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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/158868) 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).


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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. 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. 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.

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 CO₂ 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.

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 capacities, 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).

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. 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).
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. Corals either regain their zooxanthellae 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$_2$ and growing at 2-3 ppm CO$_2$ annually. For reference, under RCP8.5, emissions and temperature continue to rise through the 21st century, a ‘business-as-usual’ scenario. Under RCP4.5, emissions peak mid-century and then stabilize; further temperature increase will occur after that time but at a decelerating rate. 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.

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 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. 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.


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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).

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.

<table>
<thead>
<tr>
<th>Reef-containing World Heritage site</th>
<th>Future Severe Stress - RCP8.5</th>
<th>Future Severe Stress - RCP4.5</th>
<th>Future Severe Stress - RCP2.6</th>
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<tbody>
<tr>
<td></td>
<td>(a) Projected Year of 2x/decade</td>
<td>(b) Projected Year of Annual</td>
<td>(c) Projected Year of 2x/decade</td>
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<td>2048</td>
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Severe bleaching stress threshold defined as DHW of 8 °C-weeks.

2025 2040 2055 never onset

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.
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.

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.$^1$ 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.

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.
Acknowledgments

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Literature cited

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