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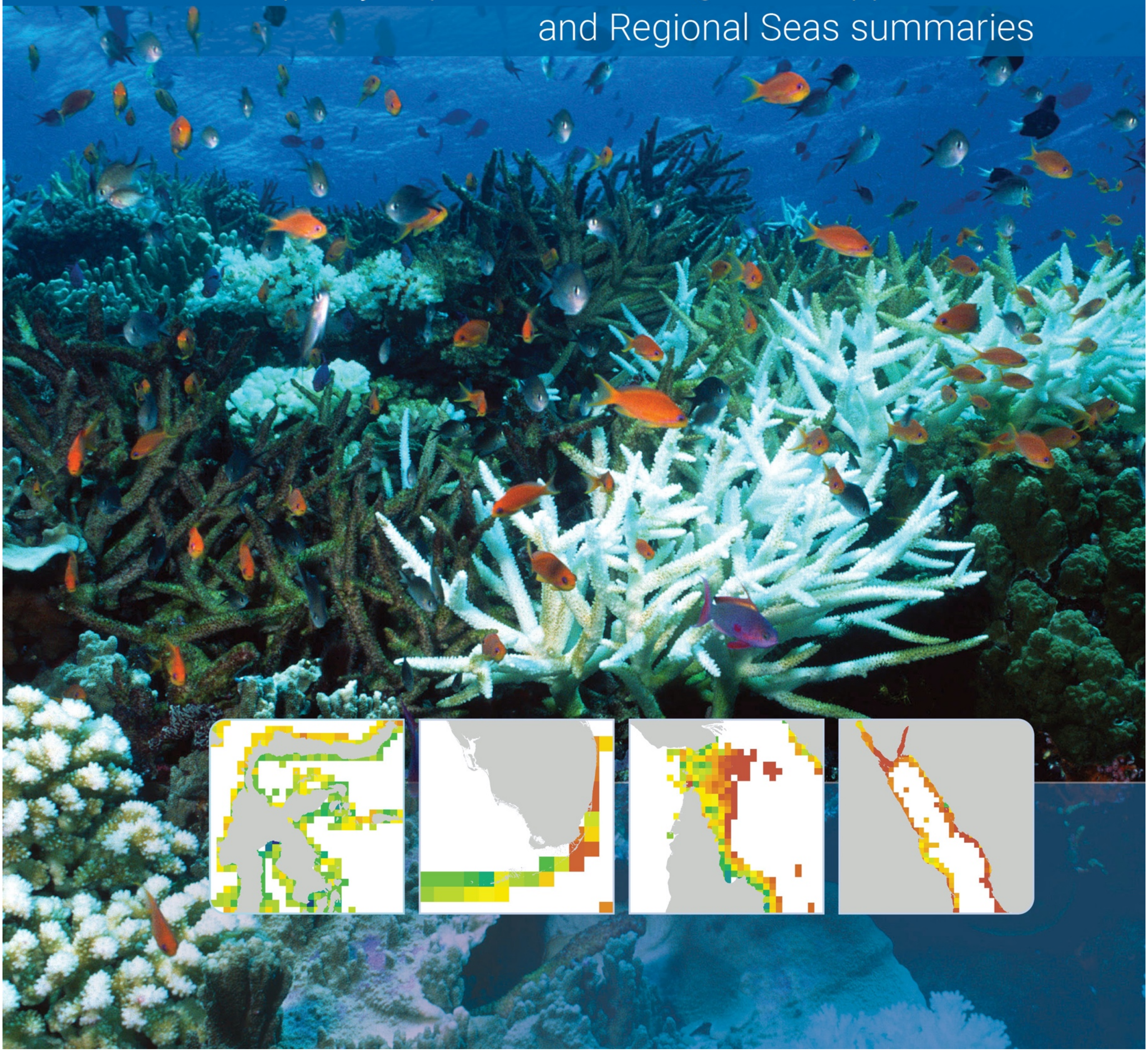
PROJECTIONS OF FUTURE CORAL BLEACHING CONDITIONS USING IPCC CMIP6 MODELS:

Climate policy implications, management applications, and Regional Seas summaries



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Summary: This report updates this UN 2017 report:

> 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

This update includes projections of the timing of exposure to severe bleaching conditions for coral reef areas under the 2019-released IPCC CMIP6 climate models (versus the CMIP5 models used in the UNEP 2017 report), using the new Shared Socioeconomic Pathways. Projections results are shared, as is an evaluation of the implications of climate policy on coral reef futures. The projections are summarized by country, territory, UNEP Regional Sea and Marine Ecosystems of the World within the report appendices. This report is complemented by publicly accessible spatial data of the projections, available from the World Environment Situation Room.

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Executive Summary

The third global coral bleaching event, which started in 2014 and extended well into 2017, was the longest coral bleaching event on record. The length of the event means corals in some parts of the world had no time to recover in 2014, 2015 or 2016 during the cool/winter season, prior to experiencing bleaching the following year. This recent global bleaching event of 2014-2017 represents what climate model projections presented in this Report suggest may become the norm over the coming two decades. Importantly though, great spatial variation exists in the projected timing of the onset of annual severe bleaching (ASB) conditions among the world's coral reefs. ASB is calculated as the projected date beyond which a reef is expected to experience severe bleaching conditions annually (at least 8 Degree Heating Weeks). Variation in ASB timing will be a major driver of differences in the relative vulnerability of coral reef ecosystems to climate change. Reef areas projected to experience ASB much later than other reef areas could be temporary refugia that have lower climate vulnerability. These refugia may provide ecosystem goods and services for longer so should be considered as potential conservation and restoration priorities.

This project team previously developed projections of the exposure component of climate vulnerability in coral reef areas. These projections were based on the World Climate Research Programme's Working Group on Coupled Modelling (WGCM) Coupled Model Intercomparison Project Phase 5 (CMIP5) generation of climate models (used by the IPCC in the 5th Assessment Report – AR5). These projections, which were statistically downscaled to 4-km are reviewed in UNEP (2017) and van Hooidonk et al. (2016).

This report updates the UNEP 2017 report with projections of the timing of severe coral bleaching conditions using the new generation of climate models used by the IPCC – the CMIP6 generation of models. The motivation in providing this update is that some CMIP6 models have >4x the spatial resolution (some have native resolutions of ¼ x ¼°; ~ 27 x 27km at the equator) than CMIP5 models (native resolution of 1 x 1°; ~110 x 110km) and include other improvements. Further, the CMIP6 models are forced by the recently released Shared Socioeconomic Pathways (SSPs – see Riahi (2017) for an overview). The CMIP6 models represent the current state-of-the-art in climate modeling to deliver climate science that informs regional and global climate policy. These projections presented here are of future exposure to bleaching conditions (i.e., temperature stress); the socio-ecology of coral reefs within all grid cells will vary and this variance is not built into these projections.

Projections of the timing of annual severe bleaching conditions are compared in this report for SSP5-8.5 and SSP2-4.5 to examine the implications of climate policy for coral reefs.

SSP5-8.5 is the pathway that represents current rates of emissions and emissions growth; it is also considered a "worst-case scenario". This scenario assumes there is no climate policy or that policy is not effective. SSP5-8.5 represents a growing world economy heavily dependent on fossil fuels. Results from the SSP5-8.5 pathway are most of the focus of this report and can be seen as using the precautionary principle in planning.

SSP2-4.5 is a highly ambitious but plausible scenario. SSP2-4.5 is a "middle of the road" pathway in which emissions continue to increase through the end of the century, reaching between 65GtCO_2 and 85GtCO_2, with resulting warming of 3.8-4.2°C. This scenario was selected because it ***could*** represent future conditions *if greater levels of emissions reduction (~150% of* *pledges) are achieved than would result from all Nationally Determined Contributions in the Paris Agreement combined.*

The purpose of this report is threefold:

1. To present projections of coral bleaching conditions (i.e., exposure to the primary climate threat to coral reefs) and potential adaptation at a spatial scale that enables use of the data in management and conservation planning and in support of other decisions influencing coral reefs and reef use;

2. To evaluate the implications of the Paris Agreement as well as failure to achieve its goal, by comparing the projected timing of annual severe bleaching between Shared Socioeconomic Pathways SSP5-8.5 and SSP2-4.5; and

3. To provide public access to the projections data as well as the main findings to catalyze research that extends the purposes and applications described in 1 and 2, and informs new research.

The report has been prepared with the coral reef scientific and management community as the primary target audience.

Results highlights include:

- Under the fossil-fuel aggressive SSP5-8.5, ASB is projected to occur within this century for 100% of the world's coral reefs. The average projected year of ASB is 2034, nine years earlier than was projected as a global average for RCP8.5 using CMIP5 models. This suggests the previous CMIP5 generation of projections of future bleaching conditions underestimated the near future threat of annual severe bleaching.

- Projected exposure to annual severe bleaching conditions varies greatly among and within countries under SSP5-8.5. Coral reefs with relatively early and late exposure to annual bleaching conditions occur in all of the ocean basins; however, some countries have more temporary refugia than others. Six of the 20 countries with the greatest reef area have >25% temporary refugia (i.e., projected ASB after 2044), including: Indonesia (35%), western Australia (70%), The Bahamas (26%), Madagascar (30%), India (37%), and Malaysia (47%). Thirteen of the 20 countries with the greatest reef area have >25% of reef areas that are projected to experience annual bleaching conditions relatively early. Some of these countries include the Philippines, Solomon Islands, Fuji, Cuba, and Saudi Arabia.

  It is important to note that these projections should not be interpreted as predictions of exactly when bleaching will occur and do not imply that any reef areas, including relative refugia, are safe from severe bleaching.

- The average year for the projected timing of ASB under SSP2-4.5 is 2045, 11 years later than the average year projected under SSP5-8.5. Successful mitigation in line with the Paris Agreement would do little to provide reefs with more time to adapt or acclimate prior to severe coral bleaching conditions occurring annually.

- There are three major results from the projections that assume coral adaptation levels between 0.25° and 2°C: 1) Each quarter degree of assumed adaptation adds ~7 years to the global average timing of projected annual severe bleaching; 2) The great majority of coral reefs ($\geq$80%) are expected to experience ASB this century even if 2°C of adaptation is assumed; 3) There is great spatial variation in the benefits to reefs, in terms of later ASB timing, at each assumed adaption level. The extent to which corals will adapt to increasing sea temperatures is unknown, but some level of adaptation is expected. If we assume 1°C of adaptation, the global average ASB timing is ~30 years later than if no adaptation is assumed.

The projections describe and quantify climate change exposure of coral reefs and thus contribute to our understanding of coral reef vulnerability. These projections can guide management, conservation and restoration planning, and be used in education and outreach programs.

Recommendations for next steps and research priorities include: downscaling the projections to 5-km scale to distinguish what are known to be local-scale differences in average summer temperatures and the bleaching threshold; better understanding the drivers and spatial patterns of coral and coral community adaptation to thermal stress; and, combining the projections with analyses of bleaching observations to identify reef areas that have fared better (‘bright spots’) or worse (‘dark spots’) than expected during recent bleaching events. Advances in any of those areas will increase confidence in the projections as well as the capacity of managers to use the projections in conservation planning, policy, and stakeholder engagement and outreach.

Introduction

Coral bleaching and climate modeling

Stony corals bleach when warm sea temperatures disrupt the mutualistic relationship between the algal symbionts, called zooxanthellae, that reside within the host coral tissues (Douglas 2003). Corals can either regain their zooxanthellae (Baker 2001) and survive or die if temperature stress persists. The third global coral bleaching event, which started in 2014 and extended well into 2017, was the longest coral bleaching event on record (Eakin et al. 2019). The length of the event means corals in some parts of the world had no time to recover in 2014, 2015 or 2016 during the cool/winter season, prior to experiencing bleaching the following year. Van Hooidonk et al. (2013, 2014, 2016 and 2017) found that a majority of coral reefs are projected to experience annual severe bleaching (ASB) by the mid-2040's under a business-as-usual emissions scenario (RCP8.5). This means that the recent global bleaching event of 2014-2017 represents what climate models suggest may become the norm over the coming few decades. Lower frequencies of bleaching events per decade (e.g., 2x or 4x per decade) are projected to occur earlier than ASB. ASB is projected here because annual severe bleaching is a time beyond which coral reefs seem certain to change (and possibly rapidly degrade). Importantly though, great spatial variation exists in the projected timing of the onset of ASB conditions among the world's coral reefs. This variation will be a major driver of differences in the relative vulnerability of coral reef ecosystems to climate change.

In the IPCC's widely adopted vulnerability assessment framework, vulnerability is a function of exposure to climate and non-climate threats and sensitivity to these threats, which yields potential impacts that are moderated by adaptive capacity (Turner et al. 2003). Sensitivity and adaptive capacity can be collectively seen as resilience (Marshall and Marshall 2007), i.e., the capacity of a system to absorb or withstand stressors such that the system maintains its structure and functions in the face of disturbance and change, and the capacity to adapt to future challenges (McLeod et al. 2019). Managing coral reefs for resilience entails reducing coral reef vulnerability to climate change by reducing exposure to non-climate threats (i.e., local-scale anthropogenic stress, Anthony et al. 2014).

A key challenge for reef management lies in deciding where to target actions to reduce anthropogenic stress, ensuring efficacy as well as cost effectiveness of actions taken. Ecosystem and Resilience Based Management (EBM and RBM) are becoming increasingly sophisticated (Mills et al. 2015, McLeod et al. 2019), and software that combines and analyzes spatial data is increasingly accessible and used in planning to strike a balance between what can be competing conservation and development objectives (Watts et al. 2009). For example, protecting biodiversity, providing for sustainable fisheries, and minimizing user conflicts are