HOT TOPICS IN MARINE BIOLOGY 15.2

Global Warming and Acidification: The End of Coral Reefs?

During the past few years, worry about the future of the world's coral reefs has eclipsed business as usual in coral reef ecology. A large number of coral reef ecologists have argued that coral reefs face severe decline, if not extinction, worldwide in the next 30–100 years. This may seem extreme, but we are moving into unknown territory with environmental conditions, especially when you consider changes in factors that have been unknown previously. A recent estimate of population change in all coral species demonstrates that about one third of all coral species face elevated extinction risk, by the standards used by conservationists.* The marine biological equivalent of the Four Horsemen of the Apocalypse has been approaching rapidly:

1. Overfishing
2. Frequent hurricane-strength storms
3. Global warming
4. Ocean acidification

Other worrisome events, like widespread human development of the shoreline, an increase in disease in the Caribbean, and the widespread outbreaks of the crown-of-thorns sea star in the Pacific, add to the discomfort.

We discussed the impact of overfishing above and how it interacted with two hurricanes to flip the coral reefs of Jamaica into a new alternative stable state, which has converted one of the most beautiful coral reef tracts in the world to a rubble covered with seaweeds. Such overfishing is widespread, and some models of global climate change predict increasing intensity of tropical storms. What about the other two factors: temperature and carbon dioxide addition?

The role of increased temperature on coral condition has been appreciated for many years, following the important work of Peter Glynn on the effects of the 1982–1983 ENSO event on coral reefs of Panama. The weather system brought unusually warm water to the eastern Pacific, and the high temperatures surpassed the physiological limits of many of the local coral species. Bleaching immediately ensued, probably resulting from death of zooxanthellae, and Glynn's excellent research tied bleaching to temperature increase. As global ocean warming continued beyond just ENSO events, bleaching events began to increase in frequency all around the tropical world. So far, sea temperatures have been rising at a rate of about one degree centigrade per century, and the twenty-first century may have a higher rate. Will this widen the occurrence of bleaching? Will this alone kill off many coral reefs? Reef corals live within the range of 18–30°C . We are approaching their upper limits all around the world, unfortunately.

While coral bleaching (Fig. 15.28) occurs in response to a number of physiological stresses, so-called mass bleaching, where zooxanthellae are expelled but coral tissue remains alive (at least for a while) usually seems to be a response to temperature stress. At least 70 percent of mass bleaching events in the 1990s were related to higher-than-average temperatures.[†] The occurrence of mass bleaching has been more frequent in recent decades, and Hoegh-Guldberg[‡] makes a convincing case that mass-bleaching events on the Great Barrier Reef were rare to absent before 1979. In the western Pacific a major bleaching event occurred in 1998, with mass bleaching and mortality in a number of islands.

A number of satellites are equipped with the Advanced Very High Resolution Radiometer, which can estimate sea-surface temperature. The United States National Oceanographic and Atmospheric Administration (NOAA) has acquired these data and translated them into useful indices of temperature stress that can predict bleaching events and coral death. For example, the degree heating week (DHW) is the occurrence of temperatures of 1°C above the mean maximum monthly temperature seen in a region for one week and one can count DHWs to get an estimate of stress. The year 2005 experienced a major mass bleaching and experienced the warmest temperatures in July in the western Caribbean and the warmest September in the eastern Caribbean in over 100 years. The degree of coral bleaching is strongly correlated with the mean maximum degree heating week (Box Figure 15.3).

A NOAA coral reef research group led by Mark Eakin now evaluates bleaching and makes predictions for the future. Since 1985, the DHW measure of stress has shown a steady increase (Box Figure 15.4). A composite map of number of Degree Heating Weeks shown for the year 2005 in Box Figure 15.5 is especially alarming.

Because the NOAA Coral Reef Task Force and other organizations have produced temperature-related measures of susceptibility to mass bleaching it is now possible to make predictions about the future of coral reefs, using standard climate change models. These models usually include best-case and worst-case scenarios, based upon different model outcomes and the range of carbon dioxide that might enter the atmosphere under different circumstances of international development and regulation. Donner and colleagues[§] used such models and concluded that dangerous conditions for mass bleaching events would be annual or biannual events in the next 30–50 years. Reefs in the western Pacific are particularly vulnerable. The only way out would be for coral populations to evolve increased thermal tolerance. As we mentioned in the section on coral reefs, some corals living in thermally extreme environments are resistant to higher temperatures, so there is evidence for evolutionary response to higher temperature. Hoegh-Guldberg[||] undertook a similar exercise, using another index of bleaching and also data on various bleaching events. The models combined with temperature thresholds predicted widespread bleaching in 30–50 years unless the coral populations evolved resistance. It is difficult to be sure about the power of these models for any one place but, overall, it appears to be robust, and it predicts a great deal of trouble as the sea-surface temperature warms up in the future.

* See Carpenter and others, 2008, in Further Reading, Hot Topics.

† See Glynn, 1993, in Further Reading, Hot Topics in Marine Biology.
‡ See Hoegh-Guldberg, 1999, in Further Reading, Hot Topics in Marine Biology.
§ See Donner and others, 2005, in Further Reading, Hot Topics in Marine Biology.
|| See Hoegh-Guldberg, 1999, in Further Reading, Hot Topics in Marine Biology.

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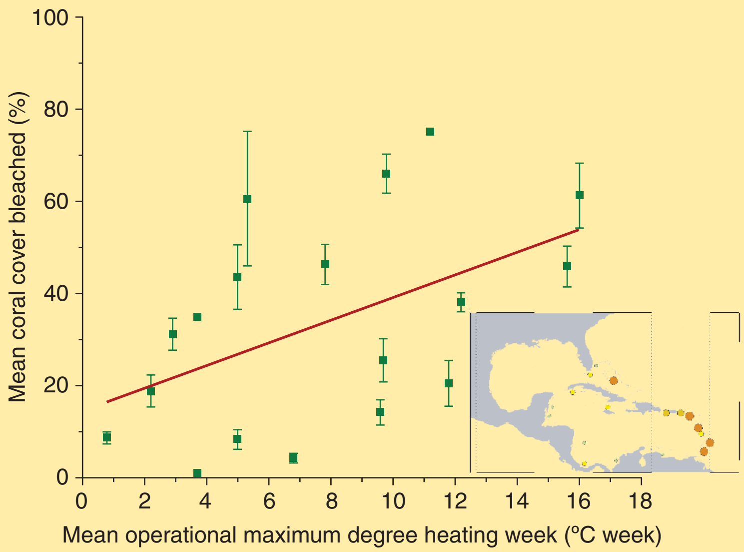
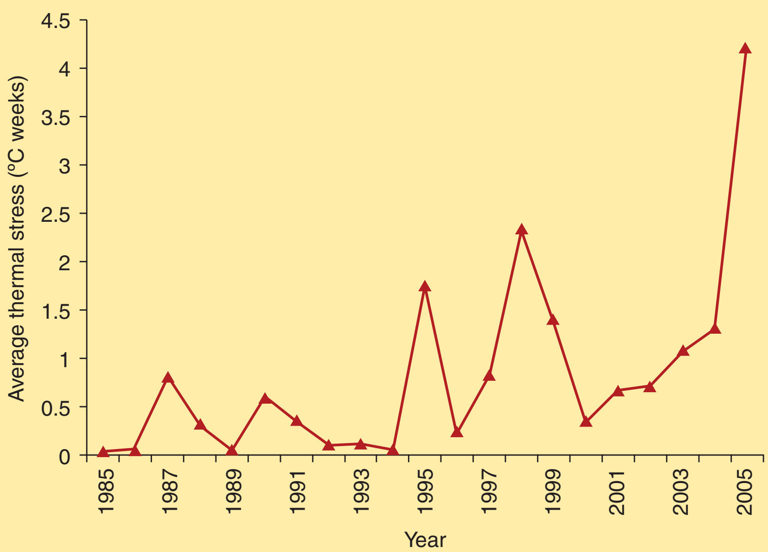


BOX FIGURE 15.3 Relationship between percent coral cover that was bleached in a number of Caribbean stations and mean maximum temperature for the hottest week at a given locality in 2005. (Courtesy of Mark Eakin and NOAA.)



BOX FIGURE 15.4 Thermal stress from 1985–2005, averaged over a group of stations in the Caribbean. (Courtesy of Mark Eakin and NOAA.)

The situation is equally grim for ocean acidity that is being caused by human-derived carbon dioxide increase in the atmosphere, which has already reduced the world ocean's pH by about 0.1 unit. The basics of calcium carbonate secretion and acidity effects were discussed in Chapter 10, where we related changes in acidity to calcareous plankton. Increases of atmospheric carbon dioxide will reduce pH and steadily reduce dissolved carbonate ions available for calcification. Calcium carbonate occurs in two forms: in a more stable calcite and in the less stable form of aragonite. Corals unfortunately are aragonite and are, therefore, among the most vulnerable to increases in acidity.

Even one of the more modest scenarios for carbon dioxide increase would make the Southern Ocean undersaturated with respect to calcium carbonate in the year 2100. Going Deeper Box Figure 10.3 shows how to calculate a parameter Ω (omega), which equals one when the water is saturated with respect to a given mineral. It turns out that Ω must be 3.3 or more for aragonite to be able to be produced by corals, which is close to the current situation. The current carbon dioxide concentration in the atmosphere is 380 ppm, and the threshold value of $\Omega = 3$ for corals that will limit calcification will be reached when that concentration reaches 480 ppm. Even the most modest carbon dioxide scenario with no correction will bring the value below 3 by the year 2100.[¶]

[¶]See Royal Society, 2005, in Further Reading, Hot Topics in Marine Biology.

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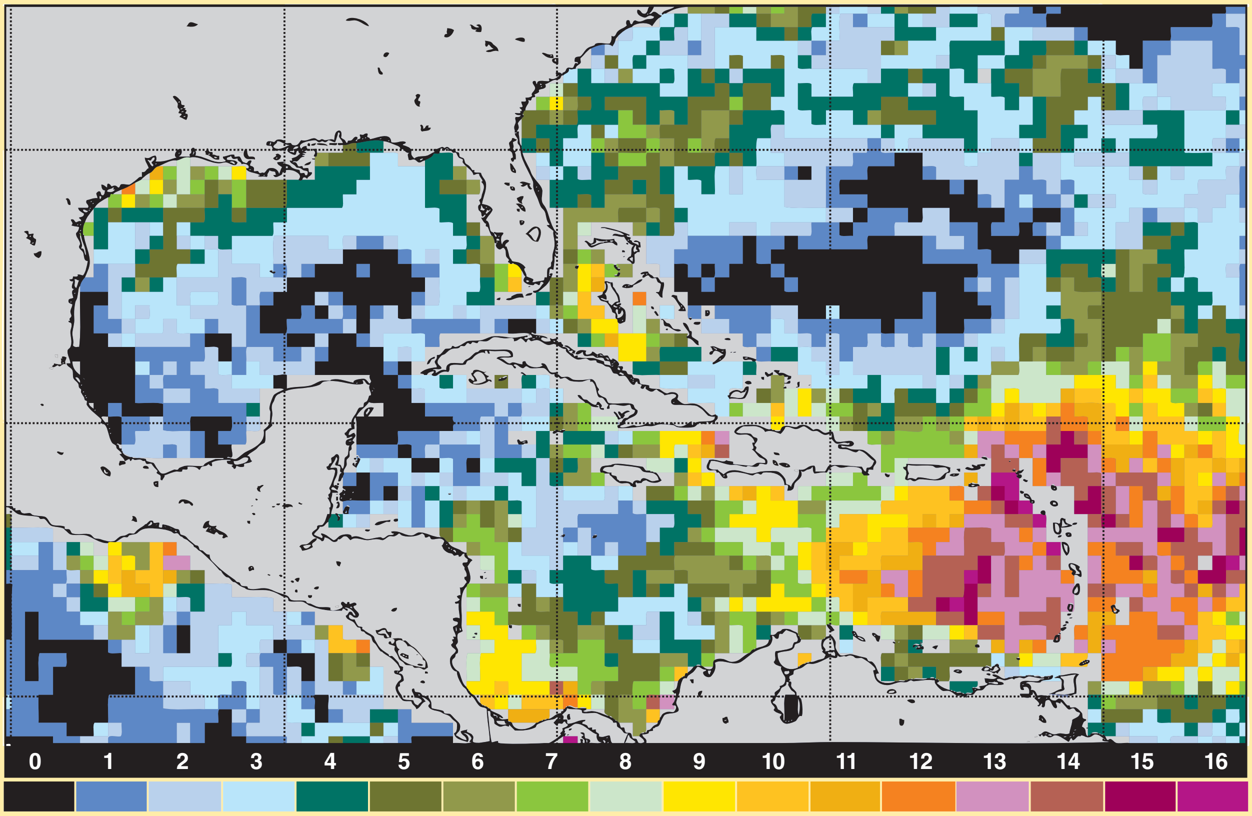

BOX FIGURE 15.5 Relationship of maximum degree heating and geography. Research shows that a value of 4 signifies a danger of bleaching and a value of 8 or more signifies a very high probability of bleaching. (Courtesy of Mark Eakin and NOAA.)

Gattuso and colleagues** found in the Pacific coral *Stylophora pistillata* that calcification increases nearly threefold in the laboratory when Ω increases from 0.98 to 3.90, the latter value of which applies to the present day in the tropical ocean. This means that further increases of carbon dioxide in the atmosphere are liable to have drastic effects on corals. But the negative effects may already have begun. A study of corals of the genus *Porites* on the Great Barrier Reef demonstrated a reduction of calcification over the last 16 years, resulting in a reduction of skeletal density of 0.36% per year and a reduction of linear growth rate of 1.06% per year. Together, these numbers suggest a reduction of calcification of about 1.3% per year.[††]

Some believe that there is an escape from catastrophe, beyond major reductions in carbon emissions. Evolution might do the trick, but it seems unlikely that corals will evolve either resistance to increased temperature or poorer conditions of calcification in time. One must remember that the generation time of the dominant corals in a reef is very long because colonies may survive hundreds of years. Thus the dominant individuals of the reef will not be able to change genetically in response to selection. Others believe that the corals can just move to higher latitudes to avoid thermal stress. This is not likely in the Caribbean basin where only small populations could creep up the Florida coast to the north. Populations could not spread southward along the coast of South America, where there are inappropriate environmental conditions for coral reefs because of high sedimentation. In the open Pacific there simply aren't seamounts available to allow the population to expand to higher latitudes. And then there's the acidification problem, which if anything gets worse in cooler temperatures and, therefore, higher latitudes. The only solution is for the science to be wrong or for carbon emissions to be drastically reduced by major carbon dioxide-producing countries, as has been strongly recommended now by the Intergovernmental Panel on Climate Change. ■

**See Gattuso and others, 1998, in Further Reading, Hot Topics in Marine Biology.
††See Hoegh-Guldberg, 1999, in Further Reading, Hot Topics in Marine Biology.