Encyclopedia of Earth

Coral reefs and climate change

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Introduction

A reefscape from the Great Barrier Reef. (Photo credit: AIMS LTMP)

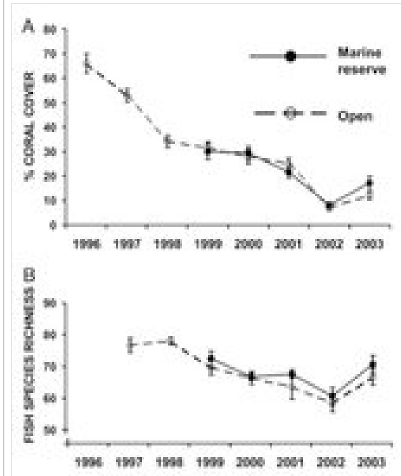
Research on the current and future impacts of human-induced climate change on reef-building corals is causing scientists and managers to become increasingly concerned about the future of coral reefs. A healthy reef ecosystem literally buzzes with sounds, activity and colors and is populated by incredibly dense aggregations of fish and invertebrates. In this respect, tropical reefs are more reminiscent of the African Serengeti than of the tropical rainforest they are often compared to, where the resident birds and mammals can be secretive and difficult to see. A coral reef can contain tens of thousands of species and some of the world's most dense and diverse communities of vertebrate animals. Unfortunately, very few remaining coral reefs resemble this pristine condition; on most, corals and fishes are much less abundant than they were only a few decades ago.

The Role of Corals on Coral Reefs

Healthy coral reefs are dominated by various forms of reef-building corals, which fill the role of trees in a forest, by generating the physical framework of the reef, benefiting thousands of associated plants and animals. Ecologists refer to corals, trees, and other organisms (e.g., kelp, oysters, etc.) that literally create habitats as "foundation species" and recognize that their loss can be catastrophic for the community and ecosystem that is built around them. The structure built up by corals over thousands of years provides complex refuges in which animals can hide from predators. When corals die, the abundance of reef fish quickly decreases, mainly due to the lack of places for larval (baby) fish to settle as they leave the open water and settle on the reef where they will spend their adult lives. For example, in Papua New Guinea reef fish communities were greatly impacted by coral loss due to ocean warming and sedimentation run-off from the conversion of forest to oil palm plantations.

Patterns of Coral Loss

We know very little about the historical biological baseline of coral reefs because we didn't really begin to study them until they were already being degraded. Based on surveys in the 1960s and early 1970s and recent studies of relatively "pristine" reefs, it appears that historically, coral cover (the percentage of the ocean floor covered by living coral) on undisturbed reefs was 70% or higher. However, even before people began degrading reefs, natural disturbances such as storms and predator outbreaks reduced coral cover locally. Thus the historical average (i.e., across all reefs in a region, including disturbed and undisturbed reefs) was surely lower and probably closer to 50 or 60%.



Declines in coral and fish populations in Papua New Guinea. (Source: Jones et al. 2004[1])

There are many examples of coral loss on individual reefs and we can get a rough idea of how coral cover has changed at regional and global scales over time by combining data from many sources. Several such "meta-analyses" have been performed recently by pooling survey data from the scientific literature with unpublished data from governmental and non-governmental monitoring programs. Examples of such organizations include the Australian Institute of Marine Science's Long Term Monitoring Program and Reef Check, which trains volunteer divers to survey hundreds of reefs a year around the world. The resulting picture is of widespread coral loss, even on some of the world's very isolated and intensively managed reefs. For example, coral cover in the Florida Keys declined to only ~ 8% by 2006. Similar losses since the late 1970s have been documented throughout the Caribbean, although some subregions such as the Lesser Antilles still have fairly high coral cover. The Pacific generally has higher coral cover than the Caribbean, although the picture is not that much brighter. An unpublished analysis of the most recent survey data indicates that Pacific coral cover is roughly 30%, probably around half of what it was several decades ago and coral loss on some Pacific reefs is on par with Caribbean loss.

Climate Change and Coral Loss

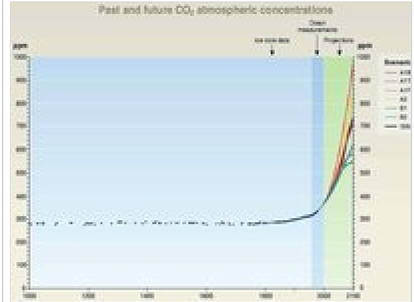
There are many causes of local and global coral loss but human-induced climate change is one of the main and undeniable threats. Climate change is having negative effects on coral populations via at least three mechanisms.

Coral Bleaching


Bleached corals off Puerto Rico in 2005. (Photo credit: E. Weil)

First, ocean warming is directly reducing coral cover through coral bleaching. Reef-building corals contain plant-like organisms called zooxanthellae that live symbiotically within their tissue. Zooxanthellae provide their coral host with food and oxygen and in return, the zooxanthellae receive nutrients, carbon dioxide, and an enemy-free shelter. This symbiotic relationship evolved tens of millions of years ago and has been critical to the success and evolutionary radiation of corals and to the development of reef ecosystems. When summertime water temperatures are just a degree or two warmer than usual for a few weeks, this critical yet delicate symbiotic relationship breaks down and the zooxanthellae are expelled, often leading to the coral's death. (The greater the magnitude or duration of the warming, the greater the mortality and effect on coral populations.) The phenomenon is called "coral bleaching" because the coral animal appears to turn white after the zooxanthellae loss. This is because without their zooxanthellae symbionts, which contain various photosynthetic pigments, corals are nearly transparent and the white, external calcium carbonate skeleton that the coral polyps live on becomes plainly visible.

Carbon dioxide, methane, and other greenhouse gases trap heat, leading to global warming. The increase in ocean temperature is variable and quite subtle: on the order of 1° C over the last several decades. But even such modest changes have caused mass-coral mortality events around the world during some of the especially warm summers we have all experienced over the last ten years. In 1998 when an intense El Niño greatly warmed much of the western Pacific and Indian Oceans, coral bleaching was widespread, causing mass coral mortality in many countries. For example, in Palau, more than 90% of the corals on some reefs bleached and at least 50% perished. Even some isolated reefs were impacted. In the *Maldives*, in the east Indian Ocean, bleaching caused coral cover to plummet to only about 5%.



Predicted increases in CO_2 under different IPCC scenarios. (Source: IPCC 2001)

Coral Disease

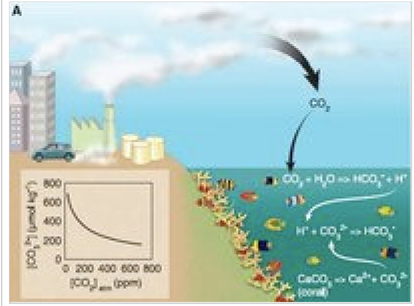
A coral colony with white syndrome. (Photo credit: AIMS LTMP)

Ocean warming can also indirectly kill corals by magnifying the effects of infectious diseases, which are one of the primary causes of coral loss, particularly in the Caribbean. The number, prevalence, and impacts of diseases of corals and many other types of marine animals have been increasing over the last 20-30 years. The severity of marine diseases could increase with temperature for several reasons. Because elevated water temperature causes corals physiological stress, it can also compromise their immune system, potentially making them more susceptible to infections. Additionally, increased temperature could also benefit bacterial and fungal pathogens, making them more fit and/or virulent.

A recent study found that anomalously high ocean temperatures greatly increased the severity of the coral disease white syndrome on the Great Barrier Reef. Disease outbreaks only occurred on reefs with high coral cover after especially warm years. The disease was largely absent on cooler reefs. The temperature increases required to trigger a white syndrome outbreaks were relatively modest as most disease outbreaks occurred on reefs where the temperature was only 1-2 °C warmer than usual. Other evidence also points to temperature as an important driver of coral epizootics. For example, some coral diseases such as black band disease become more prevalent or spread faster in the summer. However, not all coral epizootics are caused by anomalously high temperature. Some major outbreaks have occurred during relatively cool periods or years, such as white band disease, which decimated the then-dominant branching corals *Acropora palmata* and *Acropora cervicornis* in the Caribbean in the 1980s. Both species were recently listed as vulnerable under the U.S. Endangered Species Act.

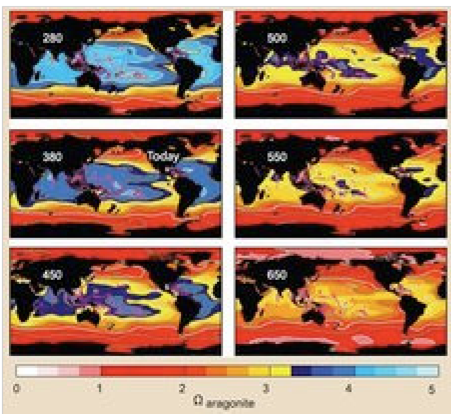
Ocean Acidification

The third and in many respects the greatest concern in the longer term, is that global change is causing the world's oceans to become more acidic. By burning immense amounts of fossil fuels, humans, particularly North Americans, are rapidly increasing the concentration of carbon dioxide (CO_2) in the atmosphere (by roughly 30% to date). A quarter of the CO_2 produced by the burning of fossil fuels enters the ocean and reacts with water to form carbonic acid, acidifying the ocean. We have already lowered the pH of the ocean by about 0.1 unit which makes it more difficult and energetically costly for corals to secrete their calcium carbonate skeleton. Several experiments have demonstrated than even modest decreases in pH can slow coral growth, which will cause and compound a number of other problems. For example, it will reduce the ability of corals to compete with other species like sponges and seaweeds and to keep up with higher rates of sea level rise (due mainly to the thermal expansion of the ocean, but also to the melting of polar glaciers and ice caps). Coral populations might also recover more slowly from other climate change-related stressors like bleaching and infectious disease or from natural disturbances and mortality agents like storms or predation.



Linkages between the buildup of atmospheric CO_2, the acidification of the ocean and the slowing of coral calcification. (Source: Hoegh-Guldberg et al. 2007[2])

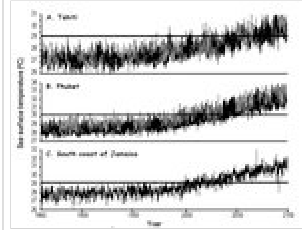
Future Climate Scenarios and Coral Reef Decline



Changes in aragonite saturation (Ωaragonite) predicted to occur as atmospheric CO_2 concentrations (ppm) increase (number at top left of each panel). Pink dots are coral reefs. Before the Industrial Revolution (280 ppm), nearly all shallow-water coral reefs had Ωaragonite > 3.25 (blue regions in the figure). (Source: Hoegh-Guldberg et al. 2007[3])

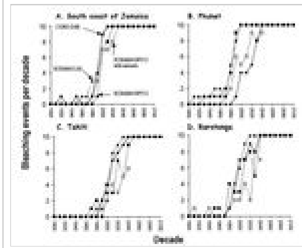
It is clear that anthropogenic climate change is already negatively impacting the world's corals and coral reefs. The threat will almost surely grow over the next several decades as the concentration of atmospheric carbon dioxide increases and ocean warming and acidification accelerate. Predicting future impacts of climate change on corals and coral reefs is complicated given all the uncertainty about the political response, future technologies, changes in human behavior, the earth climate system and the actual effects on reef inhabitants. But even conservative forecasts suggest that we could loose coral reef ecosystems by the end of the 21st century. Corals are thought to require an aragonite saturation of greater than 3.25 to successfully calcify and grow. Even under the most conservative IPCC climate change scenarios, atmospheric carbon dioxide concentration will increase to 600 ppm over the next 100 years, ocean pH will decrease by 0.1 to 0.3 units and the aragonite saturation in most of the world's tropical oceans will drop well below the 3.25 threshold. Field and laboratory experiments and climate models indicate that even more modest acidification will slow coral calcification and growth by nearly 50% by 2050. Under more extreme scenarios coral skeletons will literally dissolve.

The 4th IPCC assessment predicted an increase of 1-4 ˚C in ocean temperature during the next century.Even the low end of this range could increase summertime high temperatures well beyond the thermal tolerance of most corals and increase the frequency, geographic extent and severity of coral bleaching and mass-mortality events. Forecast models of increasing ocean temperature and coral bleaching indicate that under most ocean warming scenarios, mass bleaching will happen nearly every summer by 2030.



Predicted increases in ocean temperature. (Source: Hoegh-Guldberg 1999[4])

Local Threats and Integrative Reef Management



Predicted increases in the frequency of severe coral bleaching with increased summertime temperature. (Source: Hoegh-Guldberg 1999[5])

In addition to the global and regional effects of climate change, there are several localized threats and impacts to coral reef ecosystems. Reef fishes and some invertebrates are intensely harvested, which has greatly reduced their abundances and altered food web dynamics on all but the most isolated or intensely managed reefs. Additionally, some destructive fishing practices such as dynamite fishing and muro ami directly kill corals and can destroy the reef matrix. Reefs are also threatened by many other local activities such as coastal agriculture and development that increase sediment runoff into watersheds and sedimentation rates on coastal reefs, in some cases smothering and killing corals. Some scientists believe that these and other local impacts could act synergistically with climate change, thereby magnifying the negative effects of both types of stressors. There has been little work on this idea, but it seems clear that reef managers, policy makers and conservationists will have to act on many fronts at several political levels to begin to protect reef ecosystems from this diverse list of threats. Halting and reversing coral loss will require actions across a range of scales including: (1) local restoration and conservation of herbivores that facilitate coral recruitment and the reduction of fishing practices that directly kill corals, (2) the implementation of regional land use practices that reduce sedimentation and nutrient pollution, (3) the institution of global policies to reduce anthropogenic ocean warming and acidification.

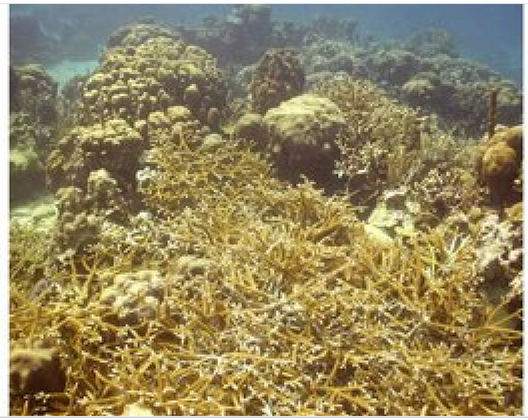
We can do a far better job of developing technologies and implementing smart policies that will reduce greenhouse gas emissions. However, there is substantial political resistance to this and no matter what we do we are already committed to at least some increased warming and acidification. But until we address and reverse anthropogenic climate change, we can reduce at least some of the local stressors that are compounding its effects.

Benefits/Ecosystem Services of Coral Reefs

When they are working properly, coral reefs provide human societies with massive economic benefits through fisheries, tourism and invaluable services like buffering from storms, estimated to be worth \$23,100 - \$270,000 km^{-2} $year^{-1}$. By allowing reefs to become degraded, we are forfeiting a gigantic natural service, an opportunity cost that will have to be paid by diverting revenue from other sources. Coral loss and reef degradation can have striking effects on local economies and family incomes. After mass-bleaching and coral mortality of 1998, dive tourism in Zanzibar decreased by 20% and the snorkeling and glass bottom boat industry in Sri Lanka declined substantially. The annual loss in tourism dollars in the town of El Nido, Philippines was estimated to be US\$ 1.5 million. In other countries the impacts of bleaching on tourism and fisheries were far less severe and difficult to untangle from other trends including overfishing. However, if some of the dire forecasts about climate change and coral reefs are accurate, it seems likely that millions of people will lose their livelihoods.

Reef Recovery and Other Reasons for Optimism

Despite the documented and projected impacts of climate change on coral refs, there is reason to be optimistic. First, it is possible that corals will acclimate or evolve to become more tolerant of rising temperature and able to calcify in more acidic conditions. There is some evidence that this has happened to some degree. Although, given the unprecedented rate of climate change and the suite of changes and stresses corals would have to adapt to, many coral biologists are skeptical that adaptation and acclimation alone will facilitate long-term survival if climate-related threats are not reduced.



A recovering Jamaican reef. (Photo credit: J. Bruno)

We are also learning that reefs are still somewhat resilient and under some conditions have the ability to recover from major impacts fairly quickly. Reefs devastated by bleaching in 1998 in many countries in the Indian, Pacific and Caribbean oceans are rapidly recovering. Even some reefs that were highly degraded by multiple disturbances have shown signs of recovery. In fact, despite the general regional and global downward trends, coral cover increased on nearly half of the world's reefs over the last decade. This suggests that we are not too from reaching a large-scale dynamic equilibrium. In fact, coral cover in some regions such as the Great Barrier Reef has been more or less static for the last 10-20 years and in others such as the eastern Caribbean it appears to be increasing slightly. Perhaps, by reducing some local stressors and curbing climate change, the current equilibrium state of reefs can be maintained or possibly moved to a higher point. Of course this assumes that the frequency, scale and magnitude of impacts don't increase, which given the best available climate forecasts seems unlikely.

Notes

1. **^**Jones, G. P. et al. 2004. Coral decline threatens fish biodiversity in marine reserves. Proc Natl Acad Sci USA 101:8251-8253.
2. **^**Hoegh-Guldberg, O. et al. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318:1737-1742.
3. **^**Hoegh-Guldberg, O. et al. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318:1737-1742.
4. **^**Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research 50:839-866.
5. **^**Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research 50:839-866.

Further Reading

- Bruno, J. F. et al. 2007. Thermal stress and coral cover as drivers of coral disease outbreaks. PLoS Biology 5:e124.
- Jones, G. P. et al. 2004. Coral decline threatens fish biodiversity in marine reserves. Proc Natl Acad Sci USA 101:8251-8253.
- Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research 50:839-866.
- Hoegh-Guldberg, O. et al. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318:1737-1742.
- Pew Center on Global Climate Change. Coral Reefs and Global Climate Change

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