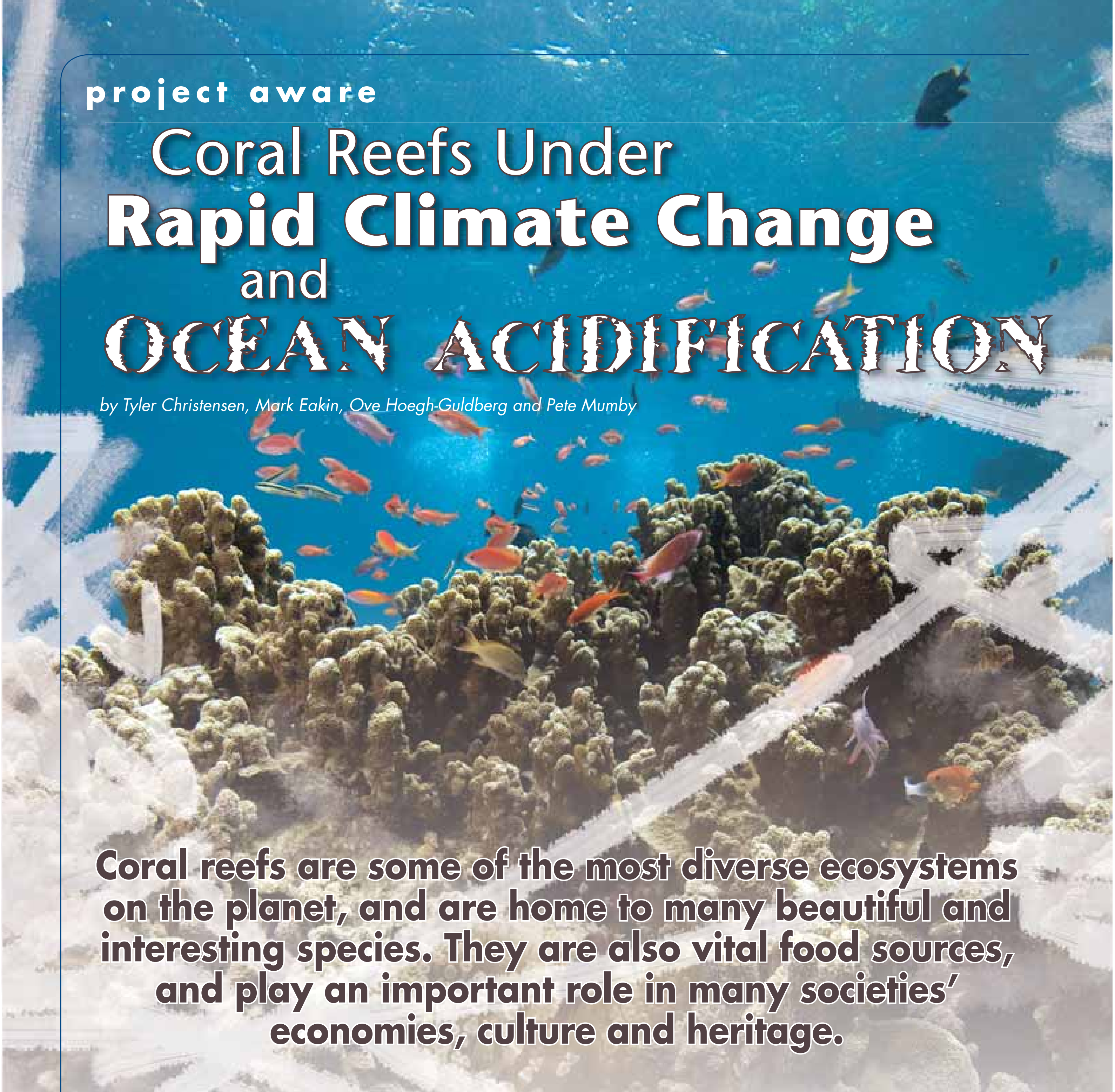
Coral Reefs Under Rapid Climate Change and Ocean Acidification



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Coral reefs are some of the most diverse ecosystems on the planet, and are home to many beautiful and interesting species. They are also vital food sources, and play an important role in many societies' economies, culture and heritage.

Coral reef health worldwide has been on the decline for decades. Warming seas and ocean acidification are already affecting them, increasing bleaching events and slowing the formation of coral skeletons. We can protect the future of coral reefs, but doing so requires action now to reduce the negative effects of climate change and local threats.

In 2007, coral scientists from around the world published a paper in the journal *Science* summarizing what we currently do and do not know about coral reefs and climate change. In this article, we present information based on that paper in easy to understand language.

What changes have already happened, and are they unusual?

As we burn fossil fuels (e.g., coal, gasoline, natural gas), we release carbon dioxide (CO_2) into the atmosphere. Before the industrial revolution, which began in the late 18th and 19th centuries, the natural level of CO_2 in the atmosphere was around 280 parts per million (ppm); today it is around 35 percent higher (380 ppm), and rising faster and faster. Many scientists think this increase in CO_2 has already contributed to air and ocean warming – global ocean temperature has risen by 0.74° Celsius (C)/1.3° Fahrenheit (F).

The ocean absorbs roughly one-third of the CO_2 we add to the atmosphere each year. This CO_2 reacts with the water to make carbonic acid. The global ocean's average pH (acidity or alkaline) level has already dropped from around 8.2 to 8.1; this is commonly called "ocean acidification." This change to the ocean's chemistry makes it much harder for corals to build their calcium carbonate skeletons.

Scientists use gases from bubbles trapped in ancient Antarctic ice to estimate the composition of the ancient atmosphere. Based on this analysis, they believe that due to fossil fuel burning, CO_2 levels are currently higher, oceans are warmer and the ocean's pH level is lower than at any time in at least the last 420,000 years. And, all three of these indicators are changing much faster than in the past. Estimates suggest that atmospheric CO_2 and temperature are changing at least 100 times faster now than in the last 420,000 years. Natural systems cannot adapt fast enough to keep up with this pace of change.

Ocean Temperature and Coral Bleaching

Corals have a symbiotic (mutually beneficial) relationship with the algae living in their bodily tissues. The algae, known as *zooxanthellae* or "zoox" for short, receive nutrients and a safe place to photosynthesize and grow. And, in return, zoox provide corals' main food source.

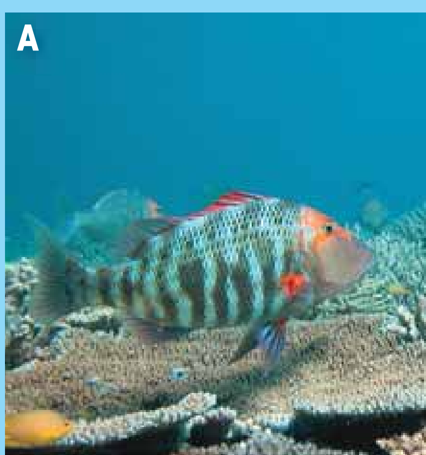
It is well known that high temperatures cause the normal photosynthetic process to break down, making zoox harmful to their coral hosts. The corals then "kick out" their zoox partners. Because their color comes from zoox, this expulsion causes corals to turn a pale white color – hence the term "coral bleaching." Temperatures just 1°-2° C/1.8°-3.6° F above normal summertime maximums can kill corals if the warm conditions last for a month or more. And, even if corals survive a bleaching event, the stress increases their chance of succumbing to disease and reduces their ability to reproduce normally for years afterwards.

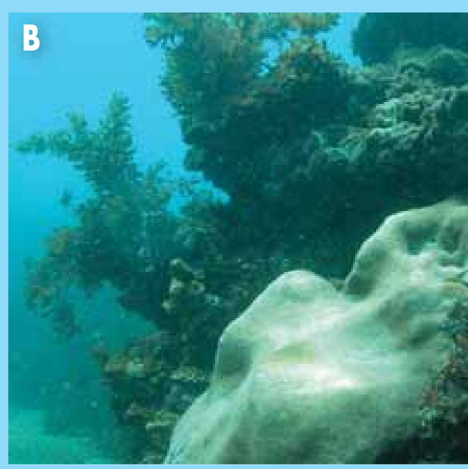
Furthermore, large-scale coral bleaching events have become more common as a result of the previously mentioned 0.74° C/1.3° F rise in average ocean temperature. And, with a global ocean temperature rise of at least 1° C/1.8° F, a certainty within this century and a rise of as much as 4° C/7.2° F a distinct possibility, bleaching events are expected to increase in frequency and severity, leaving less time for recovery between episodes.

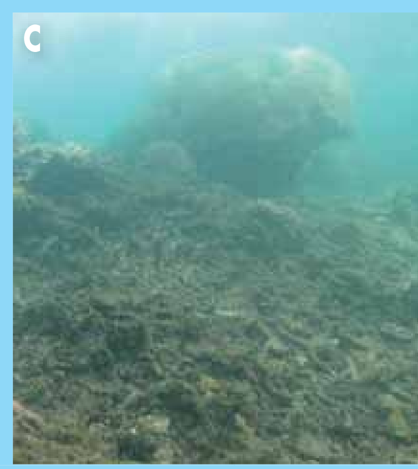
Ocean Acidification and Reef Growth

Recent experiments clearly show a relationship between ocean acidification and corals' ability to build their skeletons. As the amount of CO_2 in the atmosphere increases, so too does the amount of CO_2 in the ocean, causing many corals and other important reef community organisms to grow at a slower rate. This is because higher CO_2 levels in the ocean not only reduce ocean pH, but also reduce carbonate ion availability – critical for corals to build their calcium carbonate skeletons. Should atmospheric CO_2 levels reach 480 ppm (about 25 percent higher than today) some coral reefs may no longer grow fast enough to keep up with natural forces of erosion and dissolution.

Some evidence from Australia's Great Barrier Reef indicates coral growth rates have already dropped by 15 percent in the last 15 years.







Examples from Australia's Great Barrier Reef showing the communities we expect in the future, depending on the severity of climate change. Remember these are only examples of what the future might look like; they don't show actual areas where CO2 and temperature increases have already happened.

A. Reef slope communities at Heron Island, reflecting relatively healthy and diverse marine life after mild climate change.

B. Mixed algal and coral communities on inshore reefs around St. Bees Island near Mackay. This photo shows the crumbling reefs that might result from frequent coral bleaching and moderate ocean acidification.

C. Inshore reef slope around the Low Isles near Port Douglas, representing a severe climate change scenario where coral-dominated reefs are rare or non-existent.

Photos by O. Hoegh-Guldberg. From Hoegh-Guldberg et al., Science 318:1737-42 (14 Dec 2007). Reprinted with permission from AAAS.

Corals may also be building less solid skeletons, making them more vulnerable to erosion, storm damage, and grazing animals (such as sea urchins or parrot fish). We should point out there is still a lot we don't know about ocean acidification and its effects on coral reefs. It's a newer topic than coral bleaching, but the potential damage to reefs is chilling enough that we have to *start* talking about it even though it's not as well understood.

Non-climate threats

We cannot emphasize enough that climate change is not the only factor affecting the future of coral reefs. Local stresses threatening reef health include poor water quality, overfishing, deforestation, and sedimentation and nutrient runoff. Many reefs have lost several of their grazing animals (e.g., parrotfish and sea urchins) due to fishing pressure or disease. These animals are especially important in allowing reefs to bounce back because they control algae growth. If algae are allowed to cover a reef after a storm or a bleaching event, it is very difficult for new corals to grow back in that area.

What will the future bring?

What the future brings is very much up to all of us, and the actions we take in the next ten years are critical because it takes a while for natural systems to react. As mentioned, most scientists expect a higher ocean temperature by the end of the century just from the CO_2 *already* in the atmosphere. That is to say, even if we stop adding CO_2 to the atmosphere today, further warming and acidification will occur before the earth's system comes back into balance.

The following three scenarios demonstrate the potential effects of climate change and how our actions determine coral reefs' future. The scenarios show three possible futures:

- One where we take strong action to control CO_2 emissions (picture A);
- One where slower action allows higher concentrations of CO_2 (picture B); and,
- A worst-case scenario where CO_2 levels rise unchecked (picture C).

As you read through the scenarios, remember human activity determines which picture becomes reality. And, how we manage serious local threats is also critical (local factors can act in concert with climate change effects). Some reefs will devolve to scenarios two or three because of severe local problems, while a healthy, well-protected reef is better able to survive climate change.

• Scenario A •

This is the optimistic picture, where humans take strong action soon, and atmospheric CO_2 levels off quickly. Reefs continue to change, but may stabilize in a relatively healthy condition (picture one). Local effects from runoff, fishing and other ways humans harm reefs determine the health of each coral reef. In those areas where local stressors are minimized, corals continue to dominate, but grow more slowly than they did a century ago. Coral reefs may be less healthy than they are today, but are able to grow faster than they are eroded and coral species most sensitive to bleaching may die out, leaving reefs dominated by tolerant massive coral species (e.g., *Porites*) or by "weedy" corals that are able to grow more quickly (e.g., *Acropora* table corals).

• Scenario B •

If we don't slow emission rates fast enough, CO_2 levels could rise to 450 or 500 ppm. That's *double* the amount of CO_2 in the atmosphere before humans started burning fossil fuels. At these levels, ocean pH drops to a level where reef growth can't keep up with erosion in most parts of the world (picture two). Temperatures rise at least 2° C/3.6° F, making coral bleaching much more severe. Coral reefs become rare, coral cover and diversity declines and there is less habitat for the 25 percent of all known marine species that called reefs home.

• Scenario C •

This is a worst-case scenario where we continue our business as usual and CO_2 levels rise well above 500 ppm. Under these conditions, corals can't grow fast enough to maintain reefs, and high ocean temperatures cause frequent bleaching events. According to the paper published in *Science*, "these changes will reduce coral reef ecosystems to crumbling frameworks," with very few live corals (picture three). The potential for severe damage is highest where local stressors have already weakened or damaged coral cover. Those corals that do survive grow very slowly and are highly susceptible to local threats. And, more than half of the species that depend on coral reefs could become extinct.

Why reefs are worth saving

Hundreds of millions of people worldwide depend on healthy coral reefs for food, as protection against storms and waves and to attract crucial tourism income. The above scenarios have progressively worse consequences for those economies and societies that depend on coral reefs, e.g., less fish and other food species as their reef habitat is lost, effects of climate changes make reefs less attractive to tourists, etc. Divers in particular have a keen interest in healthy reefs and in preventing scenario three.

Degraded reefs offer less protection from waves and storms. This issue becomes more and more important as climate change causes sea levels to rise and storms to increase in strength, which also causes beaches to erode at a faster rate. Obviously, this is a problem for coastal populations, the tourism industry and for the animals that rely on beach habitats for survival.

What we do can make a difference

The situation is not hopeless – there is much we can do individually and as a society to help coral reefs survive. First, we can address the rise in greenhouse gases. Your everyday actions affect the total amount of carbon going into the atmosphere, so taking steps to reduce your carbon footprint, e.g., switching to CFL (compact fluorescent light bulbs) and using energy efficient appliances and vehicles does matter.

Because it takes time for the climate system to stabilize once we reduce emissions, we also suggest three important actions to help protect reefs unrelated to climate change:

1. **Manage Coral Grazers –** One of the most practical solutions is to increase the number of herbivores on coral reef systems to graze on the algae that grow there. Improving sea urchin populations and limiting fishing of important grazers like parrotfish is a simple, but powerful step that gives corals a fighting chance at surviving bleaching events.
2. **Coral Restoration Projects –** Coral reef restoration is not yet practical on the huge scale demanded by climate change. However, new technologies for "farming" corals may make this a better option in the future. Growing those corals best able to tolerate high temperatures improves corals' chances for survival.
3. **Manage Major Local Stressors –** Any actions we can take to reduce the effects of overfishing, improve water quality by reducing pollution, deforestation and sediment and nutrient runoff from land helps. For instance, a healthy reef environment may still bleach, but more corals will survive and regrow faster than a reef that is subjected to ongoing and severe local stresses.

The bottom line is there is still time to act, but we must act quickly. The longer we wait, the harder it is to effect positive change. Learn more about reducing your carbon footprint in your everyday actions. Support local actions to reduce major stressors on coral reefs. Most important, share your knowledge with your nondive friends, telling them about the importance of healthy coral reefs and the actions they can take to safeguard their future. For more information, please see the reference and resource lists above right. ◆

References:

Science article citation: O. Hoegh-Guldberg, et al., 2007. "Coral reefs under rapid climate change and ocean acidification." *Science* 318, pp. 1737 – 1742. Available online at http://www.sciencemag.org/content/vol318/issue5857/index.dtl (for subscribers only)

Resources:

Visit the following organizations online for more information about protecting coral reef resources, bleaching events and International Year of the Reef activities.

- Project AWARE Foundation: www.projectaware.org
- NOAA's Coral Reef Watch: coralreefwatch.noaa.gov/satellite
- International Year of the Reef: www.iyor.org