UN environment

UN environment 2017

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Downscaled projections of bleaching conditions for the world's coral reefs, implications of climate policy and management responses

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2017

Citation: UNEP 2017. ***Coral Bleaching Futures - Downscaled projections of bleaching conditions for the world's coral reefs, implications of climate policy and management responses.*** United Nations Environment Programme, Nairobi, Kenya

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ISBN: 978-92-807-3649-6

Job No: DEP/2103/BA

Acknowledgements: Financial and in-kind support for this research was provided by: UNEP, NOAA Coral Reef Conservation Program, NOAA Atlantic Oceanographic and Meteorological Laboratory, NOAA National Marine Fisheries Service via the PIFSC, World Wildlife Fund, the US National Fish and Wildlife Foundation, USGS via the Pacific Islands Climate Science Center, the Pacific Islands Climate Change Cooperative, RSMAS at the University of Miami, and the European Research Council.

Comments on the draft report by the following reviewers is acknowledged: Kanako Hasegawa, UNEP; Alessandra Vanzella-Khouri, CEP; Pulakesh Mondal, SACEP; Reynaldo F Molina, COBSEA; Maher Amer, PERSGA; Abou Bamba, Abidjan Convention; Warren Lee Long, SPREP; as well as two anonymous reviewers.

Parts of this report are based on: van Hooidonk R, Maynard J, Tamelander J, Gove J, Ahmadia G, Raymundo L, Williams G, Heron S, Planes S (2016) Local-scale projections of coral reef futures and implications of the Paris Agreement. *Scientific Reports.* doi:10.1038/srep39666

Front cover photo: Paul Marshall; Inset: Projected onset of twice-per-decade severe bleaching under a business as usual emission scenario; Back cover photo: Jerker Tamelander.

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Executive Summary

Background and Objectives

Increasingly frequent severe coral bleaching is among the greatest threats to coral reefs posed by climate change. Global climate models (GCMs) project great spatial variation in the timing of annual severe bleaching (ASB) conditions; a point at which reefs are certain to change and recovery will be limited. However, previous model-resolution projections (approximately 1x1°) are too coarse to inform reef management planning (recognized, for example, in SAMOA Pathways, paragraph 44b). To meet the need for higher-resolution projections, the first objective of this report is to present statistically downscaled projections (4-km resolution) for all the world's coral reefs using the newest generation of IPCC climate models (CMIP5). Results are reported by country and territory, grouped in bioregions based on the 10 UNEP Regional Seas programmes with coral reefs (also including countries or territories in or near the Regional Sea area but not participating in the Regional Sea).

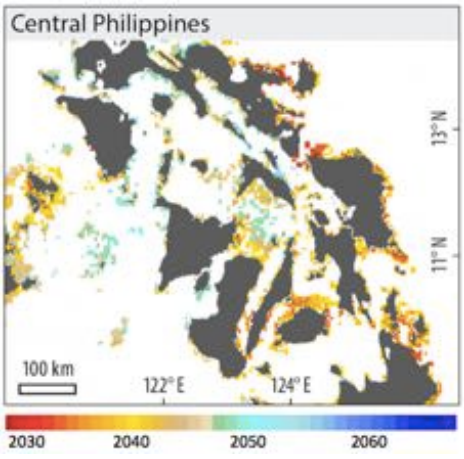
Among the goals of the Paris Agreement adopted at the UNFCCC Conference of Parties (COP) in 2015 is to hold temperature "well below" 2°C while also pursuing efforts to stay below 1.5°C. This legally binding agreement entered into force 4 November 2016. The second objective of this report is to evaluate the implications of the Paris Agreement for coral reef futures by comparing projections of ASB timing between successful mitigation in line with or exceeding the 1.5 °C 'aspiration (i.e. greenhouse gas concentration trajectory RCP4.5) and a business as usual scenario (RCP8.5).

The third objective of this report is to make the projection data and main findings publicly accessible to inform management and policy planning as well as to support education and outreach.

Projections of annual severe bleaching

Under a business as usual scenario, ASB is projected to occur within this century for 99% of the world's coral reefs. The average projected year of ASB is 2043. 5% of reef pixels (i.e. 4-km pixels that contain coral reef) are projected to experience ASB a decade or more earlier than the global average of 2043. These are relative climate losers. 11% of reef pixels are projected to experience ASB a decade or more later than 2043. These are relative climate winners or 'temporary refugia'.

Coral reef futures vary greatly among and within countries. Coral reef climate losers and winners occur in all of the ocean basins; however, some countries have more climate winners than others. Five of the 20 countries with the greatest total reef area have more than 20% climate winners (i.e. projected ASB after 2053), including: Egypt (37%), Australia (29%), Cuba (22%), Bahamas (21%), and India (20%).



Example of spatial variation in the downscaled projections for the onset of ASB. Reef areas in turquoise and blue are relative climate winners, areas in red are relative climate losers.

Five of the 20 countries with the greatest reef area have less than 5% of pixels that are relative climate losers (i.e., projected ASB before 2033), including: Saudi Arabia (33%), Egypt (33%), Papua New Guinea (8%), Madagascar (7%), and Bahamas (5%).

Exposure to bleaching conditions is sufficiently different where variation is more than 10 years to potentially be a driver of differences in relative climate change vulnerability. Therefore, the downscaled projections can inform management decision-making where variation in projected ASB timing is more than 10 years between locations. Reefs projected to experience ASB 10 or more years later than other reefs in the same jurisdiction are *relative* refugia and are conservation priorities. The range in projected ASB timing is more than 10 years in 82% (71 of 87) of the countries and territories with at least 500 km^2 of coral reef.

Regional Summaries

There is significant variation between reef regions. This report provides regional summaries of projected timing of ASB under a business as usual scenario (RCP8.5), based on the 10 Regional Seas with tropical coral ecosystems. Coral reef area of countries and territories located near but not participating in the Regional Seas governance mechanisms have been included in regional summaries, in keeping with an ecosystem approach.

The earliest average projected ASB timing is in the *Red Sea and Gulf of Aden* (2039) and the *Pacific Islands* (2042), the latest in the *ROPME Sea Area* (2069) and *South-East Pacific* (2050). Countries and territories with the earliest and latest average projected ASB timing within or near each Regional Sea are shown within the following table (further detail is provided in Appendix 1).

Region	***Earliest average projected ASB***	***Latest average projected ASB***
Wider Caribbean	Turks and Caicos (2036)	Bermuda (2050)
Western Africa	St. Helena and Ascension Island (2043)	Cameroon (2055)
Red Sea and Gulf of Aden	Israel (2012)	Eritrea (2053)
ROPME Sea Area	Oman (2055)	Bahrain (2084)
East Africa	Mozambique (2040)	South Africa (2051)
South Asian Seas	Chagos (2041)	Sri Lanka (2050)
East Asian Seas	Taiwan (2037)	PRC China (2057)
Pacific Islands	Federated States of Micronesia (2038)	Pitcairn Island (2058)
South-East Pacific	Ecuador (2042)	Chile (2069)
North-East Pacific	Nicaragua (2038)	El Salvador (2050)

Implications of the Paris Agreement

The average year for the projected timing of ASB under a successful mitigation scenario is 2054, 11 years later than the average projected under business as usual. ASB under a successful mitigation scenario is projected to be more than 25 years later than under business as usual for very few reefs (7%), and less than 10 years later for many reefs (32%).

There is great spatial variation across the globe in the differences in projected ASB timing under successful mitigation and under business as usual. Many high-latitude reefs in Australia, the south Pacific, Northwestern Hawaiian Islands, India, and the Florida Reef Tract have at least 25 more years before ASB occurs under successful mitigation. Low latitude locations in South-East Asia, the Coral Triangle, and the

eastern Pacific also have at least 25 more years before ASB occurs under successful mitigation. In contrast, there is less than 10 years difference between scenarios for reefs near the equator that are projected to experience ASB relatively early. In summary, these projections suggest that full implementation of the Paris Agreement will buy some time for some reefs to adapt and acclimate prior to severe bleaching conditions occurring annually, and for putting in place better management. However, Intended Nationally Determined Contributions (INDCs) submitted as of September, 2016 will do little to provide reefs with more time. Delayed ratification and implementation of the Paris agreement will have severe implications for coral reefs.

Applications

These downscaled projections can (1) guide coral reef management and conservation planning, (2) be used in stakeholder consultation, education and outreach, and (3) inform policy.

(1) The downscaled projections support identification of relative climate refugia at multiple levels where management planning and prioritization is carried out, from sub-national to regional scale. The projections can be used as a data layer (among other layers such as biodiversity, cultural values and ecosystem service use) in marine protected area planning and marine spatial planning, to identify where particular stress reduction measures or restrictions on use of ecosystem services should be applied. Management will have the greatest impact by reducing stress to relative refugia where anthropogenic pressure is relatively high and most amenable to management influence. This strategy maximizes the likelihood that at least some reefs will be healthy in the future and continue to provide ecosystem goods and services. The projections can also identify locations where reef dependent people and industries are vulnerable to early reef loss, and thus support prioritization of adaptation interventions.

Reef pixels with projected ASB timing that extends beyond 2055 are 'global relative climate winners' and as such global conservation priorities. However, most countries and territories have few or none of these global relative climate winners. Prioritization of management efforts thus need to identify reef areas that are climate winners relative to other reef areas *within a given management jurisdiction or planning area* (e.g. territory, country or region). Reef areas projected to experience ASB later than the average $\pm$ 1 standard deviation (for a given area) are *relative* climate winners. Relative climate winners typically represent <20% of the reef pixels in a given country or territory. Priority areas are easily identified by querying the spatial data made publicly accessible in the coral reef theme on Environment Live (see 'Accessing the Projections' below).

(2) Maps of the projected timing of the onset of annual severe bleaching conditions can be powerful