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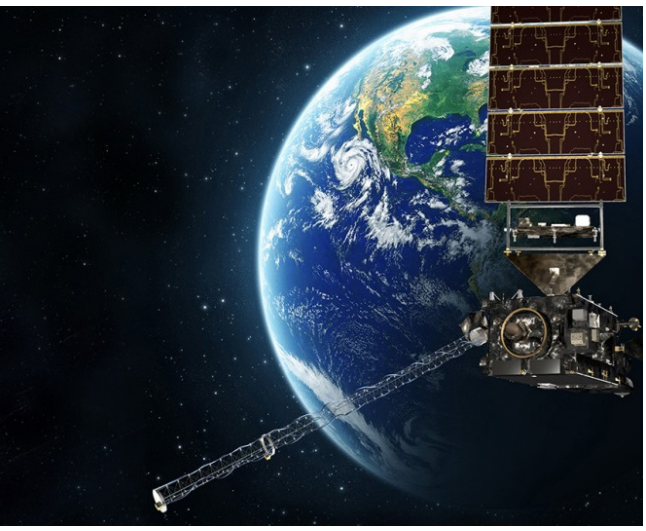

Impacts of Climate Change on World Heritage Coral Reefs:

Update to the First Global Scientific Assessment

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Suggested citation:
Heron et al. 2018. Impacts of Climate Change on World Heritage Coral Reefs: Update to the First Global Scientific Assessment. Paris, UNESCO World Heritage Centre.

CLT-2018/WS/8

This update to the assessment *"Impacts of Climate Change on World Heritage Coral Reefs: A First Global Scientific Assessment"* (UNESCO World Heritage Centre, 2017 https://whc.unesco.org/document/158688) is made in response to World Heritage Committee Decision 41 COM7 (Krakow/UNESCO, 2017). The aim is to make available the most current knowledge regarding the impacts of climate change on World Heritage properties.

This update is also responding to the 2017 *"UNESCO Strategy for Action on Climate Change"*, adopted by the 39th session of the UNESCO General Conference, in particular by raising awareness on the impacts of climate change on the world's natural and cultural heritage (art. 76).
UNESCO (2017). Available at: http://unesdoc.unesco.org/images/0025/002592/259255e.pdf

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Great Barrier Reef
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An artist's rendering of America's next-generation geostationary weather satellite
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1. Introduction

In 2017, UNESCO's World Heritage Centre published the first global scientific assessment of the impact of climate change on UNESCO World Heritage coral reefs[1]. The 'Assessment' reported that heat stress events have increasingly caused severe coral bleaching and mortality of World Heritage-listed reefs around the world over the past three decades. Of the 29 World Heritage-listed natural coral reef properties (Fig. 1), 15 were exposed to repeated severe heat stress during the 2014-2017 global bleaching event[1]. Recurrent severe bleaching was already apparent at more than half of the properties. While this global event did not trigger the onset of annual severe bleaching conditions in perpetuity, the impact of recurrent bleaching on coral reefs was clearly demonstrated[2,3].

The Assessment revealed that 25 of the 29 World Heritage reefs are projected to severely bleach twice-per-decade by 2040 under a business-as-usual CO_2 emissions scenario (RCP8.5, where emissions and temperature continue to rise through the 21st century). Under the RCP4.5 scenario, in which emissions peak around 2040 and then decline, the proportion of World Heritage-listed reefs exposed to twice-per-decade severe bleaching by 2040 was dramatically reduced to less than half (14) of the reef properties[1].

The first global assessment was released ahead of the 41st session of the World Heritage Committee in 2017 and underpinned the first decision of the Committee on coral reefs and climate change: to reiterate "*the importance of States Parties undertaking the most ambitious implementation of the Paris Agreement of the UNFCCC* [United Nations Framework Convention on Climate Change]", and to strongly invite all States Parties "*to undertake actions to address Climate Change under the Paris Agreement consistent with their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances that are fully consistent with their obligations within the World Heritage Convention to protect the OUV* [Outstanding Universal Value] *of all World Heritage properties*" (Decision 41 COM 7)[4].

Corals of the Lagoons of New Caledonia bleaching and fluorescing (both stress responses) during March 2016.

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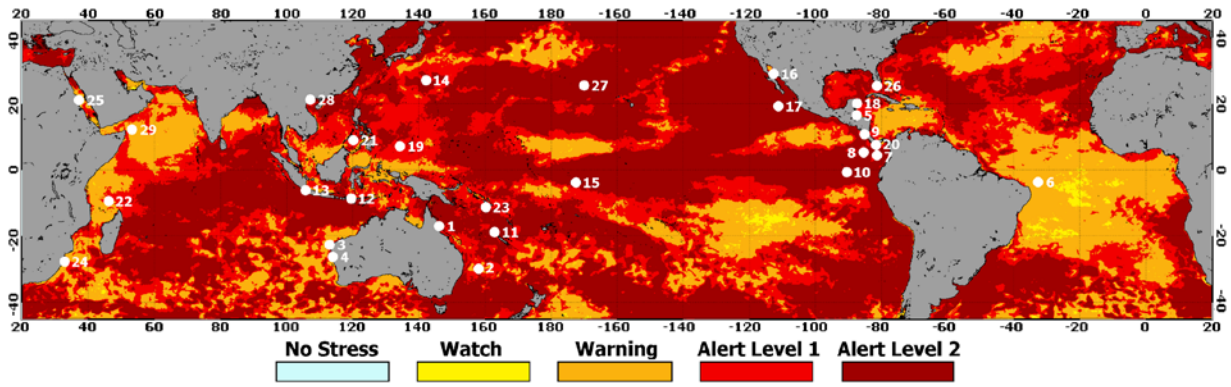
This update responds to the recommendation of the Assessment to undertake high-resolution future projection analysis under the RCP2.6 emissions scenario, in which emissions peak during the current decade (2010-2020) and achieve the limit of well below 2°C by 2100[5]. This update further responds to the World Heritage Committee request to make available the most current knowledge regarding the impacts of climate change on World Heritage properties. This updated analysis provides understanding of the implications of meeting the long-term goal of the UNFCCC Paris Agreement for World Heritage-listed coral reefs.

Figure 1. Locations of reef-containing, natural World Heritage properties (white dots) superimposed upon the highest level of heat stress during the third global coral bleaching event, June 2014-May 2017.

Heron et al. (2017).



1=Great Barrier Reef, 2=Lord Howe Island Group, 3=Ningaloo Coast, 4=Shark Bay, 5=Belize Barrier Reef Reserve System, 6=Brazilian Atlantic Islands, 7=Malpelo Fauna and Flora Sanctuary, 8=Cocos Island National Park, 9=Area de Conservación Guanacaste, 10=Galápagos Islands, 11=Lagoons of New Caledonia, 12=Komodo National Park, 13=Ujung Kulon National Park, 14=Ogasawara Islands, 15=Phoenix Islands Protected Area, 16=Gulf of California, 17=Archipélago de Revillagigedo, 18=Sian Ka'an, 19=Rock Islands Southern Lagoon, 20=Coiba National Park, 21=Tubbataha Reefs Natural Park, 22=Aldabra Atoll, 23=East Rennell, 24=iSimangaliso Wetland Park, 25=Sanganeb Marine National Park and Dungonab Bay–Mukkawar Island Marine National Park, 26=Everglades National Park, 27=Papahānaumokuākea, 28=Ha Long Bay, 29=Socotra Archipelago.

2. Coral bleaching and climate modeling

Reef-building corals bleach when warmer than normal sea temperatures disrupt the mutualistic relationship with algal symbionts (called zooxanthellae) that reside within their tissues[6]. Corals either regain their zooxanthellae[7] and survive, or die if heat stress is severe or prolonged. Bleaching on broad scales results from heat stress, associated with global warming and climatic variability (e.g., El Niño). The relationship between temperature and bleaching has enabled scientists to analyze historical, current and future occurrence of heat stress events likely to cause bleaching.

The objective of this update was to develop climate model projections of coral bleaching conditions under RCP2.6, thereby directly responding to the recommendation in the first global assessment. Climate modeling under the RCP2.6 scenario results in global temperature peaking around 2050 at 1.3-1.9°C (median 1.5°C) above pre-industrial levels, with associated peak emissions concentrations of around 442 ppm CO_2[5,8]. This scenario reflects an ambitious target given that atmospheric CO_2 concentration are currently estimated over 405 ppm CO_2 and growing at 2-3 ppm CO_2 annually[9].

For reference, under RCP8.5, emissions and temperature continue to rise through the 21st century, a 'business-as-usual' scenario[5]. Under RCP4.5, emissions peak mid-century and then stabilize; further temperature increase will occur after that time but at a decelerating rate[5]. Projected global-mean temperature increases by 2100 are 4.6°C under RCP8.5, and 2.4°C under RCP4.5, above pre-industrial levels[8].

To facilitate direct comparisons between the projected scenarios, we applied the same techniques used in the first global assessment for RCPs 8.5 and 4.5 to examine impacts on corals under RCP2.6. These are briefly summarized below.

Sea-surface temperature (SST) predictions from global climate models used in the Intergovernmental Panel on Climate Change 5th Assessment[10] were acquired. As the spatial resolution of these models is typically 1° (~100 km) or greater, SST values were downscaled to ~4 km using observed patterns and variability within an historical high-resolution satellite SST climate data record[11]. For each of the 29 natural World Heritage reef properties, grid cells that contain reefs were analyzed to identify projected heat stress, measured by the Degree Heating Week (DHW) metric, between 2006 and 2099, with the threshold for severe bleaching heat stress of DHW ≥ 8°C-weeks. The onset year for annual and twice-per-decade exposure reported for each World Heritage property represents the 90th percentile of severity across reef cells within that property (i.e., the year by which at least 10% of reefs are exposed to severe heat stress at that frequency). This is consistent with the procedure used by NOAA Coral Reef Watch (coralreefwatch.noaa.gov) in representing bleaching risk across regions in the satellite monitoring of current risk[12].

Severe heat stress in 2016 and 2017 led to coral mortality at Russell Island, Great Barrier Reef (Australia). September 2017.

3. The effects of the RCP2.6 climate emissions scenario for World Heritage-listed coral reefs

Climate model projections of coral bleaching conditions under RCP2.6 quantify the potential benefit to World Heritage-listed coral reefs of taking the necessary action to limit end-of-century global average temperature increase to 1.5°C above pre-industrial levels, as reflected in the UNFCCC Paris Agreement.

Projected onset of recurrent severe heat stress from the RCP2.6 analysis is presented here appended to the previously reported outcomes under RCPs 8.5 and 4.5[1] to facilitate comparison (Table 1).

WORLD HERITAGE-LISTED CORAL REEFS WOULD NOT EXPERIENCE ANNUAL SEVERE BLEACHING THIS CENTURY UNDER THE RCP2.6 SCENARIO, WHERE GLOBAL AVERAGE TEMPERATURES ARE LIMITED TO 1.5°C ABOVE PRE-INDUSTRIAL LEVELS.

Table 1. Onset of recurrent severe bleaching heat stress events under Representative Concentration Pathways (RCP) 8.5, 4.5 and 2.6. Event frequencies are twice-per-decade and annual.

Color categories: ≤ 2025 (dark red), > 2025 to ≤ 2040 (red), > 2040 to ≤ 2055 (orange), > 2055 to ≤ 2099 (yellow), not projected to occur by 2100 (green).

	Future Severe Stress - RCP8.5		Future Severe Stress - RCP4.5		Future Severe Stress - RCP2.6	
Reef-containing World Heritage site	(a) Projected Year of 2x/ decade	(b) Projected Year of Annual	(c) Projected Year of 2x/ decade	(d) Projected Year of Annual	(e) Projected Year of 2x/ decade	(f) Projected Year of Annual
Great Barrier Reef	2035	2044	2041	2051	-----	-----
Lord Howe Island Group	2034	2043	2036	2055	-----	-----
Ningaloo Coast	2041	2049	2052	2074	-----	-----
Shark Bay, Western Australia	2038	2047	2045	2074	-----	-----
Belize Barrier Reef Reserve System	2028	2036	2036	2044	-----	-----
Brazilian Atlantic Islands	2028	2039	2035	2049	-----	-----
Malpelo Fauna and Flora Sanctuary	2038	2050	2056	2077	-----	-----
Cocos Island National Park	2019	2032	2028	2036	2062	-----
Area de Conservación Guanacaste	2030	2043	2040	2055	-----	-----
Galápagos Islands	2017	2036	2027	2042	2070	-----
Lagoons of New Caledonia	2031	2040	2039	2050	-----	-----
Komodo National Park	2017	2025	2021	2032	-----	-----
Ujung Kulon National Park	2032	2043	2042	2053	-----	-----
Ogasawara Islands	2030	2038	2041	2049	-----	-----
Phoenix Islands Protected Area	2020	2035	2028	2040	2038	-----
Gulf of California	2044	2052	-----	-----	-----	-----
Archipiélago de Revillagigedo	2031	2042	2043	2052	-----	-----
Sian Ka'an	2025	2033	2033	2041	-----	-----
Rock Islands Southern Lagoon	2028	2036	2032	2044	-----	-----
Coiba National Park	2030	2043	2040	2053	2053	-----
Tubbataha Reefs Natural Park	2030	2039	2037	2048	-----	-----
Aldabra Atoll	2028	2036	2034	2042	-----	-----
East Rennell	2025	2033	2030	2044	-----	-----
iSimangaliso Wetland Park	2031	2040	2036	2048	-----	-----
Sanganeb and Dungonab Bay-Mukkawar Island MNPs	2037	2046	2055	2069	-----	-----
Everglades National Park	2036	2044	2056	2071	-----	-----
Papahānaumokuākea	2029	2041	2044	2052	-----	-----
Ha Long Bay	2077	2086	-----	-----	-----	-----
Socotra Archipelago	2040	2048	2061	2077	-----	-----

Severe bleaching stress threshold defined as DHW of 8 °C-weeks.

None of the natural World Heritage-listed coral reefs properties are projected to experience annual severe bleaching this century under the RCP2.6 scenario. Twice-per-decade severe bleaching is apparent in only four properties: Cocos Island National Park, Area de Conservación Guanacaste, Phoenix Islands Protected Area (PIPA), and Coiba National Park. Of these, only PIPA is projected to experience twice-per-decade severe bleaching before 2050. Significant and immediate action to reduce CO_2 emissions can prevent coral reefs of OUV from experiencing the devastating effects of recurrent severe bleaching this century.

LIMITING GLOBAL AVERAGE TEMPERATURE TO 1.5˚ ABOVE PRE-INDUSTRIAL LEVELS CAN PREVENT WORLD HERITAGE-LISTED CORAL REEFS FROM EXPERIENCING DEVASTATING EFFECTS OF RECURRENT SEVERE BLEACHING THIS CENTURY.

The dramatic reduction in projected impacts on World Heritage listed reefs is consistent with that for coral reefs globally. Scientific analysis indicates that none of the world's coral reefs are expected to experience annual severe bleaching, and only 1% experience twice-per-decade severe bleaching under RCP2.6[13]. The proportion of World Heritage-listed coral reefs exposed to twice-per-decade severe stress (14%, 4 of 29) is considerably higher than globally (1%), which demonstrates that securing the conditions necessary for long-term survival of World Heritage reefs will benefit global coral reefs.

For World Heritage reef properties, it is clear that limiting global average temperature increase to 1.5°C above pre-industrial levels is an essential action to secure their protection, give them the chance to persist in a changing climate, and continue providing benefits to associated human communities.

4. Conclusion

Bleaching and mortality of corals due to heat stress, resulting from global warming and observed over the past three decades, is expected to continue and intensify in the coming decades unless CO_2 emissions are drastically reduced. Under a business-as-usual scenario, all 29 World Heritage-listed coral reef properties are expected to experience annual severe bleaching this century, leading to dramatic deterioration in ecological functioning and associated decline in the quality and quantity of ecosystem services provided to humanity.

STRENGTHENING ON-SITE MANAGEMENT OF LOCAL PRESSURES ENHANCES REEF RESILIENCE; HOWEVER, DELIVERING ON THE PARIS AGREEMENT IS ESSENTIAL FOR THE SURVIVAL OF WORLD HERITAGE-LISTED CORAL REEFS.

In contrast, under the RCP2.6 scenario, which reflects the long term goals of the UNFCCC Paris Agreement, exposure of World Heritage-listed coral reefs to annual severe bleaching would be prevented this century. Furthermore, nearly all of the 29 analyzed World Heritage-listed coral reefs (86%) would escape twice-per-decade severe bleaching this century.

Maintaining the Outstanding Universal Value of World Heritage-listed coral reef properties will continue to require strong on-site management of pressures as well as national and/or regional enabling legislation to restore resilience and reduce local human stressors while climate stabilization occurs. However, this update confirms that delivering on the UNFCCC Paris Agreement target of *"holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C"*[14] is essential to secure a sustainable future for World Heritage-listed coral reefs.

Rock Islands Southern Lagoon (Palau), inscribed on the World Heritage List in 2012

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Acknowledgments

This study benefited from in-kind support from the United States National Oceanic and Atmospheric Administration, the University of Miami, and the University of Colorado, and was coordinated with the assistance of the UNESCO World Heritage Centre Marine Programme. Co-author R. van Hooidonk compiled and analyzed the climate model data. The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect the views of NOAA or the U.S. Department of Commerce, or of the institutions of other authors.

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This update received the financial support of the Agence française pour la biodiversité