11. Predictions for the Future of the Caribbean

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Introduction

The 2005 coral bleaching event focused attention on the threat that continued ocean warming poses to Caribbean coral reefs. The most recent assessment by the Intergovernmental Panel on Climate Change (IPCC) concluded that human-induced climate change will cause a 1.8–4.0ºC rise in global surface temperature by the end of the 21st century, with slightly less warming over most of the Caribbean. The challenge for climate scientists and coral reef ecologists has been to translate these more coarse projected changes in climate into impacts on coral reefs throughout the diverse Caribbean region. This chapter presents the most recent findings and assesses the overall threat of coral bleaching in the Caribbean over the coming century.

Challenges in Predicting the Future

Global climate models provide the means to predict how Caribbean coral reefs will respond to future climate change. The models use basic physical and chemical principles to simulate the movement of heat, moisture and energy, through a three-dimensional grid representing the atmosphere, oceans and the land surface in response to natural (solar output, volcanic activity) and human (greenhouse gases, aerosols) heating forces. The simulation of future climates depends in large part on assumptions about demographic, economic and technological change over the 21st century. For example, a 'business-as-usual' emissions scenario envisions a continuation of current activities, like fossil fuel burning and consequent increases in greenhouse gases in the atmosphere, throughout this century.

It is important when examining climate models to understand the difference between greenhouse gas emissions and atmospheric greenhouse gas concentrations. The concentration of greenhouse gases in the atmosphere depends on the rate of emissions and the rate at which the world's ecosystems and the oceans take up or remove greenhouse gases from the atmosphere. Since the rate of carbon dioxide (CO^2) emissions currently exceeds the rate of uptake, stopping the rise in emissions each year is not enough to stop the build-up of atmospheric CO^2. Stabilizing atmospheric CO^2 concentrations and eventually global temperature will require reducing CO^2 emissions well below today's rate.

Scientists use sea surface temperatures (SSTs) from these models to estimate the frequency and severity of coral bleaching events under past, present and future climate scenarios. The NOAA Coral Reef Watch program uses the accumulation of 'Degree Heating Weeks' (equal to one week of temperatures that are 1°C warmer than the maximum monthly temperature the coral reef experiences in the average year) to predict the likelihood of coral bleaching in real-time. Observations indicate coral bleaching begins to occur when the degree heating week or DHW value exceeds 4°C-week and becomes severe when the DHW value exceeds 8°C-week. The preferred method for predicting coral bleaching from the more coarse data provided by global climate models is the accumulation of 'degree heating months'. Similar to a degree heating week, a degree heating month or DHM is equal to one month of temperatures that are 1°C warmer than the maximum monthly temperature (e.g. the average temperature for September in much of the Caribbean). Historical data analysis has shown that DHM values of more than 1°C-month and more than 2°C-month are strong proxies for the lower and upper bleaching thresholds used by the NOAA Coral Reef Watch Program.

The resolution of these climate model forecasts (the size of the grid cells in the computer's picture of the world) is limited by the speed of computers and the complexity of the model. Although the resolution of climate models has improved in recent years, the size of model grid cells is still much larger than features of a coral reef. For example, most of the global climate models used in the most recent IPCC report have a horizontal resolution of only 1 degree of latitude by 1 degree of longitude (~100 km x 100 km). Therefore, the models cannot provide a direct representation of the complex bathymetry and hydrodynamics of many coral reefs.

Scientists studying climate change and coral bleaching have resolved the problem either by downscaling (using secondary models or statistical relationships to translate the climate model data to a specific location) or by studying large-scale events, like the 2005 coral bleaching event, that can be described directly by the global climate model itself. This work has provided a general picture of the expected effect of future climate change on the frequency and severity of coral bleaching in the Caribbean.

Coral Bleaching in the Future

The various studies on climate change and coral bleaching conclude that the majority of the Caribbean is expected to experience conditions that currently lead to coral bleaching (DHM > 1 or 2°C-month) every 2 years, or more, within the next 20 to 50 years.

[[PRE figure 1 in above this text – there are 2 maps in colour with different time windows]]

These two model figures show the estimated frequency of low intensity coral bleaching events across the Caribbean, based on downscaling of results from the Hadley Centre's HadCM3 climate model with more than 90% of Caribbean coral reefs expected to experience DHM > 1°C-month at least every 2 years or more in the 2030s and DHM > 2°C-month at least every 2 years by the 2050s. Greater warming is expected in the north-eastern Caribbean, including parts of Cuba, Florida and the Bahamas. In the most optimistic forecast, based on a climate model less sensitive to greenhouse gas emissions (PCM of the US National Center for Atmospheric Research), low intensity coral bleaching does not become a biannual event on Caribbean reefs until the 2050s.

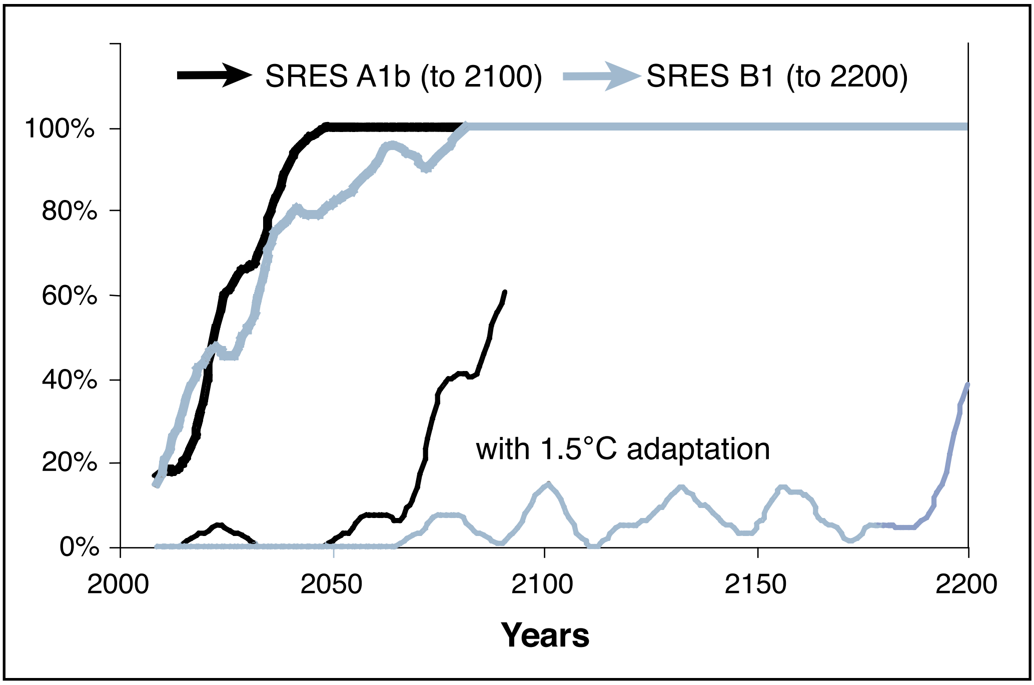
Whether coral bleaching occurs at these thresholds will depend on the ability of different corals and their symbionts to adapt or acclimate to warmer water temperatures. The warming scenarios indicate that on the majority (>75%) of Caribbean reefs, corals and their symbionts will need to increase their thermal tolerance by 0.2-0.3°C per decade over the next 30-50 years to avoid coral bleaching occurring more than once every 5 years. On about 25% of the reefs, mostly in the north-eastern Caribbean and Lesser Antilles, corals and their symbionts may need to raise their thermal tolerance by twice that amount over the same time-frame.

This forecast for the next 50 years is not very sensitive to the particular future emissions scenario, for two reasons. First, greenhouse gases like CO2 remain in the atmosphere for decades and even centuries. This causes a lag between the emissions of greenhouse gases and their mean effect on climate. Second, even if the world was determined to dramatically reduce greenhouse gas emissions, it cannot happen overnight. It will take time, for example, to build a new low-carbon energy generating infrastructure. Therefore, climate models show that the planet is 'committed' to much of the warming predicted in the 'business-as-usual' scenario for the coming decades.

A recent examination of the role of past human activity in the 2005 coral bleaching event helps disentangle the effect of such ‘committed’ warming, of possible adaptation by corals and of possible efforts to control greenhouse gas emission, on the future of Caribbean coral reefs. By focusing on the average warming over the entire region of the 2005 ‘Hot Spot’, it was possible to use climate models to assess the probability of the 2005 bleaching event occurring, with and without the effect of greenhouse gas emissions on the climate.

This analysis shows that the 2005 event would be extremely rare, possibly as low as a 1 in a 1000 year event, without the observed warming since the Industrial Revolution. The build-up of greenhouse gases in the atmosphere has increased the probability of an event like 2005 by at least an order of magnitude, to a less than 1 in a 100 year event. Furthermore, the warming projected to occur over the next 20-30 years should make this once rare occurrence a biannual event. The result is similar in a ‘business-as-usual’ scenario (SRES A1b) and a lower emissions scenario (SRES B1), in which efforts to reduce emissions cause the concentration of greenhouse gases in the atmosphere to stabilize in the year 2100 at twice the pre-industrial level (about 560 part per million of CO_2 in the atmosphere).

The picture, however, could change with some form of long-term adaptation by most corals and their symbionts. In the ‘business-as-usual scenario’, if most corals and their symbionts increase their thermal tolerance by 1.5°C, mass coral bleaching will not happen once every 5 years until the latter half of this century. Therefore, if such adaptation is possible, it could postpone the occurrence of frequent damaging bleaching events by 30-50 years or longer. In the lower emissions scenario, mass coral bleaching will not happen more than once every 5 years until the end of the 22nd century if corals are able to adapt by 1.5°C.



This model of the frequency that maximum annual degree heating month (DHM), averaged over the 2005 Caribbean bleaching region, exceeds the upper bleaching threshold of 2°C-month. The results are from the GFDL climate models under a 'business-as-usual' scenario (SRES A1b; 2001-2100) and lower emissions scenario (SRES B1; 2001-2200) in which atmospheric CO2 is stabilized at 560 ppm in the year 2100 scenario. The thick line assumes no adaptation by corals and their symbionts; the thin line assumes 1.5°C thermal adaptation. [[thick vs thin, dotted vs no dots etc. Work out which one will appear best and then adjust the text above]]]

Together, these findings indicate that an increase in thermal stress on Caribbean coral reefs in the next 20-30 years is inevitable because of 'committed' warming. However, the findings also show that some temperature adaptation by Caribbean corals and their symbionts could allow time to alter the path of future greenhouse gas emissions and avoid coral bleaching events like 2005 from becoming dangerously common this century.

A small fraction of the warming projected by climate models is actually a result of efforts to decrease another type of atmospheric pollution. The loading of aerosols, from African dust, pollution and volcanic eruptions, can lower Caribbean temperatures by as much as 1-2°C in some years. For example, evidence indicates the eruption of the El Chicon volcano in 1982 (Mexico) and the Mount Pinatubo volcano in 1991 (Philippines), may have protected the Caribbean from high SSTs and extensive coral bleaching. In both cases, the warming in the Caribbean caused by subsequent El Niño events was lower than expected because of high aerosol levels in the atmosphere. Today, the development of cleaner fuel and energy technologies (e.g. low sulphur content) and changes in African land cover in the future is expected to reduce aerosol levels and hence further increase regional temperatures.

Implications for Coral Reef Health

"… the Caribbean fits the profile of a vulnerable region: biodiversity is far lower than in the Indo-Pacific; it has been more vulnerable than the Indo-Pacific during past climate fluctuations; it is a relatively enclosed basin with a growing human population in its drainage area and abundant evidence of anthropogenic effects and terrigenous (e.g. runoff-related) influences; there are no other large-scale reef communities in the tropical Atlantic that can serve as refugia or sources of recolonization; and evidence of widely distributed reef stress has already been noted." (Smith and Buddemeier 1992)

Climate change poses an existential threat to the already heavily disturbed coral reefs of the wider Caribbean. The conditions that currently cause coral bleaching events are expected to occur more frequently (every 2 years) within 20-30 years across much of the Caribbean, especially the northern Caribbean. Thermal adaptation by corals and their symbionts could spare many Caribbean reefs from catastrophic future bleaching events, by allowing time for the world to reduce greenhouse gas emissions and change the long-term climate forecast.

The final effect of the projected increases in the frequency and severity of thermal stress events on individual coral reefs across the Caribbean will depend on the hydrodynamics of the reefs, the health of individual ecosystems, the degree of other direct human pressures, the structure of the coral community, and the adaptability of the individual corals. It will also depend on the response of corals to associated changes in ocean chemistry, hurricane activity and disease transmission.

Caribbean coral reefs subjected to the more frequent bleaching events projected for the future are likely to undergo shifts in community structure. This may already be occurring, with major losses of the Acropora coral species since the 1970s. Frequent coral bleaching events, especially when combined with direct human pressures like over-fishing, pollution and sedimentation are expected to keep both coral and fish species richness low and lead to more algal-dominated ecosystems. Aggressive reductions in greenhouse gas emissions and local marine conservation efforts are necessary to avoid the long-term degradation of Caribbean coral reef ecosystems.

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References

Donner SD, Knutson TR, Oppenheimer M (2007). Model-based assessment of the role of human-induced climate change in the 2005 Caribbean coral bleaching event. Proceedings of the National Academy of Sciences, 10.1073/pnas.0610122104

Donner SD, Skirving WJ, Little CM, Oppenheimer M, Hoegh-Guldberg O (2005). Global assessment of coral bleaching and required rates of adaptation under climate change. Global Change Biology, 11:2251-2265.

Gill JA, Watkinson AR, McWilliams JP, Cote IM (2006). Opposing forces of aerosol cooling and El Niño drive coral bleaching on Caribbean reefs, Proceedings of the National Academy of Sciences, 103:18870-18873.

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate change 2007: The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Available at http://www.ipcc.ch.

Smith SV, Buddemeier RW (1992). Global change and coral reef ecosystems. Ann Rev Ecol Syst 23:89-118