6 Changes in Ocean Temperature and Chemistry

by L. Jeremy Richardson

Earth's ocean is vast—both in surface area (covering more than 70 percent of Earth's surface) and in volume (approximately 1.3 billion cubic kilometers, or 310 million cubic miles). These are enormous figures. Given the size of the ocean, it is not surprising that it plays a critical role in the climate system.

This chapter examines how human activity—namely the ongoing release of greenhouse gases (GHGs), most importantly carbon dioxide (CO_2)—is changing the ocean in a measurable way, and how these changes will ultimately affect marine life and human society. If emissions continue to grow, the ocean will deteriorate to the point at which conditions are detrimental to shell-forming organisms and the marine food chain. Thus, it will threaten fisheries and marine ecosystems generally—with potentially large implications for human systems and the world's food supply.

The ocean and atmosphere are coupled, meaning that they interact with each other, and an action in one leads to a reaction in the other. The ocean and atmosphere, like any physical system, strive for **dynamic equilibrium.** The word *dynamic* means they are constantly changing and that they exchange heat and molecules, like water vapor, until they come into balance with each other (equilibrium). Importantly, that the ocean and atmosphere reach equilibrium does *not* mean that they are not interacting—quite the contrary. In fact, the atmosphere is constantly interacting with the surface layers of the ocean. What this means is, in a state of dynamic equilibrium, the ocean and atmosphere are always exchanging items, but the net balance of items lost and gained remains the same. Think about a bathtub that is filling: If the water is still running and you pull out the drain plug, water is running out of the tub while it's still being added, but the overall water level remains the

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.c-e	Living Things in Changing Environments
Grade 4	4.3.b	
Grade 5		
Grade 6	6.4.a; 6.4.d 6.5.e	
Grade 7	7.3.e	Responding to Environmental Change
Grade 8	8.5.e 8.6.a	

same. The tub, in this case, is in a state of dynamic equilibrium.

Human activities are throwing this system out of balance, and the climate system has yet to reach a new equilibrium state. Humans release GHGs primarily through the burning of fossil fuels such as coal, oil, and natural gas and also through deforestation. GHGs are being released in such large numbers that they are changing the physical makeup of both the atmosphere and the ocean. This is causing observed changes in Earth's climate. Here we will focus on two particular impacts GHGs are having on the ocean—temperature and chemistry—and how they affect marine life and, ultimately, humans.

The dynamic exchange between the atmosphere and the ocean includes not only gaseous water vapor but also carbon dioxide. In fact, the ocean has absorbed about 30 percent of the CO_2 emitted by human activity since the beginning of the Industrial Revolution (around 1750) (Sabine et al. 2004). If this process seems difficult for your students to comprehend, have them consider their favorite carbonated beverage. If left to the open air, it eventually goes flat—the CO_2 dissolved in the drink is released into the air. This process works in reverse just as well. As more and more CO_2 is pumped into the atmosphere, about a third of it is absorbed by the world's ocean, which helps to bring the system back into balance and reestablish that equilibrium state.

Climate Change and Ocean Temperature

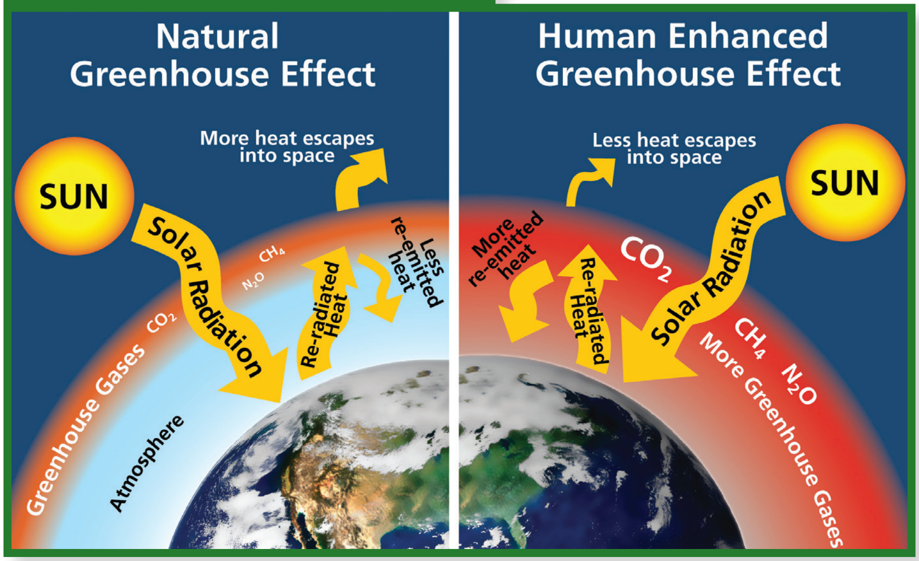
The excess GHGs in the atmosphere are enhancing the well-known **Greenhouse Effect;** as these gases effectively trap heat near Earth's surface, the atmosphere and Earth's surface absorb some of the extra heat, and the ocean absorbs the rest. Actually, the heat capacity of the ocean is about 1,000 times greater than that of the air. Since 1960, the ocean has taken up about 20 times more heat than the atmosphere (Bindoff et al. 2007). Heat capacity is a measure of how much heat energy is needed to change an object's temperature by a certain amount. Materials with high heat capacities—such as water—require large amounts of heat to produce a small increase in temperature.

CHAPTER OVERVIEW

Human activities are affecting the ocean in unprecedented ways. Every time we burn fossil fuels, we emit gases into the air that amplify our natural Greenhouse Effect. Since the 1800's, our sea surface temperatures, as well as land temperatures, have warmed on average. This warming of ocean water contributes to rising sea levels, in addition to changing existing marine ecosystems.

The ocean is also a major carbon sink. This means that the ocean uptakes carbon dioxide from the atmosphere. In fact, the ocean has absorbed up to 30 percent of the carbon dioxide emitted into our air since we started the wide-scale burning of fossil fuels during the Industrial Revolution. The uptake of carbon, however, is having potentially serious impacts on ocean life. Our ocean is becoming more acidic, and some organisms are struggling in the new environment—especially those that build shells of calcium carbonate.

ENHANCED GREENHOUSE EFFECT



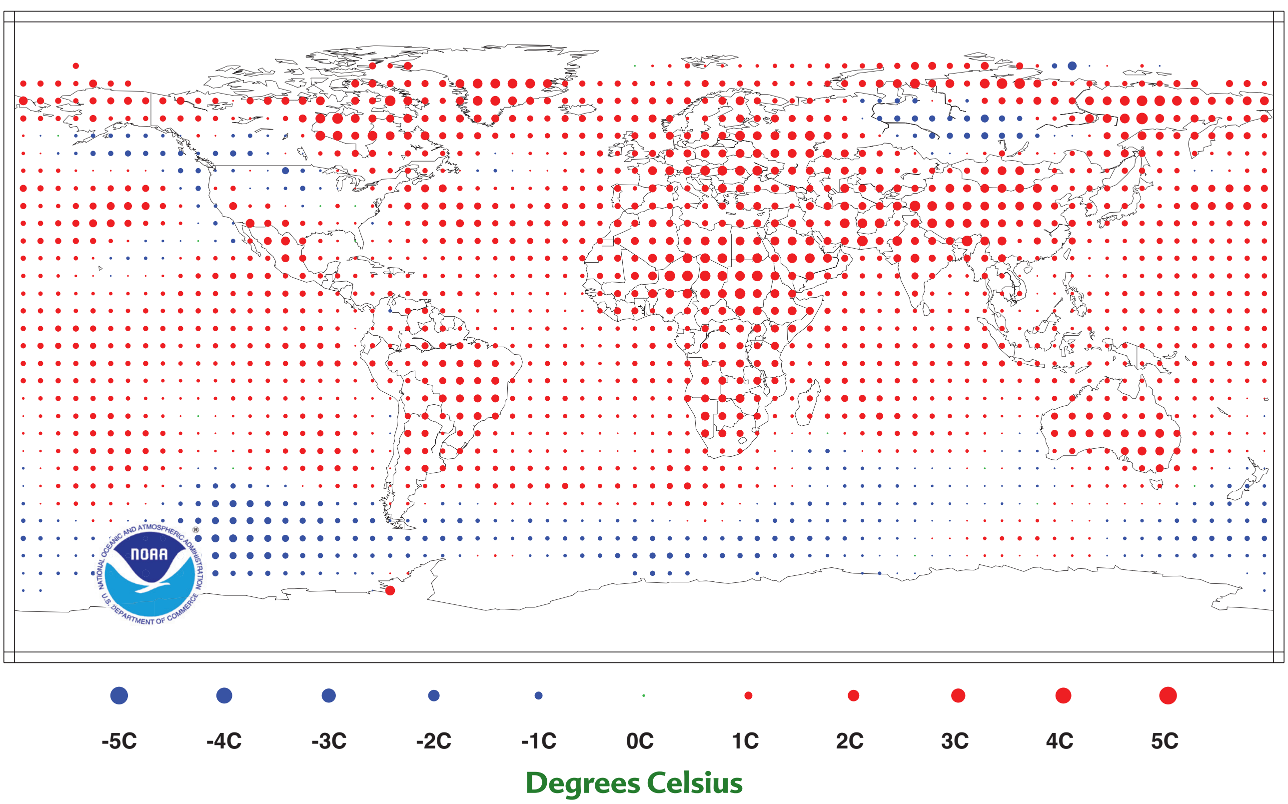
The increased amounts of GHGs, such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) from increased fossil fuel use, are trapping more and more of the sun's heat in our atmosphere.

Observations confirm that this added heat is increasing average sea surface temperatures (SSTs). From 1850 to 2005, the average increase in SSTs per decade was about 0.04°C (Bindoff et al. 2007). Because the ocean is vast and has such a high heat capacity, it takes time for it to absorb the excess heat, meaning that there is a lag time between GHG emissions and observed change. This means that even if emissions stopped completely today, it would be several decades before the ocean reached equilibrium and the climate began to stabilize.

Scientists have observed widespread changes in snow-and-ice cover around the globe, and these changes have also been attributed to human activities

RISING OCEAN AND LAND TEMPERATURES

TEMPERATURE ANOMALIES JANUARY—DECEMBER 2009



NOAA map of worldwide land and sea temperature anomalies (difference from the average temperature from 1971—2000). Areas in red were observed warmer than average; blue areas indicate that observed temperatures were cooler than average.

(as have temperature increases). A combination of increased temperatures and increased melting has led to an observed rise in global average sea level (Bindoff et al. 2007). Most of this increase, possibly as much as 75 percent, is due to the **thermal expansion** of the ocean. Your students may think that sea-level rise from climate change is only caused by melting icebergs. Physical objects expand as they warm and contract as they cool, and water behaves the same way. (This is why wooden doors sometimes swell and stick in the middle of a hot summer and why bridges have a metal connector at either end—so the bridge can expand and contract without breaking.)

An important distinction must be made here between land ice and sea ice. Land ice is ice that is on the land, supported entirely by landmass. The most important land-based ice sheets are in Greenland and Antarctica. Sea ice, on the other hand, is floating in ocean water—the Arctic sea ice that covers the North Pole in the Arctic Ocean Basin is a good example. As sea ice melts, it has important consequences for warming because the ocean absorbs most of the incoming light energy from the sun, while the bright snow and ice reflect most of the light. But melting sea ice does *not* affect sea level at all. Land-based ice, when it melts and flows into the ocean, raises sea level. As a frame of reference, if both the Greenland and West Antarctic ice sheets were to collapse and melt completely, global average sea level would rise about six or seven meters (20 to 23 feet)! In contrast, when Arctic sea ice undergoes seasonal melting, sea level does not increase at all. Fortunately, although significant losses are possible, most scientists think a complete collapse is unlikely.

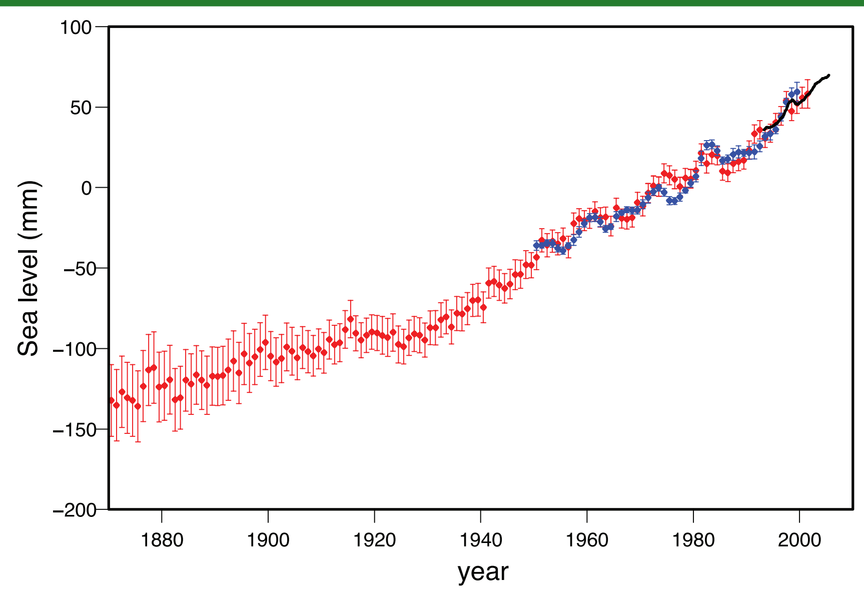
The ocean has also experienced changes in salinity, or saltiness. As discussed in Chapter 1, temperature

Teaching Tip

Students commonly think that the melting icebergs, ice shelves, and other oceanic ice will be the largest contributors to sea-level rise, but scientists know differently. There is a simple activity to demonstrate why scientists are more concerned with melting glacial ice or ice that is on land than with oceanic ice. Have students first think about a glass of ice water. Ask students, "If the ice melts, will the glass overflow?" Students will often say yes, even though they have regularly seen evidence to the contrary. Then have them create a simple experiment to show otherwise:

Take two identical bowls or beakers—clear glass works best. Into each bowl, place something to represent land; another smaller bowl placed upside-down works well. To each bowl add an identical amount of ice. In one bowl, the ice goes onto the "land" to represent glacial ice. In the other bowl, the ice goes around the land to represent oceanic ice. Then have students add water to each bowl to an identical level. Have students draw a line on the outside of the bowl at the water line—dry or wet erase markers work best. Next, let the ice melt. Once all the ice has melted, have students measure which scenario showed greater water-level increase. The bowl with the land, representing a glacial-ice situation, should have risen substantially higher than that with the oceanic ice. Have students think about and discuss what this might mean for global climate change and our ocean.

RISING SEA LEVELS



The red curve shows reconstructed sea-level fields since 1870; the blue curve shows coastal tide-gauge measurements since 1950; and the black curve is based on satellite altimetry, which measures height. The curves indicate deviations from average sea level. Reproduced from Figure 5.13, IPCC AR4 WGI, p. 410.

Pictures of Practice

Melting Ice

Students have likely heard about melting polar ice and threats to polar wildlife caused by climate change. In the last decade, we have witnessed unprecedented melting of our polar ice. Data from NASA scientists show that Arctic sea ice has decreased substantially from the long-term average, and Antarctica is also losing ice mass in certain regions, although there is more uncertainty about Antarctic melting compared to Arctic melting (for more information visit http://climate.nasa.gov/). Students may have questions about what will happen as this ice melts and enters other systems on Earth.

Students: Grade 8

Location: San Marcos, California (a coastal community)

Goal of Video: The purpose of watching this video is to listen to student ideas about melting ice in different polar regions and outcomes of melting ice on the ocean and climate.

Classroom Context

Ms. Brice taught an extensive unit on climate change to her eighth-grade students; content especially focused on current research on changes in the ocean system. This lesson was the first in the unit to bring up melting polar ice. The interviews occurred only two days after the lesson.

Video Analysis

In this video students are wrestling with possible outcomes of melting polar ice. As polar ice caps melt, scientists are concerned with outcomes of cold, freshwater entering our ocean and how this will impact sea level and ocean currents. Ice in the Arctic is mostly sea ice (save the massive ice sheet covering Greenland). The ice in Antarctica is mostly covering land. The melting of ice on land will influence sea level more than melting sea ice. But the melting of sea ice in the Arctic has another disturbing consequence—the potential to change, or halt, our ocean currents as dense, cold, freshwater enters our northern ocean (http://science.nasa.gov/science-news/science-at-nasa/2004/05mar_arctic/). Changing water temperature, chemistry, and density from melting polar ice may impact our ocean currents, which could also affect the movement of air masses, especially in the northern Atlantic. In this video, Ms. Brice teaches about the difference between melting sea ice in the Arctic compared to melting ice sheets in Greenland and Antarctica. The class talks about the percentage of an iceberg that is visible above sea level. After some discussion, the class agrees that the answer is approximately 10 percent. Once the class has understood the concept of sea ice versus ice on land melting, students explain the possible consequences of melting ice in their interviews. The class then discusses what will happen if cold, dense water enters the ocean. Listen as students describe the possibility of another ice age. What did they understand and not understand from the classroom discussions?

Reflect

What would be your next step to teach about melting ice and the ocean system?

What did students seem to understand and not understand during their interviews? What were the most important misconceptions? Given that these students have had some, but limited, discussion on the topic, what additional activities and discussions could you do with students?

and salinity play an important role in the circulation of the ocean. Combined with changes in temperature, this phenomenon has raised concerns about the effects on ocean circulation. Water moves in currents in the ocean, not only along the surface but also from the surface to the deep ocean. This movement happens because of the temperature and salinity of the water—colder and saltier water is more dense, and dense liquids sink below less dense liquids. This worldwide current is called the thermohaline circulation, or the ocean conveyor belt. Some scientists believe that freshwater from melting ice sheets, when added to the ocean, will decrease salinity and disrupt thermohaline circulation. So far there is no convincing evidence that climate change has altered ocean currents, but it remains a concern for the future.

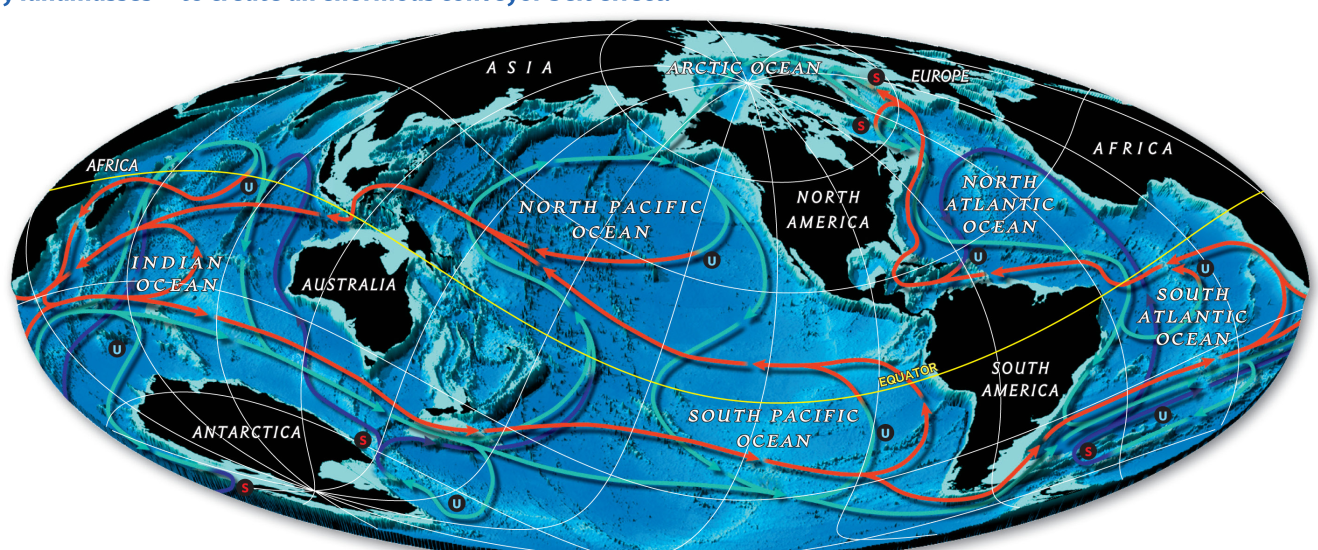
Scientists are also concerned about how changes in the ocean will affect other aspects of the climate system. Higher SSTs, for example, could lead to stronger hurricanes because these storms draw energy in part from warmer waters. Models suggest that higher maximum wind speed combined with higher maximum rainfall averages may result in an increase of stronger storms. The jury is still out on the ultimate impact on hurricanes due to climate change, but generally, experts believe that we can expect an increase in cyclone intensity but a decrease in the number of storms overall in a warmer climate. Higher sea levels and greater wind speeds will also increase the amount of ongoing coastal erosion but would be of particular concern during strong storms.

Teaching Tip

Why does it take so long for the oceans and atmosphere to reach equilibrium? Students may not understand that even if GHG emissions stop completely, the climate will continue to change for decades because the ocean takes a long time to absorb all the excess heat. Show students two clear glasses or cylinders of different sizes filled with water. Add 10–15 drops of food coloring to each one and ask students to guess which one will mix faster. Have them watch while the small cylinder quickly dissipates the food coloring, and the large cylinder takes much longer. Explain that when things are added to larger bodies of water, it takes a longer time for them to be completely absorbed. Once they grasp the effect on the small scale, it makes explaining why it will take so long for the ocean to absorb the additional carbon dioxide and heat easier.

GLOBAL OCEAN CURRENTS

The ocean is in constant motion—driven by surface winds, controlled by water temperature and density, and guided by landmasses—to create an enormous conveyor belt effect.



Surface and Deep Currents

S Sinking | U Upwelling | Warmer than 3.5°C (38.3°F) | 1°C – 3.5°C (33.8°F –38.3°F) | Cooler than 1°C (33.8°F)

Climate Change and Ocean Chemistry

As noted earlier, in addition to warming, the ocean is absorbing a significant fraction of the CO_2 emitted by human activities. This is changing the chemistry of the ocean. When the ocean dissolves atmospheric CO_2, carbonic acid is formed. As a result, seawater becomes more acidic. This is called **ocean acidification.**

As the oceans absorb CO_2, the dissolved CO_2 reacts with water (H_2O) to form carbonic acid (H_2CO_3). Carbonic acid is relatively unstable and breaks down into a bicarbonate ion (HCO_3^-) and a hydrogen ion (H^+). The conversion of CO_2 to bicarbonate removes a CO_2 molecule from the seawater solution, making room for another atmospheric CO_2 molecule to dissolve; this property of seawater allows it to absorb more CO_2 from the atmosphere than an equivalent volume of freshwater in a lake or a river. Hydrogen ions, the other product of the conversion process, make seawater more acidic; as the concentration of hydrogen ions increases, the pH decreases. Some of the free hydrogen ions react with carbonate ions to form more bicarbonate ions, shifting the balance to favor bicarbonate over carbonate, and reducing the number of carbonate ions in the seawater.

It's important to clarify that this process will *not* lead to the ocean changing completely to an acid. The term *acidification* refers to the *relative* change in the acidity levels of the ocean. Although the pH is decreasing through this process, the ocean will remain basic, or above 7.0 on the pH scale. However, organisms in the ocean are adapted to very specific conditions, and even small changes in pH can lead to major impacts.

Ocean acidification is measurably changing the pH of seawater. The ocean before the start of the Industrial Revolution had a pH of about 8.1 or 8.2, depending on latitude (Caldeira and Wickett 2005). So far, the pH of the ocean has declined by about 0.1 unit (Bindoff et al. 2007). That may not sound like much, but it represents a 26 percent increase in acidity! With continued emissions of CO_2, this situation will continue to worsen. Mid-range projections for 21st century emissions suggest that ocean pH could decline by another 0.3 or 0.4 unit by 2100, and that figure could be as high as 0.7 unit by 2300 for higher emission trajectories (Bindoff et al. 2007; Caldeira and Wickett 2003).

These changes in ocean pH could dramatically impact some forms of marine life—particularly those that depend upon the availability of calcium carbonate to make shells or skeletons

Teaching Tip

A simple way to demonstrate how water can absorb carbon dioxide is to have students exhale into a lidded cup of water. Have them check the pH of the water before they begin blowing, and then again after 2—3 minutes, and again after 5—6 minutes. Have them see how quickly they are able to change the pH of their water. (Note: to ensure proper hygiene, have each student use a separate straw to blow into the cup.)

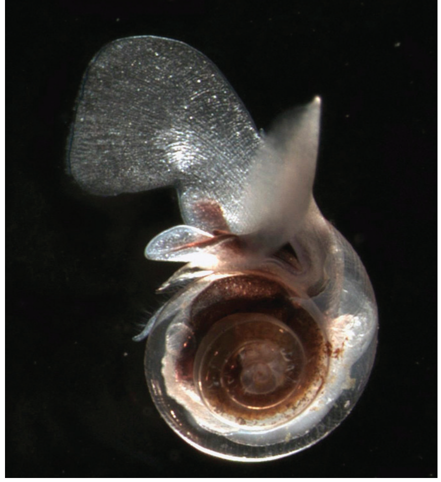
pH SCALE

	Environmental Effects	pH Value	Examples
ACIDIC		pH = 0	Battery acid
		pH = 1	Sulfuric acid
		pH = 2	Lemon juice, Vinegar
		pH = 3	Orange juice, Soda
	All fish die (4.2)	pH = 4	Acid rain (4.2-4.4) Acidic lake (4.5)
	Frog eggs, tadpoles, crayfish, and mayflies die (5.5)	pH = 5	Bananas (5.0-5.3) Clean rain (6.5)
NEUTRAL	Rainbow trout begin to die (6.0)	pH = 6	Healthy lake Milk (6.5-6.8)
		pH = 7	Pure water
		pH = 8	Sea water, Eggs
		pH = 9	Baking soda
		pH = 10	Milk of Magnesia
		pH = 11	Ammonia
		pH = 12	Soapy water
		pH = 13	Bleach
BASIC		pH = 14	Liquid drain cleaner

The pH scale measures how acidic a substance is and ranges from 0 to 14. Seawater has an average level of 8; even the slightest deviation can have adverse affects on marine life.

(called **calcification**). These organisms include corals, mollusks such as clams and scallops, and some plankton (e.g., coccolithophores). As the ocean becomes more acidic, there is less calcium carbonate in seawater for these organisms to use in building shells. If the ocean becomes acidic enough, living calcified organisms can actually begin to dissolve. There is observational evidence that more acidic waters may already be affecting certain animals in some regions; one species of microscopic plankton in the ocean waters around Antarctica has modern shell weights 30–35 percent lower than those of the past found in ocean sediments (Moy et al. 2009).

Although results are preliminary and research is ongoing, the recent collapse of the Pacific oyster appears to be connected to ocean acidification. Beginning in 2005 and continuing in 2006, 2007, and 2008, two of the largest oyster hatcheries in Washington State reported production rates falling by about 80 percent (Miller et al. 2009). One hypothesis is that more acidic seawater from the deep ocean is upwelled into coastal areas. This happens because, as winds force surface waters away from the coast, it allows deep waters to well up from below. The amount of CO_2 contained in the deep water has increased because of ocean



In more acidic ocean waters, calcium carbonate shells of organisms like this swimming pteropod, *Limacina helicina,* may be reduced.

acidification—so much so that it is corrosive to baby oysters, which cannot survive the higher acidity levels. Surface waters in a region near the California-Oregon border, not too far from the oyster hatcheries, reached record-low pH levels of 7.75 in 2007 (Feely et al. 2008).

Ocean acidification may affect other shellfish and commercial fish species, particularly in coastal ecosystems and estuaries, which may be more susceptible to changes in pH. Experiments on the edible mussel and the Pacific oyster (both species important to global seafood production) show that these organisms are very sensitive to pH—they have a much more difficult time building their shells in a more acidic environment.

Plankton are a form of marine life that encompass a variety of different species. Some of them form shells from calcium carbonate—and these species are so pervasive that they form the base of the marine food chain. Facing increased stress from more acidic waters, they could decline or disappear, which would affect larger animals that feed on them and thus potentially lead to ripple effects throughout the ocean food chain.

Because colder water contains less carbonate, the waters around Antarctica already have the lowest concentrations of carbonate worldwide. Projections indicate that by the 2030's, seawater there may become acidic enough to dissolve the shells of some marine life in the winter. This is a problem because some important species of plankton have larval development stages in the winter; if waters are too acidic in that season, it could disrupt the food chain in the waters around Antarctica.

Although there will be winners and losers under ocean acidification, it is clear that these changes in ocean chemistry will radically alter marine environments.

Finally, ocean acidification could have direct effects on human society through impacts on fisheries and tourism. Globally, fisheries produce about 15 percent of the animal protein consumed by 2.9 billion humans, employ nearly 200 million people directly and indirectly, and generate some $85 billion annually (UN Food and Agriculture Organization 2008). Declining harvests, leading to loss of fishery revenues from shellfish (and their predators), therefore, represent measurable economic losses. In the United States, where domestic commercial fisheries contributed some $34 billion to the U.S. GNP in 2007, economic costs (in the form of revenue declines and job losses) due to ocean acidification could be large, as mollusks, crustaceans, and predators that feed on these species make up a sizable fraction of the industry (Cooley and Doney 2009).

Teaching Tip

To demonstrate the relationship between acidity and its ability to dissolve chalk, you can use cups or beakers of water at varying acidities (this can be accomplished by blowing into the cups or by adding vinegar), and placing a small piece of chalk or a small shell into each cup. Have students record how quickly or slowly the chalk dissolves at each pH. (Note: Dustless chalk will not easily dissolve in vinegar.)

Student Thinking

Ideas About Acids and Bases

Students are often challenged by concepts that involve chemistry and pH. Introducing students to the general concepts of acids and bases and the pH scale is a good place to start, but also allowing students to safely explore everyday items around them can be helpful as well.

Scenario

Your students have just completed a pH-indicator test on some common grocery store items such as peppers and oranges. After testing the pH, you ask your students if they have any questions about acids and bases.

Question

What questions do you have about acids and bases after this experiment?

Scientific Answer

pH is a measure of the hydrogen concentration in a solution. A lower pH indicates an acid, and a higher pH indicates a base. Items that test to the extremes of either side of the scale (below 3 or above 10—11) can be very harmful because highly acidic items have too many hydrogen ions (H^+) and highly basic items have to many hydroxyl ions (OH^-). Water (H_2O) is pH 7, or neutral, because it has equal amounts of hydrogen and hydroxyl ions. Many common food items will not cause grave harm to humans but will test moderately acidic or basic on the pH scale.

Student Answers

Anna: I get why acids are bad, but then why are bases bad too?

Roberto: Why can we touch some stuff that's acid and not others?

Greg: My mom won't let me have soda, and I think it's because it's too acidy.

Malia: I'm not going to eat lemons anymore cause they are an acid.

What Would You Do?

1. How would you respond to Anna and Roberto's questions in upcoming lessons?
2. How would you alleviate Greg and Malia's misconceptions about foods that test weakly or moderately acidic?
3. Given these misconceptions, what challenges would you expect when teaching about ocean acidification.

The ocean is a critical component of Earth's climate system, and despite its vast size, it does respond to external forces. Human activities that release large quantities of GHGs (particularly CO_2) are now demonstrably changing the physical and chemical properties of the ocean. Ocean heat content has increased, as have sea surface temperatures. The acidity level of the ocean has increased by about 26 percent. These changes can negatively impact some marine organisms that make shells from calcium carbonate. Such fundamental changes would harm biodiversity of marine ecosystems, reduce tourism and recreational activities, interrupt the ocean's natural food chain, disrupt Earth's carbon cycle, and contribute to the decline of fisheries, thus, threatening the world's food supply. Therefore, global climate change can be viewed as a threat to the ocean, our economies, and our overall well-being.

Case Study

Coral Reefs

Coral reefs are important ocean habitats and offer a compelling case of the risks of climate change. Reefs provide a large fraction of Earth's biodiversity—they have been called "the rain forests of the seas." Scientists estimate that 25 percent of all marine species live in and around coral reefs, making them one of the most diverse habitats in the world.

Paulo Maurin, education and fellowship coordinator for NOAA's Coral Reef Conservation Program, says the reefs are invaluable to our planet's biodiversity.

"They act as productive nurseries to many fish species, giving the small fish a home and a chance to grow," he says. "Coral reefs' diversity is so rich that we do not have a firm count on all the species that live within it and every year discover new species."

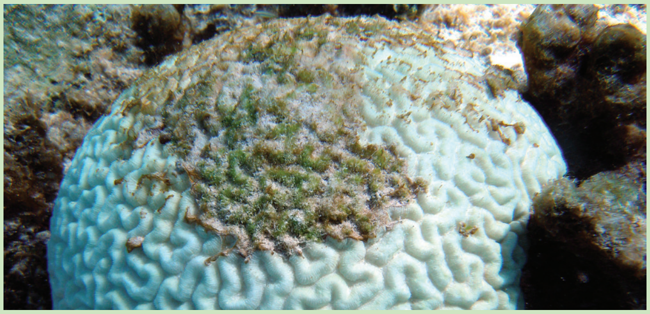
Reefs provide a variety of economic benefits, including recreational activities, tourism, coastal protection, habitat for commercial fisheries, and preservation of marine ecosystems.

"Corals are important to us for many reasons," Maurin says. "From a practical point of view, they can help protect coastlines from storm events, for instance, and help maintain fisheries that are essential to a lot of people. And complex compounds found in coral reefs hold promises in modern medicine. These are what we call ecosystem services that would be very difficult and expensive to replace.

"They also have a unique ability to inspire us to explore and visit the ocean. Can you think of any other invertebrate that people would come from afar just to see?"

Corals live with algae in a type of relationship called symbiosis. This means the organisms cooperate with each other. The algae, called zooxanthellae, live inside the corals, which provide a tough outer shell made from calcium carbonate. In return for that protection, the algae provide their host with food produced through photosynthesis. Zooxanthellae also provide corals with their striking colors.

This symbiotic relationship is strongly dependent on the temperature of the surrounding water. As the water warms, zooxanthellae are expelled from a coral's tissue, causing it to lose its color and a major source of food. This process is known as coral bleaching.



Coral bleaching does not always mean the death of a coral reef. Corals can recover their zooxanthellae in time but require cooler temperatures to do so.

Warmer ocean water also becomes more acidic. Ocean acidification is making it more difficult for corals to build their hard exoskeletons. In Australia's Great Barrier Reef, coral calcification has declined 14.2 percent since 1990—a large, rapid decline that hasn't been seen for 400 years.

The combination of rising ocean temperatures and increased acidity will likely cause major changes to coral reefs over the next few decades and centuries.

Maurin believes there are several ways people can help preserve these valuable resources.

"Over the long term, we need to reduce the amount of CO2 that is up in the atmosphere that is causing both increased bleaching and acidification," he says. "But in the more immediate time, there is other ways to help. By understanding that bleaching and acidification stress corals, we can help by building up what we call 'reef resiliency.' That is, making sure that reefs have this capacity to bounce back.

"For instance, ensuring that there is less pollution entering the ocean can help far-away corals. Also, people can help by making sure that the seafood consumed is sustainable and not contributing to a depletion of fish species that keep algae in check, following fishing regulations when fishing as well as supporting marine protected areas in key conservation sites."

Student Thinking

Climate and the Ocean

Students' understanding of global climate change as it relates to the ocean is tightly coupled with their understanding of the ocean itself. While students are often excited and engaged when learning about the ocean, they may still harbor many misconceptions and misunderstandings about the ocean itself that can hinder their overall understanding of the ocean and global climate change.

	Common Student Idea	Scientific Concept
Temperature	The ocean is already a warm place so global climate change is going to lead to it becoming really hot, maybe even boiling.	When students go swimming at the ocean, they are often swimming in warm near-shore areas, but the majority of the ocean is relatively cold. Global climate change only needs to warm the ocean by a few degrees before major impacts are felt.
	Warmer waters are good for animals.	In fact, many ocean organisms are adapted to cooler waters. Cooler waters are often more productive because they contain nutrients upwelled from below.
Biodiversity	If global climate change happens, all the animals in the ocean will die.	Studies are already showing that some species will thrive under the new conditions, especially gelatinous animals (e.g., sea jellies).
Currents	Currents will be the same; they'll just be warmer.	Many currents are driven by temperature, salinity, and density differences. A changing climate can alter all of these, thereby altering the currents.
Migration	Animals can just move someplace new if the ocean gets too hot or there isn't enough food.	Some ocean animals are capable of migrating to new ranges but not all of them. Some animals are **sessile** (don't move) as adults. It might take those species a while to adjust, as their larvae are the ones helping to expand their range.

Ask Your Students

1. How much warmer will the ocean need to be before the effects are felt by fish?
2. Why might some animals thrive during climate change?
3. How long does it take for animals to adapt to changes in their environment?

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Teaching Resources

California Education and Environmental Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm

Natural Research Defense Council acidification lab kit:www.nrdc.org/oceans/acidification/files/labkit.pdf

National Geographic's ocean acidification page: http://ocean.nationalgeographic.com/ocean/critical-issues-ocean-acidification/

National Geographic's sea temperature rise page: http://ocean.nationalgeographic.com/ocean/critical-issues-sea-temperature-rise/