on the Effects of Climate Change on the World’s Oceans, Gijón, Spain May 19-23, 2008

69. **Hoegh-Guldberg** O. Invited Key Note speech for opening of King Abdullah University of Science and Technology (KAUST) Symposium 2008 - "The Sustainability of Coral Reefs Faced by Unprecedented Environmental Change", Jeddah, Saudi Arabia

70. Schuttenberg, H., C. Corrigan, L. McLeod, P. Marshall, N. Setiasih, D. Obura, O. **Hoegh-Guldberg**, B. Causey, M. Drew, L. Hansen, G. Grimsditch, J. West, A. Skeat, M. Eakin, L. McCook, M. Crawford, P. Kramer and S. Campbell, 2007. “Building resilience into coral reef management: Key findings & recommendations,” In ICRAN and ICRI. 2007. Proceedings of the 3rd International Tropical Marine Ecosystems Management Symposium (ITMEMS3), Cozumel, Mexico, 16-20 October 2006. ICRI and ICRAN, Cambridge, UK.

71. Stacy Jupiter, Guy Marion, George Roff, Meegan Henderson, Verena Schrameyer, Ove **Hoegh-Guldberg** (2007) Linkages between coral assemblages and coral-based proxies of terrestrial exposure along a cross-shelf gradient of the Great Barrier Reef. Annual Australian Coral Reef Society Conference, Fremantle, Western Australia.

72. Marion GS, **Hoegh-Guldberg** O., McCulloch MT, Mucciarone DM, Dunbar RB (2006). Isotopes (δ15N) in coral skeleton: A proxy for historical Great Barrier Reef water quality. Annual Australian Coral Reef Society Conference, Mission Beach, QLD.

73. **Hoegh-Guldberg**, O. (2006) Climate Change and Coral Reefs: Time frames, growing risk and indecision, National University of Mexico, Mexico, December 11, 2006.

74. **Hoegh-Guldberg**, O. (2006) Global Warming and Coral Reefs: All over, except for the singing? University of Texas, Texas, November 21, 2006.

75. **Hoegh-Guldberg**, O. (2006) Coral Reefs and Environmental Change: Workshop for Cook Islands Government, University of Queensland, CRTR GEF Program, September 11, 2006.

76. **Hoegh-Guldberg**, O. (2005) The Great Barrier Reef – at risk? Plenary talk at the Davos leadership retreat, Hayman Island Resort, August 26, 2006.

77. **Hoegh-Guldberg**, O. (2006) Global ideas and networks: Opportunities and challenges in the international science arena. Plenary talk at INORMS Internationalization of Research Conferences, Brisbane Convention Centre, August 23, 2006.

78. **Hoegh-Guldberg**, O. (2006) Sustaining the Marine Environment, Pioneering a sustainable Queensland Talk Series, Queensland Museum, May 31, 2006.

79. **Hoegh-Guldberg**, O. (2006) Chairman's Panel, leadership retreat on Coral Reefs, Orpheus Island, May 24, 2006.

80. **Hoegh-Guldberg**, O. (2006) Great Barrier Reef Research Foundation dinner, Dinner address to Board, Customs House, Brisbane, May 11, 2006.

81. **Hoegh-Guldberg**, O. (2006) Address to Rio Tinto Board on Coral Reefs and Climate Change, Rio Tinto, May 10, 2006.

82. **Hoegh-Guldberg**, O. (2006) IOC-UNESCO Working Group on Coral Bleaching and Related Ecological Factors (Bleaching Working Group). Opening talk at UNESCO-IOC, Paris, April 10, 2006.

83. **Hoegh-Guldberg**, O. (2006) Coral Reefs and climate change – prognosis? SEB Conference / Thermal Biology of Coral Reefs, University of Kent, Canterbury, April 5, 2006.

84. **Hoegh-Guldberg**, O. (2006) The Great Barrier Reef and Climate Change, UNESCO conference on climate change and World Heritage sites, UNESCO headquarters, Paris, March 15, 2006.

85. Lawton, A, **Hoegh-Guldberg**, O (2006) the effect of temperature on the photosynthetic and respiration rate of reef building corals. ACRS conference, Abstract.

86. Ainsworth, TD, **Hoegh-Guldberg**, O (2006) Pathology and Microbial Ecology in Coral Disease and Bleaching. ACRS conference, Abstract.

87. Marion, GS, **Hoegh-Guldberg**, O, Jupiter, SD, McCulloch, MT (2006) Coral isotopic records (δ15N) of unprecedented land-use stress in Great Barrier Reef coastal communities. ACRS conference, Abstract.

88. Kaniewska, P., Sampayo, E., Anthony, K., **Hoegh-Guldberg**, O. (2006) Exploring factors affecting within colony light attenuation at macro and micro scale in Stylophora pistillata. ACRS conference, Abstract.

89. **Hoegh-Guldberg**, O (2006) Complexities of climate change for coral reefs: what are the key questions? ACRS conference, Abstract. Heron, M.L., **Hoegh-Guldberg**, O, Willis, B, Skirving, W, Steinberg, C, Caley, J, Bayler, J, Colton, M, (2005) HF Ocean Surface Radar as a Monitoring Technique for Coral Bleaching. IAPSO/IABO Abstract August 2005 Cairns, Australia

90. **Hoegh-Guldberg**, O. (2005) Climate change and Australia's coral reefs. Participant in joint workshop on challenges for the Great Barrier Reef at the Davos leadership retreat, Hayman Island Resort, August 2005.

91. Marion GS, Jupiter SD, **Hoegh-Guldberg** O, McCulloch MT (2005). "Mackay Whitsunday quality and coral-mangrove ecosystem linkages since European colonization." The Mackay Whitsunday Healthy Waterway Forum (MWNRM). Keynote Speaker, Sarina QLD.

92. **Hoegh-Guldberg**, O. (2005) Coral reefs in 2050: Life in a warm acid sea. Plenary, Australian Ecological Society, Brisbane, October 2005.

93. **Hoegh-Guldberg**, O. (2005) Challenges for tourism in a warming world. Responding to coral bleaching and climate change. Australian Reef Tour operator's workshop, Cairns, October 2005.

94. **Hoegh-Guldberg**, O. (2005) Coral-algal symbiosis in a changing environment. Invited Seminar, Interuniversity Underwater Institute, Eilat, Israel, June 3, 2005

95. **Hoegh-Guldberg**, O. (2005) Climate change and coral reefs - the burning issues. Invited seminar, Weizmann Centre, Israel, June 3, 2005

96. **Hoegh-Guldberg**, O. (2005) Coral reefs in a warming, acidifying ocean. Invited seminar to Intergovernmental Panel on Climate Change, Canberra, March 13, 2005

97. **Hoegh-Guldberg**, O. (2004) The Great Barrier Reef in the Current Century of Rapid Environmental Change. University of Pennsylvania, October 18, 2004

98. **Hoegh-Guldberg**, O. (2004) Coral Bleaching: A Multinational, Multidisciplinary Program to Address a Critical Global Issue. Invited talk to CZAP, Sydney.

99. **Hoegh-Guldberg**, O. (2004) Targeted Research Program to understand climate change impacts on coral reefs. Invited lunchtime seminar, World Bank, Washington, Oct 18-22, 2004.

100. **Hoegh-Guldberg**, O. (2004) The Great Barrier Reef and Climate Change. Invited seminar to the DAVOS leadership retreat. August 2004.

101. **Hoegh-Guldberg**, O. (2004) Low coral cover in a high CO2 world. In the special symposium entitled "The Ocean in a High CO2 World." hosted by IOC-UNESCO and SCOR, Paris, May 2004

102. **Hoegh-Guldberg**, O. (2004) Changing environmental envelopes. Degraded coral reefs or coral reefs off Sydney? Invited seminar at the Great Barrier Reef Water Quality conference, Townsville, March 2004.

103. **Hoegh-Guldberg**, O. (2004) Great Barrier Reef: Coral, climate and the future. Invited speaker at launch of major report. World Fund for Nature, Sydney March 2004

104. Vestergaard, O, **Hoegh-Guldberg**, O, Unluata, U (2003) Understanding Coral Bleaching Across Four Oceans - Addressing CBD's Specific Workplan On Coral Bleaching Convention of Biological Diversity (CBD), SBSTTA 8, 10-14 March 2003, Montreal,

105. Hoegh Guldberg, O. (2003) Near and long-term strategies for preserving coral reefs. Invited Discussant; 5th International Conference on Environmental Future (5th ICEF) 23-27 March 2003 ETH Zurich, Switzerland

106. Hoegh Guldberg, O. (2003) Invited Plenary and Congress Welcome: Bleaching of coral symbionts: A global threat 4-International Symbiosis Society Congress Programme, August 17, 2003; Halifax, Canada

107. Hoegh Guldberg, O. (2003) The Physiological Ecology of Mass Coral Bleaching. Invited talk at US Coral Reef Task Force Meeting: Coral Reefs, Climate, & Coral Bleaching June 18 – 20, 2003; Turtle Bay Resort Hotel, Oahu, Hawaii

108. Hoegh Guldberg, O. (2003) Climate change and the Great Barrier Reef, Invited talk, Reef Summit 2004, Townsville July 4 2003.

109. Hoegh Guldberg, O. (2003) Wishful thinking or science waiting to be done? Coral reefs, thermal thresholds and climate change. Invited lecture, Australian Institute of Marine Science. February 14, 2003.

110. Hoegh Guldberg, O. (2003) Invited plenary: Climate change and the future of Australia's marine ecosystems. Australian Maritime Engineers annual conference. Nov 2003

111. **Hoegh-Guldberg**, O (2003) Coral Bleaching TRG: Introduction and synthesis. 4th Coral Bleaching Working Group meeting (synthesis and planning), IOC/UNESCO, Paris, 29-31 March 2003

112. Hoegh Guldberg, O. (2002) Coral reefs, thermal thresholds and climate change. Australian Coral Reef Society, Annual meeting, Moreton Bay Research Station, Brisbane, July 2002.

113. Hoegh Guldberg, O. (2002) World Bank/GEF Targeted Research Initiative into coral reefs and climate change - an overview. Australian Coral Reef Society, Annual meeting, Moreton Bay Research Station, Brisbane, July 2002.

114. del Carmen Gómez-Cabrera, M., van Oppen, M., **Hoegh-Guldberg**, O. (2002) Seasonal variations in symbiotic dinoflagellate populations. Australian Coral Reef Society, Annual meeting, Moreton Bay Research Station, Brisbane, July 2002.

115. Hoegh Guldberg, O. (2002) Coral reefs, thermal limits and climate change. Biological Diversity Advisory Committee, 1-2 October 2002 (ANU, Canberra)

116. Johnson, C.R., Dunstan, P.K., **Hoegh-Guldberg**, O. (2002) Predicting the Long Term Effects of Coral Bleaching and Climate Change on the Structure of Coral Communities. World Bank-UNESCO Targeted Working Group on modeling climate change, Miami Florida, USA.

117. Johnson CR, Dunstan PK, **Hoegh-Guldberg** O (2002) Predicting the long term effects of coral bleaching and climate change on the structure of coral communities. In: Proc Int Soc Reef Studies Eur Meeting, Cambridge, Sept, Abstr vol 50

118. **Hoegh-Guldberg**, O. (2002) Critical mechanisms in coral bleaching. GEF-WB-IOC Puerto Morelos field workshop, Mexico 9-22 Sept 2002

119. Franklin D.J., **Hoegh-Guldberg**, O., Jones, RJ, and Berges, JA (2002) Oxidative stress and depressed variable fluorescence correlate with dinoflagellate death in the coral Stylophora pistillata GEF-WB-IOC Heron Island field workshop, Great Barrier Reef, 25 Feb-18 March 2002:

120. Johnson, CR, Dunstan, PK, **Hoegh-Guldberg**, O (2002) Predicting the long term effects of coral bleaching and climate change on the structure of coral communities. GEF-WB-IOC Heron Island field workshop, Great Barrier Reef, 25 Feb-18 March 2002:

121. Smith, C.R., Dove, S., **Hoegh-Guldberg**, O, Wilson, K. and van Oppen, M. (2002) The heat stress response of Acropora millepora: a population perspective. GEF-WB-IOC Heron Island field workshop, Great Barrier Reef, 25 Feb-18 March 2002

122. **Hoegh-Guldberg**, O. (2001). "Sizing the impact: Coral reef ecosystems as early casualties of climate change" invited plenary at conference"Detecting the Fingerprints of Climate Change". Gland, Switzerland.

123. Hoegh Guldberg, O. (2001) The Future Of Coral Reefs: Integrating Climate Model Projections And The Recent Behaviour Of Corals And Their Dinoflagellates. Invited seminar, Situating the Environment, Conference, St Lucia.

124. Hoegh Guldberg, O. (2001) Tropical Marine Science. Setting priorities for universities. Invited talk, Queensland State Development.

125. Hoegh Guldberg, O. (2001) Climate change and implications for fisheries. Invited Plenary, Fisheries Summit May 1 2001

126. Hoegh Guldberg, O. (2001) Climate Change and Australia's coral reefs. ACRS 2001 Annual Conference of the Australian Coral Reef Society, Magnetic Island, Townsville, Queensland, 6-8 July 2001.

127. Hoegh Guldberg, O. (2001) the Great Barrier Reef: Our Dead Sea? Invited Plenary at the Photosynthesis Conference, Sydney, June 2001.

128. Hoegh Guldberg, O. (2000) Photoinhibition and climate change: why reefs bleach. Invited seminar at Max Planck Institute, Bremen, Germany, June 16, 2000

129. Hoegh Guldberg, O. (2000) How will coral reef ecosystems react to projected changes in sea temperature? Invited Plenary speaker, Copenhagen ASLO meeting and Special session: SS27 - Climate change, weather patterns and aquatic systems

130. **Hoegh-Guldberg**, O. (2000) The future of coral reefs: integrating climate model projections and the recent behaviour of corals and their dinoflagellates. Proceeding of the Ninth International coral reef symposium, October 23-27, 2000. Bali, Indonesia,

131. Ward, S, Harrison, PJ and **Hoegh-Guldberg**, O (2000) Coral bleaching reduces reproduction of scleractinian corals and increases susceptibility to future stress. Proceedings of the Ninth International symposium for Reef Studies. October 23-27, 2000. Bali, Indonesia,

132. Ridgway, T., **Hoegh-Guldberg**, O. (2000). Reef recovery in disturbed coral reef ecosystems. Ninth International Coral Reef Society Symposium. October 23-27, 2000. Bali, Indonesia,

133. Carter, D.A., Gava, N., Loi, T.H., Loh, W.KW and **Hoegh-Guldberg**, O. (2000) Genetic diversity of symbiotic dinoflagellates ("zooxanthellae") inhabiting different scleractinian coral species. Australian Society for Microbiology Conference, Cairns, 8-11 July 2000

134. **Hoegh-Guldberg, O. (2000)** Corals - Sentinels of Global Change. Australian Marine Science Association, plenary, Townsville, Friday, 31 March 2000

RECENT PROFESSIONAL SERVICE (2016 ONLY)

1. Australian Government Great Barrier Reef Independent Expert Panel
2. ARC Centre of Excellence for Coral Reef Studies Deputy Director
3. Great Barrier Reef Foundation International Scientific Advisory Committee
4. Great Barrier Reef Marine Park Authority Bleaching Scientific Advisory Panel
5. Queensland Government's Great Barrier Reef Water Science Taskforce
6. XL Catlin Seaview Survey Chief Scientist
7. UNESCO member of working group on ethical consideration of climate change (September, Rabat)
8. World Bank Blue Ribbon Panel for the Global Partnership for Oceans Chair
9. Australian representative (one of two) on the IPCC scoping committee for the special report on the impacts of global warming of 1.5°C above pre-industrial levels (August, Geneva)
10. Australian representative (one of three) on the IPCC scoping committee for the special report on the Climate change on the Ocean and Cryosphere (December, Monte Carlo)
11. Coordinator for 3-day meeting between the Australian and Indonesian Academies of Science (Canberra)

OTHER CONTRIBUTIONS (2016 ONLY)

1. Australian Government Great Barrier Reef Independent Expert Panel Event occurred throughout Feb and March, but was confirmed in March
2. **Fighting coral bleaching:** Then-Federal Environment Minister Greg Hunt announced funding for GCI researchers to re-survey the Great Barrier Reef following the worst global coral bleaching event in recorded history.
3. 27 March to April 2. **Course on managing climate change in tropical coastal settings.** Hoegh-Guldberg, Nha Trang University, Vietnam
4. 11 March; **World Science Festival**: National Geographic explorer-in-residence Dr Sylvia Earle, James Cook University's Professor Terry Hughes and GCI's Professor Ove Hoegh-Guldberg joined a panel discussion, *Can we save our precious reefs in time?*, as part of the prestigious World Science Festival.

5. 12 March; Introduction by Hoegh-Guldberg. Thomas Oration by Hon Robert Hill AO; Festival Lab, Cultural Forecourt, Melbourne Street, South Brisbane

6. 6 April; **Sir David Attenborough Premiere**. The Great Barrier Reef Foundation joined UQ in hosting the Australian premiere of *Sir David Attenborough's Great Barrier Reef*.

7. May 28 to June 3, 2016. Hoegh-Guldberg invited and attends, Prince Albert II of Monaco Foundation will be celebrating its 10th anniversary on Thursday 30th June 2016,

8. July 7-11; Discussion of Australian and Indonesian scientific collaboration. Planning for meetings and workshop in November in Canberra between academies.

9. Aug 4 2016. Climate change and coral reef. Meetings with Bloomberg Foundation over potential collaborations; Bloomberg headquarters; New York

10. International Partnership for Blue Carbon workshop; invited by Australian Government. Global Change Institute (foundation member); 23-24 August in Bogor, Indonesia.

11. **Should climate change impacts on the ocean raise the level of climate action ambition?** Invitation by the government of Chile, Washington DC, September 14-15

12. **Scoping meeting for special IPCC report on 1.5oC and the future.** Invited expert for scoping meeting for the IPCC Special Report on the Impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways. Geneva,15 - 18 August 2016.

13. **Development of Non-binding Declaration of Ethical Implications of Climate Change.** 29-25 September, Rabat, Morrocco

14. **Reviving Melanesia's Ocean Economy: The case for action.** Global Report released (Hoegh-Guldberg, Ridgway and Boston Consulting Group), 18 October

15. Leibniz Center for Tropical Marine Ecology (ZMT). International Board meeting. Bremen, German. 24-28 October

16. **Australian and Indonesian Academies meeting convened by GCI Director. Canberra**. Convened and presented at meeting of scientists from Indonesia and Australian Academies Public day plus closed session workshops with plenary presentations on health, marine science and climate; November 28-30

17. **IPCC scoping meeting for the IPCC Special Report on climate change and oceans and the cryosphere, invited expert.** Monaco. 6-9 December 2016.

EXHIBIT B: LIST OF PUBLICATIONS (LAST TEN YEARS)

2018 (TO DATE)

1. Achlatis, M., M. Pernice, K. Green, P. Guagliardo, M.R. Kilburn, O. Hoegh-Guldberg and S. Dove. Single-cell measurement of ammonium and bicarbonate uptake within a photosymbiotic bioeroding sponge. The ISME Journal. doi:10.1038/s41396-017-0044-2

2. Brown, K. T., D. Bender-Champ, A. Kubicek, R. van der Zande, M. Achlatis, O. Hoegh-Guldberg, and S. G. Dove. 2018. The dynamics of coral-algal interactions in space and time on the southern Great Barrier Reef. Frontiers in Marine Science 5.

3. Skirving, W., S. Enríquez, J.D. Hedley, S. Dove, C.M. Eakin, R.A.B. Mason, J.L. De La Cour, G. Liu, O. Hoegh-Guldberg, A.E. Strong, P.J. Mumby and R. Iglesias-Prieto. 2018. Remote Sensing of Coral Bleaching Using Temperature and Light: Progress towards an Operational Algorithm. Remote Sensing, 10(1): 18.

4. Seneviratne, S. I., J. Rogelj, R. Seferian, R. Wartenburger, M. R. Allen, M. Cain, R. J. Millar, K. L. Ebi, N. Ellis, O. Hoegh-Guldberg, A. J. Payne, C. F. Schleussner, P. Tschakert, and R. F. Warren. 2018. The many possible climates from the Paris Agreement's aim of 1.5 degrees C warming. Nature 558:41-49.

5. Fang, J. K. H., C. H. L. Schoenberg, M. A. Mello-Athayde, M. Achlatis, O. Hoegh-Guldberg, and S. Dove. 2018. Bleaching and mortality of a photosymbiotic bioeroding sponge under future carbon dioxide emission scenarios. Oecologia 187:25-35

2017

1. Achlatis, Michelle, van der Zande, Rene M., Schonberg, Christine H. L., Fang, James K. H., Hoegh-Guldberg, Ove and Dove, Sophie (2017) Sponge bioerosion on changing reefs: Ocean warming poses physiological constraints to the success of a photosymbiotic excavating sponge. Scientific Reports, 7 1: . doi:10.1038/s41598-017-10947-1

2. Albert, Simon, Saunders, Megan I., Roelfsema, Chris M., Leon, Javier X., Johnstone, Elizabeth, Mackenzie, Jock R., Hoegh-Guldberg, Ove, Grinham, Alistair R., Phinn, Stuart R., Duke, Norman C., Mumby, Peter J., Kovacs, Eva and Woodroffe, Colin D. (2017) Winners and losers as mangrove, coral and seagrass ecosystems respond to sea-level rise in Solomon Islands. Environmental Research Letters, 12 9: . doi:10.1088/1748-9326/aa7e68

3. Brown, Kristen T., Bender-Champ, Dorothea, Bryant, Dominic E. P., Dove, Sophie and Hoegh-Guldberg, Ove (2017) Human activities influence benthic community structure

and the composition of the coral-algal interactions in the central Maldives. Journal of Experimental Marine Biology and Ecology, 497 33-40. doi:10.1016/j.jembe.2017.09.006

4. Bryant, D. E. P., Rodriguez-Ramirez, A., Phinn, S., Gonzalez-RIVERO, M., Brown, K. T., Neal, B. P., et al. (2017). Comparison of two photographic methodologies for collecting and analyzing the condition of coral reef ecosystems. Ecosphere 8. doi:10.1002/ecs2.1971.

5. Bongaerts P, Riginos C, Brunner R, Englebert N, Smith SR, Hoegh-Guldberg O. Deep reefs are not universal refuges: Reseeding potential varies among coral species. Science Advances. 2017;3:12.

6. Englebert N, Bongaerts P, Muir PR, Hay KB, Pichon M, Hoegh-Guldberg O. Lower Mesophotic Coral Communities (60-125mDepth) of the Northern Great Barrier Reef and Coral Sea. Plos One. 2017;12:16.

7. Enriquez S, Mendez ER, Hoegh-Guldberg O, Iglesias-Prieto R. Key functional role of the optical properties of coral skeletons in coral ecology and evolution. Proceedings of the Royal Society B-Biological Sciences. 2017;284:9.

8. Fang JKH, Mason RAB, Schonberg CHL, Hoegh-Guldberg O, Dove S. (2017) Studying interactions between excavating sponges and massive corals by the use of hybrid cores. Marine Ecology-an Evolutionary Perspective. 2017;38:8.

9. Fang JKH, Schonberg CHL, Hoegh-Guldberg O, Dove S. Symbiotic plasticity of Symbiodinium in a common excavating sponge. Marine Biology. 2017;164:11.

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EXHIBIT C: STATEMENT OF PREVIOUS TESTIMONY WITHIN PRECEDING FOUR YEARS AS AN EXPERT AT TRIAL OR BY DEPOSITION

I appeared as an expert witness in the objection hearing in the Land Court of Queensland in 2015. Details of that case are available at http://envlaw.com.au/carmichael-coal-mine-case/ and my expert report is available at http://envlaw.com.au/wp-content/uploads/carmichael17.pdf.

I have also appeared as an expert witness outside the four-year window. The most recent (other than for Carmichael) was the Wandoan Coal Mine in 2011 (see http://envlaw.com.au/wandoan-coal-mine-case/ including my report).

Prior to this, I acted as an expert witness in 2007 regarding the expansion of the Newlands Coal Mine (see http://envlaw.com.au/newlands-coal-mine-case/ including my report).

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EXHIBITS E–BB: VIDEO EXHIBITS

Exhibits E through AA are all video exhibits, attached hereto via portable hard drive. Exhibit BB is a spreadsheet documenting the precise location, GPS coordinates, timecode of the video clip, metadata, and dates for Exhibits E-AA, and is also attached hereto via portable hard drive.