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# ACIDIC SEAS:

## How Carbon Dioxide Is Changing the Oceans

By George Hale

ALEXA ADJUSTS HER SNORKEL, MASK, AND FINS AS SHE PREPARES TO plunge into clear, blue water. She and four other U.S. high school students are two miles from Isla Ballena, an island off the Pacific coast of Costa Rica. The waters surrounding the island—part of Costa Rica's Marino Ballena National Park—contain coral reefs that attract visitors from around the world. The students are attending Ocean Camp, a university-sponsored two-week research program that exposes students to oceanography and marine biology. Here, Alexa and her classmates will learn firsthand about marine life, as well as check the health of the reefs and 18 species of coral.

Along with their instructors and a snorkeling guide, the students swim past swaying tentacle-like coral polyps and colorful fish. All the while, they watch closely for corals that have faded color or that seem to be weakened or crumbling. Alexa and her classmates have learned that these are signs of unhealthy corals, which are being threatened by warming and increasingly acidic oceans due to rapid changes in the Earth's climate. Although corals typically thrive in warm water, it places too much stress on them if the ocean gets too warm. This causes them to lose their beautiful colors and turn white, as if bleached. And a more acidic ocean can make it harder for corals to get the materials they need to grow and that causes them to weaken and crumble.

This is concerning because although coral reefs make up less than 1% of the Earth's surface, they play a crucial role in the ocean ecosystem—corals provide shelter for perhaps a quarter of the ocean's species. This is why researchers study changing ocean waters and ask the important question: How will a warmer and more acidic ocean affect corals and what does that mean for the health of our oceans?

### The greenhouse effect

One of the lessons Ocean Camp instructors gave earlier that week covered climate change and how it affects the ocean. **A culprit behind ocean warming and acidification is an increase in carbon dioxide in the atmosphere. Carbon dioxide and other gases play a crucial role in the Earth's climate in what is called the greenhouse effect: without them, the planet would be cold and inhospitable.** These atmospheric gases and a greenhouse work in quite different ways, but the resulting effect, higher temperatures in both cases, has led to this description. Although this term is misleading, it is commonly used.

A greenhouse is a building that is heated with solar radiation so that it can stay warm even in winter. Light from the sun passes through the glass roof to heat plants and the ground inside the greenhouse. These objects then emit infrared radiation, that is heat. Thermal energy is trapped in the greenhouse, keep-



ing the building warm. The greenhouse effect is a natural process that warms the Earth's surface. When the sun's energy reaches the Earth's atmosphere, some of it is reflected back to space and the rest is absorbed by the land and the oceans, heating the Earth. The surface of the Earth loses energy back into space by emitting infrared radiation, but greenhouse gases absorb some of this infrared light, retaining the energy on Earth and so keeping it warm enough to sustain life.

Human activities, such as burning fossil fuels, agriculture and land clearing, are increasing the amount of greenhouse gases, such as carbon dioxide, released into the atmosphere. This is trapping extra heat, and causing the Earth's temperature to rise. These rising temperatures cause environmental changes, such as melting glaciers and ice sheets.

Excess heat is not limited to the air. **Ocean temperatures have also increased, which affects coral reefs around the world. When water becomes too warm, corals can become stressed, and they expel the symbiotic algae living in their tissues.** Without the algae, the coral loses its major source of food, turns white or very pale, and is more susceptible to disease.

### 1. $\text{CO}_2(\text{g}) \rightleftharpoons \text{CO}_2(\text{aq})$

Carbon dioxide gas dissolves in water.

### 2. $\text{CO}_2(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{H}^+(\text{aq})$

Dissolved carbon dioxide reacts with water and dissociates into bicarbonate ion ( $\text{HCO}_3^-$ ) and a hydrogen ion ( $\text{H}^+$ ). Because the ocean is basic (pH around 8.2), the  $\text{H}^+$  concentration is relatively low. As a result, this equilibrium is shifted almost completely to the right. Only 0.5% of  $\text{CO}_2$  is found in seawater as dissolved  $\text{CO}_2$ . Most (89.5% is in the form of bicarbonate ion). Adding more  $\text{CO}_2$  from the atmosphere increases the amount of  $\text{H}^+$  present through this reaction and contributes to lowering the pH of the ocean.

### 3. $\text{HCO}_3^-(\text{aq}) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + \text{H}^+(\text{aq})$

It is more difficult for the second  $\text{H}^+$  to split off from the bicarbonate ion (it is not very acidic) and as a result only 10% of the dissolved  $\text{CO}_2$  is  $\text{CO}_3^{2-}$  (aq).

### 4. $\text{Ca}^{2+}(\text{aq}) + 2 \text{HCO}_3^-(\text{aq}) \rightleftharpoons \text{CaCO}_3(\text{s}) + \text{CO}_2(\text{aq}) + \text{H}_2\text{O}$

Corals, plankton, and shellfish use calcium ions ( $\text{Ca}^{2+}$ ) and carbonate ions ( $\text{CO}_3^{2-}$ ) to build their calcium carbonate skeletons and shells, a process known as calcification. Equation 4 shows the precipitation reaction of calcium ions and hydrogen carbonate, which react in the ocean to form calcium carbonate. As the acidity of the ocean increases, the  $\text{H}^+$  concentration increases, there is less  $\text{HCO}_3^-$  and more  $\text{CO}_2$  (aq) available (see equation 2), and this equilibrium shifts to the left. The minor carbonate species (in equation 3) can also react with calcium ion to form calcium carbonate, but there is also relatively less of it too with increasing  $\text{H}^+$ . This makes it more difficult for calcium carbonate to form, which means shells can't form as readily.



Bleaching in Kaneohe Bay in Hawaii

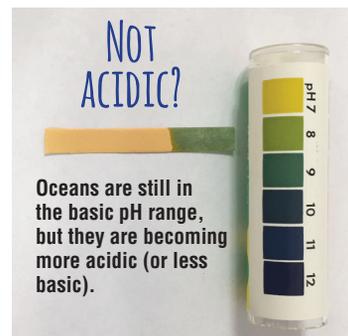
Carbon dioxide's effects on the ocean go beyond warming, though. The ocean has dissolved a lot of carbon dioxide, which keeps it out of the atmosphere. But as the concentration of carbon dioxide in the atmosphere increases, even more is added to the ocean, and it changes the water's chemistry. **As shown in the first equation above, gaseous carbon dioxide dissolves in ocean surface water to produce aqueous carbon dioxide.** Carbon dioxide reacts with the water molecules and releases hydrogen ions, increasing the pH.

OCEANOGRAPHER  
KATHRYN SHAMBERGER  
SAYS OCEAN pH HAS  
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## Shifting ocean pH

As a result of shifting the carbonate-bicarbonate equilibrium, the pH of the ocean is also changing. Texas A&M University oceanographer Kathryn Shamberger says ocean pH has dropped from 8.2 to 8.1. Continuing to release carbon dioxide at the current rate will mean the oceans will continue to increase in acidity.

The loss of reef habitats and damage to species either directly or through disruptions to the food web could also affect human populations. In many areas of the world, coral



reefs block and deflect some of the energy of ocean waves, meaning that water between the shore and reef is calmer than it would be otherwise. If coral structures weaken, they could be damaged by storms, severely reducing this calming effect. In addition, habitat loss for the 25% of ocean species that call coral reefs home could have far-reaching effects.



Coral in American Samoa before, during, and after a coral-bleaching event.

Ocean acidification also presents economic risks. An acidifying ocean could harm fish and shellfish that humans eat, either directly or by eliminating food sources for commercially valuable species of fish.

Also, about 12% of the world's population earns a living through fishing, accounting for nearly \$150 billion worldwide in 2014. Thus, ocean acidification is another factor fisheries will have to consider when planning for the future.

## Bringing it all home

These students have a lot to think about when they return from Costa Rica. Over the course of two weeks they have learned about how the oceans interact with the overall climate and how human activities can affect ocean life. **Future scientists will need to understand how pollution, warming, and ocean acidification affect marine life and come up with ways to reduce atmospheric carbon dioxide and its impact on the oceans.**

The students see that although harmful, ocean acidification affects coral reefs differently around the world, possibly because of variations in pH or ocean chemistry. They learned how ocean water, sea-floor sediments, and even Arctic and Antarctic ice are showing scientists that atmospheric carbon dioxide



Students researching and documenting coral reefs.

and ocean pH are changing faster now than in the past. Alexa and her classmates found out how increasing carbon dioxide in the air affects the ocean through changes in carbonate and bicarbonate ion concentrations and pH, how those changes might affect coral reefs, and what that could mean for the rest of the ocean, as well as for marine life and the human population.

**The lessons these students learned and activities they participated in, particularly their snorkeling tour of a coral reef, will give new perspectives on oceans and oceanography.** What they learned will serve as a guide for their course of study after high school, because even though we know quite a bit about climate change and the oceans, there is still a great deal to figure out. CM

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