ENVIRONMENTAL LITERACY TEACHER GUIDE SERIES

One Ocean

A Guide for Teaching the Ocean in Grades 3 to 8

NATIONAL GEOGRAPHIC
education

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California Education and the Environmental Initiative

California has always been a leader in environmental education and conservation, including the existence of environmental content in their academic standards.

Increasing California's impact on environmental education, Assembly Bill 1548 was passed into law in 2003 mandating the creation of a K–12 curriculum charged with incorporating more environmental education into the state's required academic content standards in Science and History/Social Science. The bipartisan law was supported by various state and nonprofit groups, and marked the beginning of the landmark Education and the Environmental Initiative (EEI). The law helped solidify California's leadership role in improving national and international environmental education.

EEI Principles and Model Curriculum

With an emphasis on students' relationship with the environment, EEI aims to increase environmental literacy in a format familiar to California teachers. Critical environmental issues, such as climate change, freshwater, ocean, energy, and other topics, are addressed in the law.

"This nation-leading initiative will educate our next generation of workers in environmental preservation and protection and will help catapult California's growing green economy."

Former Governor Schwarzenegger

ENVIRONMENTAL PRINCIPLES AND CONCEPTS

1. **People depend on natural systems.**
2. **People influence natural systems.**
3. **Natural systems proceed through cycles that humans depend upon, benefit from, and can alter.**
4. **There are no permanent or impermeable boundaries that prevent matter from flowing between systems.**
5. **Decisions affecting resources and natural systems are complex and involve many factors.**

Creation of this unprecedented curriculum began in 2004 with the development of the California Environmental Principles and Concepts (EP&C), which clearly highlights the relationship between humans and the environment. In addition to the Environmental Principles and Concepts, EEI also developed a Model Curriculum that was comprised of weeklong units for K–12 teachers to use in their own classrooms. Development of the Model Curriculum began in 2005, with a focus on aligning the unit content to California's academic standards. From 2006–2009, the California EPA worked with partners, such as the California Department of Education, to create a curriculum that would be comprehensive and innovative, while continuing to teach academic content standards for Science and History/Social Science. More than 200 teachers and 600 students in 19 school districts across the state piloted the Model Curriculum units in 2007–2008 in order to test that the materials would be easily implemented in the classroom. Even more teachers and content experts independently reviewed the materials, making certain that the units fit with established classroom and assessment practices and would not burden teachers who would be using the curriculum. At the end, EEI developed 85 curriculum units spanning grades K–12, which were approved by the State Board of Education in Spring 2010.

The EEI Model Curriculum is poised to reshape how the environment is taught and presented to California's students. The California/Environmental Protection Agency (Cal/EPA), in partnership with the Department of Education, will be reaching out to inform teachers about how the curriculum can be used independently from, in conjunction with, or integrated into current instructional materials. The EEI curriculum will be made available electronically to school districts and teachers, free of charge, which will greatly increase the number of teachers who can easily access the materials. Find out more about the EP&C's and the EEI Model Curriculum at http://www.calepa.ca.gov/education/eei/.

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.a-e	Structures for Survival in a Healthy Ecosystem Living Things in Changing Environments
Grade 4	4.2.a-c 4.3.a-b	Plants: the Ultimate Energy Resource The Flow of Energy Through Ecosystems Life and Death With Decomposers
Grade 5		
Grade 6	6.5.a-e	Energy: Pass It On! Playing the Same Role
Grade 7	7.3.a 7.3.e	Shaping Natural Systems Through Evolution Responding to Environmental Change
Grade 8		

Each teacher guide chapter includes a table that aligns the content in the chapter to California state science and social studies academic standards, and to the EEI Model Curriculum.

Connecting EEI to the Teacher Guide Series

The hope of the EEI is to provide cutting-edge environmental content to students, while supporting them in achieving academic content standards. Given the environmental topics addressed by the units, professional development is needed so teachers feel confident and effective in delivering this content in their classrooms. Whether using the EEI Model Curriculum or other educational materials about the environment, teachers will need additional preparation to feel comfortable with teaching about the latest environmental issues.

The Environmental Literacy Teacher Guide Series responds to this need, providing both content background for teachers on these environmental issues, as well as providing information about concepts that likely will be challenging for students to learn. The Environmental Literacy Teacher Guide Series includes Climate Change, Ocean, Freshwater, and Energy guides. Each teacher guide is intended to prepare upper elementary and middle school teachers for instruction in these content areas.

The content and educational components of the teacher guides are aligned to both California Standards, as well as the units in the EEI Model Curriculum, allowing teachers to use specific chapters as resource when teaching those standards and units. While the goal of the teacher guide is not to prepare teachers for using a specific EEI unit, it is hoped that the information provided by the guide helps teachers feel more confident and prepared to teach about these topics in the classroom and to anticipate what their students will know and struggle with as they learn the EEI units or similar environmental curriculum.

Why Is Ocean Education Important?

Life on Earth would not be possible without the ocean. When viewed from space, our planet is a world covered with water. All living things are intimately tied to this water in so many ways. Yet, despite its importance, a 2003 report by the Pew Oceans Commission determined that the U.S. general public knows very little about the ocean. Most people, both young and old alike, do not understand our ocean and the invaluable role it plays in our everyday lives.

But why is this important? To understand how the ocean impacts our daily lives, we need to understand how it influences weather and climate, that its inhabitants produce much of the oxygen we breathe, that the life found in the ocean feeds us, and that its currents are used to connect humans around Earth, as well as the myriad of ocean life forms that inspire and amaze us. When a person is literate in how the ocean impacts humanity on a daily basis, they are given the tools to better protect the ocean through their daily behaviors and their voting habits.

In response to reports such as the Pew report, representatives from a variety of organizations (National Geographic Society, National Oceanographic and Atmospheric Administration, the Centers for Ocean Science Education Excellence, National Marine Educators Association, the College of Exploration, NMSF—National Marine Sanctuaries Foundation, and SeaGrant, as well as many others) came together to outline the essential principles of ocean literacy. These principles identify what a person needs to know to have a good understanding of the ocean. Through collaboration among these groups, a set of seven ocean literacy principles were developed:

1. **Earth has one big ocean with many features.**
2. **The ocean and life in the ocean shape the features of Earth.**
3. **The ocean is a major influence on weather and climate.**
4. **The ocean makes Earth habitable.**
5. **The ocean supports a great diversity of life and ecosystems.**
6. **The ocean and humans are inextricably connected.**
7. **The ocean is largely unexplored.**

They identified these concepts as being integral to having a working knowledge of the ocean. What if everyone understood these principles and used them to inform the decisions they make everyday?

The ocean needs our help.

The ocean needs our help. With more than six billion people inhabiting the planet, our impact on the ocean is growing every day. More ships are using the ocean to transport goods and people than ever before. Pollution and runoff have created areas of the ocean where the fish living there are unsafe to eat; some areas have become too polluted to support life. With human health so tightly coupled with ocean health, informed and active citizens are imperative for a healthy future for both the ocean and humanity.

As a society, we recognize formal education as a key component in developing an engaged and informed population. Much of the responsibility has been placed on teachers to create knowledgeable and literate citizens. When science is taught, sometimes it is taught in a vacuum without providing students with a context for their learning. Students may be taught about

photosynthesis without being taught about the algae and vascular plants that perform it, let alone where they might see algae and plants in their daily lives. They may be taught that water is important to cellular respiration that makes life possible but are not taught about where water is in our world, how it gets to us, and where it goes when it leaves terrestrial systems. The examples of teaching science concepts without context are numerous.

Yet many teachers, and many states and local agencies, have recognized this disconnect. Teachers have struggled to develop units on their own to help address the issue, while states have tried to rectify it through legislation. California is one of those states. With the passage of Assembly Bill 1548, commonly referred to as the Education and the Environment Initiative, the state is attempting to bridge the gap between real-world and theoretical learning by connecting the concepts students are learning to their environment. As California has 1,351.8 kilometers (840 miles) of coastline and more than 32,186.8 square kilometers (20,000 square miles) of ocean under its jurisdiction, the ocean is an important part of the California life experience. The ocean brings an estimated $42 billion per year to the state's economy; therefore, being an ocean-literate citizen may be even more important in California.

This guide was developed to support teachers in teaching topics with real-world context and provide them with the background to feel competent and comfortable when teaching about the ocean. It provides a solid introduction to the ocean and the ocean literacy principles in an accessible and reader-friendly manner. In addition to general information about the ocean, the guide includes numerous education features, such as teaching tips and student thinking, that help to connect the content to classroom practice.

The ocean is an important part of the California life experience.

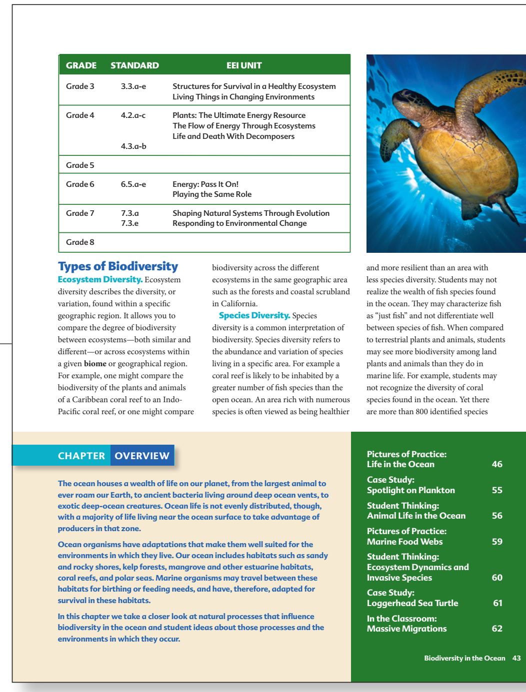
This book tells the story of our ocean today and its importance on our planet and to our lives. Chapter 1 provides an introduction to the ocean system and its basic physical properties—the currents, waves, and tides that move water throughout our one big ocean. Chapter 2 looks at how the ocean interacts with air to influence weather and climate and how it is all interconnected in the water cycle. Ocean habitats, and the unique and diverse life they harbor, is the focus of Chapter 3, while Chapter 4 looks at how human action can impact those habitats and the diversity of life found in them. Chapters 5 and 6 delve more deeply into the human impact on the ocean and examine how our impact can affect us, influencing human health and well-being. Chapter 5 focuses on more localized and smaller scale imnpacts such as oil spills and runoff, and Chapter 6 covers systemic and larger scale impacts, such as ocean acidification and global climate change. Finally, Chapter 7 addresses the protection of our ocean, outlining some of the international and federal laws that protect the ocean and its inhabitants, as well as some of the legislation that has been enacted in California to help conserve the unique ocean resources of the state. Protection of the ocean is not a passive act, however; so Chapter 7 also provides ideas for actions that teachers and students can take to help protect the ocean for generations to come.

The writers and developers of the guide hope that this book empowers and encourages teachers to teach about the ocean in their classrooms, helping to create future generations who are ocean literate—who understand just how important the ocean is to our lives.

Teacher Guide Tour

Environmental Content

Environmental science includes a wealth of content that teachers may not learn as part of their professional preparation. Content pages provide teachers with an opportunity to learn this content alongside information about how students think about these topics. The content pages also reconsider fundamental science concepts in the context of environmental issues. Interesting and new concepts are in bold and defined in the accompanying glossary.



GRADE	STANDARD	EEI UNIT
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Types of Biodiversity

Ecosystem Diversity. Ecosystem diversity describes the diversity, or variation, found within a specific geographic region. It allows you to compare the degree of biodiversity between ecosystems—both similar and different—or across ecosystems within a given **biome** or geographical region. For example, one might compare the biodiversity of the plants and animals of a Caribbean coral reef to an Indo-Pacific coral reef, or one might compare biodiversity across the different ecosystems in the same geographic area such as the forests and coastal scrubland in California.

Species Diversity. Species diversity is a common interpretation of biodiversity. Species diversity refers to the abundance and variation of species living in a specific area. For example a coral reef is likely to be inhabited by a greater number of fish species than the open ocean. An area rich with numerous species is often viewed as being healthier and more resilient than an area with less species diversity. Students may not realize the wealth of fish species found in the ocean. They may characterize fish as "just fish" and not differentiate well between species of fish. When compared to terrestrial plants and animals, students may see more biodiversity among land plants and animals than they do in marine life. For example, students may not recognize the diversity of coral species found in the ocean. Yet there are more than 800 identified species

CHAPTER OVERVIEW

The ocean houses a wealth of life on our planet, from the largest animal to ever roam our Earth, to ancient bacteria living around deep ocean vents, to exotic deep-ocean creatures. Ocean life is not evenly distributed, though, with a majority of life living near the ocean surface to take advantage of producers in that zone.

Ocean organisms have adaptations that make them well suited for the environments in which they live. Our ocean includes habitats such as sandy and rocky shores, kelp forests, mangrove and other estuarine habitats, coral reefs, and polar seas. Marine organisms may travel between these habitats for birthing or feeding needs, and have, therefore, adapted for survival in these habitats.

In this chapter we take a closer look at natural processes that influence biodiversity in the ocean and student ideas about those processes and the environments in which they occur.

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Standards Table

Chapters are aligned to California state science and social studies standards, as well as aligned to the Education and Environment Initiative (EEI) model curriculum units.

Case Study

Spotlight on Plankton

Plankton are organisms in the ocean that drift with the currents. In fact, *plankton* is Greek for "drifter," or "wanderer." Usually people associate plankton with small life in the ocean. Although most plankton are tiny, some are much larger. For example, sea jellies that drift with the currents can reach lengths of 30 meters (100 feet) or more!

There are two major types of plankton: phytoplankton and zooplankton. Both are essential to the marine food web. Phytoplankton are microscopic organisms that photosynthesize in a way similar to the terrestrial plants we live with everyday. A common misconception by students is that oxygen is only produced by trees. This is not true—at least half the oxygen we breathe is produced by phytoplankton in the ocean. Zooplankton are animals and animal-like organisms that cannot swim against the ocean current. Many are microscopic or larval animals. Shrimp, crab, and fish larva start out as zooplankton. Once they settle to the bottom to metamorphose into their adult stage or are large enough to swim against a current, they are no longer considered plankton. Other animals, such as krill and sea jellies, remain plankton their entire lives. Krill are small shrimplike marine invertebrates that are found throughout the ocean and perhaps are best known for being a critical food source for baleen whales.

Both phytoplankton and zooplankton play a vital role in the food chain of the ocean. Phytoplankton are primary producers and responsible for capturing the energy of the sun and turning it into a form of energy that other organisms in the ocean can use. Zooplankton are also very important, serving as food for many organisms in the ocean. In fact, the largest animal known to science, the blue whale, reaches its 100-foot (30 m) length on a diet made almost entirely of planktonic krill.

Sea surface temperature, surface currents, salinity, wind, and waves influence plankton. Changes in these abiotic characteristics influence movements of plankton and, thus, movements of larger animals in the ocean. These changes influence the ocean's patterns of biodiversity. For example, an increase in sunlight or nutrients will often lead to an increase in the numbers of phytoplankton, a phenomenon known as a plankton bloom. When the phytoplankton bloom, the zooplankton that prey upon them often experience population growth. This growth can lead to an abundance of food and increased survival for small fish, which can in turn support larger fish. Indeed, this increased abundance of phytoplankton can result in more food at every trophic level, including apex marine predators such as sea lions, sharks, dolphins, and pelicans. From this example, you can see how important plankton is to the biodiversity of an ecosystem. On the other hand, sometimes these plankton blooms can also result in **harmful algal blooms** (HABs). These HABs are often caused by fertilizer and chemical runoff into the ocean, which results in an increase in nutrients for phytoplankton and other algae. One result from HABs is the release of toxins that lead to paralytic shellfish poisoning (PSP), which is toxic to both ocean organisms and humans that consume them.

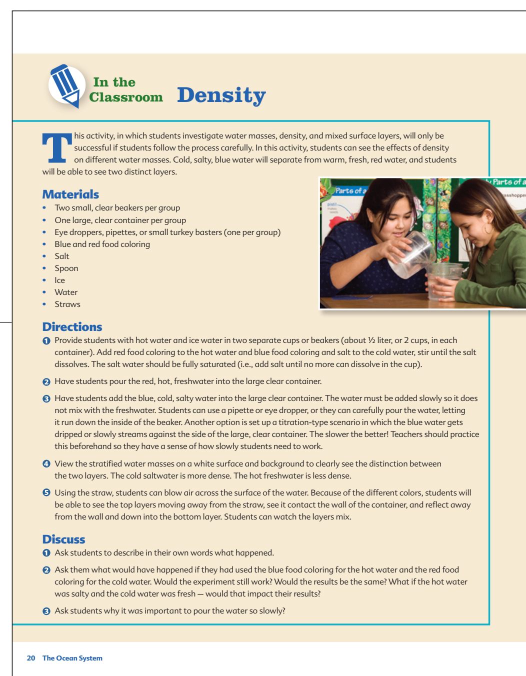
Phytoplankton

Zooplankton

Biodiversity in the Ocean 55

Case Study

Case Studies offer an in-depth look at how concepts play out in particular locations or situations. Case studies provide real-life examples of how issues affect both natural and human communities today.



In the Classroom

Density

This activity, in which students investigate water masses, density, and mixed surface layers, will only be successful if students follow the process carefully. In this activity, students can see the effects of density on different water masses. Cold, salty, blue water will separate from warm, fresh, red water, and students will be able to see two distinct layers.

Materials

- Two small, clear beakers per group
- One large, clear container per group
- Eye droppers, pipettes, or small turkey basters (one per group)
- Blue and red food coloring
- Salt
- Spoon
- Ice
- Water
- Straws

Directions

1. Provide students with hot water and ice water in two separate cups or beakers (about ½ liter, or 2 cups, in each container). Add red food coloring to the hot water and blue food coloring and salt to the cold water, stir until the salt dissolves. The salt water should be fully saturated (i.e., add salt until no more can dissolve in the cup).
2. Have students pour the red, hot, freshwater into the large clear container.
3. Have students add the blue, cold, salty water into the large clear container. The water must be added slowly so it does not mix with the freshwater. Students can use a pipette or eye dropper, or they can carefully pour the water, letting it run down the inside of the beaker. Another option is set up a titration-type scenario in which the blue water gets dripped or slowly streams against the side of the large, clear container. The slower the better! Teachers should practice this beforehand so they have a sense of how slowly students need to work.
4. View the stratified water masses on a white surface and background to clearly see the distinction between the two layers. The cold saltwater is more dense. The hot freshwater is less dense.
5. Using the straw, students can blow air across the surface of the water. Because of the different colors, students will be able to see the top layers moving away from the straw, see it contact the wall of the container, and reflect away from the wall and down into the bottom layer. Students can watch the layers mix.

Discuss

1. Ask students to describe in their own words what happened.
2. Ask them what would have happened if they had used the blue food coloring for the hot water and the red food coloring for the cold water. Would the experiment still work? Would the results be the same? What if the hot water was salty and the cold water was fresh — would that impact their results?
3. Ask students why it was important to pour the water so slowly?

20 The Ocean System

In the Classroom

In the Classroom features iconic or helpful classroom activities, as well as ideas for teaching topics. Details are provided to use the activity in the classroom, including materials lists and directions, as well as interesting discussion questions to ask your students. When possible, additional online resources are connected to the classroom activities.

Eroding the Base of the Food Web. Destructive fishing methods also cause ecological harm. Historical ocean records indicate overfishing as the catalyst for marine species decline in a variety of habitats, including kelp forests, coral reefs, sea grass beds, estuaries, and offshore benthic communities. Some practices, such as trawling and longline fishing, generate bycatch and negatively affect many species. For example, these fishing methods have led to an 80–95 percent decrease in loggerhead and leatherback turtle populations in the Pacific in the last 20 years (Lewison, Sloan Freeman, and Crowder 2004). The use of explosives and toxins by fishers can decimate coral reefs, as has occurred in the Philippines where catch rates and biological diversity have both declined. **Dredging** can uproot kelps, algae, and sea grasses and can destroy corals and overturn rocks, and snagged nets left on the bottom can harm sea life.

These fishing practices can be viewed as direct destruction, but humans are also creating indirect destruction. The ocean has been acting as a **carbon sink** for increased carbon emissions since the Industrial Revolution of the late 18th century. While much focus is often put on forests and green, terrestrial ecosystems, the primary producers in the ocean may sequester more carbon annually than all terrestrial primary producers combined. Unfortunately, the ocean has started to show indications that the increased carbon dioxide load is having a harmful effect on some marine organisms: Increased CO_2 decreases the pH of the ocean water, and organisms with silicate or calcium-based parts are becoming more brittle and starting to dissolve. Organisms, such as planktonic calcareous coccolithophores and corals, play important roles in marine ecosystems and are being threatened by fossil-fuel combustion. As these species often form the base of the marine food web, their continued survival is critical to ocean health. Whether our actions are impacting the seafloor through destructive fishing habitats or eating away the structure of the habitat or the base of the food web, biodiversity is at stake.

Invasive Species. Invasive species are those that are not native to an ecosystem. These species compete with local species and are often harmful to local ecosystems, human health, and the economy. Invasive species are most often found in estuaries and can be introduced accidentally or intentionally. Common means of marine species introduction include shipping, aquaculture, and pet, aquarium, and tourism trades. As humans introduce species into the marine environment, the species often

Teaching Tip

When students are asked about the impacts of our practices on oceans, most students conjure up negative images of how we influence the ocean ecosystem. For example, one student described dredging as mixing "poop and dead fish up into the water," and also described using dynamite as, "dyno probably kills all the fish and mix up all the stuff again and the water will be all nasty." Students readily grasp the potential negative consequences of these practices but may not understand why the practices evolved or how their own choices as consumers may or may not contribute. As students share these ideas and stories in class, ask students to elaborate on their ideas. Where did they learn about the topic? What do they mean when they say "the water will be nasty"? Following up on students' stories will better help you understand the prior knowledge that your students bring to your classroom.

The effects of El Niño on the ocean can be devastating, as this dead, bleached coral reef off of the coast of Palau in the South Pacific Ocean reveals.

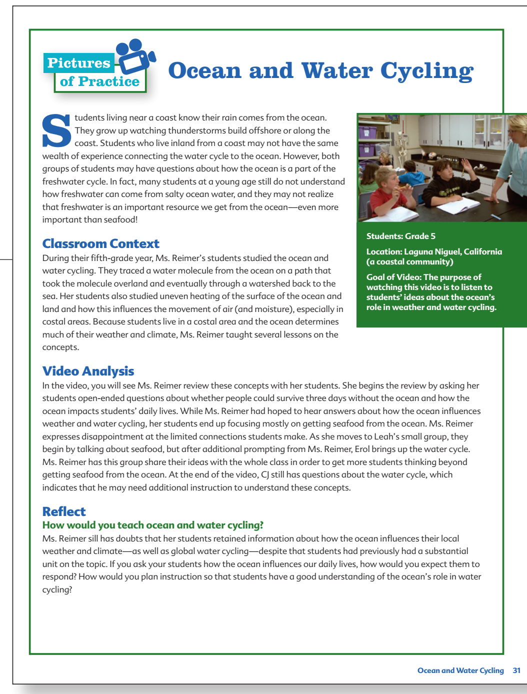
Reduction of Ocean Biodiversity 73

Teaching Tip

Throughout the content pages, **Teaching Tips** connect the content to classroom practice. Teaching Tips suggest practical activities and resources to consider when teaching about a particular topic. When available, Teaching Tips direct teachers to additional online resources.

Pictures of Practice

Classroom video is a valuable resource for reflecting on practice. **Pictures of Practice** are videos, about two to five minutes in length, focusing on student ideas. The purpose of these videos is to capture everyday classroom life and to provide real-life examples of how students learn and think about these topics. The focus of the videos is on student participation and ideas, as opposed to the teacher and instructional style. Reading the video activity prior to watching the video will help prepare you to get the most out of the videos.



Pictures of Practice **Ocean and Water Cycling**

Students living near a coast know their rain comes from the ocean. They grow up watching thunderstorms build offshore or along the coast. Students who live inland from a coast may not have the same wealth of experience connecting the water cycle to the ocean. However, both groups of students may have questions about how the ocean is a part of the freshwater cycle. In fact, many students at a young age still do not understand how freshwater can come from salty ocean water, and they may not realize that freshwater is an important resource we get from the ocean—even more important than seafood!

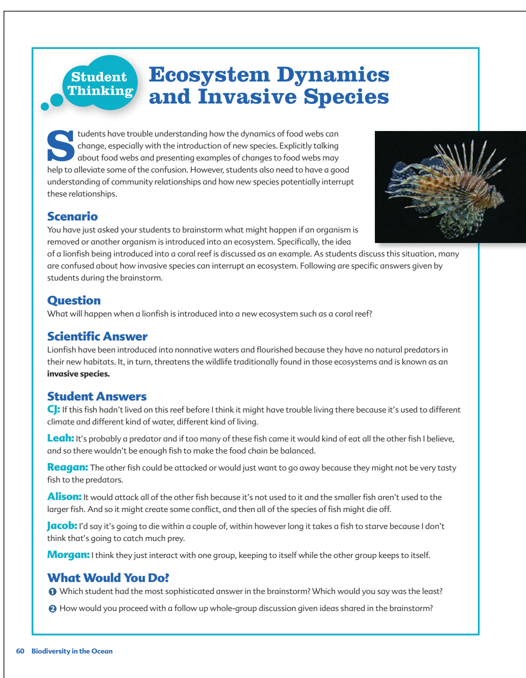
Students: Grade 5
Location: Laguna Niguel, California (a coastal community)
Goal of Video: The purpose of watching this video is to listen to students' ideas about the ocean's role in weather and water cycling.

Classroom Context
During their fifth-grade year, Ms. Reimer's students studied the ocean and water cycling. They traced a water molecule from the ocean on a path that took the molecule overland and eventually through a watershed back to the sea. Her students also studied uneven heating of the surface of the ocean and land and how this influences the movement of air (and moisture), especially in costal areas. Because students live in a costal area and the ocean determines much of their weather and climate, Ms. Reimer taught several lessons on the concepts.

Video Analysis
In the video, you will see Ms. Reimer review these concepts with her students. She begins the review by asking her students open-ended questions about whether people could survive three days without the ocean and how the ocean impacts students' daily lives. While Ms. Reimer had hoped to hear answers about how the ocean influences weather and water cycling, her students end up focusing mostly on getting seafood from the ocean. Ms. Reimer expresses disappointment at the limited connections students make. As she moves to Leah's small group, they begin by talking about seafood, but after additional prompting from Ms. Reimer, Erol brings up the water cycle. Ms. Reimer has this group share their ideas with the whole class in order to get more students thinking beyond getting seafood from the ocean. At the end of the video, CJ still has questions about the water cycle, which indicates that he may need additional instruction to understand these concepts.

Reflect
How would you teach ocean and water cycling?
Ms. Reimer sill has doubts that her students retained information about how the ocean influences their local weather and climate—as well as global water cycling—despite that students had previously had a substantial unit on the topic. If you ask your students how the ocean influences our daily lives, how would you expect them to respond? How would you plan instruction so that students have a good understanding of the ocean's role in water cycling?

Ocean and Water Cycling 31



Student Thinking **Ecosystem Dynamics and Invasive Species**

Students have trouble understanding how the dynamics of food webs can change, especially with the introduction of new species. Explicitly talking about food webs and presenting examples of changes to food webs may help to alleviate some of the confusion. However, students also need to have a good understanding of community relationships and how new species potentially interrupt these relationships.

Scenario
You have just asked your students to brainstorm what might happen if an organism is removed or another organism is introduced into an ecosystem. Specifically, the idea of a lionfish being introduced into a coral reef is discussed as an example. As students discuss this situation, many are confused about how invasive species can interrupt an ecosystem. Following are specific answers given by students during the brainstorm.

Question
What will happen when a lionfish is introduced into a new ecosystem such as a coral reef?

Scientific Answer
Lionfish have been introduced into nonnative waters and flourished because they have no natural predators in their new habitats. It, in turn, threatens the wildlife traditionally found in those ecosystems and is known as an **invasive species.**

Student Answers
CJ: If this fish hadn't lived on this reef before I think it might have trouble living there because it's used to different climate and different kind of water, different kind of living.
Leah: It's probably a predator and if too many of these fish came it would kind of eat all the other fish I believe, and so there wouldn't be enough fish to make the food chain be balanced.
Reagan: The other fish could be attacked or would just want to go away because they might not be very tasty fish to the predators.
Alison: It would attack all of the other fish because it's not used to it and the smaller fish aren't used to the larger fish. And so it might create some conflict, and then all of the species of fish might die off.
Jacob: I'd say it's going to die within a couple of, within however long it takes a fish to starve because I don't think that's going to catch much prey.
Morgan: I think they just interact with one group, keeping to itself while the other group keeps to itself.

What Would You Do?
1. Which student had the most sophisticated answer in the brainstorm? Which would you say was the least?
2. How would you proceed with a follow up whole-group discussion given ideas shared in the brainstorm?

60 Biodiversity in the Ocean

Student Thinking

The purpose of **Student Thinking** features is to help you prepare for the challenges students may face as they learn about these topics. Common student ideas are compared alongside scientific concepts or are situated in real-life classroom scenarios. Provided quotes come from real students. Suggestions for questions to ask your students are also provided. Accessing student ideas through formative assessment is a great way to learn about your students' knowledge and pique your students' interest in learning more about a topic. Students love to share what they know! You can use what you learn to help guide your teaching. You may find that you need to provide experiences for students that help them confront their existing ideas and begin to develop more scientific conceptions.

1 The Ocean System

by E. Tucker Hirsch and Amanda P. Jaksha

The ocean covers approximately three-quarters of the surface of planet Earth and makes the planet look distinctly blue from afar. Phrases such as “the blue planet” and “the water planet” make it obvious how important the ocean is to life on Earth. Without the ocean, life as we know it would not exist. This chapter explores some of the physical properties and processes that happen throughout the ocean and along its borders. Many students use terms such as *currents, tides,* and *waves* to explain processes that take place in the ocean. Although these are commonly used terms, students do not fully understand the processes that create such ocean phenomena and may use such terms interchangeably. Ways that students are often taught about the ocean can create areas of confusion. For example, memorization of the names of different ocean basins can lead to confusion and misunderstanding about the interdependence of all oceans. This chapter will explore these concepts and areas of confusion, as well as provide an overall understanding of the interconnected system and physical processes that govern the movement of water on our ocean planet.

Ocean or Oceans?

The area of water that covers the ocean basins spans more than 215 million square miles (350 million sq. km). In comparison, the United States only covers about 6 million square miles (9 million sq. km), and all of North American only comes in at about 15 million square miles (24 million sq. km)! The ocean is a large and vast system that dominates processes on Earth and governs our experiences on land.

If you were to drain all of the water out of the ocean, you would see a landscape of valleys, plains, basins, and mountain chains that looks similar to the landscapes above the ocean. When talking about **topography** below the surface of the ocean, we use words that may be less familiar, such as *trench, ridge,* and *seamount.* When you look

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.d 3.1.1	The Geography of Where We Live
Grade 4	4.1.4	
Grade 5	5.3.a	Earth's Water
Grade 6	6.2.c 6.3.a 6.4.a; 6.4.d	
Grade 7		
Grade 8	8.8.a-d	

closely at the topography of the ocean it becomes clear that all of the "individual" oceans that students memorize are, in fact, part of one large interdependent global ocean. Just as we create artificial boundaries between countries on land, we create artificial boundaries between ocean basins. Water in the ocean flows between basins, through trenches and over ridges, just as air moves around and through our mountains and valleys on land. In the same way that seeds and pollen are carried by wind, so too are some ocean species moved through patterns of ocean circulation. Boundaries, such as water temperature and density, exist in the ocean and can, therefore, restrict the movement of marine organisms.

Just as the continents have distinguishable characteristics, the topography of the four main ocean basins have distinguishable characteristics as well.

The four main ocean basins are the Pacific, Atlantic, Indian, and Arctic. The Pacific covers the widest area and has the largest average depth of the four basins. The Pacific contains the Mariana Trench, the deepest known point in the ocean, which plunges to more than 10,000 meters, or 6.7 miles. The Atlantic Basin is the second largest in area. It has a large mountain chain, known as the Mid-Atlantic Ridge, running north-south through its center. The Mid-Atlantic Ridge is more than 16,000 kilometers (9,900 miles) long, which is more than five times as long as the Rocky Mountains chain! The Indian Basin, bordered mostly by Africa, Asia, and Australia, is the third largest. Finally, the Arctic Basin surrounds the North Pole. The water that flows around the edge of Antarctica is sometimes considered the Southern Ocean, encompassing the southern part of the Indian, Pacific, and Atlantic Basins.

As mentioned previously, a common misconception among students is that there are separate oceans. Traditionally, students learn names for oceans—*Pacific, Atlantic, Indian,* and *Arctic*—and they learn to locate these oceans in particular places on a globe. Naming and locating oceans in such a way causes students to focus on the differences between them, as opposed to viewing Earth as having one connected ocean with different basins.

CHAPTER OVERVIEW

The ocean is a global, interconnected system that has regions, or basins. Water and ocean life move between these basins and up and down the water column. Ocean water circulates around the globe through ocean currents that are either wind-driven currents or density-driven currents. The circulation of water that is driven by differences in density is called thermohaline circulation, also known as the global conveyor belt. Additionally, waves are phenomena that do not move the ocean water; rather, they are a result of wind energy acting on the surface of the ocean.

Unlike currents and waves, tides are not caused by wind, density, or other actors on our planet. Tides are caused by the gravitational pull from the sun and moon.

This chapter explores these physical phenomena in the ocean and students' common ideas about ocean currents, tides, and waves.

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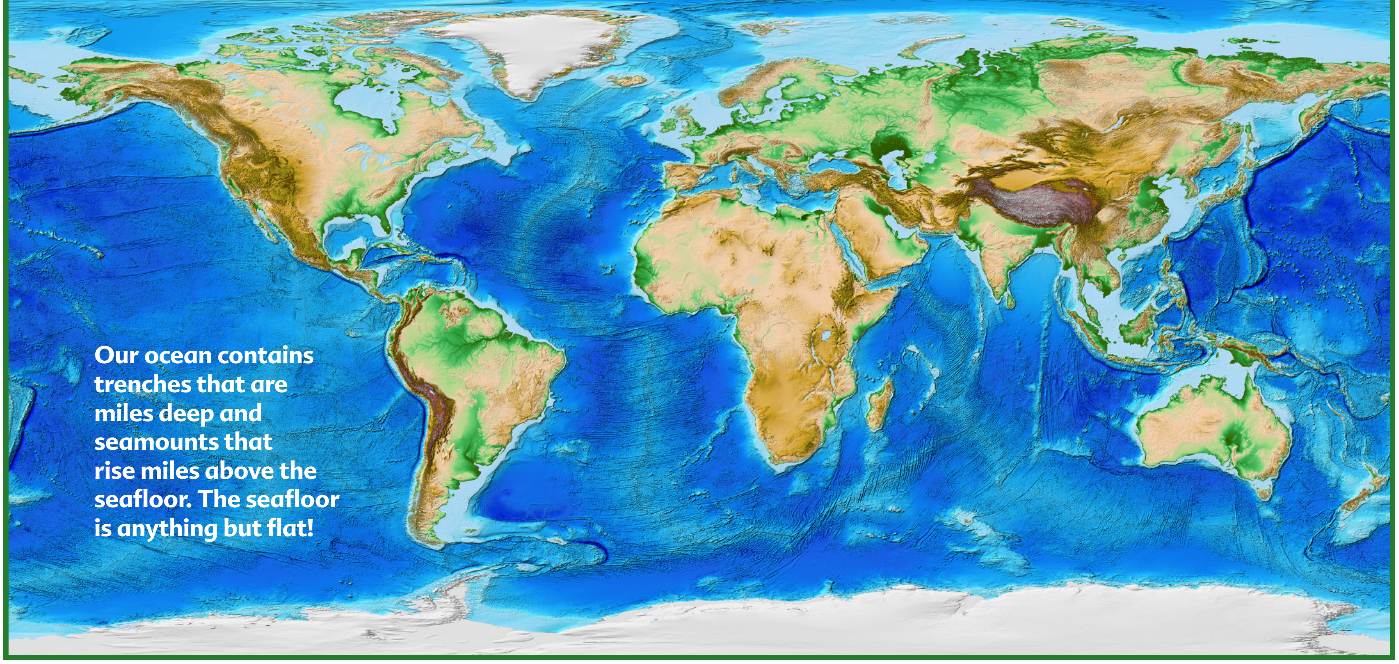


One way to help students see that the oceans are interconnected is to challenge them to decide where one ocean ends and another begins. Use students' questions during this task to develop a dialogue about the arbitrary borders that have been designated in oceans. Ask students to think about why these distinctions were made in the first place, how they may help us, and how they may limit our understanding of one world ocean.

In addition, it is important to help students understand that the ocean basins are not featureless plains, but rather contain mountains, plains, canyons, trenches, hills, and more. Have students compare the features found in the ocean to features found on land. Encourage students to look for similarities and differences. Students likely realize that the ocean is "very deep," but may have trouble imagining the depth. Students' ideas of "very deep" may range from a few hundred feet to tens of thousands of miles. Students may lack experiences that help them visualize distances. Providing experiences with distance can be helpful.

One way to help students gain experiences with distance is to have them measure off different distances. Using your school's gym or outdoor areas, have students walk or run distances you have talked about in class. See if students can run or walk 30.5 meters (100 feet), 61 meters (200 feet) or more! Older students may be able to go even farther. Ask students if any of them have ever walked or run 11 kilometers (7 miles). If so, was it easy? You can also use maps of the area surrounding your school to demonstrate these distances to them. Try having students measure the school's gym and calculate how many gyms it would take to equal a specific depth in the ocean. Make sure to reinforce with students that while they are exploring horizontal distances, some distances in the ocean are measured on a vertical plane.

Using well-known features on land may help students visualize depths as well. For example Mount Everest is only 8.9 kilometers (5.5 miles) high, in comparison to the Mariana Trench, which is 10.8 kilometers (6.7 miles) deep. As most students have not seen Mount Everest, local examples may be even more powerful. You may want to compare depths to local mountain ranges or tall buildings in cities close by that students may have visited. Some examples of ocean depths that students can explore are that the average depth of the ocean on the continental shelf is about 150 meters (500 feet), the average depth of the ocean overall is about 4,000 meters (13,000 feet), and the deepest places in the ocean are about 11,000 meters (36,000 feet) or slightly more than 11 kilometers (just shy of 7 miles)!

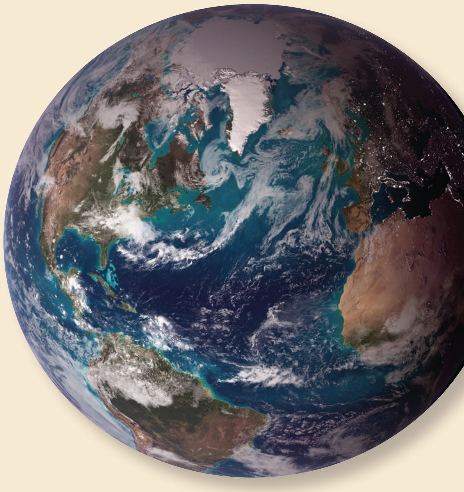
Ocean Color. What causes the ocean to appear blue? Is the water itself blue? Through experience, students understand that water is usually clear. They associate the color of the ocean with what they have seen, rather than sediment, plankton, or other

Teaching Tip

As you cover the concept of Earth having one large, interconnected ocean with many features, make sure you are consistent in your language. Making sure to say *Pacific Ocean Basin* or *Pacific Basin* instead of *Pacific Ocean* can exert a major influence on students' understanding of this difficult concept.

In the Classroom How Big Is the Ocean?

A big challenge for teachers is helping students grasp just how vast the ocean really is. Students may struggle with understanding the sheer size of the ocean, just as they struggle with large numbers and distances. Activities such as the one following can help students visualize the ocean's expanse. Teachers could ask students to do research comparing the ocean or ocean basins to things with which they have experience. For instance, how many Olympic-sized swimming pools would it take to fill up the Atlantic Ocean Basin? How long would it take for a student to swim across the Indian Ocean Basin? How many times larger is the Indian Ocean Basin than their home state? While questions like these still have large numbers in their answers, students can see that the ocean is larger than anything else they are familiar with.



Materials

- Blow-up globe (beach-ball style)
- Space to toss a ball
- Chart and art supplies to record data

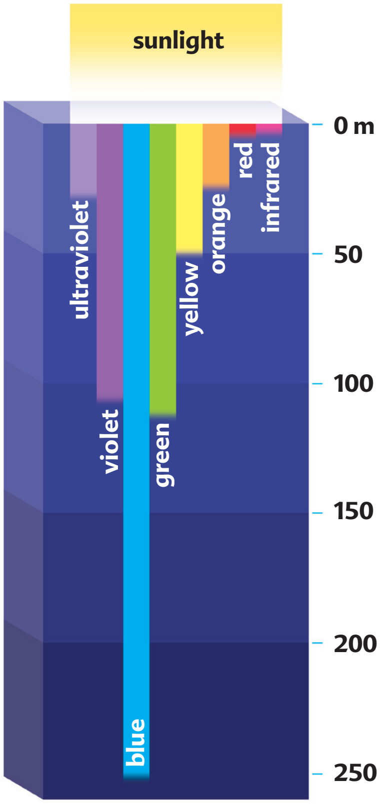
Directions

1. Students will toss a globe to one another and should be in a space that allows free movement. Either standing or sitting in a circle or sitting on top of desks works well.
2. Select an amount of time to record data (e.g., three minutes or once everyone touches the ball five times). During that time, students should individually count how many times one of their fingers (e.g., everyone's right thumb) touches an area of the ocean or an area of land. Alternatively students may count both sets of fingers for the number on land versus water, for example, seven fingers may touch the ocean while only three fingers touch land.
3. At the end of the period, students add up and record, collectively, how many "ocean hits" and "land hits" they observed.
4. Repeat the activity as time allows. For a variation, compare finger touches of land and the four different ocean basin areas.
5. This is a good visualization activity for all ages, especially younger students. For older students, this activity can also provide a good discussion about data collection, interpretation, and analysis. By repeating the activity and taking averages, teachers can point out important patterns. The data can then be used to create pie charts, bar charts, or other visual data representations. Students may also calculate ratios (7:3; ocean:land) and percentages (70 percent ocean; 30 percent land).

Discuss

1. Did the data match your expectations? How did the data support or not support your ideas about the ocean size?
2. Look at how the ocean water connects. Why is it more accurate to refer to one ocean than to many oceans?

VISIBLE LIGHT IN OCEAN



The quality and quantity of sunlight decreases with depth. Red, orange, and yellow spectrums are absorbed within meters of the surface, while blue penetrates the farthest.

contributors. For example, students may have observed patterns in water color related to depth, with lighter color typically indicating shallow water and dark blue meaning deeper water. Students can grasp that suspended algae; particles of sand, mud, or dirt; and ice can impact the ocean's color. Once they discover that some phytoplankton—tiny photosynthetic organisms—floating in the sea are green, as is common in the productive near-shore regions, while others are red (from which the Red Sea gets its name), they understand relative coloration. Additionally, explaining that sediments exist in a variety of colors will help them understand why water is sometimes very unusual colors, such as the mustard tone of the Yellow Sea.

Understanding why the ocean often appears blue requires that students understand the visible light spectrum, how different items transmit, reflect, refract, or absorb light wavelengths. For example, picture a glacial lake in Colorado or the azure waters of the Caribbean Sea. Deep, clear water, lacking in sediment and plankton, appears a brilliant blue. Of the colors of the visible light portion of the electromagnetic spectrum, those with longer wavelengths, on the red portion of the spectrum, are most easily absorbed. The blues are most easily scattered by water molecules, reflecting back into our eyes. Sediment, plankton, and other particles also result in scattering of light. For example, coastal waters, which tend to contain high concentrations of phytoplankton, appear green due to the scattering of yellow and green light from these organisms.

Ocean Currents

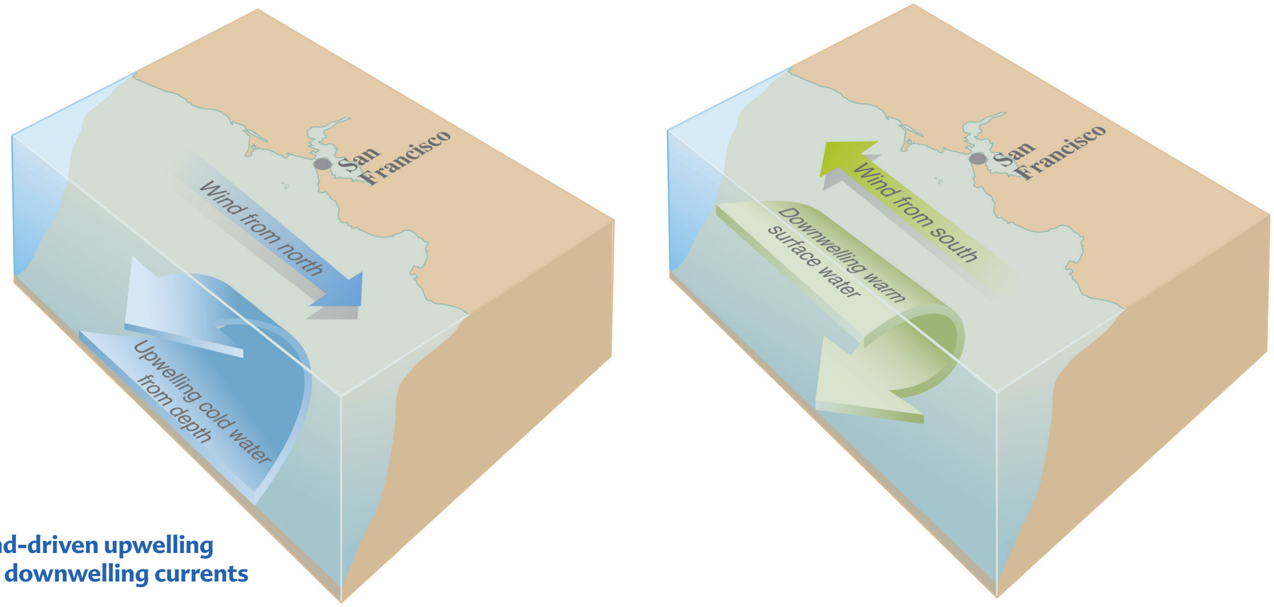
Ocean water flows between basins at the surface and at various depths under the surface of the water. Although the ocean is one body of water, water masses within different basins may behave in different ways. An analogy can be made to the air to better understand this. The air "fills up" the space above our heads and in the sky and can be thought of as one body of air. However, Los Angeles is infamous for its smog, and the Rocky Mountains are known for their clean, crisp mountain air. You can watch the movement from a breeze as it flows across a prairie, a lake, or the grass in your front yard. The open space above your head is not uniform, and L.A.'s smog and the Rocky Mountains' air could be thought of as different air masses: Each mass has its own distinct properties and can stay somewhat local but, when prompted, can move and mix with other surrounding air masses.

In the ocean, physical properties distinguish water masses from each other similar to air masses. Temperature and **salinity** as well as dissolved and suspended solids determine the **density** of water. Water of different densities creates layers, which are less prone to mix until disturbed. Ocean circulation systems move water through the ocean horizontally and vertically and on both local and global scales. The water in different basins may have different characteristics, including temperature, density, and salinity.

Wind-Driven Circulation. As wind moves water along the ocean's surface, it facilitates both horizontal and vertical water movement. Vertical mixing is when water moves from the depths of the ocean to the surface or vice versa. Students may not realize that water in the ocean mixes vertically. Vertical mixing brings cold, nutrient-rich water from the depths of the ocean to the surface. This process is called upwelling. Upwelling can occur along coasts of continents and is commonly seen along the coast of California. Winds blowing from north to south along the coast cause surface water to move offshore and away from land. As surface water is blown away from the land, water from below the surface moves up and into the area that was vacated, like on a conveyor belt. Coastal upwelling is very important to marine **ecosystems,** providing nutrients that help support robust food webs. Wind, therefore, not only affects the surface of the ocean but also has a significant influence on how water moves up and down in the vertical water column.

Prevailing winds can move ocean surface waters long distances and determine the paths of many of the ocean's surface currents. These currents are so consistent that early sailors, explorers, and voyagers sailed in them to cross large expanses of

WIND-DRIVEN CURRENTS

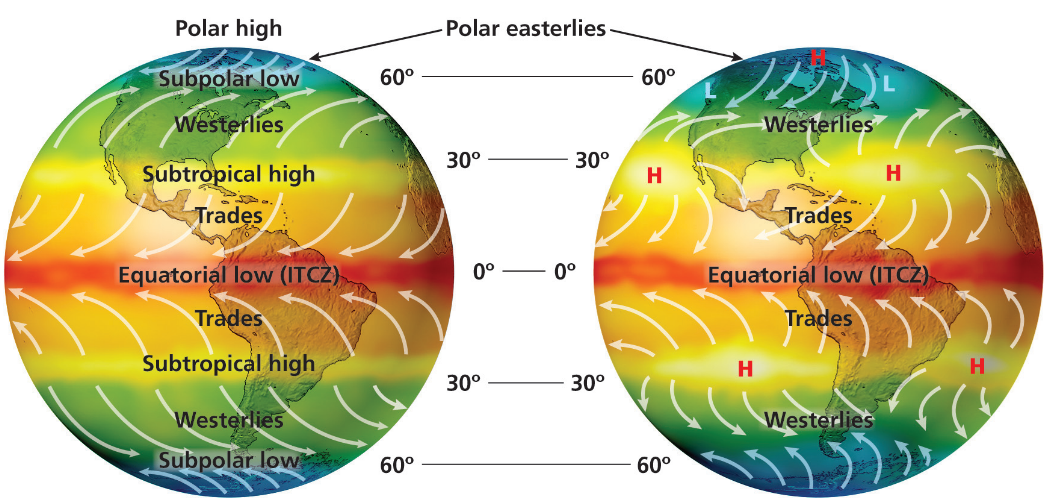


Wind-driven upwelling and downwelling currents

ocean and reliably arrive in the desired location, long before GPS and accurate navigational tools. Even today, ocean currents are integral to the shipping routes and trade industry that move goods all over the planet.

Prevailing winds and ocean surface currents aid in horizontal mixing of water masses. This mixing influences the physical characteristics of the ocean, life in the ocean, and the global climate. As water masses mix, their salinity, density, and temperature also mix and change. These changes can influence organisms that live in the ocean, from the smallest phytoplankton to the largest blue whale. The map on pages 18–19 shows some of the most significant ocean currents. These currents have well-known characteristics. For example, the dominant current near the East Coast of the United States is the Gulf Stream, which is largely driven by wind. It is a **western boundary current,** which is a type of current that is usually deep, warm, and fast flowing. On the West Coast of the United States is the California Current, which is an **eastern boundary current.** This type of current is usually shallower and moves more slowly than the western boundary currents. The California Current carries cold, nutrient-rich waters south along the western coast of the United States from British Columbia until it reaches the southern California bight, or bend, at Point Conception. There, the coastline bends eastward, which keeps the current offshore as it continues to flow south.

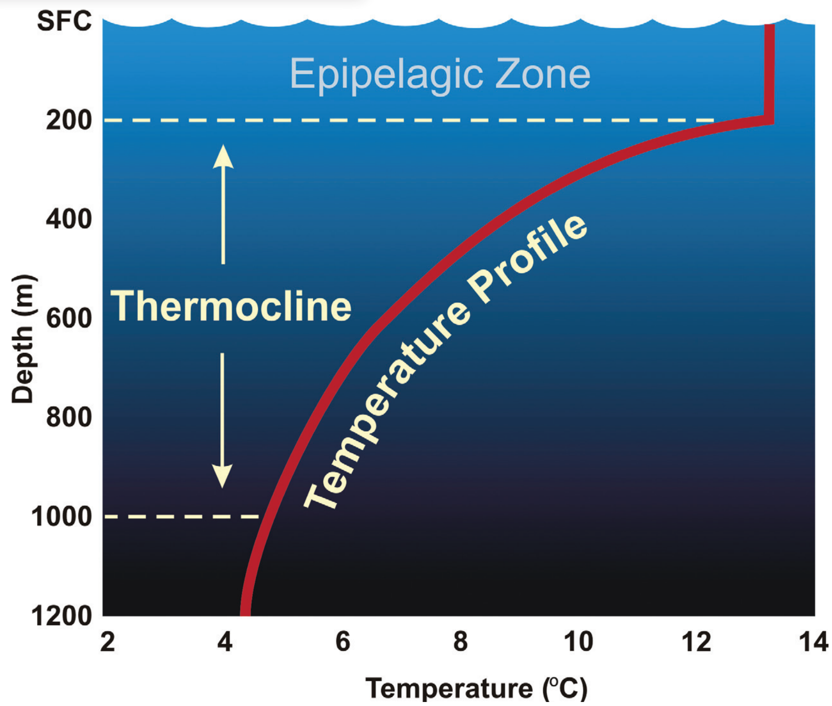
PREVAILING WINDS



Prevailing winds control how air circulates around the globe. However, the prevailing winds are affected by ongoing moving air masses that pass through the area as shown in the second figure.

A countercurrent (called the Davidson Current) flows from south to north along the coast, hugging the coastline and the Channel Islands, and bringing warmer water from the waters near Baja. Because of these very different currents, the climate of northern California can be vastly different from the climate of southern California and Baja. Many argue that the point where the two currents meet, near Point Conception, is the distinction between northern California and southern California. North of Point Conception, coastal communities such as San Francisco and Monterey experience cooler, foggy summers due to the influence of the cold California Current. South of Point Conception, the warmer, Davidson Current can keep the fog at bay, and the summers are generally warm and sunny.

THERMOCLINE DIAGRAM



As water depth increases, the temperature decreases. This diagram shows the thermocline layer that separates the warmer surface water from the colder deep water.

Density-Driven Circulation. Density of ocean water can also drive ocean circulation. Temperature and salinity are two major factors that determine water's density. Cold water is more dense than warm water and salt water is more dense than freshwater. Waters of different densities only mix if physical changes occur, such as changes in temperature or salinity. For example, as surface water cools, it becomes more dense and sinks through the water column, causing it to mix with surrounding water. On the other hand, if surface water warms, it can result in evaporation, which will lead to in an increase in both salinity and density, which also causes the water mass to sink in the water column. Water masses will continue to sink or rise in the water column until they reach equilibrium (i.e., when the water below is denser, and the water above is less dense). If new water is added—from sinking, upwelling, wind, and so on—that water will spread horizontally. Differences in water density (resulting from salinity and temperature) create layers in the water column. While much of the ocean is constantly in motion, a snapshot of the water column at any given moment will show distinct layering.

The movement and mixing of water layers, driven by density, is called **thermohaline** (heat and salt) **circulation.** A thin layer of surface water tends to be relatively more stable, warmer, and less salty than the water below it. When there is a distinct difference between the temperatures of water at a particular depth, the boundary layer between them is called the thermocline. A thermocline is the point in the water column at which the water temperature changes dramatically. Often, swimmers can feel this in a lake or the ocean; their arms and head are warm enough, but their feet, down deeper, are much more chilly!

When there is a distinct difference between salinities of water at a particular depth, that difference is called the **halocline.** The halocline is the point in the water column at which the water changes salinity significantly: The upper layer is less salty and, therefore, less dense than the deeper, denser, saltier layer. Sometimes, when snorkeling or diving in the tropics, a swimmer can actually see the zone at which the water may be slightly blurry because the less salty and saltier layers are trying to mix, but because of the their different densities and salinities, the layers remain separate. This separation is sometimes referred to as stratification. A strong thermocline or halocline can prevent the layers from mixing. In the ocean, stratification from temperature or salinity can prevent the transfer of nutrients or **biomass** unless a disturbance event occurs, such as a storm or significant seasonal changes. Often the depth of the thermocline and halocline will vary with the seasons for a particular ocean region, which can impact local climate and the organisms living, feeding, or breeding in that area.

Global Currents

Wind and water density drive the global current system that circulates the water in the ocean all over the globe. These currents circulate not just the water but also anything that is in the water, such as plankton and debris (both natural and introduced), throughout the ocean. Although these currents remain constant they are not always fast. It takes approximately 2,000 years for one drop of water to travel the entire ocean. While the global currents are complex, there are specific currents that remain stable, as can be seen in the following image. This image shows the major surface and deep currents in the ocean basins. From this diagram you can see how water and everything in it can easily travel from one side of the planet to the other.

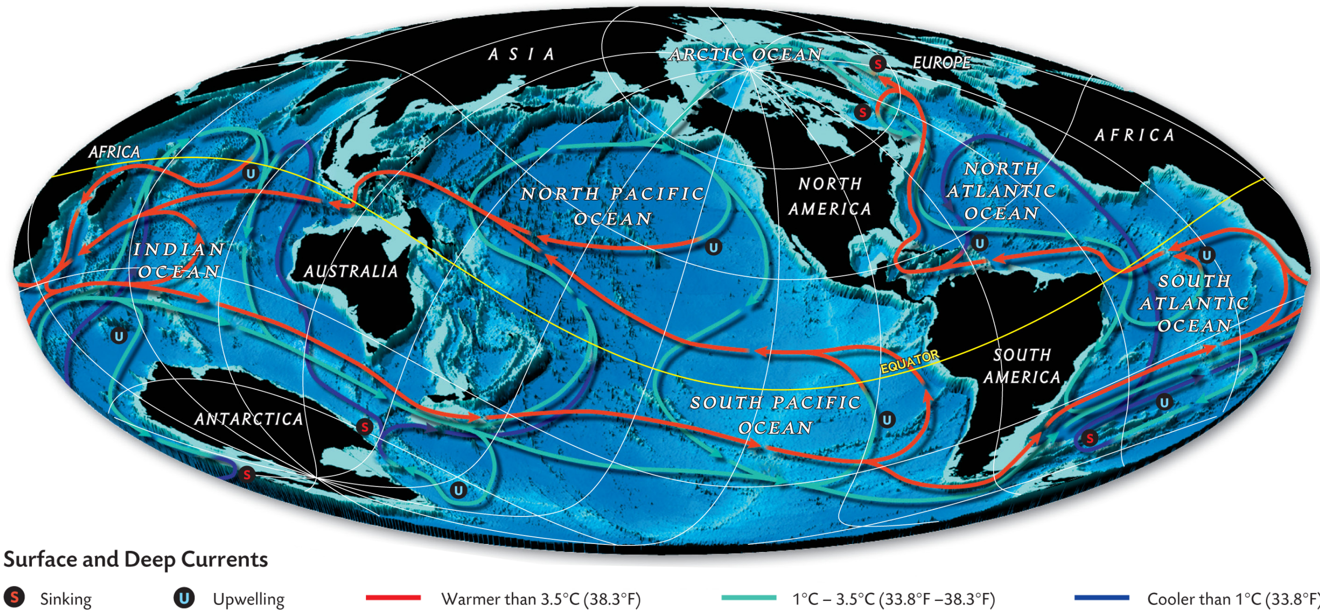
The physical and chemical characteristics of water, such as temperature and salinity, influence density and, thus, drive the global current system. Water in the North Atlantic Basin is cold, salty, and dense. This water mass sinks and travels along the bottom of the Atlantic Basin away from the ice caps, all the way to the southern end of the globe! When it reaches the Southern Ocean it mixes with more deep, cold, salty water from Antarctica. Some of this water upwells because it follows the contours of the ocean bottom and rises at the edges

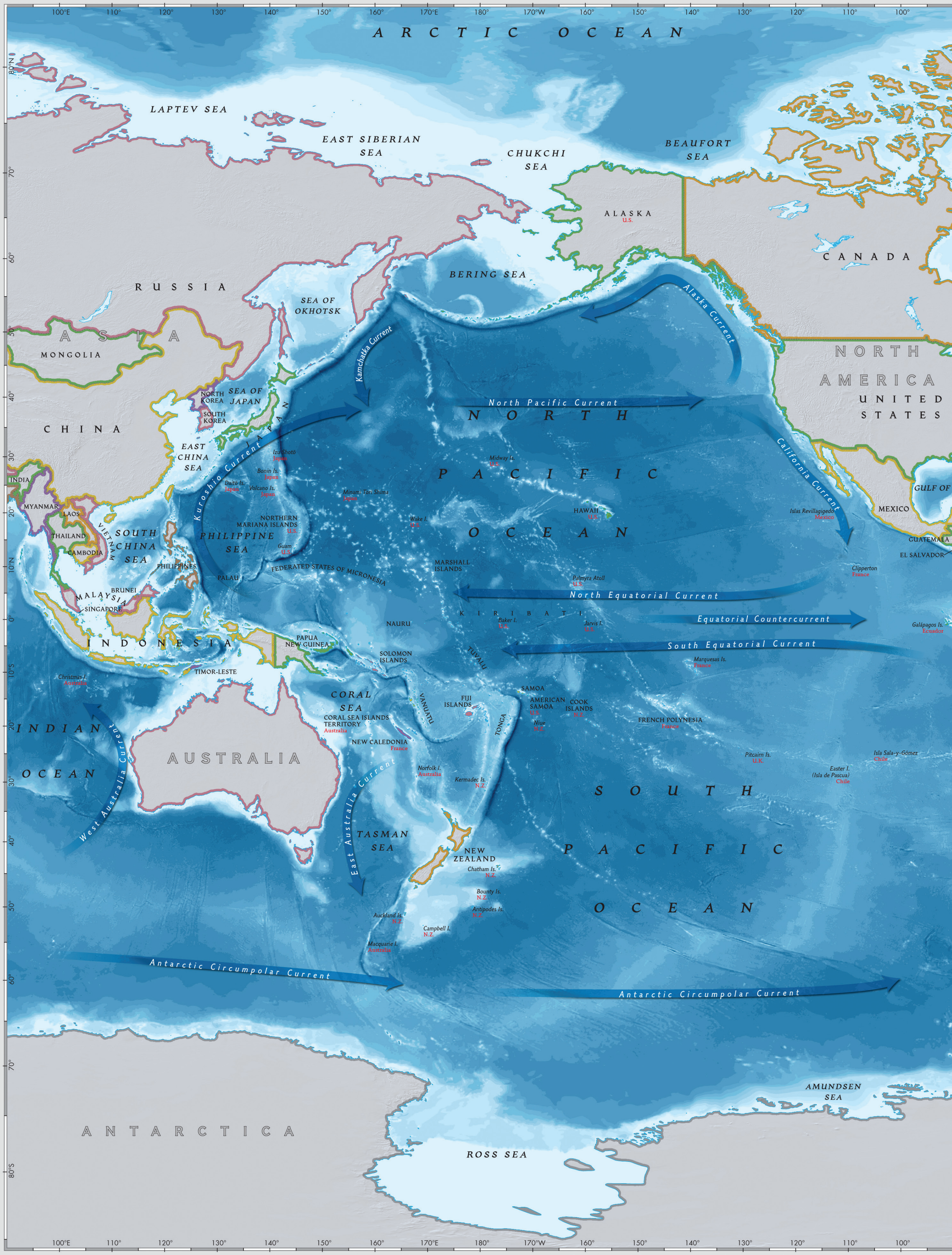
Teaching Tip

Before discussing density-driven ocean circulation, make certain your students have a solid grip on the concept of density. Density can be very difficult for students to comprehend because it relates to something happening on the molecular level—something they cannot see. Some simple activities to increase student comprehension of density include showing students images of molecules in salt water at different salinities or having students add salt to a cup of water and describe why the density is increasing (they are putting more “stuff” into the same volume of water). There are many other lessons that exist to help reinforce this student thinking, such as the Cartesian diver activity. Once the concept of density and its relation to temperature and salinity are solidified, density-driven ocean circulation becomes much more easily grasped. See activity ideas at http://www.bigelow.org/shipmates/density.html or http://www.pbs.org/wgbh/nova/teachers/activities/2402_titanic.html.

GLOBAL OCEAN CURRENTS

The ocean is in constant motion, driven by surface winds and controlled by water temperature and density. Great landmasses guide the direction of water movement, creating an enormous conveyor-belt effect.




ARCTIC OCEAN
LAPTEV SEA
EAST SIBERIAN SEA
CHUKCHI SEA
BEAUFORT SEA
ALASKA
U.S.
CANADA
RUSSIA
BERING SEA
SEA OF OKHOTSK
ASIA
MONGOLIA
CHINA
NORTH KOREA
SOUTH KOREA
SEA OF JAPAN
JAPAN
EAST CHINA SEA
Kamchatka Current
Alaska Current
North Pacific Current
Kuroshio Current
California Current
NORTH PACIFIC OCEAN
NORTH AMERICA
UNITED STATES
MEXICO
GULF OF
INDIA
MYANMAR
LAOS
THAILAND
CAMBODIA
VIETNAM
SOUTH CHINA SEA
PHILIPPINES
PHILIPPINE SEA
Izu Shotō
Bonin Is.
Daitō Is.
Volcano Is.
Minami Tori Shima
Midway Is.
Wake I.
NORTHERN MARIANA ISLANDS
Guam
HAWAII
Islas Revillagigedo
GUATEMALA
EL SALVADOR
PALAU
FEDERATED STATES OF MICRONESIA
MARSHALL ISLANDS
Palmyra Atoll
Clipperton
France
North Equatorial Current
BRUNEI
MALAYSIA
SINGAPORE
INDONESIA
NAURU
KIRIBATI
Baker I.
Jarvis I.
Equatorial Countercurrent
Galápagos Is.
Ecuador
PAPUA NEW GUINEA
SOLOMON ISLANDS
TUVALU
South Equatorial Current
Marquesas Is.
TIMOR-LESTE
Christmas I.
Australia
CORAL SEA
CORAL SEA ISLANDS TERRITORY
VANUATU
FIJI ISLANDS
SAMOA
AMERICAN SAMOA
COOK ISLANDS
Niue
FRENCH POLYNESIA
TONGA
NEW CALEDONIA
INDIAN OCEAN
AUSTRALIA
West Australia Current
East Australia Current
Norfolk I.
Kermadec Is.
Pitcairn Is.
U.K.
Isla Sala-y-Gómez
Chile
Easter I. (Isla de Pascua)
SOUTH PACIFIC OCEAN
TASMAN SEA
NEW ZEALAND
Chatham Is.
Bounty Is.
Antipodes Is.
Auckland Is.
Campbell I.
Macquarie I.
N.Z.
Antarctic Circumpolar Current
Antarctic Circumpolar Current
AMUNDSEN SEA
ANTARCTICA
ROSS SEA


ARCTIC OCEAN
GREENLAND
Denmark
GREENLAND SEA
BAFFIN BAY
Svalbard
Norway
Franz Josef Land
Russia
BARENTS SEA
KARA SEA
Jan Mayen
Norway
NORWEGIAN SEA
Norwegian Current
East Greenland Current
Labrador Current
ICELAND
Faroe Is.
Denmark
HUDSON BAY
NORWAY
SWEDEN
FINLAND
RUSSIA
ESTONIA
LATVIA
LITHUANIA
BALTIC SEA
NORTH SEA
UNITED KINGDOM
IRELAND
DENMARK
NETH.
BELGIUM
GERMANY
POLAND
BELARUS
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SLOVAKIA
UKRAINE
FRANCE
SWITZ.
AUSTRIA
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MOLDOVA
ROMANIA
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CROATIA
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SERBIA
ITALY
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KOS.
BULGARIA
ALBANIA
MACED.
BLACK SEA
GREECE
KAZAKHSTAN
ASIA
CASPIAN SEA
UZBEKISTAN
KYRGYZSTAN
GEORGIA
ARMENIA
AZERBAIJAN
TURKMENISTAN
TAJIKISTAN
TURKEY
CHINA
North Atlantic Drift
Gulf Stream
NORTH ATLANTIC OCEAN
Azores
Portugal
PORTUGAL
SPAIN
MEDITERRANEAN SEA
TUNISIA
CYPRUS
SYRIA
LEBANON
ISRAEL
JORDAN
IRAQ
IRAN
AFGHANISTAN
PAKISTAN
NEPAL
KUWAIT
BAHRAIN
QATAR
U.A.E.
SAUDI ARABIA
OMAN
INDIA
Madeira Is.
Portugal
Canary Is.
Spain
Canaries Current
MOROCCO
ALGERIA
LIBYA
EGYPT
RED SEA
Bermuda Is.
U.K.
MEXICO
BAHAMAS
CUBA
DOMINICAN REP.
Puerto Rico
U.S.
ANTIGUA & BARBUDA
Guadeloupe
France
HAITI
JAMAICA
BELIZE
HONDURAS
CARIBBEAN SEA
ST. KITTS & NEVIS
DOMINICA
ST. LUCIA
ST. VINCENT & THE GRENADINES
BARBADOS
GRENADA
TRINIDAD & TOBAGO
NICARAGUA
COSTA RICA
PANAMA
VENEZUELA
GUYANA
SURINAME
FRENCH GUIANA
France
COLOMBIA
Isla del Coco
Costa Rica
Isla del Malpelo
Colombia
ECUADOR
WESTERN SAHARA
Morocco
MAURITANIA
MALI
NIGER
CHAD
SUDAN
ERITREA
YEMEN
CAPE VERDE
SENEGAL
GAMBIA
GUINEA-BISSAU
GUINEA
BURKINA FASO
BENIN
NIGERIA
AFRICA
DJIBOUTI
SOMALILAND
Somalia
ETHIOPIA
SOMALIA
ARABIAN SEA
BAY OF BENGAL
SRI LANKA
North Equatorial Current
SIERRA LEONE
LIBERIA
CÔTE D'IVOIRE
GHANA
TOGO
CAMEROON
CENTRAL AFRICAN REPUBLIC
Equatorial Countercurrent
EQUATORIAL GUINEA
SAO TOME & PRINCIPE
GABON
CONGO
DEMOCRATIC REPUBLIC OF THE CONGO
UGANDA
KENYA
RWANDA
BURUNDI
TANZANIA
MALDIVES
Equatorial Countercurrent
North Equatorial Current
South Equatorial Current
BRITISH INDIAN OCEAN TERRITORY
U.K.
St. Peter and St. Paul Rocks
Brazil
Arquipélago de Fernando de Noronha
Brazil
South Equatorial Current
SOUTH AMERICA
BRAZIL
PERU
BOLIVIA
PARAGUAY
Ascension
U.K.
CABINDA
Angola
ANGOLA
ZAMBIA
MALAWI
SEYCHELLES
COMOROS
Mayotte
France
MOZAMBIQUE
MADAGASCAR
INDIAN OCEAN
MAURITIUS
Réunion
France
St. Helena
U.K.
Ilhas Martin Vaz
Brazil
Benguela Current
NAMIBIA
ZIMBABWE
BOTSWANA
SWAZILAND
SOUTH AFRICA
LESOTHO
Agulhas Current
Brazil Current
Peru (Humboldt) Current
Isla San Félix
Chile
Archipiélago Juan Fernández
Chile
CHILE
ARGENTINA
URUGUAY
SOUTH ATLANTIC OCEAN
Tristan da Cunha Group
U.K.
Île Amsterdam
France
Île St.-Paul
France
Crozet Is.
France
Prince Edward Is.
South Africa
Îles Kerguelen
France
Heard I.
Australia
Falkland Is.
U.K.
Shag Rocks
U.K.
South Georgia
U.K.
Bouvet
Norway
SCOTIA SEA
South Sandwich Is.
U.K.
Antarctic Circumpolar Current
BELLINGSHAUSEN SEA
WEDDELL SEA
ANTARCTICA
Miller Cylindrical Projection
SCALE 1:79,773,530
1 CENTIMETER = 798 KILOMETERS; 1 INCH = 1260 STATUTE MILES
0 2000 4000
KILOMETERS
0 2000 4000
STATUTE MILES
0 2000 4000
NAUTICAL MILES
Scale at the Equator
80° 70° 60° 50° 40° 30° 20° 10°W 0° 10°E 20° 30° 40° 50° 60° 70° 80°E
80°N 70° 60° 50° 40° 30° 20° 10°N 0° 10°S 20° 30° 40° 50° 60° 70° 80°S

In the Classroom Density

This activity, in which students investigate water masses, density, and mixed surface layers, will only be successful if students follow the process carefully. In this activity, students can see the effects of density on different water masses. Cold, salty, blue water will separate from warm, fresh, red water, and students will be able to see two distinct layers.

Materials

- Two small, clear beakers per group
- One large, clear container per group
- Eye droppers, pipettes, or small turkey basters (one per group)
- Blue and red food coloring
- Salt
- Spoon
- Ice
- Water
- Straws

Directions

1. Provide students with hot water and ice water in two separate cups or beakers (about ½ liter, or 2 cups, in each container). Add red food coloring to the hot water and blue food coloring and salt to the cold water, stir until the salt dissolves. The salt water should be fully saturated (i.e., add salt until no more can dissolve in the cup).
2. Have students pour the red, hot, freshwater into the large clear container.
3. Have students add the blue, cold, salty water into the large clear container. The water must be added slowly so it does not mix with the freshwater. Students can use a pipette or eye dropper, or they can carefully pour the water, letting it run down the inside of the beaker. Another option is to set up a titration-type scenario in which the blue water gets dripped or slowly streams against the side of the large, clear container. The slower the better! Teachers should practice this beforehand so they have a sense of how slowly students need to work.
4. View the stratified water masses on a white surface and background to clearly see the distinction between the two layers. The cold saltwater is more dense. The hot freshwater is less dense.
5. Using the straw, students can blow air across the surface of the water. Because of the different colors, students will be able to see the top layers moving away from the straw, see it contact the wall of the container, and reflect away from the wall and down into the bottom layer. Students can watch the layers mix.

Discuss

1. Ask students to describe in their own words what happened.
2. Ask them what would have happened if they had used the blue food coloring for the hot water and the red food coloring for the cold water. Would the experiment still work? Would the results be the same? What if the hot water was salty and the cold water was fresh—would that impact their results?
3. Ask students why it was important to pour the water so slowly.

of the continent of Antarctica. Some of it continues to move around the globe or into the Indian Ocean Basin. At the northern parts of the Indian Basin, this cool, salty, North Atlantic water mixed with the Southern Ocean upwells as it comes into contact with Africa and India. As the water masses move away from the Poles and toward the warmer waters of the Equator, they gradually warm and continue to rise to the surface due to the decreased density of warm water. On the surface, they are pushed through different ocean basins by currents from prevailing winds and tides. As the water masses on the surface return to the Poles, wind traveling over the ice sheets cools the water and aids in freshwater evaporation, driving it back down and completing the global current. This is a simplified model of the actual mixing and movement of water that occurs, but it demonstrates how water, driven by differences in density and the wind, moves through the ocean. Scientists refer to this simplified model of the global ocean currents as the global conveyor belt.

Teaching Tip

What do rubber duckies, messages in bottles, and Nike shoes have in common? They have all helped scientists learn more about ocean circulation and ocean currents after being accidently lost by cargo ships. Ask students to think about what might happen to a box of rubber duckies lost near Hawaii? What about near England? How far might these bath toys float before they make land? Encourage students to trace the paths that such items could take using maps of ocean currents. Explain to students that currents cause marine debris, such as plastic, to build up in particular locations in the ocean. Encourage students to find out more about this phenomena by researching the Great Pacific Garbage Patch online. Although there are other places in the ocean where this same phenomenom occurs, this is one of the largest and most well-known cases.

Tides

While currents are driven by physical and chemical properties of the ocean, tides are driven by forces acting on the entire planet. The moon and sun exhibit gravitational pulls on Earth. At the same time, the spinning and orbiting of Earth create **centrifugal force.** These opposing forces push and pull on Earth's surface, creating ocean tides. As the relative positions of Earth, moon, and sun change, the ocean bulges, creating the tides. The gravitational pull of the moon is the dominant force in these interactions. Because of this, the tides cycle along with the moon.

Imagine Earth as a flattened sphere, covered by a uniformly deep layer of water. Now imagine that the moon is pulling the water toward it through gravitational force. That force is felt all the way through the planet. Therefore, water in line with that pull on either side of the planet bulges. While on the far side of Earth, opposite the moon, it looks like the water is pulling away from the planet, that bulge is an artifact of the moon's pull, a result of inertia. Therefore, there are two points of high tide at any moment: both points in line with the moon's pull—one on each side of the planet.

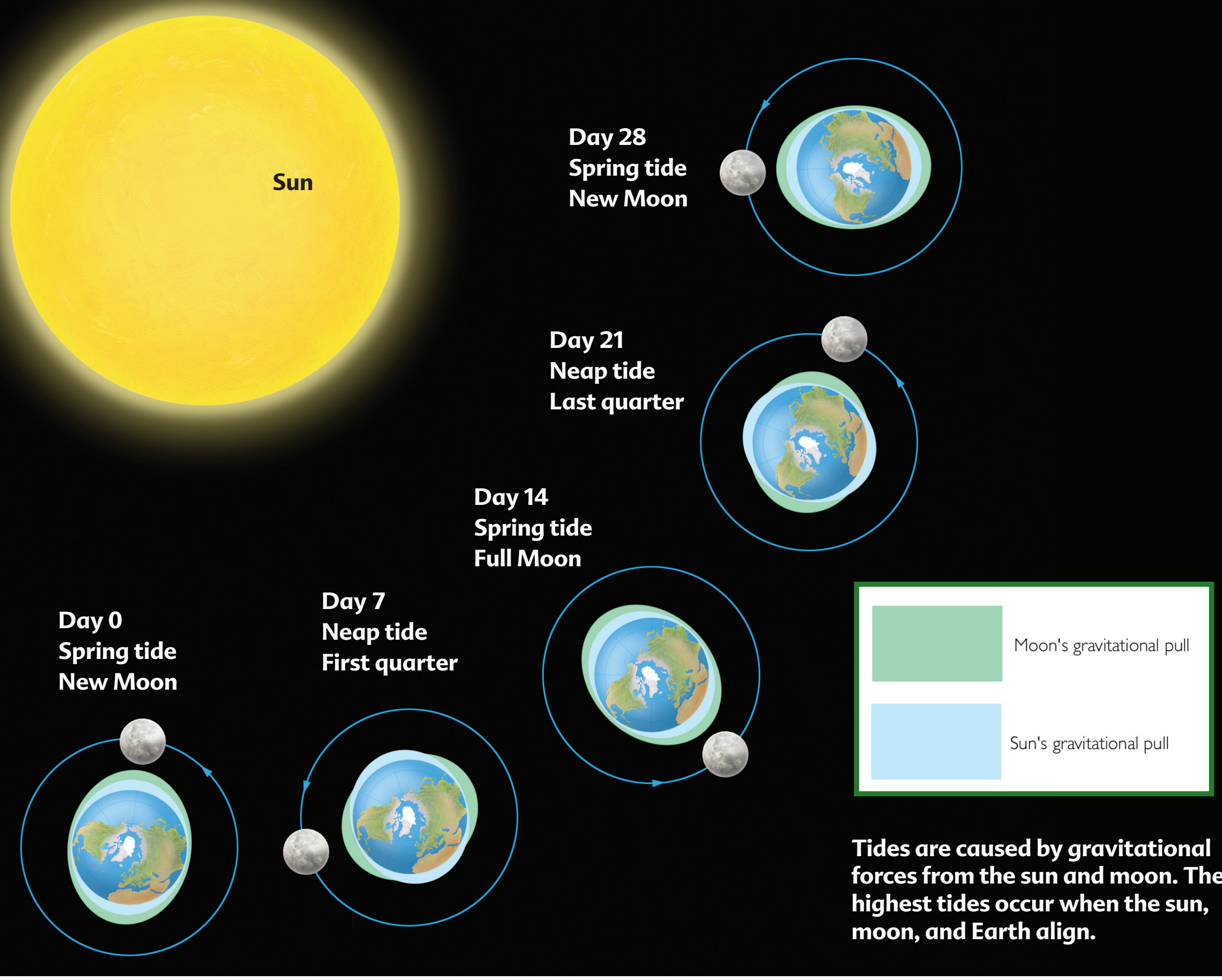
As the moon pulls on the water in line with its gravitational force, the water opposite the moon's pull must follow, leading to an area of low tide. As there are two points directly opposite the moon's pull, there are two low tides at any moment—each at approximate right angles to the high tide if looking down on the planet from space.

This is the most basic tide. On the side of Earth closest to the moon, and on the side opposite the moon, the tide is high. Other places on Earth experience low or intermediate tides at the same time depending on their relative locations.

To understand the effect of the sun in this model, imagine the sun in line with the moon. Now the gravitational forces are all aligned and have created even larger bulges in line with the sun and moon, leading to deeper troughs where the water is pulled away. Therefore, when the gravitational forces of the moon and sun are in the same plane, there are extremely-high high tides, and extremely-low low tides. (This occurs when we see a full or new moon.) This phenomenon is called a spring tide (although it has nothing to do with the spring season). When the sun and moon are in line, the ocean experiences the highest high tides and lowest low tides of the tidal cycle.

As the moon travels around Earth, the bulge of water follows the moon's pull. When the moon and sun are at a 90 degree angle, the bulges are pulled in opposite directions and not as exaggerated. This scenario occurs during the quarter-moon phase and produces what we call neap tides. During neap tides the difference between the high and the low tides can be small.

The level of the tides between different tidal scenarios, such as spring and neap tides, is not static. As the angles between Earth, moon, and sun are constantly changing, so are the tidal levels. Just



Tides are caused by gravitational forces from the sun and moon. The highest tides occur when the sun, moon, and Earth align.

as we can predict the moon cycles, we can predict the tidal cycles. Because the tidal cycles follow the moon cycles, they repeat approximately every 28 days.

These images and descriptions represent a very basic explanation of the tides and explain the driving force behind tides. However, the actual heights and timing of tides vary throughout the ocean and along our coastlines. If the perfect sphere mentioned previously increases in complexity, with underwater mountain chains, deep canyons, volcanoes, and other features, the bulge of the ocean cannot move as smoothly around the sphere. This is the effect that continents and the topography of ocean basins have on the tides. The depth, size, and underwater features of the ocean basin affect tidal cycles, as do the shape of the coastline and the surrounding land features. Some areas experience extremely drastic tides—differences of more than 38 feet (10 m) between high and low tides can occur on a daily basis. Other areas experience nearly imperceptible tidal changes every day. Many areas, including California and much of the East Coast of the United States, have semidiurnal tides: a high tide and a low tide occur twice daily. Other areas, such as the northern Gulf of Mexico, have diurnal tides in which only one high and one low tide occur daily. These cycles are predictable and are often published in Tidelogs for a year's tides for a specific area.

Tides are most evident along coastlines, where rocks, sand, and other coastal features are visible during low tides and are covered with water during high tide. The shape of harbors, bays, and other coastal features also influence the tidal range, the vertical distance between low and high tide, as measured along the coast. In some areas where the coast is extremely narrow and shallow for long distances the tidal range can be drastic. For example, the northern end of the Gulf of California can have tidal changes up to 7 vertical meters (23 vertical feet). In comparison, the maximum tidal range for San Diego is 2.4 vertical meters (8 feet). Although it is hard to see, tides affect the open ocean as well. However, the effects are not as significant.

Waves

Most waves are created by the wind moving across the surface of the water. The energy from the wind is being transferred to the water, and that energy moves through the water in waves that we can see. In the open ocean, these waves are often swells and may not break until they come into contact with land. Closer to land, the momentum of the swell as it travels toward the coastline is often disturbed by a sudden or gradual decrease in the depth of the ocean floor. This slows the bottom part of the wave, but the upper portion of the wave carries forward with its momentum, causing the wave to increase in height and eventually fall forward, or break. This action could be compared to a person tripping. Imagine tripping on a doorstep that you did not see—your feet slow down and your head lunges up and then falls forward.

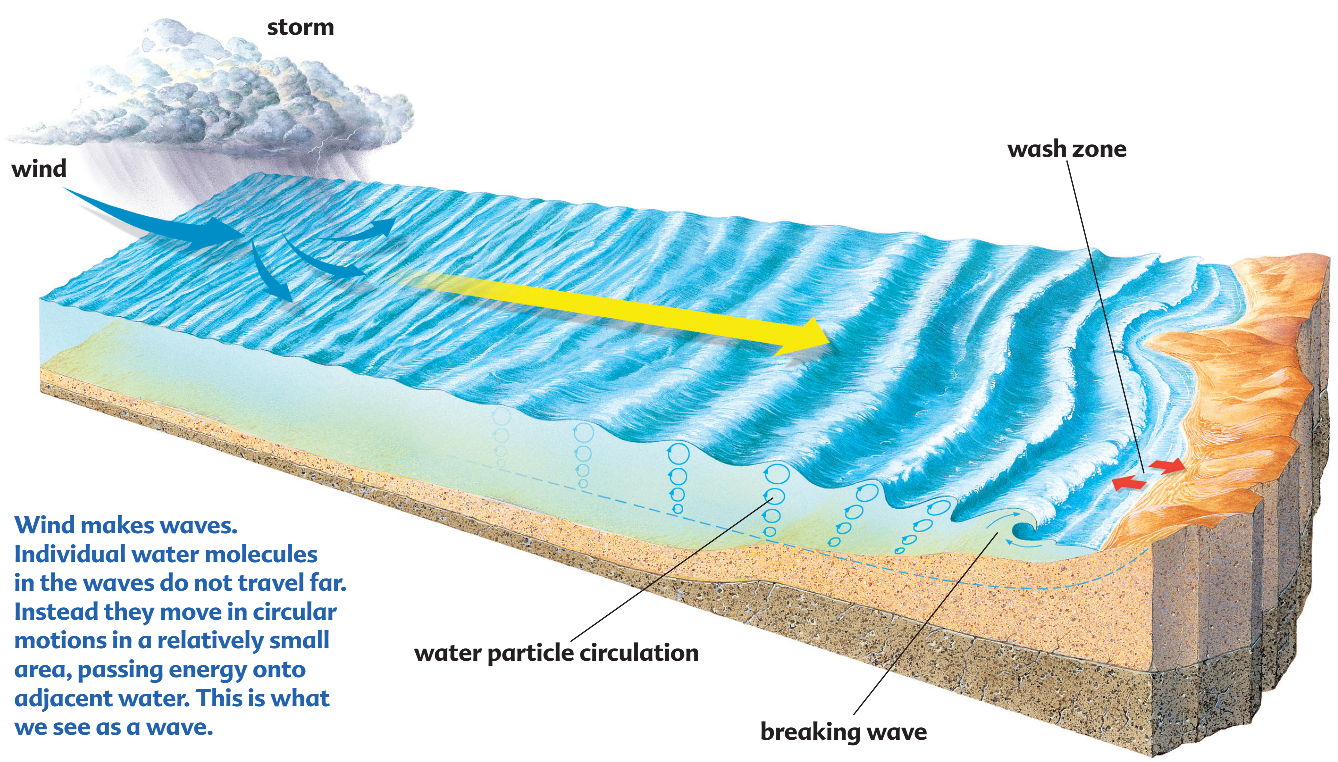
As a wave approaches the shore and breaks, water is moving vertically beneath the surface. The water in a wave moves in a circular motion, while the energy travels horizontally and eventually reaches the beach. The energy from a wave is released onto the beach, creating sea spray and movement of rocks and sand. If you watch a bird sitting on the sea surface, you can see it move up and down with the vertical motion of the water, but the bird does not experience horizontal motion.

At sea the height of a wave, referred to as a swell, is determined by a number of different conditions, including the depth of the water, the speed of the wind, the length of time the wind has been blowing, and the fetch of the wind, or the distance over which it blows. These characteristics influence the wave in the open ocean and as it approaches the shore. The point at which a wave breaks can be described by a mathematical equation that takes into consideration the height of the wave, the depth of the water, and the speed the wave is traveling.

Teaching Tip

The use of a Slinky can provide students with a simple visual representation of how energy travels through waves. Add a small piece of tape to the Slinky somewhere in the middle. Tell students the tape represents a single water molecule. Have two students hold the spring. One student should play the role of the wind and move the spring up and down. As the Slinky moves, students will be able to see the wave motion of the spring and view how the water molecule (i.e., tape) moves in a small circle. This simple activity can help alleviate the common confusion that waves transport water molecules from Japan all the way to California where they break upon the shore.

HOW WAVES ARE MADE

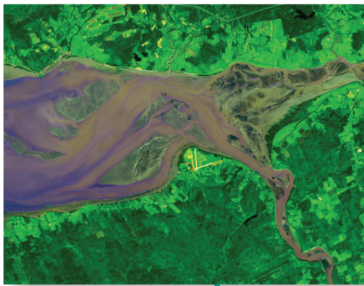


Wind makes waves. Individual water molecules in the waves do not travel far. Instead they move in circular motions in a relatively small area, passing energy onto adjacent water. This is what we see as a wave.

Student Thinking

What Causes Tides?

Students, especially those living near a coast, experience daily changes in their ocean. They routinely hear about high tide and low tide, but students still struggle with understanding what mechanisms cause tides to occur (Ballantyne 2004). They also question why tides are sometimes more dramatic than at other times and why tides happen at different times of day.



Scenario

You are teaching a set of lessons on tides to your students. Halfway through the lessons you hear students sharing incorrect ideas during small-group work. You decide to conclude the day's lesson with a quickwrite because you want to see how many students understand that the gravitational pull of the moon (and partially the sun) causes tides. The following is a sample of responses you received from students.

Question

Explain as much as you know right now about what causes tides.

Scientific Answer

The primary mechanism that causes tides is the gravitational pull of the moon. The gravitational pull of the sun is also a factor, as is the rotation of Earth. When the two pulls are aligned, there are more dramatic differences in tides (tides are amplified). When the two pulls are offset, the difference in tides is less dramatic. Other factors, such as local coastline and physical topography of the marine and land environment, will affect tidal activity.

Student Answers

Ryan: The tides change because Earth moves on its axis. And tides that are also created by tremors, underwater volcanoes, things that set-off automatically.

Caleb: I think the gravity from the sun and the Earth moving around the sun makes the tides lower or higher, and then when we get farther from the sun they're lower, and when we are closer to the sun, the tides get higher. When we're spinning around the sun in the wintertime, the tides are normally lower because we're farther away from the sun, and in the summertime they're higher because we're closer to the sun.

Leslie: The tides are drawn by the moon.

Alice: I don't really know a lot about tides, but there can be high tides or low tides. I think the weather causes tides.

Jackson: Low tide is when the water is pulled back. That's usually caused by when there is a new moon.

Meghan: If it's winter the tide would be high, just with the weather I guess, because it's colder and then the summer it would be a lower tide because it's warmer outside.

What Would You Do?

1. What concepts do students understand at this point? What are the incorrect ideas that students are still retaining even after a couple of lessons about tides?
2. Which misconceptions would you want to address? How would you do this?

Student Thinking

Ocean Currents, Tides, and Waves

Students typically are not clear how currents, tides, or waves differ. They associate information—often incorrectly—about depth, the moon, and gravity and their effects on currents, tides, and waves. When asked what the difference among the three is, the confidence and clarity of students' responses waiver. Occasionally, tectonic activity is included in students' associations of these physical processes (i.e., confusion of the difference between a tidal wave, or tsunami, and a tide). When asked what causes currents, students often refer to the wind as a driving factor, or they may claim currents are caused by moon's gravitational pull (confusing currents and tides). Students do not generally think about tides, currents, or waves specifically as global or local processes.

	Common Student Ideas	Scientific Concepts
Currents	Currents move in one direction	A specific current has a standard direction of flow, but changing winds and interaction with other currents can affect its motion. See pages 17—19.
Tides	Tides are a local process in which water goes up and down at different times in the day. Something pushes the water ashore. Some students may see that gravity is involved but identify the wrong external factor. High tide brings larger waves.	Tides are caused primarily by the moon's gravitational pull on the waters of Earth. (Simanek 2009) See page 22.
Waves	Waves are caused by boats or ships on the water or storms and strong winds. Waves move in one direction—onshore to the beach.	Wind transfers its energy to the water as it travels across the surface of the ocean. This kinetic energy of wind motion is translated into wave motion. Strong winds that accompany a storm can create large waves. Waves move in the direction of the wind creating them. Wind blowing to the shore creates waves that travel approximately toward the shore and vice versa. See page 23.

Ask Your Students

1. Explain how a drop of water on the California coast would travel to Japan. What are other places it could travel?
2. Where does the water go during low tide? Why does it go there?
3. Where do waves start? What determines the direction a wave will travel?

Pictures of Practice

Explaining Waves

Students in coastal areas may have daily or weekly experiences with currents, tides, and waves. They may drive by a coast and see waves coming to shore. They hear about times that low tide and high tide are expected to occur. They may go fishing or surfing or hang out at a beach with friends or family. When they are at the beach, they know about areas to avoid swimming near because of rip currents or undertows. Even students living in inland communities have experiences with coasts, either through trips to a beach or what they see in movies. Students may have a difficult time understanding the different mechanisms that drive rip currents and undertows (see **Student Thinking: Ocean Currents, Tides, and Waves,** on page 25, for more information). While waves are relatively easier to understand compared to currents and tides, students still struggle with identifying wind as the driving mechanism.

Students: Grades 5 and 7

Location: California (in coastal communities)

Goal of the Video: The goal of watching this video is to hear students describe what causes waves and compare these ideas to a scientific explanation.

Classroom Context

The interview clips shown in this video were taken during the spring of the school year after both sets of students learned about the ocean. The first part of the video shows fifth-grade students describing mechanisms that cause waves. The second half of the video shows seventh-grade students answering the same question. Think about the different types of responses you hear from students in the same grade as well as differences between grade levels. How do these compare to a scientific explanation?

Video Analysis

In this video, fifth and seventh graders were asked the same question: What causes waves? A scientific explanation of waves focuses on wind moving across the surface of the water. Dominant wind patterns determine the direction of the waves. Tsunamis are a very specific kind of wave initiated by ocean floor activity, such as earthquakes on the ocean floor. But most waves are wind-driven. As you listen to the fifth-grade and seventh-grade students describe waves, think about how their answers match or do not match the scientific description of waves. For example, some students point to gravitational pull or Earth's rotation as driving waves. These students seem to be confusing mechanisms that cause tides with mechanisms that cause waves. Other students seem to have more developed ideas but could still improve their understanding to be more in line with a scientific explanation. As you listen, compare each student's answer to the scientific description and think about how to help each student improve his or her understanding.

Reflect

What patterns do you see in student ideas about waves?

What ideas seem to be common across students? Which misconceptions would you choose to address? How would you do this in your own classroom?

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2 Ocean and Water Cycling

by Marcia S. Matz and Tara G. Treiber

As mentioned in Chapter 1, Earth is known as "the water planet." This nickname is appropriate because the surface of Earth is covered almost entirely by water. It is also probably the most important chemical on the planet. Although we may not even think about this fact, it is the presence of water that allows us and other life forms to even exist on the planet.

Water and its unique properties determine much of Earth's atmospheric conditions. It drives our global and local weather, and water vapor is a critical **greenhouse gas** that regulates temperatures on Earth. It is crucial to remember that while our planet's surface is mostly water, it also has landforms and is topped by air, and that water is found in these places as well. Water is present within soils and aquifers and provides humidity to the air. Water, land, and the air are interconnected in important ways, and the interplay between them creates what we come to experience as weather and climate. Areas where water meets land are of particular interest and are known as interfaces. Interfaces among water, land, and air play a significant role in transforming water and moving water from and into our ocean. In turn, the ocean affects life on land and makes life on our planet possible.

The Water Cycle

As water moves around our planet, it does so as part of what we call the water cycle. Most of Earth's water is present in the ocean. As the sun shines on the water, it heats the water and causes it to evaporate. As each molecule of water on the surface of the ocean evaporates into the air, it pulls another water molecule to the surface. Now this next molecule of water is exposed to the heat and drying effects of the air, and it also will evaporate. As the water molecules evaporate, the minerals or salts that they may have been carrying are left behind in the salty ocean. As evaporation occurs, the air becomes more and more humid. This water vapor

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.e-h	
Grade 4	4.5.c	
Grade 5	5.3.a-e 5.4.a-c	Earth's Water Changing States: Water, Natural Systems and Human Communities Precipitation, People, and the Natural World Our Water: Sources and Uses
Grade 6	6.2.b-c 6.4.d	The Dynamic Nature of Rivers
Grade 7		
Grade 8	8.5.d	

is an invisible gas and can move quickly. As it moves about, it often travels upward or inland—carried by currents in the air (wind). As the moist air gains elevation, the molecules become colder and condense, turning into liquid. As more and more of these water molecules condense, they cluster together around particles (primarily suspended dust) in the atmosphere and form clouds. Students may think that clouds form by sucking water from the land. They may be confused whether clouds are gas or liquid. However, a cloud is comprised of liquid water droplets, which is why one can see them, as compared to the water vapor, invisible gaseous water molecules suspended in the atmosphere.

When the mass of water molecules is high enough, the clouds will dispense their contents as precipitation. This precipitation can occur as rain or snow or ice, depending on surrounding air temperature. When the precipitation falls onto land, gravity causes it to flow topographically downhill, where the individual droplets combine to form creeks or streams that, in turn, combine to form rivers. The rivers then continue the water's journey to the lowest topographical point, where they all combine and accumulate the water drops into a lake or the ocean. The process of evaporation from this body of water continues, which demonstrates the basic **water cycle.**

The more thorough water cycle recognizes that water is sometimes removed from this loop of evaporation, condensation, precipitation, and accumulation for bits of time. It can be removed by percolation, or infiltration, or used by plants and animals. Students in upper elementary and middle school may be ready to explore some of these other processes. In **percolation,** infiltration, water seeps through the soil and rock, percolating to underground pockets of water. As it infiltrates through the layers, most pollution is removed. This is why underground pockets of water, known as aquifers, are valued as an important source of clean drinking water. When people drill water wells, they are trying to reach these aquifers. Students may wonder how water

CHAPTER OVERVIEW

The ocean is an important driver of the global water cycle. Our local weather and climates are dependent upon the ocean's role in this cycle. As the surface of the ocean is heated, evaporation occurs, sending water vapor into the atmosphere. As this water vapor cools and condenses, it eventually forms clouds and will precipitate, oftentimes back into the ocean. Some of the evaporated water condenses and falls as precipitation onto land.

In addition to latitude and physical geography, proximity to the ocean or other large bodies of water is a key determinant of local weather and climate. El Niño and La Niña are examples of how precipitation patterns change in the Americas, depending on ocean conditions.

This chapter will explore the role of the ocean in the water cycle and take a closer look at properties of water, air, and land to better understand how the ocean interacts with other systems on Earth.

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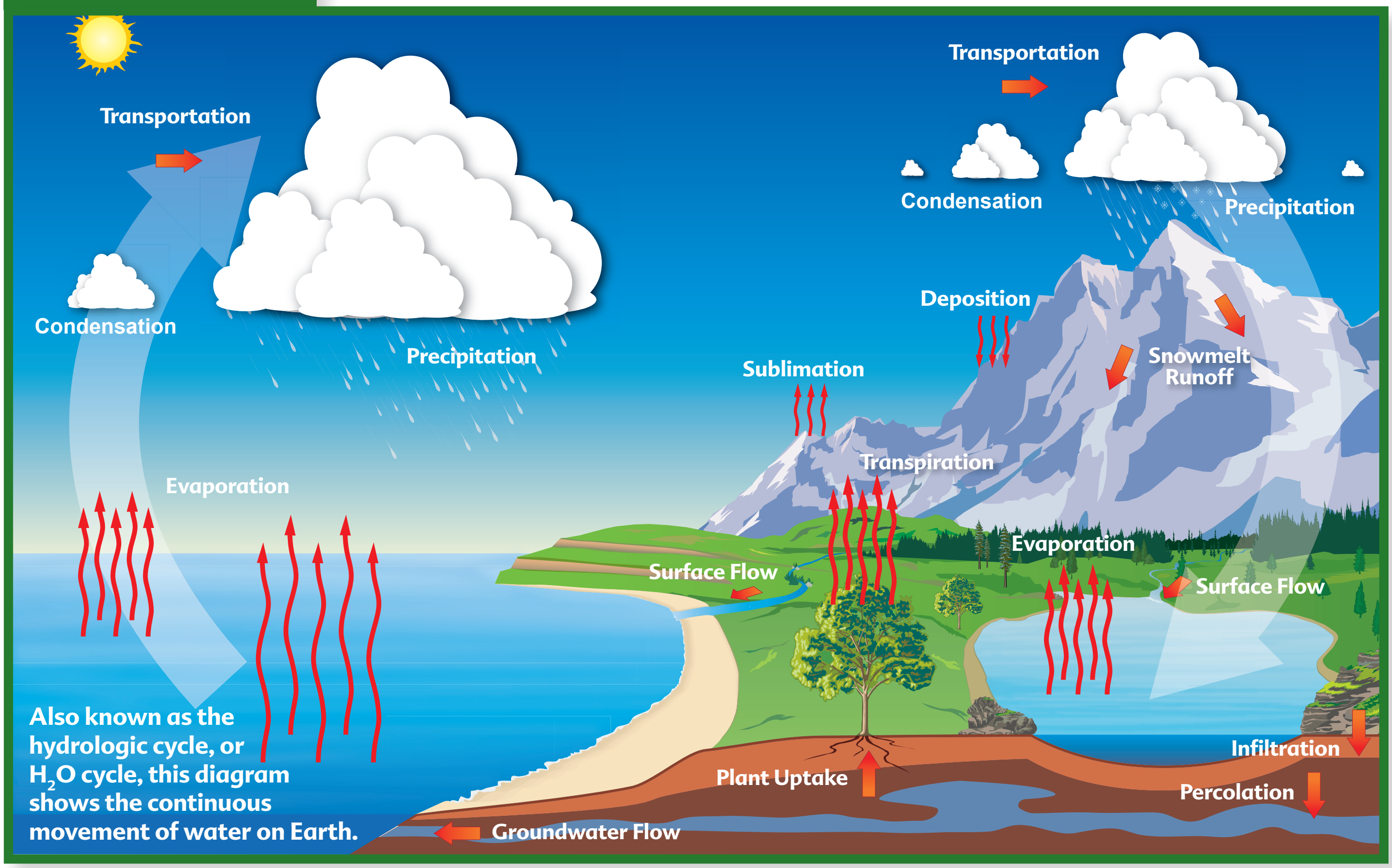
In the Classroom: Splish, Splash: Water's Journey to My Glass 36

Student Thinking: Ocean and Water Cycling 37

Student Thinking: Estuary Interfaces 40

HYDROLOGIC CYCLE



gets into wells in the first place, so percolation is an important concept to learn. A rare step in the water cycle is when solid water, in the form of ice or snow, sublimates into a water vapor under very warm and sunny conditions. Sublimation tends to occur in snowy mountains in the spring when ice changes directly to water vapor.

Water can also be used by plants for photosynthesis and **cellular respiration.** Plants absorb most water through their roots and release it through their leaves. When water is released by plants to rejoin the water cycle, it is known as **transpiration.** The molecule of water that evaporates through the stomata on the underside of a leaf pulls the adjoining molecule of water to the surface. Students may think water only enters and exits plants through the roots. Water is also used by animals for cellular respiration and is released from the body through urination, exhalation, and sweat. As water is released from living things, it can evaporate and return to the basic water cycle. So all living things are part of the water cycle!

Watershed. As freshwater from rain or melting snow descends through a **watershed** by the force of gravity, it erodes and carries materials downstream from along the edges and bottom of the stream. These materials can include natural items such as small particles of soil and decaying plant and animal

Teaching Tip

Students tend to understand the concepts of precipitation and accumulation easily, as they are processes they can see. Evaporation can be tricky but is easily demonstrated by boiling water or leaving a cup out overnight. Condensation is the step of the water cycle that causes students the most trouble, yet most students are familiar with it without even knowing it. Ask them what happens to the outside of a cold soda can when it is removed from the refrigerator. Many will be able to tell you that it gets wet. Explain that the wetness is condensation. The soda can provides something for the molecules to condense around instead of dust which helps clouds form. This simple, real-world example helps many students conquer this confusing concept.

Pictures of Practice

Ocean and Water Cycling

Students living near a coast know their rain comes from the ocean. They grow up watching thunderstorms build offshore or along the coast. Students who live inland from a coast may not have the same wealth of experience connecting the water cycle to the ocean. However, both groups of students may have questions about how the ocean is a part of the freshwater cycle. In fact, many students at a young age still do not understand how freshwater can come from salty ocean water, and they may not realize that freshwater is an important resource we get from the ocean—even more important than seafood!

Students: Grade 5

Location: Laguna Niguel, California (a coastal community)

Goal of Video: The purpose of watching this video is to listen to students' ideas about the ocean's role in weather and water cycling.

Classroom Context

During their fifth-grade year, Ms. Reimer's students studied the ocean and water cycling. They traced a water molecule from the ocean on a path that took the molecule overland and eventually through a watershed back to the sea. Her students also studied uneven heating of the surface of the ocean and land and how this influences the movement of air (and moisture), especially in costal areas. Because students live in a costal area and the ocean determines much of their weather and climate, Ms. Reimer taught several lessons on the concepts.

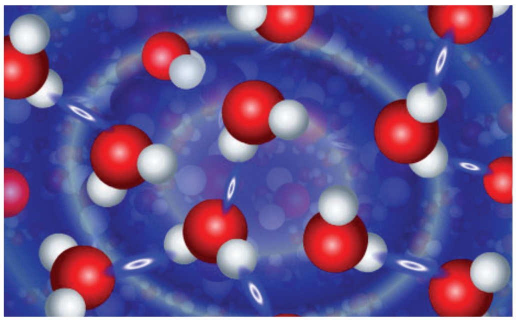
Video Analysis

In the video, you will see Ms. Reimer review these concepts with her students. She begins the review by asking her students open-ended questions about whether people could survive three days without the ocean and how the ocean impacts students' daily lives. While Ms. Reimer had hoped to hear answers about how the ocean influences weather and water cycling, her students end up focusing mostly on getting seafood from the ocean. Ms. Reimer expresses disappointment at the limited connections students make. As she moves to Leah's small group, they begin by talking about seafood, but after additional prompting from Ms. Reimer, Erol brings up the water cycle. Ms. Reimer has this group share their ideas with the whole class in order to get more students thinking beyond getting seafood from the ocean. At the end of the video, CJ still has questions about the water cycle, which indicates that he may need additional instruction to understand these concepts.

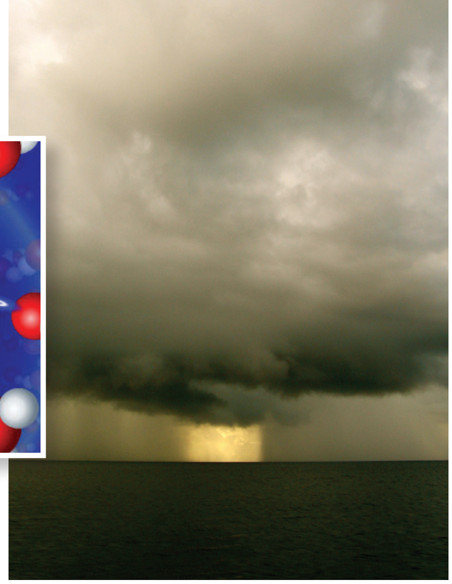
Reflect

How would you teach ocean and water cycling?

Ms. Reimer still has doubts that her students retained information about how the ocean influences their local weather and climate—as well as global water cycling—despite that students had previously had a substantial unit on the topic. If you ask your students how the ocean influences our daily lives, how would you expect them to respond? How would you plan instruction so that students have a good understanding of the ocean's role in water cycling?



The dynamic interactions of water molecules include the forming of links that vary in strength and span.



materials or unnatural pollution such as chemicals and trash. During a storm, when the volume and force of the water are much greater, the swiftly moving water can carry large rocks, branches, and even fallen trees. A watershed is the land area drained by water into a particular feature, usually a river or stream. For example, in central North America, you have the Arkansas River watershed, which consists of all the rivers, creeks, streams, and land surfaces that drain into the Arkansas River as it travels from Colorado to Arkansas, where it spills into the Mississippi River. Many watersheds are made up of smaller watersheds. The Mississippi River watershed is made up of the Arkansas, Ohio, Red, Tennessee, and Missouri rivers watersheds, just to name a few! The Mississippi River watershed drains more than a million square miles, carrying with it the pollution and minerals from all its tributary watersheds, to the Gulf of Mexico. Have your students explore their own watershed and learn more about the area that contributes to water flowing in their backyards.

As water picks up rocks and soil, the minerals they contain are dissolved and washed downstream through the watershed, eventually reaching the ocean. This contributes to the ocean's salinity, or saltiness, which your students may wonder about.

The ocean is an important driver of weather and climate, but before we explore this further, let us take a closer look at the properties of water, land, and air.

Water

Some of the special properties of water can be better understood by taking a closer look at the structure of the molecule itself. Water is comprised of one atom of oxygen and two atoms of hydrogen. Each of the hydrogen atoms is bonded at an angle to the oxygen atom, in a Y configuration. The shape of the molecule resembles Mickey Mouse's head, with the hydrogen atoms representing the character's ears. Chemists sometimes jokingly refer to it as the Mickey Mouse Molecule. Because of this architectural skew of the hydrogen bonds, the more positively charged hydrogen atoms form a slightly positive side to the molecule, while the more negatively charged oxygen atom forms a slightly negative side; the molecule overall is a stable one that is ionically balanced, meaning it does not easily bond with other molecules or elements. This **polarity,** or positive/negative charge distribution, allows the water molecule to behave like a magnet, with the negative (oxygen) side attracting positively-charged atoms and molecules, and the positive (hydrogen) side attracting negative atoms or molecules. This attraction means that it can act as a powerful solvent. Solvents are substances that are good at dissolving or dispersing other chemicals and particles. For example, common table salt, NaCl, is an ionic compound, comprised of a positively-charged $Na+$ (sodium) atom and a negatively charged $Cl-$ (chloride) atom. In water, this solid salt can dissolve. The Na is attracted to the oxygen side of the water molecule, and the Cl is pulled toward the positively-charged hydrogen side. The result is that the salt molecule is pulled apart; it dissolves into the powerful solvent of water. It is water's polarity

Teaching Tip

A quick classroom demo or student exploration for surface tension: Fill a glass to the very top with water. Have students estimate how many more drops can be added to the glass before it will spill over. Gently add additional drops, one by one. The water will form a dome—the molecules of water are holding onto each other because of their polarity. Students may be surprised by how many additional drops of water can be added. Ask students what force eventually is too much for the polarity. The answer is gravity, of which many students may already have a basic understanding. If students need more exposure to surface tension to really grasp the subject, lessons or activities related to bubbles can help them to better grasp this concept.

that allows for salinity in our ocean. Common food items, such as Jell-O and Tang, take advantage of water's solvent powers to deliver the other ingredients to us in a tasty form.

The negative (oxygen) side of the water molecule can also lightly bond with the positive (hydrogen) side of other water molecules, a phenomenon known as hydrogen bonding. In this case, the water molecule's polarity leads to properties known as cohesion and surface tension. Cohesion is the attraction of water molecules to one another. Because of this property, water molecules tend to stick together, forming clumps. Cohesion allows for water to flow through plant tissues and blood vessels by capillary action. At the surface of a container or puddle, water will appear to take on a domed shape. This **surface tension** is due to the cohesion of water molecules.

Water is a very heavy substance. One experiences the weight when lifting a bucket of water or by feeling the difference between wet and dry beach towels. Water is constantly acted upon by the force of gravity pushing the water downhill. The more water available and the faster it is moving, such as during floods and storms, the greater its power. This power is ubiquitous and obvious on our planet, if you know where to look for it. Seaside cliffs are worn down by the constant surges of water. River rocks that have been tumbled smooth by water's action are often used in decorating. One of the most amazing natural wonders of our planet, the Grand Canyon, which is so huge it can be seen from space, was created over millennia largely by the power of river water. After breaking away rock and sediment from landforms such as inland mountains and seaside dunes, the river carries these substances. Due to water's nature as a solvent, many substances, such as salts and gases, are dissolved into the water, forming a solution. Other substances, from huge tree limbs to tiny bits of clay, float in the water, either at or below its surface. This mixture of water and other solids is known as a suspension.

Like all compounds, the water molecule is able to exist as a solid (ice), liquid, and a gas (water vapor). Something unique about water is that it is the only substance that is naturally found in all three phases at normal Earth temperatures. Your students may not realize this fact, but it is actually quite amazing. Changes in temperature and pressure affect how closely the molecules are packed and how quickly or actively they can move around. At low temperatures and high pressures, water exists as ice. Medium temperatures and pressures, which are found on much of the Earth's surface, allow water to exist as a liquid. While at high temperatures and low pressures, water usually exists as a gas, or water vapor. (At extreme temperatures and pressures, water can also exist as a plasma, but those are very rare on Earth.) As water circulates about our planet, it is able to change its phase.

Teaching Tip

Students may be challenged to understand that soil and water have different capacities for holding heat. A simple demonstration can help them witness this with their own eyes. Take two similar containers and fill one with water and one with soil, approximately equal volumes. Place them both in a sunny spot and put a thermometer into each container. Take daily temperature readings for a few days—first thing in the morning and just before leaving in the afternoon. Compare the fluctuations in each. Which substance had the greatest fluctuation in temperature? Which substance changed the least? If you have a classroom thermometer, record and then compare the changing air temperatures. This helps to complete the picture of the different ways that water, land, and air react to changes in temperature.

The Colorado River carves out Horseshoe Bend in the Grand Canyon of northern Arizona.

Land

Land has different properties from water, and, therefore, it behaves differently. Land is not made of one

As the sun reaches the ocean, it warms the surface and increases the water temperature.

uniform molecule, like water. Land is made of different minerals and elements, depending upon where it's found. Some land is made of loose soils, while other land is made of solid rock. Land also responds to heat differently from water. As most beachgoers know, the sandy distance to the cool water can be uncomfortably hot in the daytime, but icy cold at night. Soil, sand, and rock do not hold onto heat the way water does. As a general rule, the land heats up quickly and loses its heat quickly. Moisture also evaporates more easily and quickly from the land than it does from the ocean.

Air

Finally, there is air. Air is made of gases and so is technically considered a fluid. Students may think fluids only include liquids. The molecules of fluids vibrate rapidly and are constantly in motion. Because of this, molecules are easily influenced by changes in temperature or altitude. Heat causes the molecules to speed up, while cold causes them to slow down. We witness this when boiling water. When a kettle or pan of water with a loose lid is brought to a boil, the lid rattles as the heated water molecules become water vapor and begin to move faster and vibrate. The movement and rattling stop when the heat is turned off, causing the molecules to slow down.

Air also has a tremendous range in its ability to hold water vapor. In deserts, the water content of the air is fairly low. Even though it can be very hot, people usually describe the heat as dry heat or a low humidity—like a sauna. In coastal areas, or during a storm, the water content is much higher, and so the heat is experienced as wet heat, with a high humidity—more like a steam bath if it's hot enough. Remembering the water cycle, many water molecules have evaporated (from the ocean, rivers, and lakes) and are present in the adjacent air, and it's these evaporated molecules that determine the air's humidity.

The Ocean, Weather, and Climate

Weather, at its most basic, is water moving among the air/atmosphere, the land, and the ocean. Weather takes place in the lower atmosphere, known as the troposphere, because this is the area in which water vapor is found. In the water cycle, the sun heats the ocean (or any other body of water) causing water molecules to evaporate and flow into the atmosphere. Water molecules, in the form of liquid (such as in clouds) or as vapor are carried great distances, both vertically and horizontally within the atmosphere. Factors on land, in the ocean, or in the atmosphere can all lead to the right conditions for precipitation. For example, in the tropics, the sun's energy is strong and direct, leading to a good deal of evaporation and water vapor in the air, which is why the air often feels so humid. If the water evaporates quickly enough, it will travel upward within the atmosphere where it is cooled and condenses into clouds. Due to water's high **heat capacity,** the top layers of the ocean absorb and retain much more energy than does the atmosphere. The solar energy leads to evaporation, driving predictable vertical and horizontal movements of air molecules (including water vapor) in the atmosphere. The horizontal movements are prevailing winds that drive the movements of air masses and weather patterns.

Landmasses can also affect airflow and, therefore, weather. As clouds that have formed over the evaporating ocean travel inland, they often encounter mountains. As the moist air approaches the mountains, it tends to travel upward in elevation, cooling as it goes. The air then reaches that critical point of cooling (known as the dew point) when the water molecules become too cool and condensed to remain as water vapor and they precipitate out. This is why the Pacific Northwest tends to be so moist. The humid ocean air is quickly cooled as it hits the Cascade Mountains, and it precipitates out—leading to lush rain forests and other wet habitats of this region. If there are no mountains and the land below retains its warmth at night, the clouds can carry their watery load for very long distances before precipitation may occur. Prevailing winds in the atmosphere, driven by differential heating and the water cycle, carry clouds and storms, resulting in weather. The energy and water vapor from the tropical ocean lead to the development of storm systems. In fact, most of the rain that falls on land was evaporated in the tropical ocean. Because so much of our weather is driven by the evaporation occurring over the ocean, the ocean is said to control the planet's weather and climate.

El Niño is one ocean phenomenon that demonstrates how tightly the ocean and atmosphere are tied. Your students may have heard of El Niño but not understand exactly what it means.

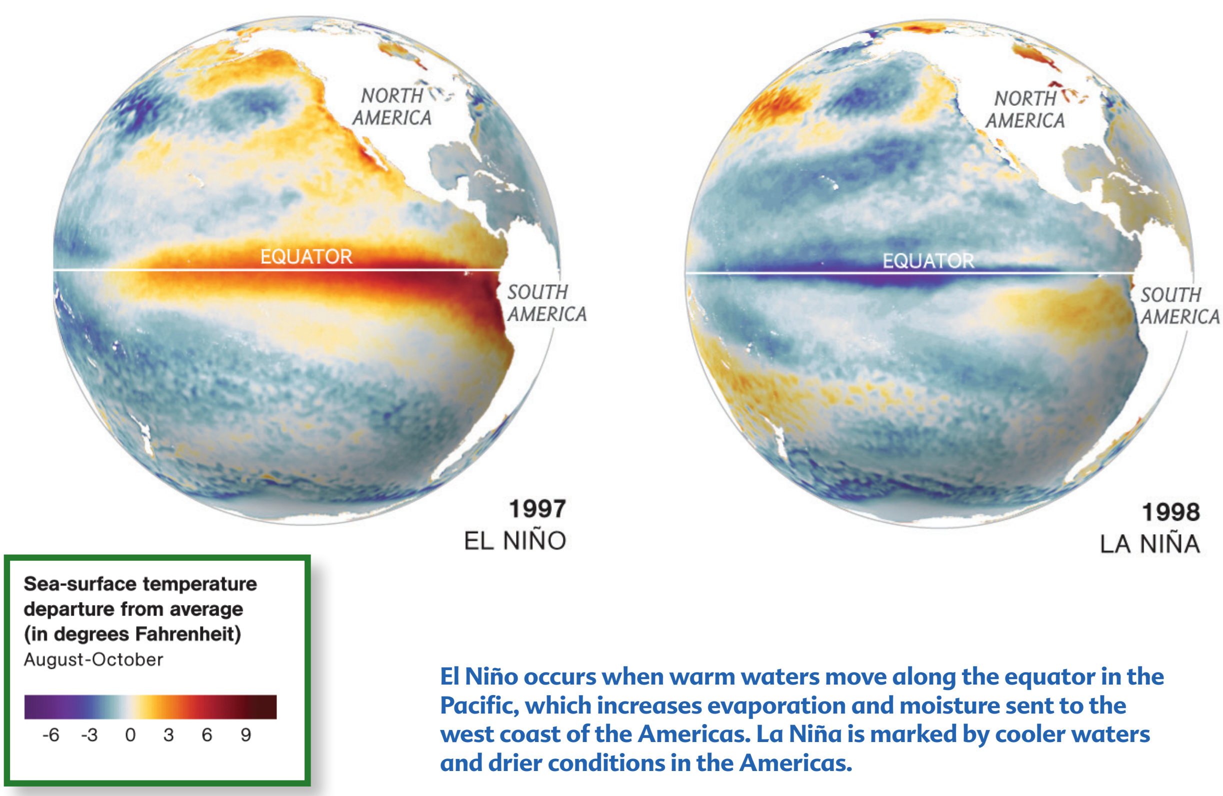
El Niño is also known as ENSO (El Niño-Southern Oscillation). It gets its name from the Spanish term for Christ child, or the little boy, because it often starts to occur near Christmastime when people celebrate the birth of Jesus. These events are characterized by warm Pacific waters, which usually stay in the western Pacific, slowly making their way across the Pacific to remain in the eastern Pacific for a while. The warmer waters are more prone to evaporation and, therefore, tend to bring more rain to the western coasts of North, Central, and South America. In California, El Niño years tend to be very wet. It should also be noted that, during an El Niño, the thermocline is depressed due to the influx of warmer water from the western Pacific. As a result, the water that is upwelled is from above the thermocline and, thus, is nutrient-poor. Therefore, El Niño not only affects weather but also influences the food web.

El Niños, however, are not permanent. Cold upwelling along the west coast of South America and along the Equator may strengthen, along with the easterly trade winds. The tropical Pacific's subsurface water temperatures become cooler than normal as well. This phenomenon is referred to as **La Niña.** With cooler waters off the western coasts of North, Central, and South America, there is less evaporation to help fuel rain and the coasts once again return to their drier climate.

This brings us to an important point of clarification. Climate is the average weather conditions over wide areas and long periods, such as decades and centuries. Weather, in contrast, is the moment-to-moment conditions of temperature, wind, barometric pressure, and precipitation at a particular location. The difference between the two can be confusing, especially for your students. While El Niño brings conditions that influence the weather over months or sometimes even a few years, it does not change the overall climate. El Niño is a change in the ocean that influences a change in the atmosphere over the short term, not a permanent condition. If it were to be a permanent condition, or at least one that existed for decades, it could be said to influence climate as well.

Climate is influenced by the atmosphere, land, and ocean. The interaction between the ocean and atmosphere greatly affects climate. For example, San Francisco and Kansas City, Missouri, are located at nearly the same latitude. One would expect, therefore, a similar climate in these two cities. In actuality, San Francisco enjoys a much more moderate climate, with cooler summers and warmer winters than Kansas City, largely due to the California city's proximity to the ocean and its high heat capacity. Other climatic patterns, such as seasonal

EL NIÑO AND LA NIÑA



El Niño occurs when warm waters move along the equator in the Pacific, which increases evaporation and moisture sent to the west coast of the Americas. La Niña is marked by cooler waters and drier conditions in the Americas.

In the Classroom

Splish, Splash: Water's Journey to My Glass

Critical to our existence, water sustains all life on Earth. Water moves continuously through the stages of the hydrologic cycle (evaporation, condensation, and precipitation). How does our drinking water fit into the hydrologic cycle? Where does the water we drink come from? This lesson will explore the hydrologic cycle, and students will map the path of drinking water from the origin of precipitation to the tap.

Materials

- Topographic map of your region
- Blank map of your region
- Information from your local water provider (location of aquifer, reservoir, or well from which the school tap water comes)
- Paper, pencils/pens

Directions

1. Review the basic principles of the water cycle.
2. Brainstorm and list the various types of water sources found on Earth.
3. Explain that the water they drink probably traveled a great distance to end up in their drinking glass. Identify the aquifer, reservoir, or well from which the school tap water comes. Tell students they will work back from this point to trace the water source origin.
4. Ask students to predict where the headwater, or source of origin, for their drinking water might be.
5. Using the topographic map of your region, challenge students to explore the path the water travels. Encourage students to consider the role of the water cycle in this journey.
6. Working from the immediate source of your drinking water (a reservoir, for instance), students will follow rivers and streams back to their headwaters. Students may want to work in groups for this. Be sure to discuss water flow, such as elevation changes that might send a stream flowing in another direction!
7. Students will finish by using the blank regional map to highlight boundaries that define the drainage basin or watershed from which their drinking water comes. Students will also label the paths and names of the waterways within this area.
8. Reinforce the idea that precipitation that falls within the boundaries might also wind up in their drinking glass or water fountain, without following the elaborate path from the headwaters.

Discuss

1. How did your prediction compare to the actual water-source origin?
2. What path does local water follow in order to get to your tap?
3. Name something you learned about water that you did not know before.

Explore more National Geographic Freshwater activities at http://environment.nationalgeographic.com/environment/freshwater/.

Student Thinking

Ocean and Water Cycling

Students may take a land-centered view of weather, seeing it as more a phenomenon on land rather than ocean-driven. Evaporation of water from the ocean can sometimes be a tricky concept to learn. Students may believe that water molecules themselves expand during evaporation, rather than understanding the molecules move apart from one another. (Henriques 2002; Tytler 200). Students may also wonder why rain clouds from the ocean move onshore, which relates to how the sun heats the ocean and land. They may not realize that land and ocean heat differently.

Scenario

A student teacher has asked to do research in your class about student knowledge of the water cycle. The student teacher designs an interview assessment that she uses with a few of your students as practice. The interview is about what students know about the water cycle, but one question in particular asks students to explain how the land and ocean heat and cool. The transcripts of student responses to this question follow.

Question

Describe what happens to the ocean when sunlight heats the ocean? Is this different from what happens on land?

Scientific Answer

Land and water behave differently when exposed to heat. Land heats and loses heat more quickly than water, which means moisture evaporates more easily and quickly from land than it does from water. Water evaporates when heat from the sun warms land or ocean surfaces. In the ocean, as more water evaporates, the air becomes humid and it travels upward or inland (see **The Water Cycle,** page 28). The differential heating and cooling of land and ocean also influence the movement of air and moisture, leading to weather and climate patterns we experience all the time.

Student Answers

Marian: The ocean's temperature is different from the land's temperature. And the oxygen and air atoms pick up the same temperature. I think the land can heat up faster and cool down faster than the ocean. So if it's summer, it's really hot on the land. But in the ocean, it's still pretty cold. It's harder for the ocean to take in the heat.

Jessie: The ocean cools off faster than the land, so I think the air closest to the surface of the ocean will become cooler, faster than the air on land. The ground absorbs the heat faster than the water, and I think it lets it off faster as well. And so winds come off the ocean so it kind of pushes the warm air away and keeps it cooler than the air on land.

Kevin: If it's hotter in summertime, then more water is evaporating from the ocean. The ocean is gathering more salt when the water evaporates because the water leaves behind all this salt when it evaporates. So the surface of the ocean could get a lot saltier. I know the ocean heats up different from land, but I'm not really sure why.

What Would You Do?

1. What do the students' answers show they understand about ocean/land heating and cooling? What do they misunderstand?
2. How could you use information from this interview to plan your teaching? What concepts would you address?

monsoons in South Asia, result from air/sea interactions.

The Other End of the Cycle: Where Freshwater Meets the Sea

Land, sea, and freshwater interface at areas around the globe known as **estuaries.** Estuaries, often simply described as "where rivers meet the sea," are characterized by the interface of two types of water—freshwater from rain and snowmelt and salt water from the ocean. The semi-salty water that forms by their mixing is called **brackish water.** Your students may wonder if estuaries are freshwater or salt water, or they may wonder what *brackish water* means. The freshwater has carried organic (plant and animal) and inorganic (rocks, minerals, chemicals) materials downstream to the estuary. The ocean waves, tides, and surges have encroached upon the otherwise freshwater habitat. It is in estuaries that water is transformed.

Estuaries are shaped by the size and flow of the river joining the ocean, the local sediment or rock type, and how exposed the area is to the open ocean. These differing physical profiles greatly determine the dynamics within each estuary. If an estuary is around steep cliffs, there will be little opportunity for the river to pick up sediment and other items enroute to the ocean, as well as a dramatically shortened area of ocean-freshwater mixing. If the estuary is in gently rolling hills, then the freshwater has more opportunity to pick up and carry sediments and other natural materials along the way, and the incoming ocean waters will extend deeper into the estuary. Because of the differences in the physical structure of the surrounding land, an estuary can exist in myriad forms, such as a bay (San Francisco), a salt marsh (Bolsa Chica), a delta (Sacramento), a mudflat (Morro Bay), a wetland (Elkhorn Slough), or a lagoon (Malibu). If the estuary has a deep bottom, then there will actually be stratification zones—with the less dense freshwater floating on top of the denser salt water and perhaps a middle layer of mixed waters if the tidal movement is sufficient to cause turbulence and blending (similar to the layering in the open ocean discussed in Chapter 1). If the estuary is shallow, these stratification zones may be absent.

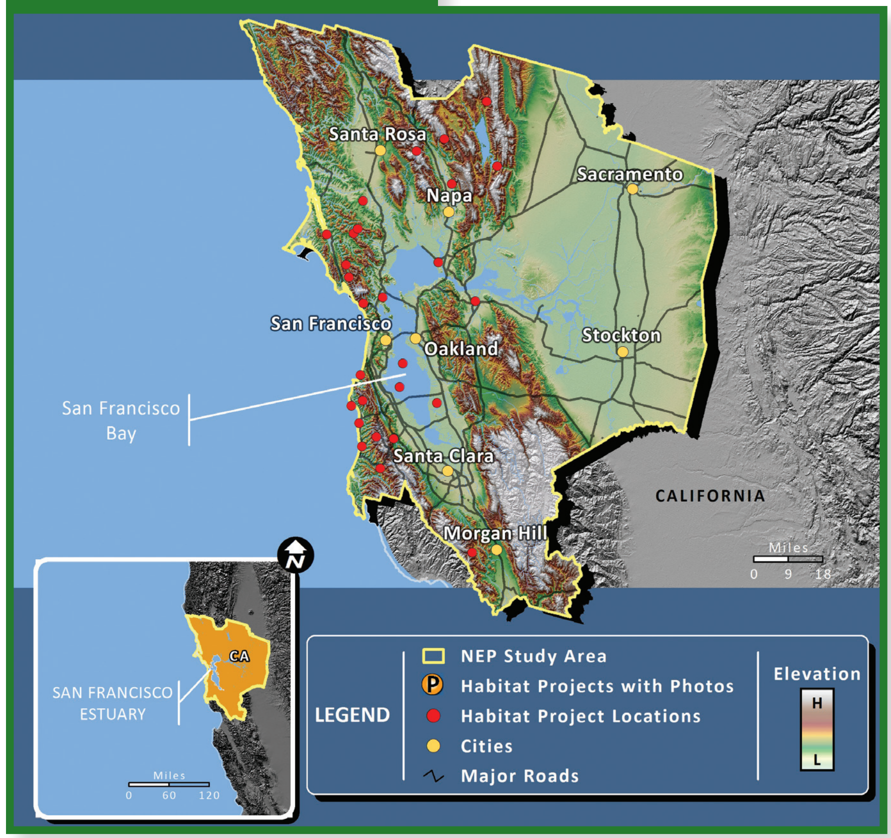
There are normal tidal and seasonal fluctuations in a healthy estuary. Along most of the West Coast, there are two high tides and two low tides each day. During times of a high tide, the salty ocean waters will move upstream into the estuary. Again, the physical configuration of the particular estuary will determine how far upstream it moves. If there are inlets or islets that form barriers, the salty water will not travel as far as it might in an estuary that is unimpeded and shaped like a long river with little change in elevation. During high tides, the waters are naturally saltier as higher salinity ocean water creeps upstream. During low tides, the ocean recedes and it is common to see large areas of the estuary bottom exposed. Particularly in mud flats and salt marshes, low tide is prime feeding time for the many birds that hunt in the estuary because they have increased access to the animals living in the mud. As one would expect, during the rainy season and spring's melting of snow, the estuaries have a greater influx of freshwater than they do in the dry months. During drier periods, especially if there's a drought, estuaries can have very little freshwater. Lack of circulation within an estuary can occur when outlying sand bars build up (in the absence of freshwater outflow) and block water movement or due to human activities such as the construction of jetties.

Besides the mixing of the two types of waters, estuaries are distinctive in that they provide a remarkable service to the planet. This can seem surprising to both students and teachers because estuaries often look like a wasteland. Viewed quickly and superficially, one sees the changing water level, scrub vegetation, and often litter floating in the water and might make the judgment that an estuary is worthless. Ironically, these scrubby plant species enable estuaries to make such a huge contribution to the health of our planet.

Estuaries provide a buffer zone between freshwater and the ocean. This buffer zone provides an area of refuge from direct wave action which impacts the topography of the local beach, the water quality, and the **biodiversity** of the habitat. During storms, estuaries can accommodate extra water and keep neighboring regions from flooding. This buffer zone also allows the upstream water to circulate and percolate within the estuary before moving out to sea. While the water is in the estuary, it seeps down between the pores in the sediment, through pebbles and decaying organic material. As the water percolates through the sediment, the process acts as a natural filter, removing chemicals and impurities in the water. Additionally, many estuarine plant species are able to absorb chemicals, including toxic metals, and transform them into harmless compounds. The longer water stays in the estuary, the more it is filtered by the local species and geological processes.

The water in an estuary is greatly impacted by its surroundings—upstream and adjacent. Run-off from industrial plants and agriculture, as well as oil, soaps, sewage discharge, pesticides, and herbicides that are used by the people living upstream, increase the demands placed on the filtering capacity of an estuary. The pesticides and herbicides that are used to protect gardens also kill plants and animals in the estuaries. Chemicals, such as the phosphorus in

RESTORING OUR ESTUARIES



the detergents we use to wash our cars and the oil that drips onto our driveways and streets, also add to the chemical mix found in estuaries. **Eutrophication,** or nutrient loading, can overwhelm estuaries. All the extra nutrients, including the added phosphorous, can promote rapid growth of algae (algal blooms). When the algae die off, the oxygen levels in the water greatly decrease, imperiling the other organisms living in the estuary. Higher levels of carbon dioxide resulting from increased emissions from cars and industry has made our waters increasingly acidic. Many of the organisms that live in and by the water have calcium carbonate shells (similar to chalk) that dissolve in acidic waters. Many estuaries also have been beset by invasions of nonnative species of plants and animals, which can be introduced through the **ballast** water and hulls of ships. Because they have no local natural predators, these nonnatives out compete the native species, and the balanced food web becomes unbalanced.

The perception of estuaries as wastelands has put them in peril. California has lost about 90 percent of its wetlands due to urbanization and agricultural development. As demand for land grew, these undeveloped areas were purchased and developed. The natural ability of estuaries to filter impurities out of the water before it reaches the ocean has been seriously overloaded by the decrease in acreage and the increasing level of toxins that are flowing in the water. This means more pollutants are entering the ocean. The decrease in wetlands has also impacted wildlife that rely on estuaries as feeding, nesting, and nursery areas.

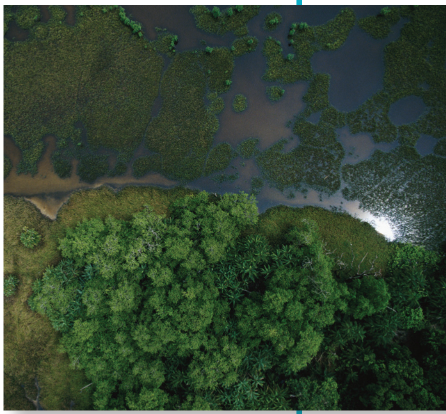
The good news is that in recent years, we have become more aware of the importance of estuaries in the filtering and health of our water. Several laws have been passed to protect our ocean and estuaries. National and state agencies have been funded and are endowing local groups to monitor and reclaim estuaries. Volunteers, partnering with scientists, are now able to use modern monitoring tools, such as aerial photography and more user-friendly chemical testing kits to help monitor the health of the estuaries. Concerned locals can research and share available resources and data banks in their efforts to reclaim our oceans and estuaries (e.g., The National Estuarine Research Reserve System—NERRS). Restoration projects are currently underway in California's San Francisco Bay, Santa Monica Bay, Bolinas Lagoon, Goleta Slough, and Long Beach's Colorado Lagoon (http://www.era.noaa.gov/). Each restoration project faces special challenges unique to its location. Some sites have to dredge toxic chemicals, while others are getting rid of asphalt parking lots that seep oil. A common thread is concern for the water quality and the preservation of native plant species to reestablish the natural balance in the habitat. The projects discussed here and those that are similar strive to assure the health of estuarine ecosystems and the natural filtration structure in these systems.

The active exchange of fresh and salt waters in estuaries provides a significant service to our planet. The fresh rain and snowmelt that have journeyed downstream—collecting minerals, organic materials, chemicals, and debris along the way—gets filtered. This filtered water is returned to the ocean where it will evaporate and start its journey through the water cycle once again. This constant cycling of liquid, gas (vapor), and solid (snow /ice) water is fueled by the energy and heat of the sun. The differences in heat retention of water and land create changes in winds and air patterns. These winds move both water and air currents that come ashore and distribute rain across the continents. The ocean drives our weather and has a profound effect on our climatic zones.

Student Thinking

Estuary Interfaces

While students may be familiar with some marine ecosystems, such as coral reefs, few are familiar with estuaries. These important ecosystems can be home to many unique species. Unless you enjoy birding or paddling, estuaries are not a common place to choose for outdoor recreation. Some may think estuaries are "swampy," "buggy," or that they smell funny. Yet, estuaries are an important ecosystem teeming with life, and as you teach about estuaries, you may find students have incorrect ideas or simply lack a general understanding of these ecosystems.



Loango National Park, in Gabon, was established to protect diverse coastal habitats.

Scenario

You are going to start teaching about marine ecosystems to your students. In order to determine what your students already know, you decide to give them a quiz. One question on this quiz asks about estuaries. As you read answers to the following question, think about your plans for teaching estuaries to students.

Question

Why are estuaries important to the ocean?

Scientific Answer

Estuaries act as a barrier between land and ocean, and fresh and salt water. They act as a basin for extra water, often accommodating excess water during storms, preventing flooding in nearby areas. They also act as a filtering system, allowing for percolation of freshwater in the sediment and filtration through vegetation before it enters the ocean. Lastly, estuaries are important nurseries for many marine species.

Student Answers

Leah: Estuaries might be important for the ocean because they are filters almost, for other animals that probably shouldn't go in the ocean, they can live there.

CJ: They might be important because the water from the estuaries flows to the ocean, and during that process, it gathers salt and creates salt water.

Allison: Estuaries may be important for the ocean because it can be a safe place for other living things to stay away from harmful creatures to them.

Jacob: An estuary is good for the ocean because a lot of things that migrate from the ocean into freshwater, or from freshwater into the ocean, like salmon. They need the estuaries because that's almost like a gate to get into the ocean or out from the ocean.

Tony: Wetlands are important to the ocean because wetlands take water from the ocean, then they renew it and they give it back. And sometimes the wetland purifies the water and turns it to freshwater so animals can live in it.

What Would You Do?

1. What misconceptions do you observe? Which ones do you think should be addressed and why?
2. How would you use the students' prior knowledge to plan your lessons so that students' ideas about estuaries become more sophisticated?

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Tytler, R. "A comparison of year 1 and year 6 students conceptions of evaporation and condensation: dimensions of conceptual progression." *International Journal of Science Education* 22.5: (2000) 447–467.

Teaching Resources

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

EPA's Estuary Kids resources: http://water.epa.gov/learn/kids/estuaries/index.cfm

EPA's videos on estuaries: http://water.epa.gov/type/oceb/nep/nepvideos.cfm

Estuary Protection Act: http://www.fws.gov/laws/lawsdigest/estuary.html

Heal the Bay watershed resources: http://www.healthebay.org/about-bay/current-policy-issues/keeping-ocean-healthy#openspace

Marine Life Protection Act: http://www.dfg.ca.gov/mlpa/

NASA Lesson on El Niño: http://mynasadata.larc.nasa.gov/preview_lesson.php?&passid=57

National Coastal Condition and NEP State of the Estuary Reports: http://water.epa.gov/type/oceb/nep/bay.cfm#sob

NOAA Activities on El Niño: http://www.oar.noaa.gov/k12/html/elnino2.html

NOAA Water Cycle Game: http://response.restoration.noaa.gov/watercyclegame

NOAA Ocean Role in Climate and Weather: http://oceanservice.noaa.gov/education/pd/oceans_weather_climate/welcome.html

3 Biodiversity in the Ocean

by Amanda P. Jaksha

Earth is unique among the planets in our solar system because it has large amounts of water. Lucky for us, most of this water is in the liquid state rather than being ice or water vapor. Most of the water on Earth is contained in the ocean. Not only does this water help to regulate Earth's climate and atmosphere, it also provides a habitat for life. In fact, 80 percent of life on Earth is found in the ocean, spread across countless ecosystems throughout millions of square miles covering Earth's surface.

Biodiversity

The ocean is amazingly diverse. Life in the ocean ranges from the smallest microscopic bacteria and viruses to the largest animal ever to have lived on Earth—the blue whale. Biodiversity refers to variation among living things within an ecosystem. This includes variation in plants, animals, fungi, and microorganisms. While students may recognize differences between organisms, they may not recognize different levels of biodiversity and why these levels matter. The different levels of biodiversity include ecosystem diversity, species diversity, and genetic diversity. Even though students may be able to point to differences within and between ecosystems, they likely do not recognize these differences in terms of biodiversity of species or genetic diversity.

Humpback whales often travel in groups, or pods, throughout the ocean.

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.a-e	Structures for Survival in a Healthy Ecosystem Living Things in Changing Environments
Grade 4	4.2.a-c 4.3.a-b	Plants: The Ultimate Energy Resource The Flow of Energy Through Ecosystems Life and Death With Decomposers
Grade 5		
Grade 6	6.5.a-e	Energy: Pass It On! Playing the Same Role
Grade 7	7.3.a 7.3.e	Shaping Natural Systems Through Evolution Responding to Environmental Change
Grade 8		

Types of Biodiversity

Ecosystem Diversity. Ecosystem diversity describes the diversity, or variation, found within a specific geographic region. It allows you to compare the degree of biodiversity between ecosystems—both similar and different—or across ecosystems within a given **biome** or geographical region. For example, one might compare the biodiversity of the plants and animals of a Caribbean coral reef to an Indo-Pacific coral reef, or one might compare biodiversity across the different ecosystems in the same geographic area such as the forests and coastal scrubland in California.

Species Diversity. Species diversity is a common interpretation of biodiversity. Species diversity refers to the abundance and variation of species living in a specific area. For example, a coral reef is likely to be inhabited by a greater number of fish species than the open ocean. An area rich with numerous species is often viewed as being healthier and more resilient than an area with less species diversity. Students may not realize the wealth of fish species found in the ocean. They may characterize fish as "just fish" and not differentiate well between species of fish. When compared to terrestrial plants and animals, students may see more biodiversity among land plants and animals than they do in marine life. For example, students may not recognize the diversity of coral species found in the ocean. Yet there are more than 800 identified species

CHAPTER OVERVIEW

The ocean houses a wealth of life on our planet, from the largest animal to ever roam our Earth, to ancient bacteria living around deep ocean vents, to exotic deep-ocean creatures. Ocean life is not evenly distributed, though. A majority of life lives near the ocean surface to take advantage of producers in that zone.

Ocean organisms have adaptations that make them well suited for the environments in which they live. Our ocean includes habitats such as sandy and rocky shores, kelp forests, mangrove and other estuarine habitats, coral reefs, and polar seas. Marine organisms may travel between these habitats for birthing or feeding needs, and have, therefore, adapted for survival in these habitats.

In this chapter we take a closer look at natural processes that influence biodiversity in the ocean and student ideas about those processes and the environments in which they occur.

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Case Study: Loggerhead Sea Turtle 61

In the Classroom: Massive Migrations 62

Scientists estimate that 25 percent of all marine species live on coral reefs, making them one of the most diverse habitats in the world.

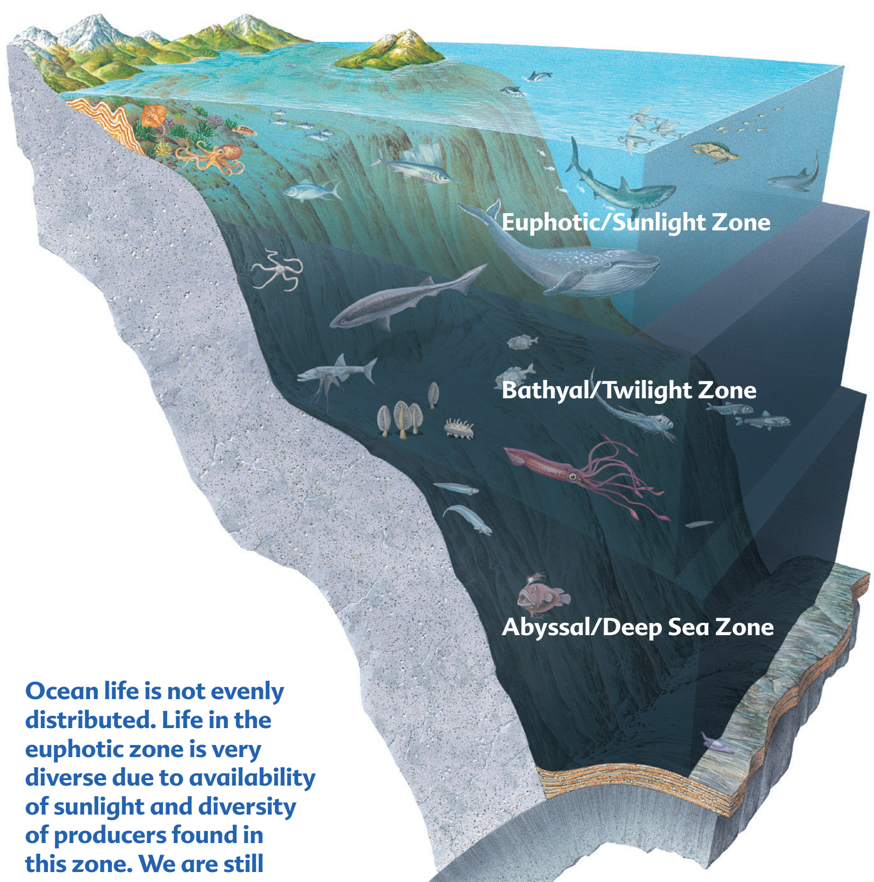
of reef-building coral alone, and many hundreds more species of soft coral and deep-sea coral (NOAA Coral Reef Conservation Program 2010).

Genetic Diversity. Genetic diversity refers to the variation in the **genome** of a species. For example, in a population of snails, some will have genes that code for thicker shells while others have genes that express thinner shells. In a year filled with many predators, the snails with thicker shells might survive better to produce more offspring. In another year, those with thinner, lighter shells might move faster to more quickly locate food, helping them to compete against their thicker-shelled relatives and produce more offspring. This genetic diversity allows species to adapt to changing survival pressures. Students may think physical characteristics, such as thick or thin shells, are something an organism can change within its lifetime, given the will to survive. Genetic diversity, however, is about reproduction in a species, and it's important that students see that the benefits of this type of diversity occurs over generations rather than within a particular organism's lifetime.

Value of Biodiversity

Students may not realize that biodiversity is important for ecosystem health. They may believe that too many living things results in excessive competition. They may also think that an ecosystem with less diversity means that there is less conflict among species. However, scientists typically characterize ecosystems rich with both species and genetic diversity as healthy ones. Given environmental pressures, such as **pulse disturbances** (e.g., catastrophic storms) or **press disturbances** (e.g., climate change), an ecosystem with species diversity has a greater probability that some, if not many, species can survive the disruption, even when other species might struggle. In a degraded ecosystem, one may find very limited types and numbers of organisms. If additional environmental disruptions occur in these ecosystems, there is less chance that species will overcome the disruption. For example, imagine an ecosystem that has large

LIFE IN THE OCEAN



Ocean life is not evenly distributed. Life in the euphotic zone is very diverse due to availability of sunlight and diversity of producers found in this zone. We are still discovering new and exotic creatures of the deep sea.

numbers of living things, but these organism represent only a few species. There is limited species diversity. In this ecosystem, a large population of fish may survive on a few species of prey, and the ecosystem functions well as long as the number of prey are sufficient to support the predator fish population. Yet when a disruption occurs that decreases the population of prey, the food chain quickly breaks down, and the large population of fish will struggle to survive because they have few options for food. In another example, the sea otter population in southern California was greatly impacted by fur trade, which resulted in a sea urchin population explosion. The sea urchins then devastated many kelp forests in southern California. Likewise, genetic diversity ensures that when given environmental pressures occur, a proportion of species will continue to reproduce and survive the change in the environment.

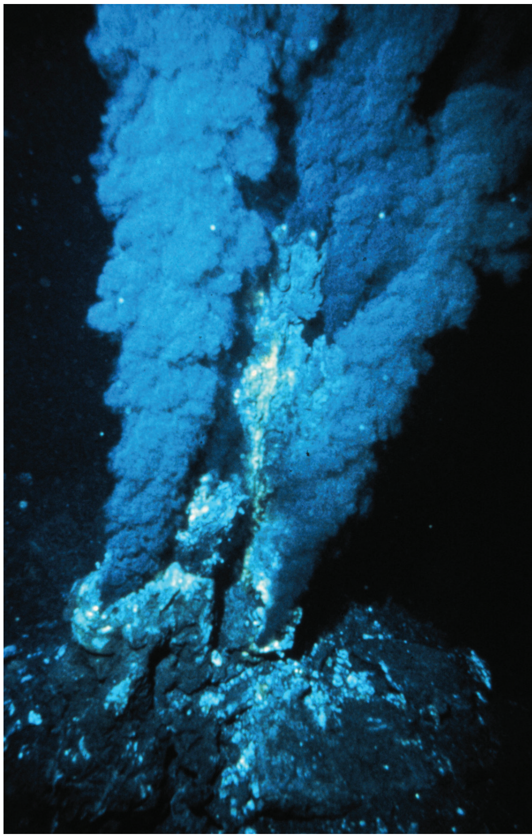
Biodiversity has economic and intrinsic values. Their economic value is because people all over the world rely on the biodiversity of the ocean for food, animal feed, fertilizers for crops, building materials, cosmetics, pharmaceuticals, and tourism. Aside from these more obvious values, the biodiversity of the ocean is also part of the heritage of many cultures and has intrinsic value for its beauty, unique qualities, and the exotic life that calls the ocean home.

Earliest Life May Have Originated in the Ocean

The biodiversity of the ocean offers clues as to how life evolved throughout Earth's history and is continuing to evolve today. More than 95 percent of the ocean is still unexplored, and scientists believe that many new species are yet to be discovered. Scientists also think that the earliest evidence of life comes from the ocean. The **archaea** (Greek for "ancient ones") are simple microorganisms that inhabit diverse habitats, including some of Earth's most extreme environments, such as methane seeps, salt lakes, and hot springs. Inhabiting areas near deep, dark, superheated underwater volcanoes, archaea make nitrogen available to the deep ocean food web through a process called nitrogen fixation. It is believed that archaea species with these characteristics may have been the first life on Earth approximately 3.5 billion years ago. Nitrogen is an important component in DNA and proteins. Through this fixing of nitrogen, these archaea may have contributed to the changing atmosphere of the planet, altering Earth's chemistry and processes and making the evolution of life on Earth possible.

Distribution of Life

While the ocean contains great diversity of life, living things are not evenly distributed throughout the ocean, due to abiotic factors in the ocean environment. Abiotic factors are the nonliving components of an ecosystem or habitat—the physical characteristics such as salinity of the water, water temperature, and light availability. As you travel from the surface of the ocean to the deepest canyons, these abiotic factors change. For example, as you get deeper there is less light. Because of these abiotic factors, the diversity of life varies in different parts of the ocean.



Deep hydrothermal vents in the ocean and underwater volcanoes may be where life originated on Earth.

Surface Life. Sunlight is very important for life because it is where almost all of the energy in the marine food chain originates. Marine plants and phytoplankton, which includes blue-green

Teaching Tip

Many inhabitants of the ocean ecosystem are microscopic, which makes them hard to fathom. Students can be introduced to the local microscopic life, making those found in the ocean more real. Local lakes, rivers, streams, and even outdoor puddles can contain freshwater plankton. Showing students these organisms under a microscope can really open their eyes to the life around them. See a video of small ocean life at http://news.nationalgeographic.com/news/2010/04/100418-coml-hardtosee-video/.

Pictures of Practice

Life in the Ocean

At an early age students develop ideas about living things, but most of their ideas are based on experiences with land plants and animals. Students learn that plants are producers, and through photosynthesis, they make their own food. Sunlight is a key part of the process, so plants need sunlight in order to survive. Students also learn that areas rich with vegetation and food sources are also rich with animal life. Applying these ideas to marine environments may be new to students, and some students may struggle with these concepts. They may be confused about where the plants, or producers, are located in the ocean. They may recognize coastal vegetation such as grasses but not recognize phytoplankton and algae that live in the open ocean. How can students' previous knowledge about land flora and fauna affect how they will learn about and understand marine plant and animal life?

Students: Grade 5

Location: Laguna Niguel, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students learn about biodiversity found in the euphotic zone and to listen to their questions about the topic.

Classroom Context

In this video you will see Ms. Reimer teach her students about distribution of life in the ocean. In previous lessons, students learned about different ocean habitats and the ocean's role in weather and water cycling. They are at the beginning of the ocean ecology lessons.

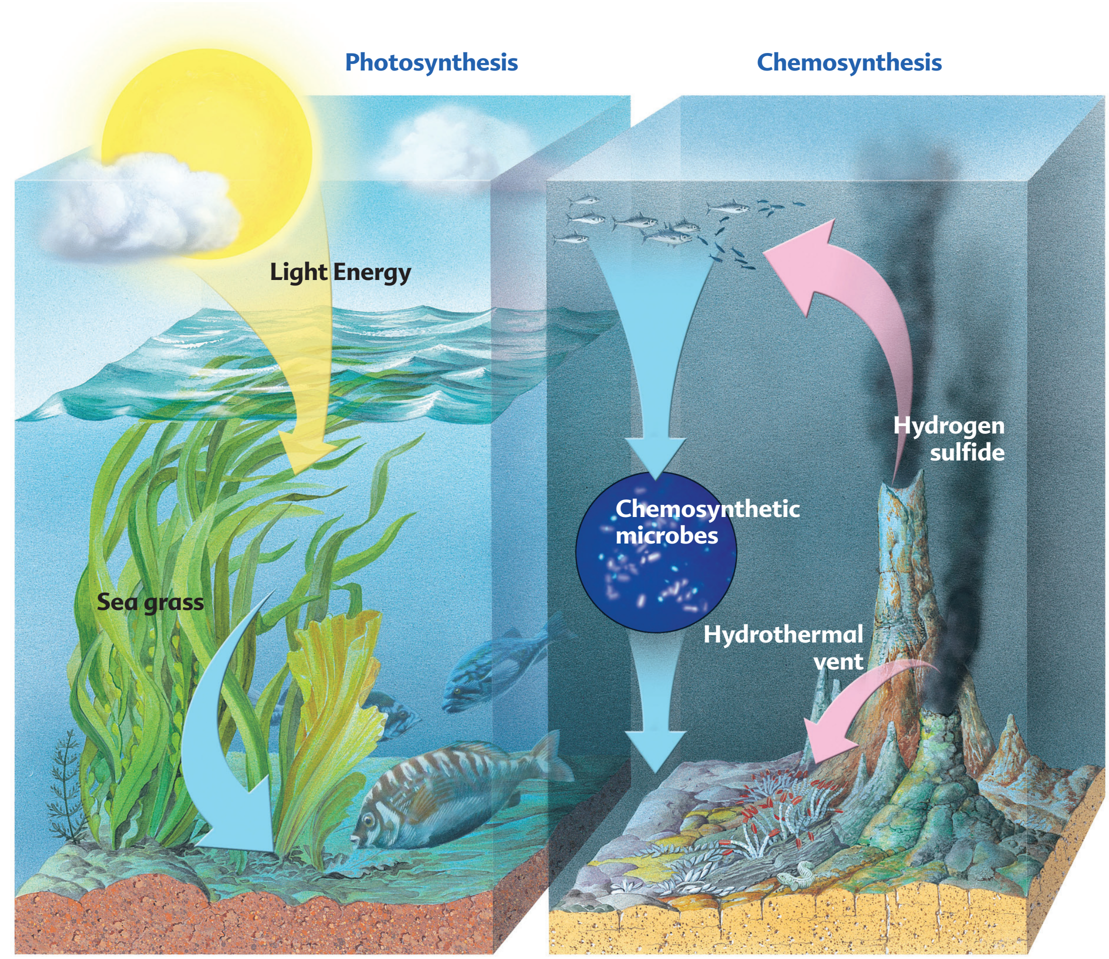
Video Analysis

The purpose of this video is to better understand the challenges students face as they learn about ocean biodiversity. The ocean contains a wealth of biodiversity, and most of this diversity lives in the sunlit area called the euphotic zone (see **Distribution of Life,** page 45, for more information). At the upper-elementary and middle-school levels, students should begin piecing together what they know about producers and food chains to what they learn about biodiversity. As students learn about the euphotic zone, Ms. Reimer hopes they will realize that the abundance of producers in this area gives rise to an abundance of consumers. Once students have listened to Ms. Reimer's lesson on the ocean zones, they make predictions about where they believe the most life would live in the ocean. As students discuss their ideas, they question whether more animals would be found in the euphotic zone or in the area just below it. By having students place stickers on a diagram of the ocean's zones, Ms. Reimer was able to gauge how many students understood the concept. During the class discussion, you hear Kate explain that "there would be the most plants up in the euphotic area because the sunlight is there so a lot of the primary consumers would live there to get a lot of the supplies that they need." An answer like this would reaffirm that students are understanding the concept of where life is found in the ocean. However, Leah and Reagan have remaining questions about *why* consumers *choose* to live in those areas, showing that they still have some gaps in their understanding of ocean ecology.

Reflect

How would you respond to these questions about ocean life?

In the post interviews, Reagan and Leah still had questions about where animals choose to live. Given these questions, how would you teach these concepts so that students understand that consumers must live near their food sources, even given the threats from humans or other factors? How would you explain clearly that animals live in all areas of the ocean while highlighting that the *most* biodiversity is found in the euphotic zone?

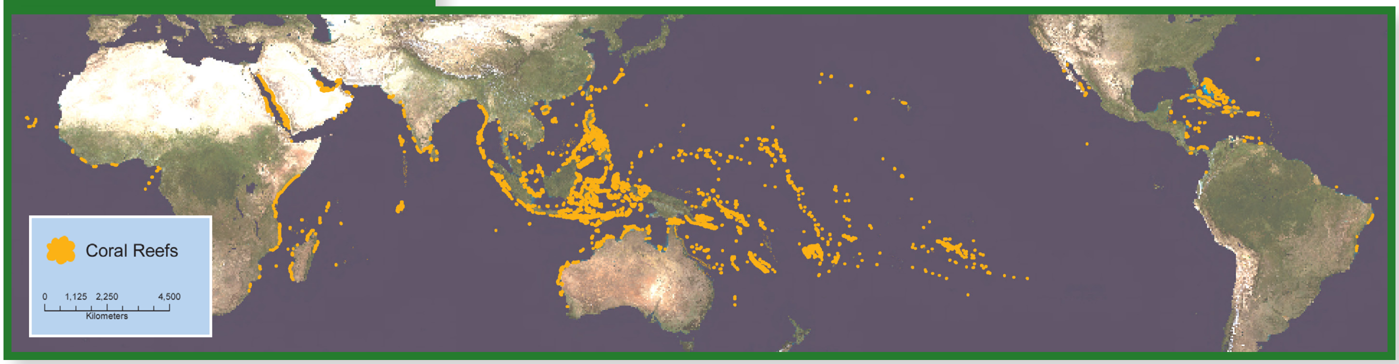


Photosynthesis is the process by which plants convert the sun's energy to produce food. Chemosynthesis is the process by which food is made using chemical energy, rather than sunlight, and occurs in the deep sea where sunlight is not present. These different ways of producing food shape the ecosystems that occur in the sunlight, twilight, and deep sea zones.

bacteria, are responsible for capturing the energy from the sun and turning it into a form of energy usable by most other organisms in the ocean. The photic zone is the portion of the ocean reached by sunlight and is made up of the euphotic zone and twilight zone. The euphotic zone includes the depths of the ocean exposed to enough light for photosynthesis to occur. If you have ever been underwater and looked up at the sky you probably saw the sunlight streaming through the water. As you get deeper, more light is filtered (reflected, refracted, and absorbed) by the water, and it gets darker and darker. The depth of the photic zone depends on how clear the water is, with clearer water having a deeper photic zone compared to water that is cloudier or murky. On average, light reaches 200 meters below the surface. At the bottom of the euphotic zone is the twilight zone, a zone where some light reaches, but no longer enough for plants to photosynthesize. Because producers, especially phytoplankton, are the base of the marine food chain, scientists currently think there is more biodiversity found in the euphotic zone than in other depths of the ocean, but as scientists continue to explore these depths, they discover new and exotic species.

Deep Ocean Life Most living organisms in the ocean rely on photosynthesis in the photic zone to sustain their food source. However, life in the deep ocean cannot directly rely on sunlight to provide a source of energy. Instead, creatures in the deep ocean have adapted to use other sources of food. When organisms in the ocean die, they sink to the bottom and decompose. We refer to this decomposed matter as **detritus.** Animals that eat detritus to survive are called detrivores. While detritus is a source of food for many organisms that live in the deep sea, many other deep-sea animals are predators on those detrivores. In some areas of the deep sea, organisms are able to create their own food by using chemicals to make sugars instead of using sunlight. This is called **chemosynthesis.** Archaea that live around deep-sea hydrothermal vents are an example of organisms that produce their food through chemosynthesis. These organisms are able to survive on the energy derived from chemical reactions involving hydrogen sulfide (H_2S) or methane (CH_4) produced by the hydrothermal vents.

CORAL REEFS OF THE WORLD



Coral reefs are found worldwide, but the largest reef is the Great Barrier Reef near the coast of Australia.

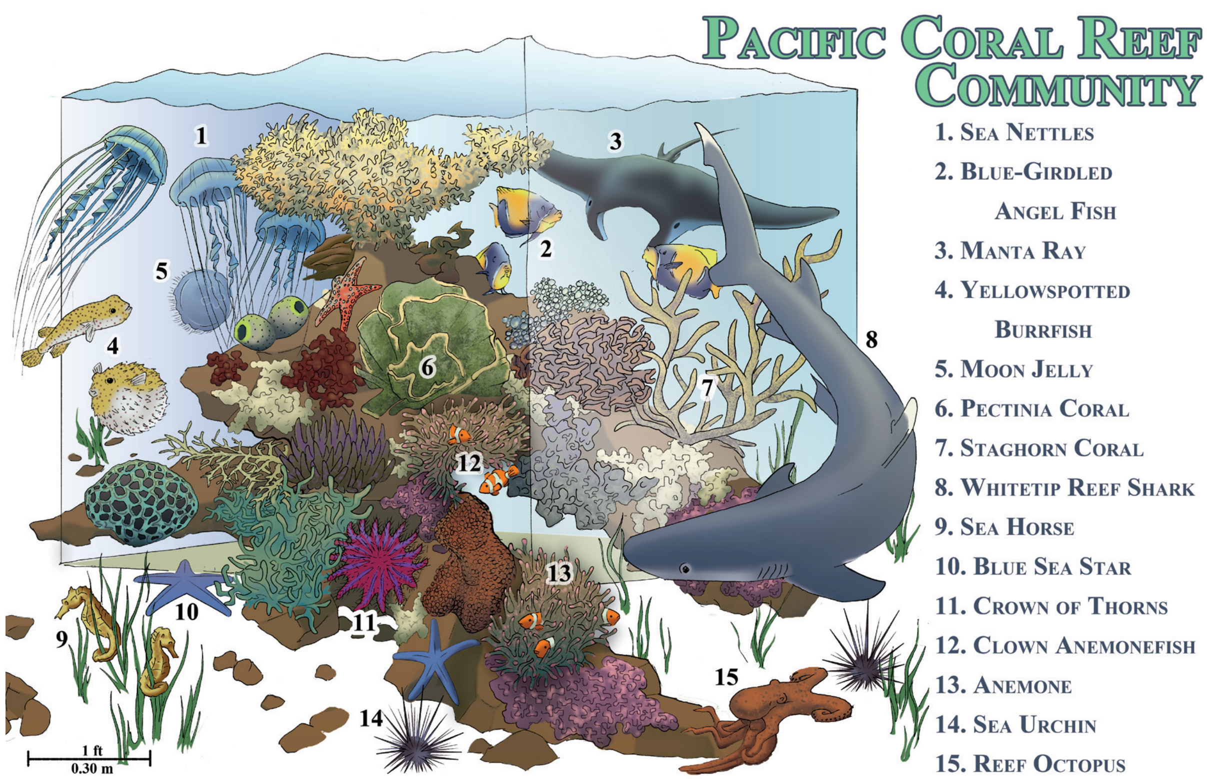
Marine Ecosystems and Ecosystem Diversity

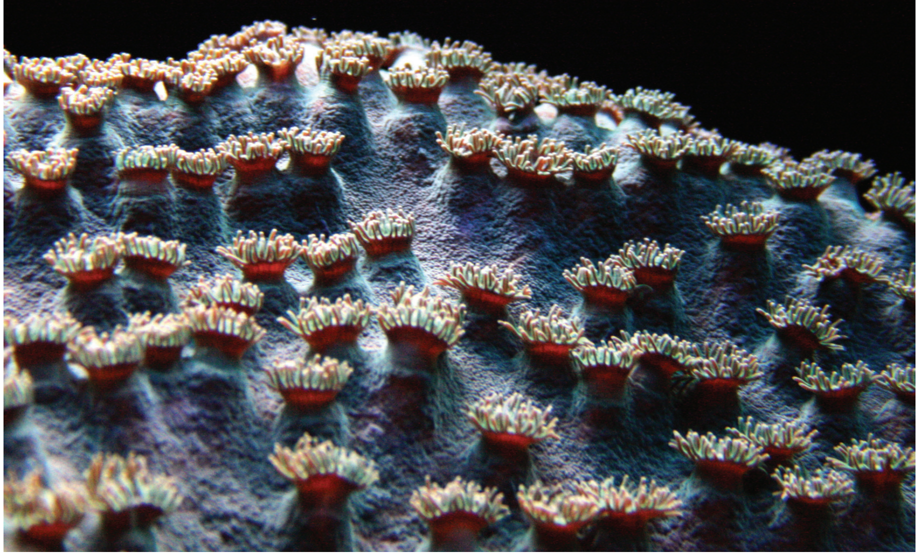
An ecosystem is composed of both the living organisms and the abiotic factors in an environment. The ocean contains many diverse and unique ecosystems. We will explore some of the ecosystems found in the ocean, including coral reefs, coastal shores (both rocky and sandy), mangrove forests and estuarine environments, kelp forests, and polar seas.

Coral Reefs

Most reef-building corals thrive in warm, clear, shallow water, and therefore, coral reefs are found primarily in coastal areas of the tropics and subtropics. Coral reefs are fragile and sensitive to temperature change in water. Stress caused by changes in water temperature, water chemistry, or other environmental parameters can impact the health of a reef—sometimes with fatal consequences. This stress can lead to corals expelling their colorful, **symbiotic** zooxanthellae (microscopic algae the corals host that provide them with food produced through photosynthesis in exchange for protection), leading to a change in color—a phenomenon known as **coral bleaching.** Corals can recover their zooxanthellae if the stress is removed. The following illustration shows the areas of the ocean where tropical coral reefs are found.

Corals come in many different shapes and sizes. Although many coral species may look like rocks, corals are actually animals! Coral polyps live in colonies





Colonies of coral polyps capture planktonic organisms from the water column with their tentacles.

and build the rocky structures in which they live. The structure that you see when thinking of coral is actually like a self-built apartment house. One coral may contain thousands of tiny coral polyps. If you look closely at a live coral (such as the one pictured above) you can see the tiny coral polyps (which look similar to sea anemones). The white structure that most people think of as coral is actually the skeleton left behind once the coral polyps have died. The structure of hard or stony corals is very important to the health of the reef. Without the reef-building corals, other organisms would not have a habitat in which to live and places to hide from predators.

Coral reefs are often compared to rain forests because of the diversity of the species that call them home. Some scientists estimate that 25 percent of the animals in the ocean live in coral reefs. Every **phylum** of animals in the ocean can be found in coral reefs.

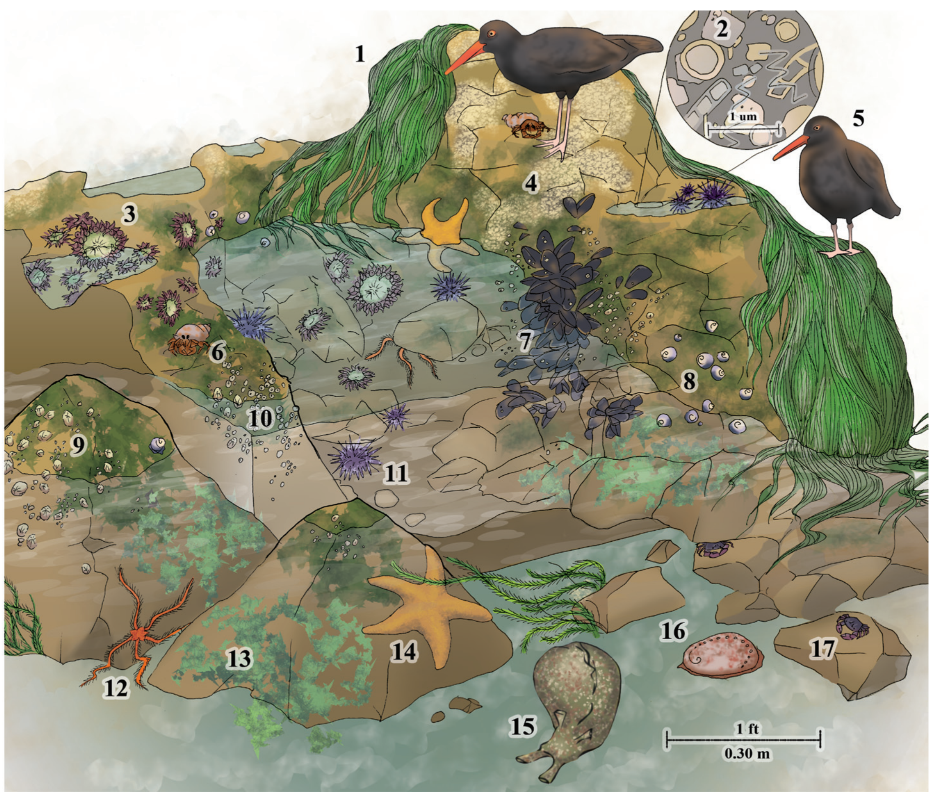
Coastal Shores

If you live near the ocean you have probably been to the shore. Whether rocky or sandy, the shores of the ocean share some characteristics with each other. The shore is a very harsh environment for species to live because it is constantly pounded by waves and covered and uncovered by tides. Next we will explore the unique characteristics of rocky and sandy shores and discover some of the species that call them home.

Rocky Shore. The rocky shore is a hard place to live. Plants and animals that call these environments home must have special adaptations for survival. Organisms must also be able to cope with frequent and rapid changes in abiotic factors such as salinity, pH, temperature, and oxygen availability. The rocky shore is frequently pounded by waves. Many organisms living there have also developed adaptations to attach or hold onto the rocks to prevent being washed away with the waves. These adaptations also help rocky-shore invertebrates survive predation when exposed at low tide. As the tides move in and out, the shore and its

Rocky Shore Community

1. Surf Grass
2. Plankton
3. Aggregating Anemone
4. Lichen
5. Black Oystercatcher
6. Hermit Crab
7. Mussels
8. Black Turban Snail
9. Limpet
10. Barnacles
11. Purple Sea Urchin
12. Brittle Star
13. Intertidal Algae
14. Ochre Sea Star
15. Sea Hare
16. Abalone
17. Striped Shore Crab

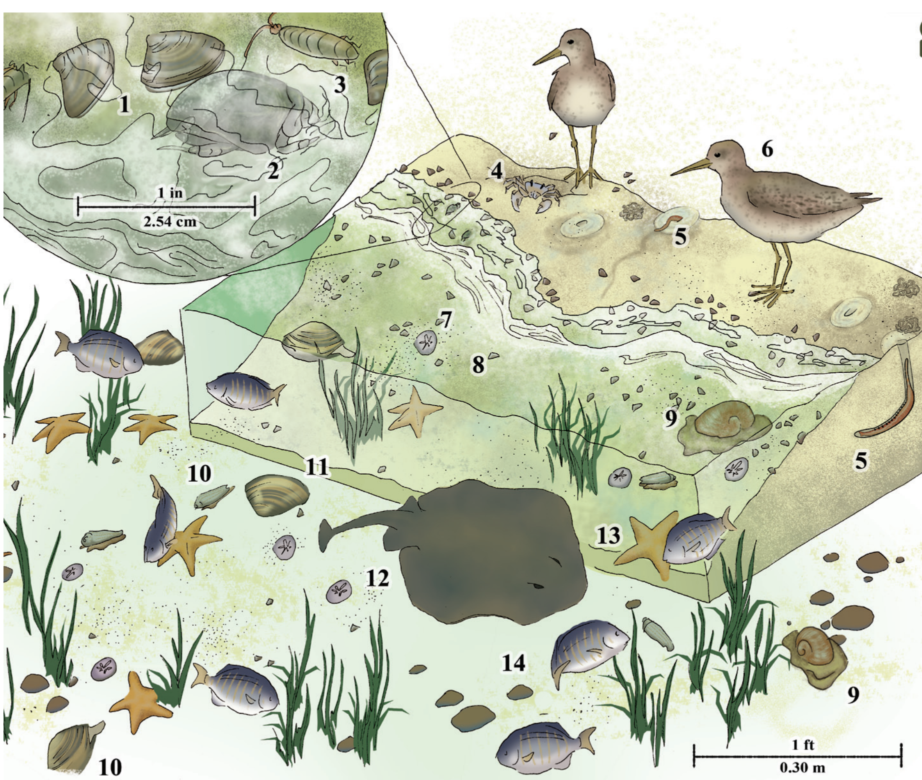


This tidal pool details the complex biodiversity of the ocean floor with colorful sea urchins, sea anemones, sea stars, and other organisms.

inhabitants are exposed to air. When the tide goes out, water is trapped in pools in the rocks, called tide pools. Tide pools provide an important habitat for animals living on the rocky shore that are not adapted for being exposed to air for long periods. Too much air and not enough water is not a good thing for most ocean organisms. At low tide, out of a tide pool, they risk desiccating, or drying out. Scientists often talk about the rocky shore by zones. Organisms that can withstand long periods of exposure to air and sun live in the splash and high-tide zones, while those that must be covered by water are found in the low-tide and submerged zones. The intertidal zone is sometimes called the littoral zone as well.

Some animals, such as mussels and barnacles, can close up tightly to reduce water loss. Because of their ability to conserve water, they can live in areas such as the supratidal zone, which experiences long periods of exposure to the air and sunlight. Other animals, such as sea urchins, can withstand a short period out of the water. These animals would be found in the intertidal zone or possibly in tide pools. Animals such as fish and nudibranchs (sometimes called sea slugs), however, must remain covered by the water to survive. These animals live in areas that are always submerged, such as deep tide pools or below the low-tide line in the subtidal zone. Still other animals, such as sea stars and whelks, can crawl back into the water if need be, giving them the freedom to move to various areas of the rocky shore. Seaweeds and other producers found on the rocky shore have similar restrictions. Algae such as sea lettuce that need to remain wet must live closer to the low-tide line. Varieties such as crustose, or coralline red algae that can handle exposure to sun and air, live higher on the rocky shore.

Sandy Shore. Most people, when they think of the beach, picture sandy shores where they can lay their towels



Sandy Shore Community

1. Shell of Bean Clam
2. Mole Sand Crab
3. California Beach Hopper
4. Ghost Crab
5. Lugworm
6. Western Sandpiper
7. Western Sand Dollar
8. Bean Clam (Donax)
9. Lewis' Moon Snail
10. Olive Snail
11. Pismo Clam
12. Round Stingray
13. Northern Pacific Sea Star
14. Barred Surfperch

Seaweeds such as kelp help to shape the diverse ecosystems found in the ocean.

out and relax for the day. When spending time at the beach students may be unaware of the life around them. At low tide, organisms burrow into the sand for protection from waves and to stay moist. When the water comes back at high tide, the organisms living in the sand may partially emerge to feed. High tide is beneficial to organisms because it brings with it increased oxygen levels and food sources from deeper areas. High tide also holds dangers for organisms buried in the sand. At high tide, animals such as stingrays have access to exposed invertebrates. Stingrays have strong jaws with flat teeth used to crush the shells of invertebrates, so they can eat them.

The sandy shore has zones it can be divided into, just like the rocky shore. The zone that is rarely exposed to water is called the supratidal zone. In this zone you will find animals such as beach hoppers, a shrimp-like species of amphipod that has the ability to easily move in and out of areas covered by water, depending on its need. The area that is covered and uncovered by water, depending on the tides and waves, is called the intertidal zone. In this zone, you will find animals, such as bean clams (*Donax*) and sand crabs, that can burrow into the sand when the tide is out. A great diversity of shorebirds visit the sandy shore to feast upon buried animals when the tide is out. The area of the sandy shore that is always covered by water is called the subtidal zone. In this area you will find small fish, stingrays, and sand dollars. These animals must remain submerged to survive.

Kelp Forests

Kelp forests are found in nutrient-rich, cold, clear water usually on the western coasts of continents. This is because of the direction ocean currents transport cool water. Cold water from the polar seas moves toward the west coasts, while the eastern coasts of continents receive warm water from the Equator. This cold water supports an important

Kelp Forest Community

1. Norris Top Snail
2. California Sheephead
3. Giant Kelpfish
4. Sea Mussels
5. Sea Otter
6. Giant Kelp
7. Kelp Bass
8. Rockfish
9. Garibaldi Fish
10. Pacific Jack Mackerel
11. California Sea Lion
12. Brittle Star
13. Red Algae
14. Abalone
15. Sea Urchin
16. Sunflower Sea Star
17. Sea Hare
18. Polychaete Worm

and fascinating ecosystem. Additionally, upwelling of nutrient-rich waters often occurs on the western coast of continents. Kelp is dependent upon those nutrients to thrive. One of the places kelp forests can be found is along the coast of California.

Kelp is the term used for large brown algae, a type that is commonly referred to as seaweed. Kelp is known for its size. Some species of kelp can reach 80 meters (~262 feet) in length and grow as fast as half a meter (1.5 feet) a day! Kelp is attached to the rocky sea floor by its holdfast (the holdfast resembles the roots of land plants but does not provide nutrients to the kelp the way roots would to land plants). Kelp can only grow in places where it can attach to a hard surface, such as rocks. It will grow as deep as light is available to photosynthesize. Some species of kelp float vertically in the water column due to their air-filled bladders known as pneumatocysts, giving the kelp a forest-like feel when viewed underwater.

The canopy created by massive kelp blades provides a rich habitat for other species to live. Underneath the canopy of kelp, sunlight dapples through, creating many shadows. This does not bother the animals that live there. Animals, such as the so-called lace animals known by scientists as bryozoans, polychaete worms, small crustaceans, brittle stars, and other invertebrates can be found attached to the kelp and the holdfast. Many invertebrates can be found on the rocks near the kelp. It is common to find diverse species of fish swimming among its blades. Fish found in the California kelp forests include garibaldi (California's marine state fish), California sheephead, and kelp bass. Sea lions and sea otters are also common visitors to kelp forests, feeding on the fish and invertebrates found there. Although many animals use the kelp forest as habitat, many other species of algae find a home there as well. Smaller species of kelp exploit the area between larger species, and hardy species such as shorter red algae can live in patches of diffuse sunlight.

Estuaries

Estuaries are unique ecosystems that form where rivers meet the ocean. When this happens, you have mixing of the freshwater from the river with the salt water of the ocean. Environmental conditions may fluctuate widely in estuaries due to changes in tides and the flow of rivers. Such fluctuations can cause changes in salinity and water temperature. Species that live in estuaries must be adapted to deal with these changes. Despite harsh conditions, estuaries have large amounts of primary production, or photosynthesis. One reason estuaries have high productivity is that the water is shallow and exposed to lots of sun. Another reason estuaries are highly productive is due to runoff from land that contains nitrogen, phosphorus, and silica—essentially, fertilizers. There are different types of estuaries, including mud flats, oyster beds, salt marshes, sea-grass communities, and mangrove forests.

Species diversity is not as great in estuaries as in other near-shore habitats. Because of the harsh, often dynamic, conditions that animals must tolerate to survive in estuaries, competition is limited, and populations of species can grow very large. The animals that are adapted to live in estuaries tend to be generalists, feeding on a variety of foods, depending upon what is available. The plants and animals that live in estuaries have specialized ways of dealing with the fluctuating salinity levels. For example, cordgrass is able to excrete excess salt through specialized glands in its leaves.

Estuaries are often referred to as the nurseries of the ocean. Small fish are protected in estuaries because the water is shallow. Often these small fish are flushed in and out of the estuary by tides every day. The shallow water prohibits larger species from entering the estuary to feed on juveniles. Although larger ocean animals cannot feed on animals living in estuaries, birds and humans can. Estuaries are an essential habitat for more than 75 percent of America's commercial fish catch. These animals include species of oysters, crabs, and scallops, as wells as

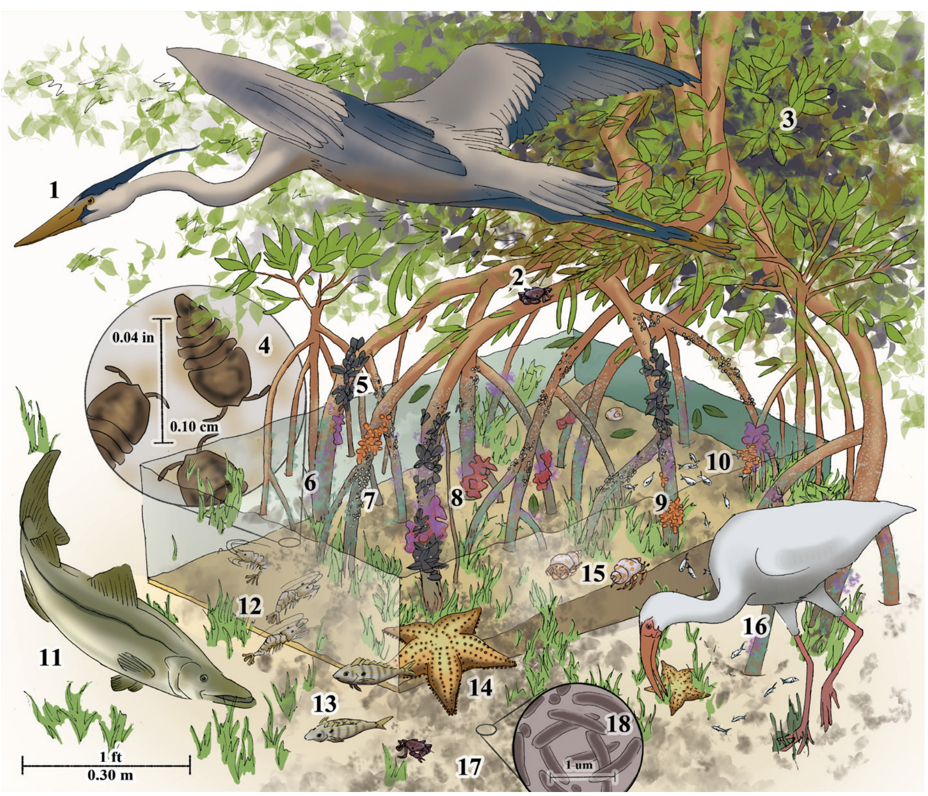
Smooth cordgrass is the dominant grass species found growing along tidal salt marshes of the Gulf and Atlantic coasts.

fish such as flounder, bluefish, striped bass, and herring.

Mangrove Forests. As mentioned on page 52, mangrove forests can occur in estuaries, although they are not limited to these areas. In some tropical and subtropical parts of the world, mangrove forests cover 60–75 percent of the coastline. *Mangrove* is a term that can be applied to those trees and shrubs that are unique because they are land plants that have adapted to living in brackish estuary waters or even to the saltier ocean environment. More specifically, *mangrove* can refer to a member of the genus *Rhizophora*. While all Rhizophorans are mangroves, not all mangroves are Rhizophorans. Living along the coast, many species of mangroves are immersed in saltwater at high tide. Just like the cordgrass discussed previously, some mangroves are able to excrete excess salt; other species are able to prevent it from ever entering the plant. Different species of mangroves have varying tolerances to salinity based on their mechanism of salt removal. This creates zonation of the species of mangroves, with some species living closer to terrestrial environments while others live closer to intertidal areas.

From its canopies to its submerged roots, the unique habitat of the mangrove community allows many plant and animal species to thrive there.

Mangroves are very important to coastal areas for a few reasons. First, the tangled roots of mangroves can help to hold sediment in place, preventing erosion, and even building land as sediment and detritus accumulate among the roots of the trees. In some parts of the globe, coastal mangrove forests, also known as mangals, have been destroyed. Eroded sediment from the shore has washed out over nearby coral reefs, smothering them. Second, mangroves provide habitat for small species such as juvenile fish, crabs, sponges, and oysters. These species often find protection among the roots of the mangrove, as can be seen in the picture above. Mangroves can also protect land from the destructive forces of storms, hurricanes, and even tsunamis as their



Mangrove Community

1. Great Blue Heron
2. Mangrove Crab
3. Red Mangrove
4. Copepod
5. Oysters
6. Algae
7. Barnacles
8. Sponges
9. Mangrove Tunicate
10. Silver Jenny
11. Common Snook
12. Grass Shrimp
13. Pinfish
14. Cushion Sea Star
15. Hermit Crab
16. White Ibis
17. Detritus
18. Bacteria

extensive root systems retain sediment, which can absorb flood waters.

Polar Seas

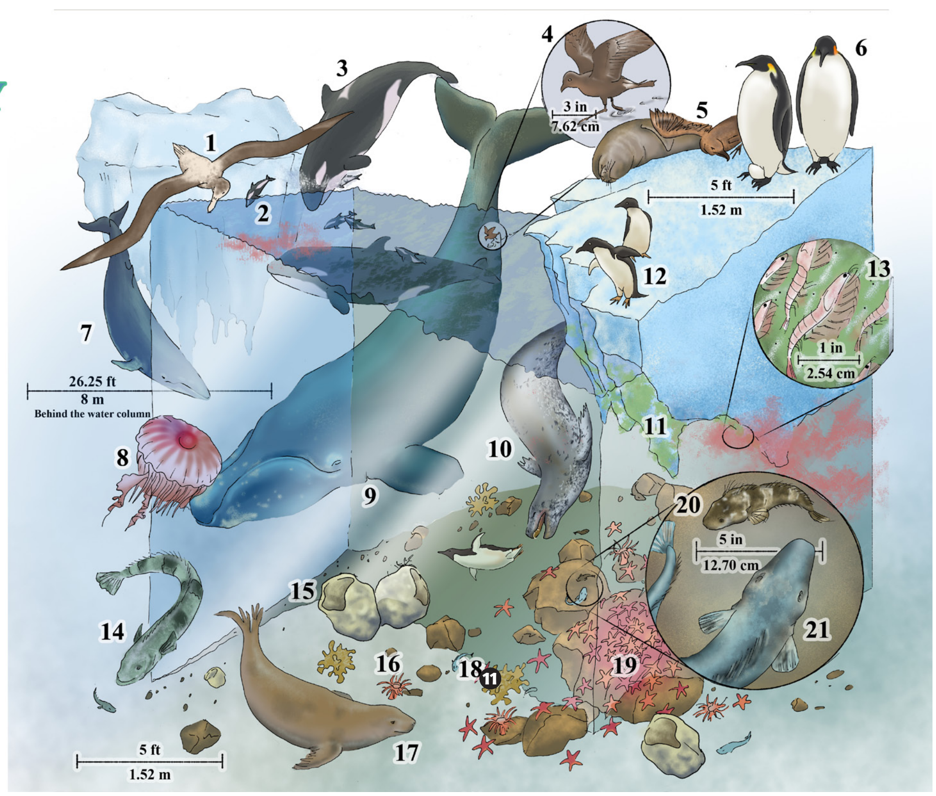
The polar seas are made of the Arctic Ocean Basin in the Northern Hemisphere and the ocean waters that surround Antarctica in the Southern Hemisphere. Although both polar seas share some similar characteristics, they are not exactly the same. The Arctic Ocean Basin is surrounded by land and is covered by ice in the winter. In the summer, the amount of ice decreases to cover less than half of the ocean surface. Antarctica, on the other hand, is a continent covered by a thick layer of ice (almost 90 percent of the world's ice is found here, containing almost 70 percent of the world's freshwater), surrounded by ice shelves, sea ice and icebergs. Both of these seas are rich in nutrients. However, the waters around Antarctica are colder and more nutrient-rich than the Arctic Ocean Basin.

Polar bears and penguins are the two iconic animals that students think of when imagining polar seas. Students sometimes think that polar bears eat penguins. This could never happen because they live on opposite ends of the Earth! Both polar seas are distinct ecosystems with unique food webs. Although the killer whale is at the top of the food web in both of these polar seas, and phytoplankton and ice algae are at the bottom, the species in between are distinctly different. The Arctic Ocean Basin is rich with life such as puffins, murres, auklets, walrus, beluga whales, narwhals, polar bears, and sea jellies, including the lion's mane jelly. This jelly is one of the world's largest, with a bell size of more than 1.8 meters (6 feet) in diameter and tentacles of more than 30 meters (100 feet). Antarctica, on the other hand, is home to krill, squid, cod, albatrosses, skuas, penguins, crabeater seals, Weddell seals, and leopard seals (the world's only seal that eats other mammals). Whales such as humpbacks, fin, blue, and sperm whales are found in

Antarctic penguins and Arctic polar bears are part of the unique ecosystems that exist at opposite poles of Earth.

Antarctic Community

1. Wandering Albatross
2. Hourglass Dolphin
3. Orca Whale
4. Wilson's Storm Petrel
5. Antarctic Skua
6. Emperor Penguin
7. Common Minke Whale
8. Jellyfish
9. Southern Right Whale
10. Leopard Seal
11. Algae Mat
12. Adelie Penguin
13. Antarctic Krill
14. Antarctic Cod
15. Volcano Sponge
16. Anemone
17. Crabeater Seal
18. Octocoral
19. Red Sea Star
20. Antarctic Spiny Plunder Fish
21. Black-finned Ice Fish



Case Study Spotlight on Plankton

Plankton are organisms in the ocean that drift with the currents. In fact, *plankton* is Greek for “drifter,” or “wanderer.” Usually people associate plankton with small life in the ocean. Although most plankton are tiny, some are much larger. For example, sea jellies that drift with the currents can reach lengths of 30 meters (100 feet) or more!

There are two major types of plankton: phytoplankton and zooplankton. Both are essential to the marine food web. Phytoplankton are microscopic organisms that photosynthesize in a way similar to the terrestrial plants we live with everyday. A common misconception by students is that oxygen is only produced by trees. This is not true—at least half the oxygen we breathe is produced by phytoplankton in the ocean. Zooplankton are animals and animal-like organisms that cannot swim against the ocean current. Many are microscopic or larval animals. Shrimp, crab, and fish larva start out as zooplankton. Once they settle to the bottom to metamorphose into their adult stage or are large enough to swim against a current, they are no longer considered plankton. Other animals, such as krill and sea jellies, remain plankton their entire lives. Krill are small shrimplike marine invertebrates that are found throughout the ocean and perhaps are best known for being a critical food source for baleen whales.

Both phytoplankton and zooplankton play a vital role in the food chain of the ocean. Phytoplankton are primary producers and responsible for capturing the energy of the sun and turning it into a form of energy that other organisms in the ocean can use. Zooplankton are also very important, serving as food for many organisms in the ocean. In fact, the largest animal known to science, the blue whale, reaches its 100-foot (30 m) length on a diet made almost entirely of planktonic krill.

Sea surface temperature, surface currents, salinity, wind, and waves influence plankton. Changes in these abiotic characteristics influence movements of plankton and, thus, movements of larger animals in the ocean. These changes influence the ocean’s


Phytoplankton


Zooplankton

patterns of biodiversity. For example, an increase in sunlight or nutrients will often lead to an increase in the numbers of phytoplankton, a phenomenon known as a plankton bloom. When the phytoplankton bloom, the zooplankton that prey upon them often experience population growth. This growth can lead to an abundance of food and increased survival for small fish, which can in turn support larger fish. Indeed, this increased abundance of phytoplankton can result in more food at every trophic level, including apex marine predators such as sea lions, sharks, dolphins, and pelicans. From this example, you can see how important plankton is to the biodiversity of an ecosystem. On the other hand, sometimes these plankton blooms can also result in **harmful algal blooms** (HABs). These HABs are often caused by fertilizer and chemical runoff into the ocean, which results in an increase in nutrients for phytoplankton and other algae. One result from HABs is the release of toxins that lead to paralytic shellfish poisoning (PSP), which is toxic to both ocean organisms and humans that consume them.

Student Thinking

Animal Life in the Ocean

When considering life in the ocean, students usually think about sharks, whales, sea turtles, sea jellies, and fish, overlooking other organisms, including those, such as plankton, that they cannot see. Students' ideas of what animals look like is based upon their experiences with animals on land. Animals such as sponges, corals, and sea jellies are less familiar—it's difficult for students to identify them as alive when they don't move or have recognizable features. Students may also characterize species as good or bad. For example, students may think sharks are scary or mean. The reality is that all organisms play a role in the ocean ecosystem. For example, as predators sharks play a vital role in the overall health of ecosystems by helping to clean the ocean, often feeding on animals that are already sick or injured. Students may also personify communities in the ecosystem and explain relationships and conflict in ways that apply to human communities.

Common Student Ideas	Scientific Concepts
Animals choose whether they will be a predator or prey.	All animals are adapted to fill a particular niche and eat specific food. Mouth shape, tooth shape, and many other physiological factors contribute to what an animal *can* eat. Very few animals can change what they eat or how they search/hunt for that item. They either eat what they have evolved to eat, or they adapt to eat different food.
Coral and sea anemone are plants or rocks found in the ocean.	Coral are actually animal species that play a vital role in the food chain and also create habitats for other organisms.
Phytoplankton, and small animals, are not as important as larger organisms in the ocean.	Phytoplankton and zooplankton play one of the most essential roles in marine food webs. They serve as the base of the food web. Bacteria are also critical recyclers of ocean nutrients. See **Spotlight on Plankton,** page 55.
Land-based ecosystems have higher biodiversity and productivity.	Marine ecosystems contain more species and genetic diversity than most land ecosystems. Coral reefs and estuaries are some of the most productive ecosystems on Earth.

Ask Your Students

1. Are there good and bad animals in the ocean?
2. How does an animal become a predator or prey?
3. Are coral and sea anemone plants or animals?
4. What is the role of phytoplankton in the ocean? Do they impact large animals such as whales?
5. What has a higher biodiversity: land-based ecosystems or marine ecosystems?

the polar seas of both the Arctic and the Antarctic.

Natural Processes That Influence Biodiversity

The biodiversity of ecosystems is both sustained and changed through natural processes such as genetic mutation, predation, and natural selection. These processes are continually occurring, resulting in continuous changes to biodiversity. We will examine these processes in more detail and the barriers students may have as they learn about these processes. We use Wilson et al. (2007) framework for characterizing different biodiversity processes.

Processes That Generate Biodiversity. One way that biodiversity can increase is through genetic mutation. All individuals within a species have similar DNA. A genetic mutation is a change in a part of the DNA of an individual, resulting in a change to an inheritable gene. This change could make no difference to the organism, or it could result in an advantage or disadvantage for the organism. If it results in a disadvantage, the organism likely won't survive, and the new gene won't be passed on. If the gene mutation provides the organism with an advantage over other individuals of the same species, the organism will likely reproduce, thus, passing on the mutated gene to its offspring. Over generations, individuals within the population that have this mutated gene (and, thus, an advantageous trait) will become more common. Over time, this can result in the evolution of a new species that is distinctly different from the old species.

An example of genetic mutation can be seen in a group of fish who inhabit the waters around Antarctica. These fish belong to the family **Notothenioidei.** All fish are **poikilothermic** (poikilos = varied, thermic = related to temperature), which is often referred

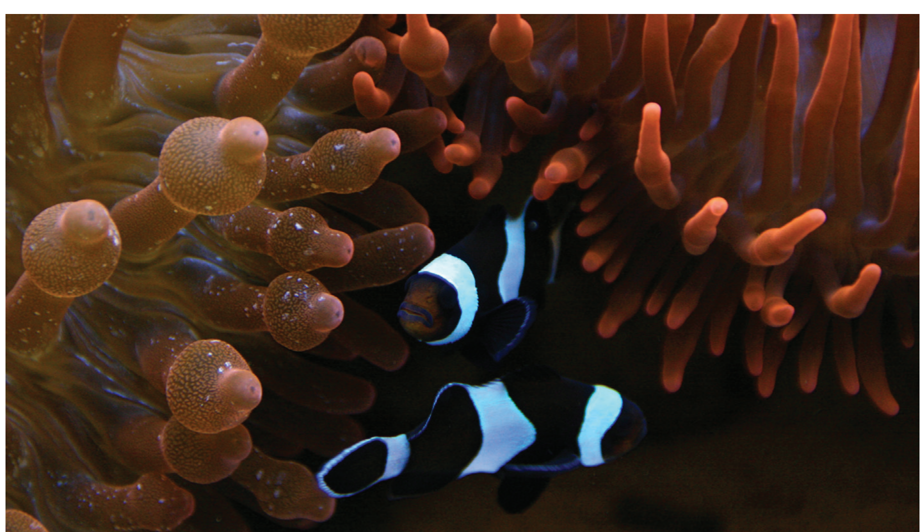
The coconut is the most common drift fruit found in the ocean.

to as cold-blooded. They do not use energy to keep their bodies (and blood) at a specific temperature, resulting in their body being the same temperature as the water they are swimming in. As a result, many fish can't survive in the frigid waters around Antarctica. However, many Notothenioids, or ice-fish as they are commonly called, have special glycoproteins in their blood that work as antifreeze within their body, allowing them to live in water with temperatures as low as −2°C (28°F), below freezing.

Another way that biodiversity can increase is through **colonization** by new species. One example of this is drift seeds. Drift seeds have thick woody seed coats and internal air-filled cavities. The air cavity allows them to float on water. These seeds take advantage of the ocean and its processes (i.e., tides and currents) as a form of transportation. A coconut is an example of a drift seed. When a coconut is washed onto a new beach and grows into a coconut palm, it may be the first of its species to grow in that location, thus increasing biodiversity.

Processes That Sustain Biodiversity. Biodiversity can be sustained across species in numerous ways. One way species sustain their population is though reproduction. As long as all species within an ecosystem continue to reproduce at their current rates, biodiversity will remain unchanged. There are two different ways that species can reproduce—sexually and asexually. Many marine organisms have the ability to reproduce both sexually and asexually. One common example is the sea anemone. Sea anemones spend most of their lives attached to the same rock, making sexual reproduction tricky. To reproduce sexually, males release sperm into the water. This stimulates the females that are nearby to release eggs. With luck, the sperm and eggs meet in the water column and fertilization occurs. A fertilized egg develops and eventually settles onto a rock and grows into a single polyp. As this type of reproduction, known as broadcast spawning, has a high rate of failure, sea anemones maximize their proliferation potential by reproducing asexually as well. Sea anemones can reproduce asexually by producing buds like the ones

Clown fish utilize their symbiotic relationship with sea anemone to protect themselves from predators.



seen on the sea anemone in the following picture. These buds eventually separate, becoming their own organism, living separately from the parent anemone.

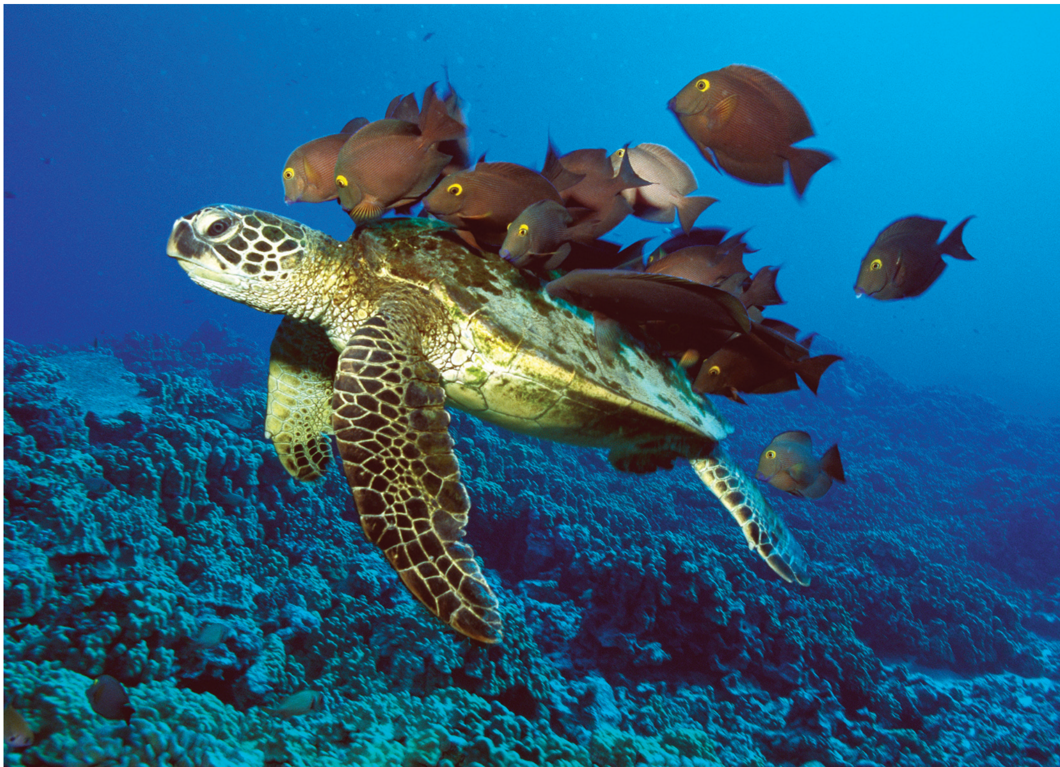
Reproduction is not the only way that biodiversity can be sustained. Although it may seem counterintuitive, predator-prey relationships also help sustain biodiversity. A great example of this is the relationship between sea otters and sea urchins. Both sea otters and sea urchins inhabit kelp forests near the coast of northern California. Sea urchins are a popular source of food for sea otters. When sea otter populations decrease, the population of sea urchins in the kelp forest increase. Without predation by sea otters, sea urchin populations grow rapidly. Sea urchins feed on kelp. If the sea urchin population continues to grow unchecked, it results in a drastic reduction of the kelp forest. Without the kelp forest, the overall biodiversity of the coastline is reduced. The sea otter population is essential to the biodiversity of California kelp forests. Because of the important role they play in this ecosystem, sea otters are referred to as keystone species. Just as an arch would collapse without the keystone (the stone at the top of the arch), the biodiversity of an ecosystem collapses without its keystone species.

Symbiosis is another process that sustains biodiversity. Symbiosis is when two species live together in such a way that each species is affected. Some symbiotic relationships benefit both organisms, and are known as **mutualism;** some benefit one organism while the other is harmed, known as **parasitism;** and some benefit one organism while the other is neither harmed nor benefitted, which is known as **commensalism.** A mutualistic relationship that many are familiar with is that of the sea anemone and clownfish. Sea anemones have stinging cells that serve as protection from predators. Clownfish have a mucus coating that protects them from being stung. The sea anemone provides a habitat and protection for the clownfish and its eggs, while the clownfish cleans food scraps and algae from the anemone, reducing its chances of developing an infection. The clownfish also provides better water circulation to the anemone. As the clownfish swims around, it fans the anemone with its fins. In this mutualistic relationship, sea anemones are protecting the clownfish, which are in turn protecting the anemone. In this case, the symbiotic relationship between the sea anemone and the clownfish sustains biodiversity. Without the relationship described, these two species may not be able to fend for themselves, leading to extinction and the reduction of biodiversity.

Processes That Reduce Biodiversity. Extinction is one process that reduces biodiversity. Although we often hear extinction discussed in relation to human influences, species become **extinct** through natural processes as well. In fact, more than 99 percent of the species that have ever existed on Earth are extinct today. Natural causes of extinction include drought, natural climate changes, asteroid impacts, and spread of disease. In addition to environmental changes that can cause extinction, reduction in biodiversity can also take place though the process of natural selection. Natural selection acts on traits that are inherited.

Within an ecosystem each different species takes a position, or a niche. If two species inhabit the same environment in a similar way and eat the same resources, they are considered to be in the same niche. This niche sharing is fine as long as there is enough food to support both populations. If the populations grow too large, they will run out of resources. When two species are fighting for the same resources, the result is competition. Competition can have two outcomes. If there is enough variation between the two species competing for the niche, each may adapt and start to occupy different niches. If there is not enough genetic variation to permit coexistence, one species will overcome the other, which will, in turn, become extinct and result in reduced biodiversity. This is natural selection in action. Competition is commonly seen in tide-pool ecosystems in which space and resources are limited.

The image shows a symbiotic relationship between the fish and the sea turtle. How do you think each of these species benefits from this relationship?



Pictures of Practice

Marine Food Webs

Food chains are relatively easy concepts for students to understand. They show linear, one-way relationships between organisms within a given ecosystem. Students learn to explain food chains as connections between living things that need food. Students, however, may not know that arrows in food chains represent the flow of matter and energy to the next trophic level. Another potential challenge is that students are taught about food chains with land-based plants and animals as examples. The plant grows, a deer eats the plant, and a wolf eats the deer. But what does the food chain look like in the ocean? Additionally, feeding relationships between organisms are much more complicated than simple food chains, especially as shown in food webs.

Students: Grade 5

Location: Laguna Niguel, California (a coastal community)

Goal of Video: The purpose of watching this video is to see examples of ways students describe differences between food webs and food chains in the ocean.

Classroom Context

In this video you will see Ms. Reimer teach her students about the differences between food chains and food webs. Previously, students learned about food chains, using the rhyme "a food chain shows how the energy flows." This concept was meant to solidify to students the understanding that animals eat in order to get energy. Students are now moving from the food-chain concept to the food-web concept in the context of an ocean ecosystem.

Video Analysis

Food chains are depictions of relationships in a community that simplify the predator-prey relationship and the flow of food. Food webs are representations that show much more complex feeding relationships in a community. At this grade level students should learn that food webs, while more complicated, are actually more realistic ways to describe how living things get energy in an ecosystem. Higher-level consumers eat multiple food sources, so food chains are a limited way to describe that. Ms. Reimer uses animal cut-outs to help students visualize a marine food web. Right away one student guesses a food web is the term used for how food in the ocean gets to humans. Leah then demonstrates she understands the concept a bit better by describing how multiple fish might eat the phytoplankton and that the food chain "spreads out" instead of being in a line. A good analogy is made by one of her group members as he equates a food web to a spider web that "goes everywhere," and not like a chain that stays in one line. Once the whole-class discussion begins, Cameron's group shares an interesting misconception—explaining to the class that food webs are underwater, while food chains are on land. Ms. Reimer is eventually able to steer the class discussion to the concept that a food web shows more choices than a food chain. This leads to a key scientific concept that food webs show energy and biomass following many different paths in an ecosystem and not only one path as in food chains. Yet, in the post interviews students have remaining questions.

Reflect

How would you respond to misconceptions about food webs?

While two students demonstrated an understanding of food webs, Reagan still confides that understanding the difference between a food web and food chain is difficult. How would you ensure that students understood that food webs are useful representations to multiple paths of energy and biomass in a system?

Student Thinking

Ecosystem Dynamics and Invasive Species

Students have trouble understanding how the dynamics of food webs can change, especially with the introduction of new species. Explicitly talking about food webs and presenting examples of changes to food webs may help to alleviate some of the confusion. However, students also need to have a good understanding of community relationships and how new species potentially interrupt these relationships.

Scenario

You have just asked your students to brainstorm what might happen if an organism is removed or another organism is introduced into an ecosystem. Specifically, the idea of a lionfish being introduced into a coral reef is discussed as an example. As students discuss this situation, many are confused about how invasive species can interrupt an ecosystem. Following are specific answers given by students during the brainstorm.

Question

What will happen when a lionfish is introduced into a new ecosystem such as a coral reef?

Scientific Answer

Lionfish have been introduced into nonnative waters and flourished because they have no natural predators in their new habitats. It, in turn, threatens the wildlife traditionally found in those ecosystems and is known as an **invasive species.**

Student Answers

CJ: If this fish hadn't lived on this reef before I think it might have trouble living there because it's used to different climate and different kind of water, different kind of living.

Leah: It's probably a predator and if too many of these fish came it would kind of eat all the other fish I believe, and so there wouldn't be enough fish to make the food chain be balanced.

Reagan: The other fish could be attacked or would just want to go away because they might not be very tasty fish to the predators.

Alison: It would attack all of the other fish because it's not used to it and the smaller fish aren't used to the larger fish. And so it might create some conflict, and then all of the species of fish might die off.

Jacob: I'd say it's going to die within a couple of, within however long it takes a fish to starve because I don't think that's going to catch much prey.

Morgan: I think they just interact with one group, keeping to itself while the other group keeps to itself.

What Would You Do?

1. Which student had the most sophisticated answer in the brainstorm? Which would you say was the least?
2. How would you proceed with a follow up whole-group discussion given ideas shared in the brainstorm?

Case Study

Loggerhead Sea Turtle

People often think of ecosystems and the animals within them as separate from other ecosystems. The reality is that many ocean animals are migratory. Throughout the course of their lives, these migratory species will interact with a number of different ecosystems as they travel across the seas.

Sea turtles are migratory species that interact with a diverse array of marine plants and animals. There are seven species of sea turtle found all over the world, and females of all species return to the same beach that they hatched on to lay their own eggs.

One particular population of loggerhead sea turtles hatches their eggs on the coast of Japan. Some of the turtles ride a large ocean current that takes them to feeding grounds about 12,000 kilometers (7,456 miles) away, in Baja California, Mexico.

Loggerheads have adapted their diet to the long journey. They usually eat bottom-dwelling invertebrates such as clams, mussels, crabs, and shrimp. Because bottom-dwelling organisms are not readily available as loggerheads journey across the open ocean, the turtles shift their diet, eating jellies, squid, floating egg clusters, and other surface-dwelling invertebrates.

Loggerhead migrations can take them through the Great Pacific Garbage Patch, an area in the Pacific Ocean where debris collects near the ocean surface. The turtles frequently ingest plastic bags and popped balloons floating in the garbage patch—they mistake these materials for their gelatinous prey.

While in the open ocean, loggerheads are susceptible to predators such as sharks. However, humans are their greatest threat, says Jeffrey Seminoff, program leader at the NOAA Fisheries Science Center's Marine Turtle and Assessment Program in La Jolla, California.

The turtles' interactions with marine fisheries are particularly dangerous, Seminoff says, "whether it is longlines or drift nets."

"Certainly with the loggerheads in the north Pacific, they are transitioning through a lot of habitats that have some pretty intense fishing pressures," he says. "Once they get into coastal habitats, there are threats of direct harvest. There are a number of countries throughout the Pacific Rim nations that still do harvest sea turtles, whether it's illegal or not."

This loggerhead turtle will travel thousands of miles in its 50 years or more.

Longlines are fishing lines that can be kilometers long and include hundreds, if not thousands, of baited hooks. Large fisheries that use longlines and gill nets are located in the loggerheads' migratory route off the west coast of North America. The sea turtles often become tangled in these gill nets or mistake the longline bait for food. The fishing equipment is often unattended, and the result is usually the drowning of trapped turtles.

Seminoff says fishermen and conservationists are attempting to reduce the unintentional capture of turtles in the Pacific. Strategies include changing the shape of hooks and attaching a device to the end of a trawl net that allows turtles to escape if they are caught.

"It's important, I think, to note that while the fisheries' bycatch is one of the biggest conservation challenges, there is also a cadre of scientists and conservation practitioners throughout the world that are trying to mitigate those impacts through creating these technological fixes to gear," Seminoff says.

A closer look at the journey of the loggerhead sea turtle reveals just how many of the world's ecosystems are connected. It also shows how nations must work together to conserve migrating species like the loggerhead.

"I think sea turtles in general, whether it's a loggerhead or any of the other species, really underscore habitat connectivity in the oceans...and really, from a conservation standpoint, it underscores the need for multinational cooperation when we are trying to conserve sea turtles," Seminoff says. "One nation can't solve all the problems."

In the Classroom Massive Migrations

Students may know about migrations made by land animals such as birds or butterflies because they are easy to see or because these animals may migrate through their communities. They may not, however, be aware of the vast migratory patterns and ranges of ocean animals such as whales, sea turtles, sharks, or even plankton. Migration is a behavioral adaptation that allows organisms to take advantage of favorable environmental conditions. For example, gray whales, an iconic species in California, use the warm, shallow waters near the Baja peninsula of Mexico as a birthing ground for their young. During the winter, this environment is a perfect place for nursing calves to grow. As the seasons change, the whales make their way north toward Alaska, to areas that include the Bering and Chukchi seas. The cold, nutrient-rich waters and long hours of daylight support a robust food web, including many species of whale. Like gray whales, the blue whale travels to colder regions to feed but to warmer waters to give birth. Blue whales recently began to reestablish historical migration routes to the Pacific northwest (NOAA 2009). Due to commercial whaling practices during the previous centuries, whale population numbers declined and migration routes were altered. Many whale populations have rebounded, like the California gray whale, but scientists are still studying whether whales are reestablishing their original migration routes.

Land and Ocean Migration. Have students explore why animals migrate by looking at examples they are familiar with, such as birds and butterflies (http://www.learner.org/jnorth/search/Monarch.html#Migration). When students become aware that land animals move to have access to a particular resource (e.g., find food or a safe nesting/mating/birthing/hatching ground) or to escape predators and other harsh conditions, it becomes easy for them to understand that animals in the sea might need to migrate as well. Exploring the life cycle of California gray whales (at http://www.learner.org/jnorth/gwhale/), tuna, or even American lobsters can help drive home this concept.

Tracking and Mapping Migration. Satellite technology has helped scientists discover that numerous fish, sharks, sea turtles, sea birds, and marine mammals regularly migrate across ocean basins. Various groups allow the public to view the data they receive from animals that are currently equipped with satellite tags. One project, the Tagging of Pacific Predators (TOPP) is a great resource to help students track animals (http://topp.org/). Have your class choose an animal from the website to track. As the class tracks the specific animal during its migration, have them map each new data point once or twice a week. You can also choose to split the class into small groups, each tracking a different animal. These maps can be combined to show how different species migrate during a particular time. As an extension, have students break into small groups and analyze the tracking information they have collected. What important details about the animal have been learned through tracking? How do you think scientists use this information? Who is benefitting from the tracking of these animals?

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Teaching Resources

Websites for animal tracking:

- National Aquarium, Baltimore http://www.aqua.org/oceanhealth_animaltracking.html
- TOPP (Tagging of Pacific Pelagics) http://topp.org/
- The Great Turtle Race http://www.greatturtlerace.com/
- Resources for gray whales being tracked can be found at Journey North website: http://www.learner.org/jnorth/gwhale/
- National Geographic Crittercam: http://education.nationalgeographic.com/education/topics/crittercam/?ar_a=1
- National Geographic Ocean Education materials: http://www.nationalgeographic.com/geography-action/oceans.html
- Marine Conservation, especially Deep Sea Conservation: http://www.teamorca.org/
- Heal the Bay critter resources: http://www.healthebay.org/santa-monica-pier-aquarium/meet-locals/habitats
- California Education and Environmental Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm

4 Reduction of Ocean Biodiversity

by E. Tucker Hirsch, Rachel J. Fisher, and Meghan E. Marrero

"Biodiversity, the planet's most valuable resource, is on loan to us from our children."
Reaka-Kudla, Wilson and Wilson (1997)

The ocean provides our society with natural resources such as water, food, and fuels and a means for transportation and also supports a profitable tourism industry. Humans have been taking from the ocean for centuries: Even early coastal indigenous people relied upon the ocean for food and water. Today, our reliance upon that body of water has increased dramatically. The fishing industry employs more than 500 million people worldwide (FAO 2009), and fishing and **aquaculture** generates more than $120 billion annually worldwide (FAO 1998). From that industry, some studies suggest that 40 percent of **fisheries** have been overexploited. Furthermore, the number of top-predatory fish have been reduced by 90 percent from overfishing. This means that large, long-lived species, such as bluefin tuna and some Pacific rockfish, are no longer viable fisheries. Meanwhile, we're seeing an increase in the catch and consumption of lower-level food-web species such as jellies and hagfish.

Fisheries have a history of leaving an impact on both the biotic and abiotic components of marine habitats. Indiscriminate fishing practices can leave behind a devastated scene: Dredging for bottom-dwelling species, such as rockfish, shrimp, or scallops, can destroy coral reefs, kelp forests, and rocky-bottom habitats; the use of poison or dynamite to stun and capture shallow-water species, such as those that inhabit coral reefs, often leaves **benthic** environments in tatters; and **purse-seining** for **pelagic** species, such as tuna or anchovies, can leave unintended bycatch, such as turtles or sharks, dead

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.c-e 3.1.2 3.5.1-3	Living Things in Changing Environments The Geography of Where We Live California Economy—Natural Choices
Grade 4	4.2.a-c 4.3.b	Plants: The Ultimate Energy Resource The Flow of Energy Through Ecosystems Life and Death With Decomposers
Grade 5		
Grade 6	6.5.a-e	Energy: Pass It On! Playing the Same Role
Grade 7	7.3.e	Responding to Environmental Change
Grade 8	8.12.1 8.12.5	Agricultural and Industrial Development in the United States Industrialization, Urbanization, & Conservation Movement

or dying behind the fishing fleet.

Oil and mineral exploration also impacts the marine environment. Offshore oil rigs increase the chance of oil spills in the drilling, transportation, and refining stages of oil extraction. Rigs create artificial reefs under the water's surface where juvenile fish and invertebrates congregate and establish large populations. The overall impact of the rigs' artificial reefs is unclear. Once a rig has reached the end of its economic life, its owner must decommission it. Where the rig ends up and what happens to the artificial reef at its base varies from site to site, and no standard cleanup practices are yet in place in the United States. If left alone, these artificial reefs could become important habitats for many ocean species.

The ocean is also a source of minerals, including manganese, gold, zinc, and others. Extraction of these minerals does not currently take place on a large scale, as it is not cost effective.

Humans take advantage of the ocean water itself, as well as what is in or under the water. Seawater may be pumped from the ocean to onshore facilities for a variety of reasons. Power plants often use seawater for cooling their reactors and desalination plants may use seawater to create freshwater. While some coastal communities have regulations on the use and release of seawater, regulations are not universal for all discharges. Returning water may have different chemical, physical, or biological characteristics, such as a different temperature from the surrounding water

In this chapter, we look at some of the more specific effects of the human impact on marine ecosystems and the threat to biodiversity. We examine some case studies—overfishing, illegal fishing, invasive species—and we also

CHAPTER OVERVIEW

Human activities have had a profound effect on our marine ecosystems. In fact, we have changed the ways in which ecosystems are able to function. Our activities have led to the degradation of much of the natural coastal habitats. We've introduced species from other environments that outcompete native species, exploited species both high and low on the food chain, and caused acidification of our waters, which in turn affect many important organisms that form the base of our energy pyramids. Marine habitats, from coral reefs to polar seas, are in jeopardy due to our activities. We dredge seabeds and drill for oil, cripple benthic communities to catch bottom-feeding organisms, and pollute our ocean in countless ways.

In this chapter you will learn more about the problems affecting our ocean community. Through awareness and good decision-making, we can begin to reverse some of our harmful effects on the ocean and preserve its resources for the future.

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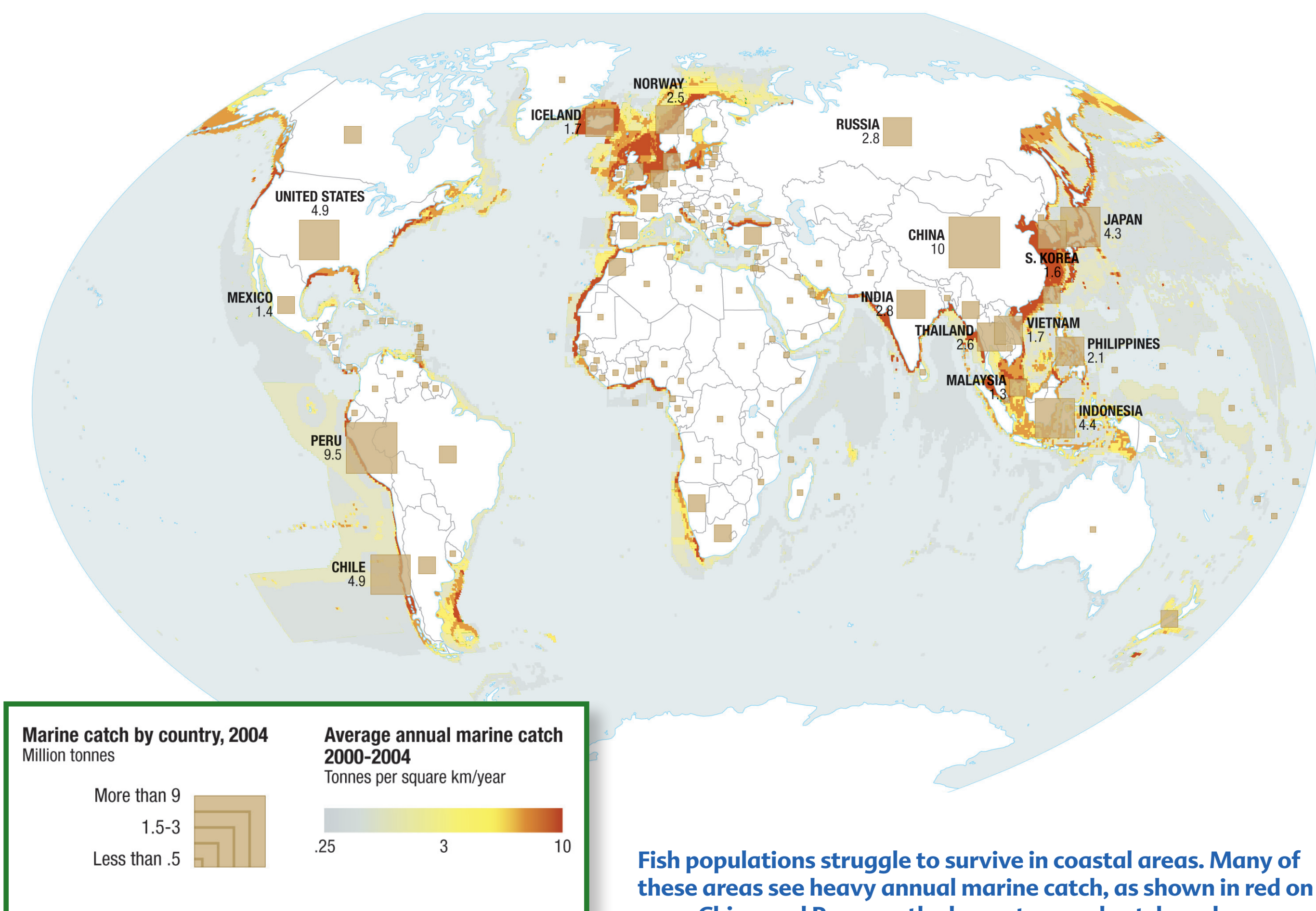
Shoppers at a Washington, D.C., seafood market find a fresh variety of local catch.

look at the ecosystem services we receive from estuaries and the stress we place on estuarine habitats. Understanding human-induced changes in biodiversity can lead to improved understanding of ocean-ecosystem dynamics. This understanding can provide us with the knowledge of how to solve some of the problems humans have created as well as prevent other problems in the future. A side effect of understanding and appreciating threats to biodiversity could be understanding what services diverse ecosystems provide to our society.

While some students in grades 3–8 can define biodiversity and recognize the importance of living organisms, many may not understand the importance of biodiversity for long-term health of both natural and human communities. As we saw in Chapter 1, the ocean conjures images of seafood and coral reefs with regard to what lives in the marine environment. When students are asked about fishing and overfishing, they generally think of how they fish or what they would fish for, rather than commercial fishing and the wide array of fishery products available to the consumer. Some students recognize that on a commercial level we are taking too much seafood out of the ocean or that we are putting too much pollution into the ocean, but students tend to focus on immediate impacts of observable events, such as oil spills and plastics, rather than large-scale processes that are affecting the global ocean system. Many students make personal associations with biodiversity in the ocean; their reference points for fishing, pollution, and number and type of species relate directly to what they have seen, done, or read about.

Change in Ecosystem Dynamics

As humans rely more and more on the ocean for a livelihood, we increase pressure on the ocean, its inhabitants and its ecosystems. More people on the planet than ever before means



Fish populations struggle to survive in coastal areas. Many of these areas see heavy annual marine catch, as shown in red on the map. China and Peru see the largest annual catch each year.

constantly increasing pressure on ocean resources. As we change the ocean, the organisms it houses must adapt. At times, they are successful and their populations continue to thrive. At other times, they are unable to survive our effect on their homes. Lower population numbers, less available habitat, and introduced contaminants all decrease a species' chance of survival. As species go **extinct** or move out of a given area, the biodiversity of that area decreases. In the following text, we examine three ways humans are decreasing the biodiversity of the ocean: through **overexploitation** of fish and seafood resources, via habitat destruction from fishing, pollution, and reconfiguration, and by introducing invasive species, some of which can out-compete existing, native populations. Other invasive species can increase biodiversity in an area if they occupy an open niche, one that is not currently being used by another organism.

Habitat Destruction. Habitat destruction is considered to be one of the most pressing threats to ocean health and biodiversity in the ocean. Without the habitat they are perfectly adapted to, many species have trouble surviving. Habitats provide species with crucial food and shelter, without which survival is difficult if not impossible. Wherever one looks under the ocean's surface, habitats are at risk from a variety of threats, including human development, unsustainable fishing practices, aquaculture, pollution, and global climate change. This section will briefly cover some of the major threats to those ocean ecosystems covered in Chapter 3: coral reefs, kelp forests, estuaries, mangrove forests, polar seas, coastal shores (both rocky and sandy), and the deep sea.

Tropical reef-building corals are perfectly adapted for surviving in warm, clear waters. When development occurs on the shores near reefs, the building can disturb sediment. Rain, in these often wet areas, can quickly carry large amounts of sand and other sediment out over the reef, smothering the corals and their symbiotic zooxanthellae, the photosynthetic algae lives inside the coral and provides them with as much as 90% of their nutritional needs. Another threat to coral reefs is overfishing. Some fishing methods, like bottom trawling or fishing with dynamite, literally destroy the reef itself. Others impact the reef by the species that they remove. Herbivores are important in a reef community for keeping the amount of algal growth to a minimum. Without constant grazing, the reefs can quickly become overgrown with and smothered by algae. Often times, herbivores are targeted as food species in tropical areas. In other cases, the predatory fish are targeted, but their removal can throw off the balance of the food web, leading to herbivore population crashes. Whatever the cause, the removal of these herbivores allows the algae to bloom and thrive, while corals suffer. When the balance of the reef is off, reefs cannot recover from events such as hurricanes and tsunamis. Stressed reefs are also susceptible to coral bleaching. In addition to the other factors listed, the warming waters associated with global climate change are adding even more stress to coral reefs around the world.

Kelp forests are subject to similar stresses as coral reefs. These habitats are also adapted to clear waters, albeit usually temperate ones. Coastal development and its accompanying sediment runoff can smother young kelp as they settle and begin to grow. They are also influenced by excess herbivores, though in this case the herbivores are targeting the kelp itself. In large numbers, sea urchins can mow through entire patches of kelp forest in a matter of days or weeks, creating what is known as an urchin barren. Historically, urchin numbers have been kept in check by predators, including spiny lobsters, sea otters, and some species of fish—all species whose numbers have been driven down by fishing and hunting. Kelp forests are also susceptible to stress by the warming waters of El Niño events and global climate change.

Mangrove forests tend to be destroyed in a more direct manner—they are cut down. Sometimes they are removed to create shrimp farms or other forms of aquaculture. At other times, they are removed for development. Mangroves tend to be found near sandy beaches, prime real estate for hotels and vacation homes. Whatever the case, scientists estimate that between 35 percent and 86 percent of mangrove forests have been destroyed in recent history.

Estuaries, especially coastal wetlands, tend to be near sandy beaches as well. They too have been removed or filled in to make way for hotels and homes, as well as agricultural fields. In California alone, scientists estimate that almost 90 percent of the wetlands have been destroyed since settlement by Europeans. Coastal shores, too, are primarily impacted by human development but also suffer substantially from runoff and irresponsible recreational use.

In polar seas, overfishing and global climate change are the biggest threats to habitats and biodiversity. Overfishing is throwing food webs out of balance, which is a threat to biodiversity wherever it occurs. Some fisheries, such as Alaskan salmon or king crab, are well-managed, while others, such as Chilean seabass, are not. The warming waters of global climate change have lead to changing patterns of polar ice. The new distribution patterns of polar ice, or in some cases, an entire lack of ice, are affecting species as diverse as krill, walruses, penguins, beluga whales, and polar bears. If these species cannot adapt, there is a very real chance that

Industrialized fishing is a result of the high demand for seafood products. Bycatch, like this marine turtle, has devastating effects on ocean biodiversity

some of the larger predators, such as the polar bear and walrus, may go extinct in the next 50 years.

It is difficult to assess human impacts on the deep-sea ecosystem. This part of our ocean is hard to reach, and scientists are regularly learning new things about the deep sea. Oil exploration and drilling are two threats to the deep sea that we do know about. Drilling, even when done safely and responsibly, interrupts the deep sea communities and can destroy deep reefs. Accidents that have resulted from drilling practices demonstrate that as exploration of this hard-to-reach portion of our planet continues, more threats to its health and the biodiversity it hosts will become evident.

Overexploitation. Humans began ocean fishing on a commercial scale in parts of Europe around the beginning of the 11th century. Over the next few centuries, the practice spread in geographic location and intensity as horses began bringing freshly caught seafood inland at faster rates for upper-class citizens and nobility in urban areas, such as Paris. As populations grew, the need for food increased accordingly. As early technologies for fishing and transportation improved, so did the popularity and feasibility of fishing. By the late 1800s, intensive fishing was a common practice, and the sea and its resources were viewed as an inexhaustible resource. After the Second World War, commercial fishing was bringing in catches in amounts never before seen. Landings continued to increase until, finally, toward the end of the 20th century, catches peaked at 85 million metric tonnes per year (Callum 2007). However, the fishing industry had seen an increase in effort and size of the fishing fleets, suggesting that the fish were harder to find, and there were fewer to catch. The worldwide demand for seafood has led to industrialized fishing on a scale that has severely depleted fish stocks and has negatively impacted the health of marine ecosystems. The effects of unsustainable fishing have led to changes in the trophic structure of ocean food webs. The biomass of higher trophic levels of fish has decreased significantly since 1900, and in response to this decline, fish landings have shifted away from larger predators and have been replaced by smaller planktivorous fish and invertebrates (Pauly et al 1998). Additionally, fish species have been removed from parts of their global ranges, and overfishing has caused the collapse of numerous fisheries, such as the bluefin tuna and the Canadian cod fishery that has lost 99.9 percent of its cod population (Hutchings and Reynolds 2004; Schmidt 1993). Declining stocks as a result of overfishing have shortened fishing seasons. Catch quotas in Europe have been substantially reduced, putting many fishers out of work. Globally, we are overfishing at a cost of billions of dollars per year (Schmidt 1993).

Bycatch. When fish and shellfish are caught using some of the methods described previously, unintended species are often caught. This phenomenon is known as **bycatch.** For example, shrimp are typically caught by **trawling,** or dragging a large net behind a boat. Some scientists estimate that for every one pound of shrimp caught, ten pounds of other species, including sea turtles, fish, and other invertebrates, are also captured. This bycatch is often discarded. Other examples of bycatch include seabirds and sea turtles becoming ensnared on longlines, which are used to catch pelagic species such as swordfish.

Eroding the Base of the Food Web. Destructive fishing methods

Case Study Big Fish: A Short History of Whaling

People have been whaling for thousands of years. Norwegians were among the first to hunt whales as early as 4,000 years ago. The Japanese may have been doing so even earlier.

Traditions as varied as the Inuit (who hunted in the Arctic Ocean), Basque (who hunted in the Atlantic), and Japanese (who hunted in the Pacific) relied on whales to provide material goods as well as part of their cultural identity.

Nearly every part of the whale was used. Meat, skin, blubber, and organs were eaten as an important source of protein, fats, vitamins, and minerals. Baleen was woven into baskets and used as fishing line. In warmer climates, baleen was also used as a roofing material. Bones were used primarily for toolmaking and carving ceremonial items such as masks.

During the Middle Ages and Renaissance, whaling gained popularity throughout Northern Europe. Whale oil and baleen (sometimes called whalebone, although it's not bone at all) were valuable commodities. Whale oil comes from the blubber of right and bowhead whales, and the head cavity of sperm whales. It was used primarily for oil lamps. Corsets and hoop skirts were constructed from whalebone.

Whaling in America

Over time, European whaling ventures spread to North America. American colonists relied on whale oil to light most of their lamps.

By the mid-1700s, it became increasingly difficult to find whales near the Atlantic coast. The American whaling fleet expanded its operations throughout the world's oceans, including the whale-rich waters of the Arctic and Antarctic.

Whaling in the United States hit its peak in the mid-1800s. New technologies, including gun-loaded harpoons and steamships, made whalers around the world more efficient. Whaling was a multi-million dollar industry, and some scientists estimate that more whales were hunted in the early 1900s than in the previous four centuries combined.

By the early 1970s, the United States had listed eight whales as endangered species. The United States officially outlawed whaling in 1971.

Whaling Today

In 1946, several countries joined to form the International Whaling Commission (IWC). The IWC's purpose is to prevent overhunting of whales. Its original regulations, however, were loose, and quotas were high. Whale stocks continued to decline.

The IWC eventually established whaling-free sanctuaries in the Indian Ocean (1979) and the ocean surrounding Antarctica (1994).

The IWC called for a moratorium on commercial whaling in 1982. Both Japan and Norway voted against this policy. Today, Norway supports hunting minke whales for meat. Japan allows whaling for scientific purposes, although many experts question if more whales are taken than are necessary. Meat from whales killed for research is sold as food.

Many species of whale have benefitted from the IWC's moratorium. Dave Weller, a research biologist at NOAA's Southwest Fisheries Science Center in La Jolla, California, says the IWC's moratorium on whale hunting is one of two major steps the organization is taking.

"The other thing that the IWC has very successfully done is to collect information and provide analysis of data to help us understand the status of various populations that in some cases we knew very little about," he says.

Despite the general moratorium, limited whaling is permitted to indigenous groups.

"In the United States, the Inuit Eskimos in the north slope of Alaska, in Barrow, Alaska, still hunt for bowhead whales," Weller says. "There is a request by the Makah Indian tribe, which is in northern Washington State, to resume gray whale hunting, which they had traditionally done. But that's pending deliberations right now."

Student Thinking

Our Fishing Practices

Twentieth century improvements in technology and increased demand for seafood and other ocean resources have led to the overexploitation of the ocean. Unfortunately, conceptualizing abstract ideas of far away species in a seemingly endless ocean can be difficult. Having mostly been exposed to recreational fishing, students may not be familiar with commercial fishing and the amount of seafood that makes it to global food markets. Therefore, students' ideas often focus on the immediate impacts we have on our ocean through recreational fishing and may not readily think about how large-scale fishing affects the dynamics of an ocean food web.

Scenario

You have just received a worksheet back from students that you will use to assess their prior knowledge of fishing. As you review the worksheets, you notice that many students focused exclusively on recreational fishing. As you look at the following student answers, keep in mind that you will be planning a lesson to help the whole class understand the negative impacts commercial fishing has on the environment. Think about how you can use this information to help you plan.

Question

How does commercial fishing affect ocean biodiversity and habitat?

Scientific Answer

Commercial fishing has many negative impacts on the ocean, including overexploitation and bycatch, which can lead to animal endangerment. Methods such as trawling and longline fishing are the main contributors to these threats. Recreational and artisan fishing are much less invasive types of fishing.

Student Answers

Alan: "Taking fish probably messes up their habitat because all our hooks and bait."

Juan: "Probably wrecking the habitat because if we fish off boats, the gasoline from the boats will get into the water."

Julie: "Other waste from the boat, like a snack or trash, fish could eat it and get sick."

Olivia: "We might eat fish that are good for the environment and that might cause problems."

Keith: "We're taking a lot of them out of their natural habitat because we eat them for food."

What Would You Do?

1. How would you grade these answers? Which is the most sophisticated?
2. These worksheet responses indicate that many of your students have not grasped the negative impacts of commercial fishing. How would you teach these concepts in a way to ensure students will understand and retain the information?

In the Classroom

Shop for Solutions!

Consumer pressure can lead to reform of fishing practices. Perhaps the best-known example is that of "dolphin-safe tuna." In the 1980s and 1990s, the American public became more aware of tuna fishing practices that led to high dolphin mortality. Using large purse-seine nets, fishers caught both the tuna and dolphins. Being air-breathing mammals, the dolphins drowned in the nets. Through public pressure, tuna fishers were forced to change their practices to avoid capturing the marine mammals. Advocates of sustainable commercial fishing are hoping that similar consumer vigilance will reduce fishing pressure on overexploited species, leading to their recovery. In this activity, students will explore how the decisions their family makes at the grocery store can influence biodiversity in the oceans.

Materials

- Local Seafood Watch Pocket Guides or other Consumer Guides (http://www.montereybayaquarium.org/cr/cr_seafoodwatch/download.aspx)
- National Oceanic and Atmospheric Administration's (NOAA) Fish Watch Guide (http://www.nmfs.noaa.gov/fishwatch/)
- National Geographic's Sustainable Seafood link (http://ocean.nationalgeographic.com/ocean/take-action/impact-of-seafood/# marine-food-chain/?source=A-to-Z)
- Drawing and art materials

Directions

1. In groups, have students explore menus of local restaurants that serve fish. Find menus that list specific fish species and menus that might be vague. Have students circle the fish listed using one of four colors according to their Seafood Watch card (i.e., red = avoid, yellow = caution, green = okay to eat, and blue = more information).

2. Groups should then exchange menus and research the catch method and origin of the fish on the menu. Different consumer guides may make different recommendations for the same fish species. The class can discuss the challenges in recommending seafood and also the challenges in using consumer guides.

3. Have students work together to decide if the fish are sustainably harvested or if harvesting them would be detrimental to the fish stock or the environment. For those species that are not sustainable, students should explain and record what negative impact that product has (e.g., bottom dredging for orange roughy destroys benthic environments and produces high quantities of bycatch).

4. After the research is complete, create one class menu that incorporates students' findings from their research.

Ask Your Students

1. How did you decide which seafood to include in your final menu? How or why did they differ from those in your original menu?

2. If you were on a budget and trying to feed your family, which would be more important to you the cost of the seafood or the sustainability of it? Why?

3. What surprised you most about some of the fishing practices? How might we work to improve them?

Pictures of Practice

How We Fish Our Ocean

Fishing has been around for thousands of years. With advances in technology and population growth, commercial fishing now dominates the way we fish our ocean. Commercial fishing practices allow us to take large amounts of fish from our ocean, but these practices now threaten the health of our ocean. As described in **Overexploitation** and **Bycatch,** both on page 68, how we fish our ocean has important consequences for the overall health of the ecosystem. It is important to look at not only the volume of fish taken by commercial fishing but also how we fish and what components of the ecosystem we are removing. Overfishing large numbers of top predators or large numbers of organisms at the base of the food web can impact all other organisms in that food web.

Students: Grade 7

Location: Carpinteria, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students learn about trophic levels and human activities.

Classroom Context

In this video you will see Ms. West discuss with her students the trophic levels of the ocean. During her preinterview, Ms. West points out that her students do not understand the indirect impacts fishing has on the ocean system. In previous lessons students have been able to identify direct affects of fishing, but they do not fully understand how removal of one species of marine organisms may influence the health of another. Ms. West decides that teaching trophic levels will help her students understand the greater consequences of commercial fishing and other human activities on ocean ecosystems.

Video Analysis

This video focuses on learning about trophic levels and trophic charts as a precursor to discussing how human activities impact ocean ecosystems. Trophic levels are a common way we show relationships among organisms in an ecosystem. Trophic charts are representations that show how trophic levels are related and how energy principles govern populations in an ecosystem. Ms. West introduces the trophic chart because she wants her students to learn that taking too many organisms from one trophic level or another has consequences for the whole ecosystem. After Ms. West has taught about the trophic chart, she uses a discussion to gage student understanding of the topic. Many students are able to identify that the trophic chart is shaped like a pyramid, but students also share several misconceptions about the chart. For example, one student says that fishing is the reason higher-order consumers have smaller numbers. No student associates the trophic chart with an energy pyramid. In the post interviews you see three students describe what they learned about human activities (i.e., fishing) and the trophic levels. All students show they understand that human activities affecting one trophic level will impact the other levels. Yet, students still seem confused about how to use trophic charts to make sense of direct and indirect impacts. Jacob, for example, focuses on artisan and recreational overfishing as opposed commercial fishing. Tony believes that if one fish goes, then all the fish go.

Reflect

How can you help students connect trophic levels to human activities?

What do these students seem to understand and not understand about trophic levels? Think about taking traditional science concepts, such as trophic levels, and connecting those concepts to human activities. Where would you go next to connect trophic levels to ocean issues?

also cause ecological harm. Historical ocean records indicate overfishing as the catalyst for marine species decline in a variety of habitats, including kelp forests, coral reefs, sea grass beds, estuaries, and offshore benthic communities. Some practices, such as trawling and longline fishing, generate bycatch and negatively affect many species. For example, these fishing methods have led to an 80–95 percent decrease in loggerhead and leatherback turtle populations in the Pacific in the last 20 years (Lewison, Sloan Freeman, and Crowder 2004). The use of explosives and toxins by fishers can decimate coral reefs, as has occurred in the Philippines where catch rates and biological diversity have both declined. **Dredging** can uproot kelps, algae, and sea grasses and can destroy corals and overturn rocks, and snagged nets left on the bottom can harm sea life.

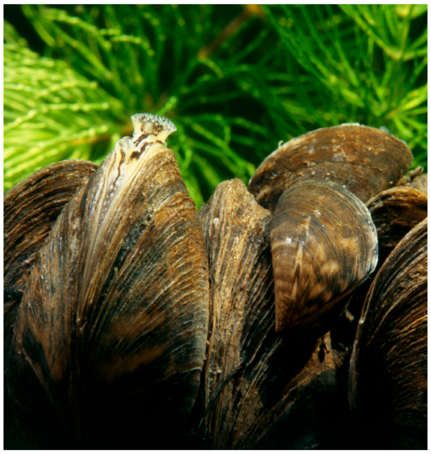
Teaching Tip

When students are asked about the impacts of our practices on oceans, most students conjure up negative images of how we influence the ocean ecosystem. For example, one student described dredging as mixing "poop and dead fish up into the water" and also described using dynamite as, "dyno probably kills all the fish and mix up all the stuff again and the water will be all nasty." Students readily grasp the potential negative consequences of these practices but may not understand why the practices evolved or how their own choices as consumers may or may not contribute. As students share these ideas and stories in class, ask students to elaborate on their ideas. Where did they learn about the topic? What do they mean when they say "the water will be nasty"? Following up on students' stories will better help you understand the prior knowledge that your students bring to your classroom.

These fishing practices can be viewed as direct destruction, but humans are also creating indirect destruction. The ocean has been acting as a **carbon sink** for increased carbon emissions since the Industrial Revolution of the late 18th century. While much focus is often put on forests and green, terrestrial ecosystems, the primary producers in the ocean may sequester more carbon annually than all terrestrial primary producers combined. Unfortunately, the ocean has started to show indications that the increased carbon dioxide load is having a harmful effect on some marine organisms. Increased CO_2 decreases the pH of the ocean water, and organisms with silicate or calcium-based parts are becoming more brittle and starting to dissolve. Organisms, such as planktonic calcareous coccolithophores and corals, play important roles in marine ecosystems and are being threatened by fossil-fuel combustion. As these species often form the base of the marine food web, their continued survival is critical to ocean health. Whether our actions are impacting the seafloor through destructive fishing habitats or eating away the structure of the habitat or the base of the food web, biodiversity is at stake.

Invasive Species. Invasive species are those that are not native to an ecosystem. These species compete with local species and are often harmful to local ecosystems, human health, and the economy. Invasive species are most often found in estuaries and can be introduced accidentally or intentionally. Common means of marine species introduction include shipping, aquaculture, and pet, aquarium, and tourism trades. As humans introduce species into the marine environment, the species often take over habitats or consume food items that previously existing, native

The effects of El Niño on the ocean can be devastating, as this dead, bleached coral reef off of the coast of Palau in the South Pacific Ocean reveals.



Teaching Tip

For more exploration of invasive species, have your class investigate the zebra mussel. The zebra mussel is one of the most notorious and prolific invasive species in the United States today. Originating in Asia, the zebra mussel made its way across Europe over the last three centuries, reaching the United States as recently as the 1980s, and has become a very recent nuisance in California. Learn more at http://www.invasivespeciesinfo.gov/aquatics/zebramussel.shtml.

species would otherwise have access to. Some new species can act to decrease the biodiversity in an area if they outcompete native species (often due to lack of predators) and, therefore, prevent the native species from existing in these habitats any longer. Alternatively, some nonnative species can also act to increase the biodiversity in an area. They can do so if they occupy an open niche, one that is not being used by other organisms.

For example, the beautiful lionfish (mainly *Pterois volitans* but possibly *Pterois miles* too) that is native to the Indo-Pacific, was introduced into the Atlantic in 1992 and has quickly spread throughout the region. It can now be found throughout the Caribbean and as far north as Rhode Island. It is suspected that the lionfish was introduced via an accidental aquarium release in Florida. As adults, these fish have few predators in their native range and none in their introduced range due to their venomous spines. Without any predators to keep their numbers in check, these fish are outcompeting local fish for food sources. Overfishing has already thrown many of the food webs in the lionfish's new range out of balance;

The introduction of nonnative lionfish to distant habitats often have a negative impact on local species that must compete for food and survival.

Explore More

- Ships take on weight so they are heavier and more stable at sea when transporting goods across the ocean. Often, they suck up water or load dirt, rocks, and sand from their port of origin right before leaving the harbor. This additional weight is called ballast. When the ship gets to the next port, it is often too deep in the water to reach the unloading dock, so the water ballast is disposed of as the ship enters the new port. Given the speed of shipping, many organisms survive the transit and are able to establish themselves in the new environment.
- Aquaculture productions often occur in rivers, estuaries, or coastal zones in pens or cages that are open to the environment. As water flows in and out of the aquaculture pens, so too do the parasiticides, food, wastes, and water-cleaning chemicals used in the aquaculture. The water flow increases the chance of disease, escaped species, and unnatural hormones and chemicals added to the surrounding environment.
- Where do all those brightly colored fish in your home fish tank come from? The pet, tourism, and aquaculture trades are culprits for removing many species from their native environment, and owners may release species into new environments. Have students research where popular pet fish such as clownfish and regal tang come from. Ask students what the positive and negative effects of home aquariums are.

Case Study

Ecosystem Invaders: Spartina

From 2000 to 2005, a nonnative plant and its hybrid rapidly changed the makeup of California's San Francisco Bay.

The invasive species, *Spartina alterniflora,* created an even more adaptable hybrid with its relative, the Bay's native marsh plant, *Spartina foliosa.* The hybrid threatened to turn tidal mudflats into meadow, eliminate shorebird foraging habitat, and push the native *S. foliosa* toward extinction.

Peggy Olofson, director of the Berkeley-based San Francisco Estuary Invasive Spartina Project, says the nonnative *S. alterniflora,* also known as smooth cordgrass, was introduced to San Francisco Bay's eastern shoreline by contractors and workers for the U.S. Army Corps of Engineers during the 1970s, as part of a dredging restoration program.

S. alterniflora, and especially its hybrid, quickly took over large swaths of the Bay.

"In San Francisco estuary, we have thousands of acres of open mudflat, and many of the plants, the hybrids, decided they loved it there," she says. "So they started filling in all of the mudflats. They decided that they also liked the high marsh area, where there are just a couple of species that live native in our state. So they started taking over those areas and displacing the natives from those areas also."

The native cordgrass was just one species *S. alterniflora* and its hybrid threatened. The invasive species changed parts of the Bay where the endangered California clapper rail, a salt-marsh bird, forages and shrank the habitat of the endangered salt-marsh harvest mouse.

The plants not only became a problem for animal species. One unexpected consequence of the hybrid was its ability to thrive in pond water. The number of biting mosquitoes increased dramatically, inconveniencing the local community and discouraging public use of the area.

The plants also began to change natural drainages in the Bay Area.

"One of the things that is a concern for people who were responsible for flood control and protecting human houses is that the plant clogs the storm channels, the channels that are tidal right by the bay where all of the creeks and streams have to discharge in order to get the storm water off the hillsides. It clogs those up and causes them to back up and causes flooding in the adjacent areas and the upland areas."

Established by the California State Coastal Conservancy in 2000, the San Francisco Estuary Invasive Spartina Project set about eliminating *S. alterniflora* and its hybrid from the estuary. The project is a partnership between government agencies, environmental organizations, and individuals.

In 2005, the organization began eradicating the invasive *Spartina* with the herbicide imazapyr.

"This is a very low-toxic substance, which just happens to work very, very well on this plant," Olofson says.

Due largely to the organization's efforts, the footprint of the invasive *Spartina* and its hybrid has been reduced from more than 800 acres in 2006 to fewer than 90 acres today. Still, Olofson says the work is not done.

"Now that we are getting close to being successful with eradicating the hybrid, the marsh is left without any [native] *foliosa,*" she says. "What we are doing now is we are starting a very large revegetation program and going back and introducing the native cordgrass into areas where it was completely removed or displaced by the hybrid."

some scientists worry that the presence of lionfish could be the deathblow for some species already on the brink of extinction. Additionally, human swimmers and divers are susceptible to injury from the lionfish's spines. Once introduced, invasive species such as the lionfish are difficult, if not impossible, to **eradicate.** Prevention is key.

Teaching Tip

Prior to beginning lessons on marine debris, you may consider starting off with a KWL (*Know, Want to Know, Learned*) chart or another type of graphic organizer that helps determine prior knowledge of a subject. Organizers, such as these, may help to assess students' knowledge of the origin of marine debris. Do they know where trash in the ocean originates? Do students think they are the cause of the buildup of debris in the ocean?

Marine Debris

The types of **marine debris** are wide-ranging, but all can have significant impacts on the marine ecosystem. As defined by NOAA, marine debris is "any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes."

Debris, or litter, is a persistent worldwide issue in many aquatic ecosystems, from wetlands and estuaries to coastal areas. We will take a closer look at the types, sources, movement, and effects of debris in marine environments. Litter that eventually makes its way into the marine environment can originate from one of two sources: land or the ocean.

Land-Based Marine Debris.

Many types of marine debris originate from inland or the coast and make their way into the water through wind or precipitation. Land-based marine debris can include individual use of products from beachgoers who leave trash, such as cigarette butts, cups, or plastic toys on the beach, which eventually moves to the ocean.

Additionally, debris from industrial sources, such as hard hats or other material from building sites, is another major source of debris found in marine environments. Plastic is a major component of industrial debris. Nurdle are small (2 mm, or ¾ inch, in diameter) plastic pellets that are feedstock for manufacturers but look like fish eggs to wildlife.

Storm-water discharge is another major source of marine litter that originates inland. Precipitation events, such as rain or snow, can carry trash—such as medical waste and street litter that was either intentionally or unintentionally thrown onto the ground—from city streets into storm drains. The trash in the storm drains eventually makes its way into nearby waterways, including the ocean.

Natural events, including tornadoes, hurricanes, or floods, are additional tsources of debris that eventually run into the ocean. The litter that is transported into the ocean during these events is wide-ranging and depends upon the scale of the event. Items may include portions of roofs, windows, everyday trash, and even car parts.

Approximately 60–80 percent of all debris found in oceans is made of plastic, most of which is land-based in origin. In California alone, people use 19 billion plastic bags each year, most of which come from grocery store chains and pharmacies. When people throw away these single-use bags, the bags

Marine debris that ends up in the ocean can eventually wash back onto shore and pollute beaches.

can end up in landfills; if the bags end up as litter, they can eventually land in storm drains, which lead to the ocean. Plastic bags eventually breakdown into smaller and smaller pieces in the environment through a process known as **photodegradation,** but they never fully biodegrade.

When plastic bags make their way to the ocean, they can have a detrimental impact on the wildlife. Plastic bags can entangle and kill marine organisms. Additionally, sea turtles, birds, and marine mammals ingest plastic as they may mistake it for their food source. In particular, leatherback sea turtles are known to feed on different species of sea jellies. Unfortunately, plastic bags resemble the sea jellies, and as a result, a large number of leatherbacks have become injured or died from ingestion of plastic bags. A 2009 study of leatherback turtles that had died showed that 34 percent of them had plastic in their digestive tracts, though what role the plastic played in their deaths is unknown.

Because plastic-bag litter is an issue in our oceans, people are working to decrease the number of bags that are used and ultimately that end up in our ocean. In California, efforts are underway via legislation to reduce the number of plastic bags used. The city of San Francisco was the first in the United States to ban single-use plastic bags in pharmacies and grocery stores. Other cities have followed suit. Several bills have been introduced to the California State Legislature as well. Some nations, including Belgium, Ireland, China, and South Africa, have taken on the issue and imposed single-use plastic bag bans, fees, taxes, or some combination of them in an effort to battle the scourge of plastic in the marine environment.

Ocean-Based Marine Debris.

Similar to land-based marine debris, ocean-based debris can be the result of either intentional or unintentional acts of humans. Fishers may dump old fishing lines, nets, or crab traps into the ocean, where they will remain for a long time. Recreational and commercial fishers also lose or abandon gear and nets, so derelict fishing gear and ghost nets are a debris concern. Old shipping vessels are another source of debris, as they are either abandoned or sank near coasts. ttAdditionally, present-day shipping vessels dump a lot of debris into the ocean.

Natural events that occur over the ocean, such as hurricanes or strong storms, can cause shipping vessels to accidentally release waste into the ocean or dump materials that are being transported, such as plastics, clothing, or shoes.

Movement of Marine Debris.

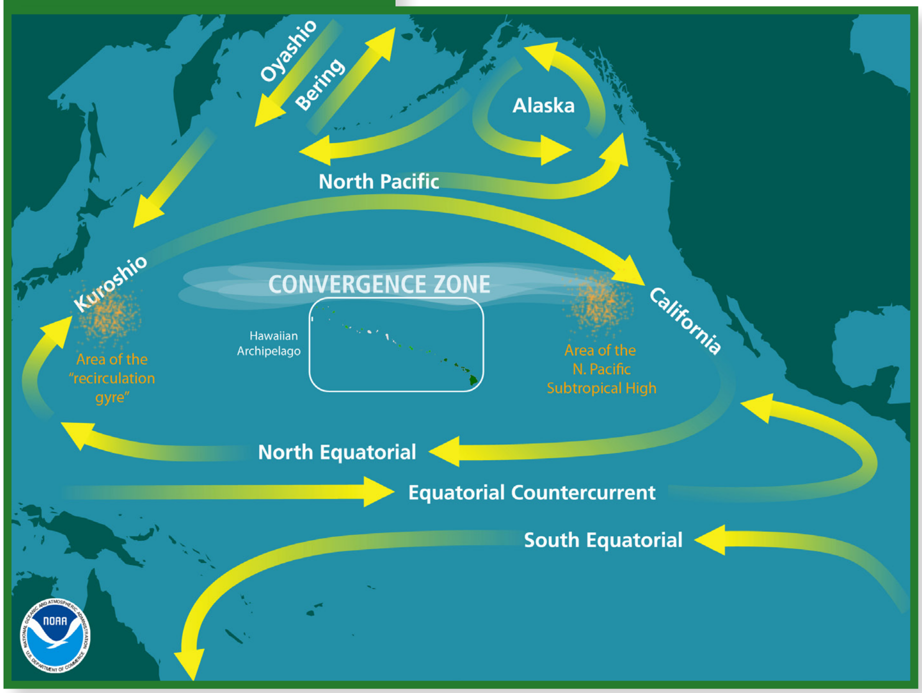
Litter that enters the ocean can be moved far distances because of atmospheric winds or ocean currents. Ocean gyres, or "large scale circular features made-up of ocean currents that spiral around a certain point" (NOAA 2010) spiral clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

There are five major subtropical oceanic gyres, but the most-studied is the Northern Pacific Gyre, which collects debris into floating "patches." This gyre consists of four rotating

Marine organisms mistake debris for food or may be strangled by nets or lines.

Evidence of human interference with nature can be seen on the sea floor. Human-made items, such as this plane propeller, have become imbedded into the environment.

THE NORTH PACIFIC GYRE



A gyre is a large, circular oceanic surface current. In the center convergence zone, trash from all over the Pacific has collected into one giant, floating landfill.

currents that move clockwise in the ocean and covers approximately 11 to 14.5 million square kilometers (≈ 7 to 9 million square miles).

Of notable interest is the Great Pacific Garbage Patch, an area of large accumulation of marine debris. As currents come together in the North Pacific Gyre, they concentrate marine debris in the North Pacific Subtropical Convergence Zone. The Great Pacific Garbage Patch is not a solid island of floating trash. The debris in this large area is a concentration of very small pieces of litter, most of which cannot be seen with the naked eye. Scientists have measured concentrations of at least six times as much plastic as zooplankton (by weight) in some parts of the patch. The currents of the gyre also concentrate marine life, and this area is rich with pelagic species. Ironically, this diversity of life in the area makes clean up difficult. Additionally, the debris accumulated in the Great Pacific Garbage Patch has been known to float onto beaches of remote islands such as in the northwestern Hawaiian Islands and even more populated areas, particularly when currents shift as a result of El Niño events.

Effects of Marine Debris on Wildlife. The litter that ends up in our oceans may not only have an impact on the aesthetics of an area but can also have devastating effects on the health of wildlife. Birds, sea turtles, fish, and other marine organisms can be injured or killed by debris floating in marine ecosystems. These and other organisms may accidentally ingest debris, such as plastic, called nurdles, or fishing line, because many times this litter looks similar to the food they normally consume. Additionally, many types of seabirds feed on fish eggs; however, plastic pellets and Styrofoam pieces floating in the ocean resemble this food source and are often found floating among it. There are toxins found in plastic, which can make these organisms quite sick. The ingestion of marine debris can injure the internal organs of these organisms or cause malnutrition, starvation, or even death.

In addition to ingestion, marine organisms can also become entangled in marine debris, such as old fishing line, crab traps, or soda-can rings. This can lead to injury, suffocation, or death.

Marine debris can have devastating effects on the habitats of wildlife, both plants and animals. For example, coral reefs, which are crucial for the existence of a diversity of marine organisms, can be destroyed by the impact of debris, such as sunken vessels or old fishing materials. If these habitats are destroyed, the populations of the organisms that inhabit them will decline.

Teaching Tip

Students often do not understand why marine organisms cannot just get out of marine debris when they become entangled. A very simple way to help them understand this is to give each student a rubberband. Have the student loop the band over their thumb, along the back of their hand, and looping the other end over their pinky finger. Instruct the student to try and dislodge the rubberband without using their other hand or rubbing against any surfaces—as the open ocean does not contain any surfaces for rubbing. A few students will be able to free themselves, but many may not be able to do so. This activity can be a great lead-in to a fruitful discussion about entanglement.

Student Thinking

Marine Debris

It is important to realize that many students, especially younger ones, may not understand the basics of marine litter, including its far-reaching effects in the ocean. A toxin is an abstract concept that may need to be taught in detail, as it is important to understand especially when teaching the effects of plastics on marine life. The patterns of trash movement in different directions must be clarified and can be simplified by showing the movement of hands on a clock in both a clockwise and counterclockwise direction. More advanced concepts, such as gyres and the STCZ, can be explained to older students; however, an explanation of the Great Pacific Garbage Patch is important for all learners.

	Common Student Ideas	Scientific Concepts
What is debris?	Students tend to focus on those debris items they can see, such as plastic, and think that water without things they can easily see is clean and safe.	Pollution can be visible, such as plastic, or it can be invisible to the naked eye, such as bacteria, viruses, and toxins. Plastic debris in the ocean accumulates organic toxins such as PCBs (polychlorinated biphenyls).
Origination	Students may focus on littering that they can see locally, such as trash that is thrown onto a beach.	Trash travels as runoff from both coastal cities and inland communities (after it has been thrown onto the ground).
Movement	Students tend to focus on trash that washes onto a beach because it is easy to see.	Trash can travel with the currents of the ocean and concentrate into patches of trash miles from the shore. This movement can take trash quite a distance from its source and affect marine life and the environment.
Pacific Gyre	Students may picture a mat of garbage floating on the ocean's surface.	The Great Pacific Garbage Patch is an area in the ocean, where, due to the action of winds and currents, marine debris is found in greater concentrations than in other areas of the ocean.

Ask Your Students

1. What is marine debris? What does it look like? Are debris only items you can see?
2. Where does marine debris come from? Do you need to live near the ocean to contribute to marine debris?
3. Where in the ocean can you find marine debris? Does marine debris stay in one place once it enters the ocean?
4. What is the Great Pacific Garbage Patch? What does it look like?

Pictures of Practice

Marine Debris

Students who have been to a beach may have seen trash washed onto the shore. Some students may have heard about a tax on bottles or plastic bags to reduce use of these items and the chance those items make their way to the ocean. Marine debris is a major environmental threat to our ocean, and students clearly understand some of the negative consequences that debris has on ocean health. Yet, when most students describe debris they focus on intentional littering at the beach and may not recognize that much of the debris also comes from inland communities where runoff carries trash to our ocean. Students may not realize that widespread use of "disposable" plastics around the world and poor management of plastic waste has lead to massive buildup of debris in certain parts of our ocean (see **Student Thinking: Marine Debris,** page 78, for more information).

Students: Grades 5 and 7

Location: California (in coastal communities)

Goal of Video: The purpose of watching this video is to see how students describe pollution in the ocean.

Classroom Context

Students in this video live near the California coast. The interview clips shown in this video were taken during the spring of the school year after both sets of students learned more about the ocean and ocean biodiversity. The first part of the video shows fifth-grade students describing ocean pollution. The second half of the video shows seventh-grade students answering the same question. Think about the different types of responses you hear from students in the same grade as well as differences between grade levels.

Video Analysis

In this video fifth and seventh graders were asked the same question: What is pollution in our ocean? One type of ocean pollution is marine debris. When students were asked this question, most answered describing some type of litter or debris. Marine debris typically includes human-made objects, such as plastics, glass, old fishing gear, or other materials, that have been discarded by people and made their way to the ocean. Marine debris originates from coastal and inland communities, as well as from ships and boats on the ocean (see **Marine Debris,** page 78, for more details). Due to movement of ocean currents, this debris collects in particular locations. For example, the Great Pacific Garbage Patch is one such location found within the North Pacific Gyre. Although the size is unknown, it is generally estimated to be as large as the state of Texas, or larger, and most of the trash is so small that it is invisible to the naked eye. As you listen to the fifth-grade and seventh-grade students describe debris in the ocean, think about how their answers match or do not match the description of debris on this page. For example, some students only describe intentional littering at a beach. Other students, such as Jacob, describe runoff of chemicals into our ocean. Compare each student's answer to the scientific description provided, and plan how to help students improve their understanding.

Reflect

How would you plan your instruction given these student ideas?

Given the diversity of ideas you heard during the video, how could you use this information to plan your instruction on ocean pollution and marine debris? What are the main misconceptions you heard? How would you target these misconceptions during your teaching?

In the Classroom

Some Things Change

Ecosystems have evolved over time to be relatively resilient environments. A healthy ecosystem can withstand and recover from a wide array of natural impacts, such as hurricanes, tsunamis, and El Niño events, and can even handle occasional human impacts. But an ecosystem can only handle so much. Repeated or consistent damage by humans, in combination with natural events, can leave an ecosystem in ruin. Warming oceans, unsustainable fishing practices, heavy use for tourism or shipping, predator or keystone species removal, excessive harvest, as well as runoff and other pollution issues, to name a few, can result in unhealthy, unbalanced ecosystems. Once an ecosystem is damaged, it is not a lost cause. Thoughtful and thoroughly implemented remediation and restoration can help an ecosystem recover. In this simple activity, students will explore healthy ocean ecosystems and hypothesize how humans could impact them.

In the Everglades, 10,000 acres of sea grass have been damaged by powerboats, causing mass destruction to native wetlands.

Materials

- Before and after pictures:
  - — Coral reef: healthy; bleached. Coral reef: healthy; broken from fishing or tourism.
  - — Rocky kelp forest: healthy; dredged. Rocky kelp forest: healthy; overpopulation of urchins.
  - — Estuarine sea grass bed: healthy; damaged from anchoring boats. Estuarine sea grass bed: healthy; polluted, and so on.

Directions

1. Present students with pictures of the healthy ecosystems. Ask them to brainstorm different ways that humans might utilize each of the ecosystems. For example, a healthy coral reef may see a lot of snorkelers or scuba divers, could be a collection site for the aquarium trade, and could be a fishing ground. Students should then make predictions on what would happen to the sites if those activities occurred there.
2. Present students with pictures of the ecosystems that have been degraded. Ask students to hypothesize which activity lead to the decline of the ecosystem.
3. Ask students to determine the species diversity and abundance in each picture.
4. Optional: Research ways to restore each habitat, how long it would take to bring the ecosystem back to health, and what indicators the community would use to determine the health of the ecosystem.

Ask Your Students

1. What are some natural ways in which these habitats are negatively impacted? Compare and contrast the natural and human-induced changes.
2. How is biodiversity affected in each ecosystem? What will be the long-term effects of these changes?
3. Why is the health of these ecosystems important to humans on land?

Student Thinking

Threats to Ocean Biodiversity

Students are aware of some hot topics regarding threats to global biodiversity. They may get this information from sources they come into contact with daily: the media, school, family, and so on. Many students know that we are taking too many fish from the ocean, that we are polluting the ocean, and that there are things that are good and bad in the ocean. However, they may not associate their own actions as contributing to biodiversity threats. Bridging the gap between students' daily actions and global threats to biodiversity can help students understand the large impact we have on the ocean and how our everyday actions can impact the ocean.

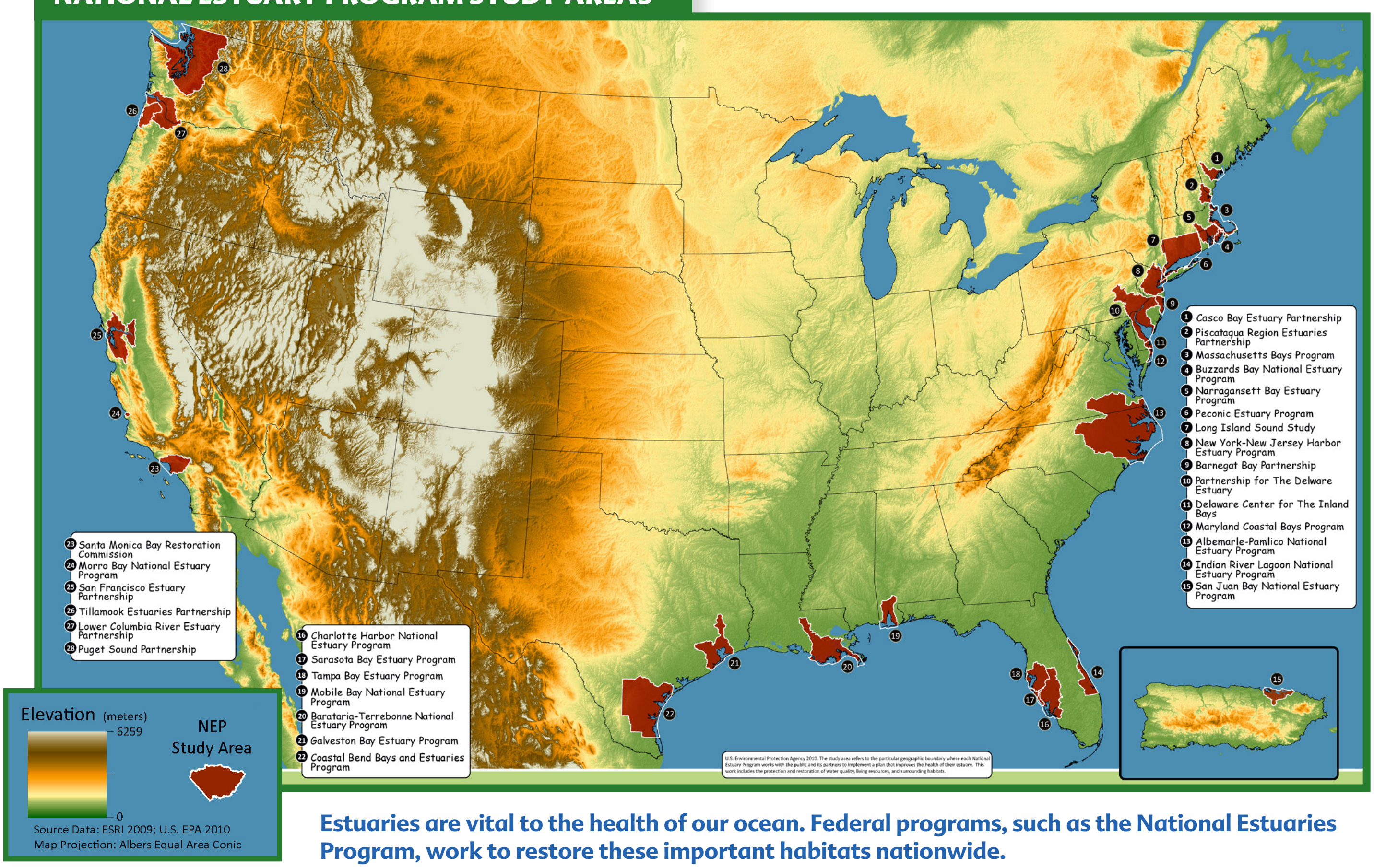
	Common Student Ideas	Scientific Concepts
Hidden seafood footprint	Youth are removed from the process of commercial fishing and may not recognize the actual costs of the seafood people eat every day. Students acknowledge the impact of the act of fishing, such as hooks catching onto things they're not supposed to.	Bycatch affects many different levels in the food web. From turtles to sharks to mammals to birds, bycatch is wasteful and detrimental to biodiversity. One-third of all fish caught are discarded as bycatch. (Lovgren 2007)
Fishing and food webs	Overfishing is about numbers. Fisheries are taking too many fish and recreational fishing (like what a kid does with a parent during summer vacation) contributes to the problem.	The problem with overfishing is not only a numbers problem. We need to be thoughtful about the species we fish and where they fit into the ocean food webs (i.e., trophic levels).
Pollution	Students think *dirty* and *polluted* are the same thing, and they may classify naturally, seasonally, or occasionally disturbed or turbid waters as polluted. Surveyed adults view ocean-based environmental issues as less concerning than other issues (e.g., air pollution) (The Ocean Project 2009).	Increased sediment loading from human-induced erosion and nutrient loads from farming, industrial, and urban runoff severely affect marine ecosystems and can reduce biodiversity significantly by creating "dead zones," especially along coastal areas.
Invasive species	There are fish that are good for the environment and others that might be harmful. Invasive fish species need to try to "get along" with native fish.	Invasives are generally introduced by humans, sometimes intentionally, sometimes accidentally. New species compete for food and space with native species, often without predators to keep them in check.

Estuaries: Ecosystem Service Providers for Humans and Marine Life

The Leschenault Estuary in Western Australia is home to hundreds of waterbirds and other wildlife.

Estuaries are critical ecosystems for humans and for marine life. Estuaries are highly productive zones, rivaling coral reefs and rocky kelp-forest habitats in levels of primary productivity. Such high productivity levels are a benefit to humans and marine organisms because they offer support and nutrients to organisms in higher trophic levels in the food web. The support at the base of the food web extends to juveniles, adult species, and fish that humans consume. While estuaries often have low numbers of permanent marine residents, they are often teeming with juveniles of nonresident and migratory species using the estuary as a feeding or breeding ground. Estuaries, at the intersection of fresh and salt water from rivers and the ocean respectively, see vast exchanges of water and all it contains with every change in the tidal cycle. Given this large flux, estuaries can filter different components of the water. In the following, we discuss these two important ecosystem services of estuaries as well as the challenges they face: their

NATIONAL ESTUARY PROGRAM STUDY AREAS



Estuaries are vital to the health of our ocean. Federal programs, such as the National Estuaries Program, work to restore these important habitats nationwide.

role as nursery habitats and their ability to filter the brackish water within their systems.

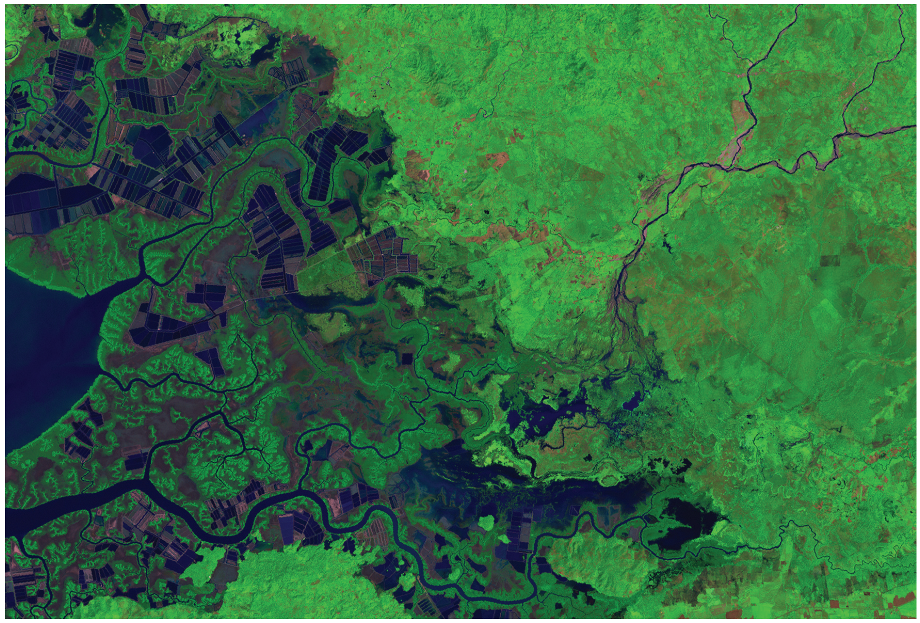
Estuaries as Nursery Habitats. Estuaries are one of the most productive ecosystems in the ocean. Sources of primary productivity in the estuaries include sea grasses, kelps, and phytoplankton. Sea grasses and kelp offer protection and act as a nursery habitat for juveniles and planktonic larvae that would otherwise be exposed to predators. High-phytoplankton biomass supply food directly to larvae and juveniles or are the base of a food chain that supports the growing organisms. The rich nursery environment supports the juveniles, which then act as the source for the adult population as the organisms grow and move out of the estuaries into the habitat of the adults. The juveniles also play their role in the food web as prey for predators.

As humans find more and new ways to utilize estuaries, the nursery habitats are diminishing, impacting the food and habitat available for juveniles and, thus, the recruits and food for larger predators. In California, humans have filled in large areas of the San Francisco Bay for different uses: salt ponds, construction expansion for business and residences, deposition of dredge spoils, ports and transportation, landfill and wastes, and other uses. These changes not only decrease habitat but also can disrupt water flow and change current patterns. The filling of estuaries can also affect migratory or seasonal species, such as salmon on the U.S. west coast.

Many aquacultural practices are also detrimental to estuaries. In Southeast Asia, shrimp farming in coastal areas and estuaries has severely depleted the mangroves. Mangroves and coral-reef ecosystems support each other—mangroves serve as nursery areas for species that live on coral reefs as adults. Additionally, mangroves provide food for juvenile marine species. As irresponsible shrimp farming grows around the world, mangroves continue to decline, taking important estuarine habitats with them.

Estuaries' Ability to Filter. As rivers flow into the sea, they bring with them many chemicals, sediments, and organisms collected as they flow from their sources high in the mountains and

Shrimp farming in Southeast Asia leads to habitat loss and high nutrient levels.



Estuaries filter sediments and chemicals that are carried by rivers. Sediments may collect and form a barrier near the mouth of rivers.

A bald eagle swoops down for its next meal as the unfortunate fish gets too close to the surface.

far inland. In many cases, this collection includes pollutants and contaminants from a variety of human sources. In the United States, federal, state, and local governments have made many, often successful, attempts to regulate the flow of wastes and pollutants that enter rivers by enacting legislation such as the Clean Water Act of 1972. However, such regulations can only control so much, and rivers are still threatened by nonpoint source pollution: pollution coming from a variety of sources that may not be easily identifiable. Examples of this type of pollution include pesticides from farms that runoff and enter the river after a rain event, animal waste with hormones and excess nutrients coming from feed lots or aquaculture centers, or oil, gas, and other petrochemicals from highways.

As these pollutants make their way toward the sea, they are often dumped into estuaries near the mouth of the river. Nonpoint source pollutants may settle to the bottom and banks of an estuary while their associated sediments settle out as the flow of the river slows upon entering a wider, deeper estuarine bay. Filter-feeding organisms in the estuary, such as mussels or sand dollars, may incorporate pollutants into their tissues as they retrieve their nutrients from the river water entering the estuary. Some pollutants have the ability to travel up the food chain and can contaminate higher trophic animals. This has been a large problem in the United States with DDT and PCBs released years ago, as well as the on going introduction of mercury and lead.

Fortunately for the organisms in the estuary and for humans that rely on those organisms, estuaries have the ability to filter much of what enters their boundaries. Many filter feeders that live in estuaries, including oysters, filter toxins out of the water and into their bodies. Many estuarine plant species are also capable of breaking down harmful chemicals into less toxic ones. While this is a natural treatment for contaminants, estuaries can only filter so much of what flows into them before seeing side effects. Estuaries and their organisms can handle higher loads of pollutants than many other, more fragile, ecosystems, but they too have their thresholds.

For most of the history of our planet, estuaries only have needed to filter natural contaminants: sediment from erosion in the mountains, ash and dead materials from fire events, increased sediment loads from seasonal fluxes or cyclical floods, and so on. As humans began to impact the land, estuaries have had more input to handle, with the same capability of filtering and tidal cleansing. As our technologies have advanced, these practices have included more and more unnatural contaminants, from farming and cultivating practices, to raising livestock, clearing forests and developing the land, mining, and so on. While estuaries filter as they are inundated with cycles of fresh and salt water, they may have a limit as to how much **anthropogenic** runoff they can bear. We are starting to see some of these limits. The Chesapeake Bay and Mississippi river delta have large dead zones from nutrient overloads (also known as eutrophication) and many organizations are still working diligently to restore the health of these estuaries.

Student Thinking

Adapting to Change

Building a new road in Babeldaob, Palau, requires dredging for gravel, a process that destroys the local marine ecosystem.

Students may struggle with understanding biological adaptations, especially adaptations to environmental stress such as habitat destruction, overexploitation, pollution, and other threats. They may see adaptation as something individual organisms can "choose" to do, rather than a genetic predisposition toward survival. Students may wonder why organisms cannot find other places to live when their homes are changing.

Scenario

Your students are in small groups discussing animal adaptations with a specific focus on climate change as a driving factor. As you walk around the class, you overhear some answers your students are giving to the discussion, and you decide to give your students a short journal-writing assignment at the end of the discussion in order to see how many students do not understand adaptation. Look at the following journal responses, and think about how you would respond in your teaching.

Question

How do plants and animals adapt to changing environments? How does this happen? How long does it take?

Scientific Answer

Some species may have adaptations that allow them to continue to exist in areas experiencing environmental changes, but other species may be less successful when these changes occur. Adaptations are genetically determined and passed on to offspring. Individuals that do not possess a certain adaptive trait are less likely to survive. Those that have the adaptive trait will pass this trait to their offspring, eventually changing the genetic makeup of a population as the adaptive trait becomes more common.

Student Answers

CJ: If an organism was adapted to live in a specific habitat and that habitat changes, then the animal might die or it would have to adapt to the new climate. I think it would take about a few years for it to adapt.

Leah: If an animal had adapted to a certain habitat and then that habitat was changed, I think that animal would have to change the way they live to keep life going. I think it would take about a century to actually have the animals fully adapt to their new climate or the change for their new habitat.

Reagan: I think it would take quite a bit of time to readapt. Because it's kind of like moving to a new place and trying to make new friends. Because you can't just say, "Want to be my friend? Okay." You have to get to know them. So in readaptation, you would say, "This is where I am now. This is what I have to do." And you have to try really hard to get do it. If the water was going darker, it would need to try to see better. It would need to work on its eyeballs, and it would need to use its senses more.

What Would You Do?

1. What do these students not understand about adaptation? What are the key misconceptions that you see in their answers?
2. What type of follow-up could you do with the class to ensure all students understand this topic?

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Teaching Resources

TED Talks:

- Enric Sala: Glimpses of a pristine ocean: http://www.ted.com/talks/lang/eng/enric_sala.html
- Jeremy Jackson: How we wrecked the ocean: http://www.ted.com/talks/lang/eng/jeremy_jackson.html
- Sylvia Earle's TED Prize wish to protect our oceans: http://www.ted.com/talks/lang/eng/sylvia_earle_s_ted_prize_wish_to_protect_our_oceans.html
- Dee Boersma: Pay attention to penguins: http://www.ted.com/talks/lang/eng/dee_boersma_pay_attention_to_penguins.html

Monterey Bay Aquarium Seafood Watch: http://www.montereybayaquarium.org/cr/cr_seafoodwatch/sfw_gear.aspx#longline

National Geographic Ocean Education: http://www.nationalgeographic.com/geography-action/oceans.html

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

5 Health Concerns for People and Wildlife

by Rachel J. Fisher

The ocean greatly benefits humans by providing sustenance, oxygen (most of which comes from photosynthesis of phytoplankton), employment, recreation, and the potential for scientific discovery with pharmaceuticals. However, the ocean is also the repository of human-made pollution. This chapter will explore these and other factors that not only affect the health of the wildlife that inhabit the ocean, but also the health of humans that depend upon the ocean.

First, we examine the difference between point-source and nonpoint-source pollution. Then we will explore the impact that pollution, such as marine debris, oil spills, and fertilizers, has on both public health and ocean wildlife. In the last portion of this chapter, we look at the process of bioaccumulation in marine organisms and the effect of biomagnification of toxins on the wildlife and the humans that consume these marine creatures.

Pollution in Our Ocean

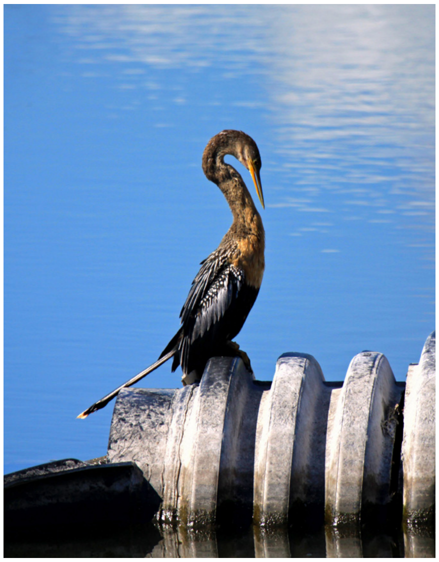
Our ocean is currently being polluted by a variety of sources. There are two main types of pollution, point and nonpoint source. Students may know about pollution sources but likely cannot differentiate between these two main types. We can contrast these two types of pollution by looking at the source of the pollution, or where it originates.

Point-source pollution is pollution that has an identifiable, even visible, source. With **nonpoint-source pollution,** it is less clear where the pollution originates. Yet, even in distinguishing between these types of pollution, we still find that both are detrimental to the health of wildlife and humans.

Point-Source Pollution. Point-source pollution is easier to control than nonpoint-source pollution because it is easy to identify where the pollutants originate. The following definition of point-source pollution comes from the Environmental Protection Agency: "any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack."

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.c-e 3.5.3	Living Things in Changing Environments California Economy—Natural Choices
Grade 4	4.2.a-c 4.3.b	Plants: The Ultimate Energy Resource The Flow of Energy Through Ecosystems Life and Death With Decomposers
Grade 5		
Grade 6	6.5.a-e	Energy: Pass It On! Playing the Same Role
Grade 7	7.3.e	Responding to Environmental Change
Grade 8	8.12.1 8.12.5	Agricultural and Industrial Development in the United States Industrialization, Urbanization, & Conservation Movement

The ocean receives pollution from many different sources that contaminate the water and destroys marine habitats.



The pollutants from industry and sewage treatment plants flow out as discharged waters. The discharged waters with their pollutants often are released directly into water sources, such as streams or rivers, and many eventually reach the ocean. At high concentration, these pollutants can make water dangerous for consumption, endanger the lives of aquatic organisms, and affect the usability of an area for recreation.

Nonpoint-Source Pollution. Unlike point-source pollution, there is no single, identifiable area where nonpoint-pollution originates. Often pollution found in the ocean is the result of many sources, not just one. Runoff from the land is usually the cause of nonpoint-source pollution in the ocean. Rain or snow can pick up chemicals on land and deposit them into coastal areas, wetlands, or freshwater sources. These chemicals can come from a variety of runoff sources, such as runoff from industrial, agricultural, municipal, or construction sources. Additionally, about one quarter of all carbon dioxide emissions are absorbed by Earth's ocean. When the ocean waters interact with this gas, it causes acidification, which can be harmful to marine organisms.

Nonpoint-source pollution is a major cause of health-related issues

CHAPTER OVERVIEW

The ocean can have serious effects on human health and the health of wildlife. Oil spills and harmful algal blooms (HABs) can cause respiratory and neurological problems. Toxins, hydrocarbons, heavy metals, and endocrine disruptors can be passed to humans through the food chain and cause immunological, neurological, and reproductive problems. Through our activities, we are often the source of these health issues. Point sources of pollution, such as oil spills and sewage treatment plants, lead to the increase of hydrocarbons and other chemicals in the ocean. Nonpoint-source pollution (e.g., from storm-water and agricultural runoff) causes nutrient loading in estuaries and other coastal ecosystems, leading to more frequent HABs. As we enjoy our seafood, we must be aware of the buildup of chemicals and toxins in animals' tissues (bioaccumulation), as well as the increase in concentration of these contaminants through trophic levels (biomagnification).

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Pictures of Practice: Biomagnification 102

Runoff from farms and factories carries substances to nearby water sources that ultimately lead to the ocean.

in wildlife, and it has had detrimental effects on public health and coastal economies. Most marine pollution is nonpoint source.

Storm-Water Runoff

Storm-water or urban runoff is a major source of ocean pollution. Most stormwater runoff is point-source pollution. Precipitation carries pollutants into storm-water drains, where it then enters waterways untreated and eventually ends up in the ocean. While runoff is often nonpoint-source pollution, storm-water is collected and discharged at particular locations, so it is treated as point-source pollution. Toxins in storm-water are distributed to the world's ocean, and we can learn about the potential impact on human and wildlife health.

In urban areas, a large percentage of the ground is **impervious** to precipitation, for example sidewalks, driveways, and streets. Several cities in California, including Los Angeles, have this problem. When it rains in urban areas or when snow melts, there is no percolation or infiltration into the ground by water; rather, it flows off these paved areas and into nearby storm-water drains and then eventually makes it way into the ocean. On its way to the storm drain, the water picks up a variety of pollutants, including oil from cars, pet waste, pesticides from lawns, and dirt and lawn debris.

The pollutants that enter the ocean through storm-water runoff can carry with them bacteria and other pathogens, which can have devastating health effects on swimmers or marine organisms. Swimming near a flowing storm drain or at a beach that is heavily

Teaching Tip

You may want to consider doing a brief activity with point-source and nonpoint-source pollution. If you show different pictures of these types of pollution, and students can point with their finger to where the pollutants are coming from, that will help them remember that those are *point-source* pollutants. If they cannot point to the specific source, such as a drain or a pipe, then the image is an example of *nonpoint-source* pollution. You may consider developing a table such as the one following, as you teach the different types of pollution. You may also add a column to the table to have students explain why a type of pollution is either point source or nonpoint source.

	Point Source	Nonpoint Source	Explanation
Litter on each			
Oil spills			
Fertilizer runoff			
Storm-water overflow			

impacted by storm-water runoff has been linked to ear infections, respiratory infections, and stomach flu.

Marine Debris and Human Health

The last chapter introduced the topic of marine debris and its effects on wildlife. Marine debris can affect humans too. Swimmers, surfers, and other beach-goers can potentially be injured by marine debris either in the ocean or just on shore. Glass or metal parts from marine debris can cut swimmers, surfers, or people who are walking on the beach. This can ultimately lead to infection or other damage to the person's skin. Needles that were disposed of improperly can also puncture the skin. Old fishing gear, such as fishing lines or crab traps, can entangle a person's limbs and cause injury.

The presence of plastics in the ocean can also have harmful effects on humans. Many plastics, such as plastic bags, are made from a byproduct of petroleum and natural gas called **polyethylene.** When plastics degrade in the ocean they add chemicals to the water. Another effect that is still under intense study is the effect of plastics on the human endocrine system. Considerable attention has been paid to the use of **bisphenol A (BPA),** a chemical used in the production of plastics that has been categorized as an endocrine disrupter. BPA has been shown to affect the endocrine system, potentially leading to neurological, reproductive, and immunological problems, which is of concern in fetuses, infants, and children (National Toxicology Program 2007). Therefore, this chemical is being phased out from its previous uses in baby bottles, water bottles, canned foods, and so on. Today, you see signs that advertise "BPA free" on plastic products such as water bottles. Your students have likely seen these ads on television or in stores.

As tiny plastics enter the oceanic food web, there is potential for humans to be affected by endocrine disruptors, such as BPA and other chemicals. Students can identify many plastic materials that end up in our ocean, from plastic bags to plastic soda rings, but they probably only see these as detrimental to wildlife.

In some places of Bangladesh, debris in the water is so common that the people who live nearby ignore the dangers and swim amongst the flotilla of garbage.

Talking with students about plastics and how they break down may help students better understand that marine debris is not only unsightly on our beaches but is a health concern as well.

Oil Spills

Oil discharges, both intentional and unintentional, have had devastating effects on aquatic organisms and their habitats.

Students have heard stories of oil spills and may have even seen an oil sheen on the ocean surface near recreational boats. Given recent attention to oil spills and the use of dispersants, students may wonder how oil is broken down or cleaned up. They also have ideas about oil floating on water—although oil often floats on salt water, sometimes oil is denser than salt water, and remains under the surface of the ocean. As you teach about oil spills, think about the experiences your students have (directly or vicariously) and the visual images they have of oil spills. These experiences and images conjure up emotional reactions—images of birds covered in oil or fishers out of work. It may seem obvious to students that oil spills are bad for the environment, but they may be less familiar with the causes of these problems (i.e., how we use oil in our everyday lives) and the long-term consequences on wildlife and human health.

Uses of Oil. You may not realize it, but oil is used to make plastics found in many products we use everyday, such as radios, iPods, and even the pens we use to write. Students are probably not aware that these are petroleum-based products. Additionally, oil is used to make fertilizers we may use on our lawns and medicines that we take every day. Many people use oil to heat their homes on cool days, and we use oil to fuel cars that take us to and from school and work. The antifreeze that is used in

Bird species are among the first victims of an oil spill, as they seek their food sources within the contaminated waters.

our cars is a derivative of oil as well. The trucks on the highways and the ships on the seas use oil as fuel too. Many of the roads we drive on are made of oil-based asphalt. As you can tell, oil is all around us, and it is a very important resource. It is not just used to make gasoline! This same resource that keeps us warm in the winter or helps us get from work to home can have devastating effects on the environment if we are not careful with its extraction and disposal.

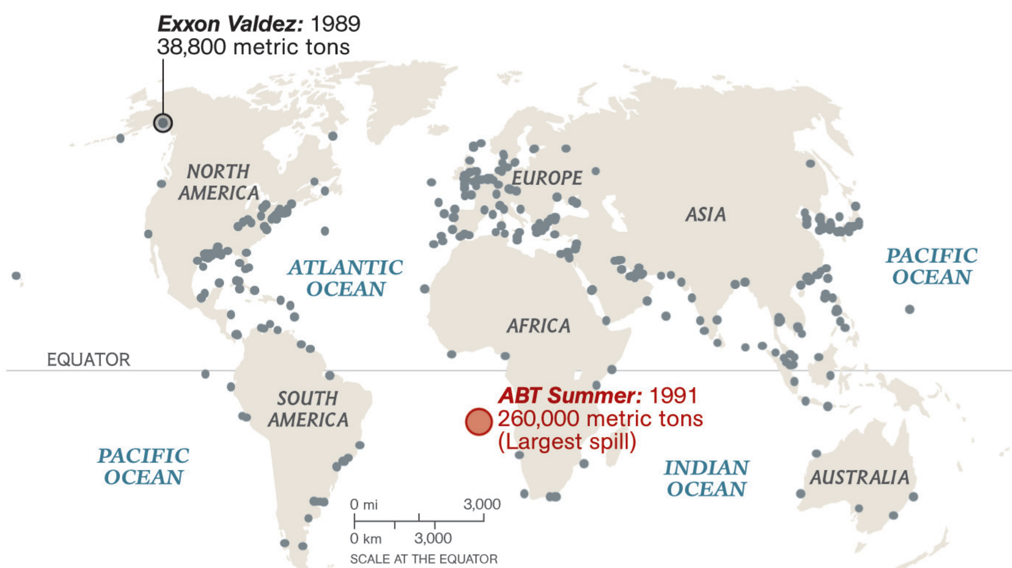
How Do Oil Spills Happen? Oil spills, for the most part, are the result of both accidental and intentional acts of humans. A minor cause for oil spills is when someone releases a can of oil into a storm drain, from which the oil eventually finds its way to the ocean. Storm-water runoff can carry oil from the roadways into drains and into the ocean; this is an often overlooked nonpoint source of oil pollution, as are minor leaks from personal watercraft, particularly as gas tanks are refilled.

While most of the oil pollution in the ocean originates from small spills that are aggregated, large-scale spills have the most visible effects on wildlife and humans (National Research Council 2003). These spills result from any of the following human actions: oil tankers sinking in the ocean, blowouts at the site of oil extraction, oil tankers' gas tanks overfilling, or collisions between tankers or barges as oil is being transported from one nation to another, to name a few. The 2010 Gulf of Mexico oil spill was a result of a blowout on an oil rig drilling in approximately 1500 meters (~5000 feet) of water. In addition to human-induced spilling, natural oil can seep from many areas of the ocean bottom. One of the most notable locations for this seepage is along the California coast near Santa Barbara, just a few miles from the shoreline, called Coal Oil Point.

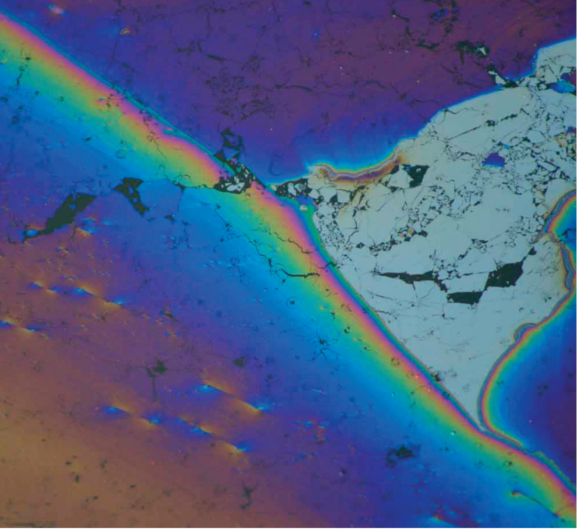
How Oil Interacts With Salt Water. Oil and water, in general, do not mix, because oil is less dense than water. Saltwater changes how oil behaves; in fact, oil floats more in salt water than in freshwater because of salt water's higher density. When large quantities of oil enter the ocean, such as that which occurred during the Santa Barbara Oil Spill of 1969 (see the following for more information), most of this concentrated oil floats on the surface of the water. There are exceptions; when the oil is heavy enough, it will sink. Once oil has entered a large body of water, the winds, currents, and tides spread the oil on the water surface, which is also called an oil slick. Many times, you will notice a rainbow on the surface, which is called a sheen. If you have ever observed gas leak onto pavement, you may have noticed a

TANKER AND BARGE OIL SPILLS

A WORLD OF SPILLS
This map shows the 439 reported oil spills of ten metric tons or more from tankers and barges between 1989 and 2007. Since the 1980s, spills of 700 metric tons or more dropped from an average of nine a year to four.



NGM MAPS. SOURCES: INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION; *EXXON VALDEZ* OIL SPILL TRUSTEE COUNCIL



After an oil spill, attempts are made to clean up the water, shores, and wildlife affected.

similar sheen.

Effects of Oil Spills. Any type of oil spill, especially those of larger scale, can have devastating effects on wildlife and human health. Even though many major oils spills take place in the ocean, the toxic effects of oil spills can reach the shore and farther inland.

Because most spills affect the surface of a body of water, organisms that live near the surface, such as aquatic and marine birds (herons, eagles, osprey, cormorants, pelicans, and scoters) and small marine mammals such as sea otters and sea lions, are most commonly affected. Oil can damage the feathers of sea birds by destroying the waterproof property of their feathers, and it can also affect their ability to fly. Oil destroys the insulating properties of fur and feathers by not allowing them to trap air near the body. Without this layer of air to keep the birds and mammals warm, many die of hypothermia in the relatively cold water. Additionally, oil can harm the internal organs of these birds and other aquatic organisms, as they ingest it through attempting to groom the oil away, and in many cases, kill them. Some studies have shown that a coating of oil keeps the animal's skin from respiring, which can kill them as well.

Oil from many large-scale spills can eventually be shifted on shore by winds, currents, or tides. The organisms that inhabit these environments, such as sea grasses, clams, and crabs, can become inundated by oil as well. Many birds nest on the beach, and these birds, including any eggs or hatchlings, can become sick or die as a result of the invasive oil. Additionally, predators of these eggs or hatchlings can become sick after consuming the contaminated birds or eggs.

In addition to wildlife, humans that live in areas affected by oil spills can become sick. Fumes released from oil can irritate the eyes, nose, or lungs. Additionally, oil contains **hydrocarbons,** which can be **carcinogenic** (cancer-causing) to humans.

Teaching Tip

Most students do not realize the importance of oil in their daily lives. Have your students predict what will happen if we run out of oil. Most likely students will bring up problems with cars, transportation, and maybe home heating and air conditioning. Then have your students generate a list of things that are made from or use oil. Help your students conduct research on other oil-based products to expand their list. Have them also take note of alternative products. They should discover that plastics, fertilizers, asphalt, medicines and medical equipment, and so on should be on their list (see example list at http://www.anwr.org/features/oiluses.htm). Students should have a much broader perspective on this issue after their research. Revisit the original question about what would happen if we run out of oil, and ask students to share what they learned about alternative products.

Case Study The Santa Barbara Oil Spill

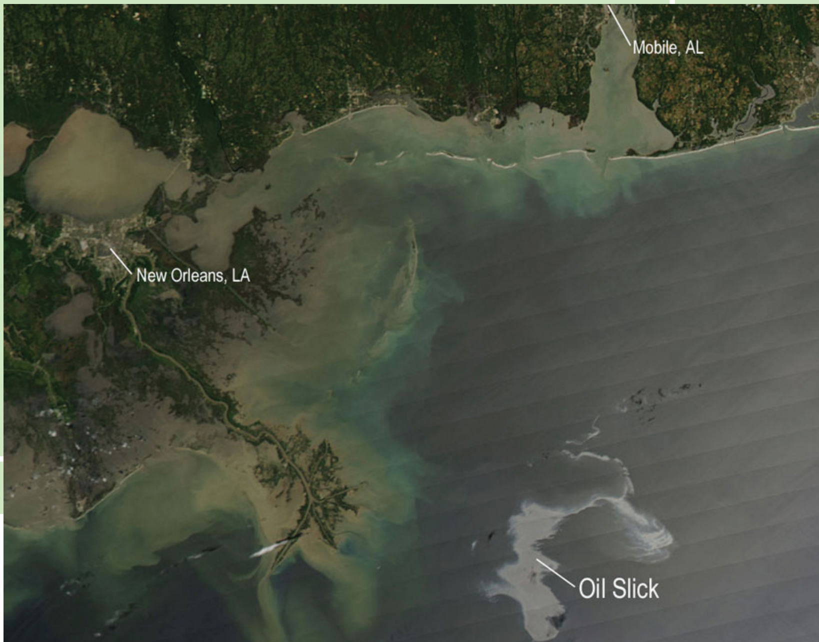
Oil and tar wash onto California beaches from spills and natural seepage.

One of the worst incidents in the United States involving an offshore oil-drilling platform took place approximately 8 kilometers (5 miles) from the coast of Santa Barbara, California, on January 28, 1969. The Santa Barbara oil spill ranks as the third-largest oil spill in U.S. history behind the Exxon Valdez spill (second) and the Deepwater Horizon spill (first). A "blowout" occurred as drill bits were being changed on the platform. This resulted in a massive spill (up to 210,000 gallons of oil spilled in the first two weeks) as a mixture of gas, oil, and mud blew to the surface for several days. The winds, currents, and tides eventually moved this material on shore, so it had a great effect on aquatic organisms and their habitats. Sea walls and buildings onshore became coated with this oil mixture. Birds, intertidal invertebrates, and kelp forests were also destroyed in the process. Additionally, this spill had significant economic effects on the fishing industry. It caused a loss of recreational facilities, and personal property damage (boats, buildings, seawalls) was far reaching as well.

The cleanup after the oil spill involved more than 54 boats, more than 1,000 people, and approximately 125 pieces of equipment. In total, it cost about $4.5 million to completely clean the Santa Barbara area after this spill. Many people were involved in manually removing the oil that was on beaches and floating offshore by using straw to absorb the oil. Additionally, rocky beaches were cleaned using high-pressure washers, and a mixture of naphtha and talc was used to dissolve the tar-like oil on rocks and sea walls. More than 3,700 birds died as a result of this oil spill as well; in particular, gulls and grebes were most heavily affected. Many people were involved in trying to remove oil from the feathers of the birds that were still alive during clean up.

Other Notable Oil Spills

The Exxon Valdez Spill that occurred in 1989 spilled more than 10 million U.S. gallons of oil into the Prince William Sound of Alaska. It took many years to clean, and its impacts, some scientists argue, are still being felt today. The Cosco Busan oil spill, which occurred in 2007 in San Francisco Bay, resulted when a container ship struck the Bay Bridge. While the spill was considered "medium-sized," it resulted in many beach closings both north and south of San Francisco Bay and affected organisms, including seabirds and seals. The April 20, 2010, oil spill in the Gulf of Mexico was much larger than the Santa Barbara, Cosco Busan, and Exxon Valdez spills. The Deepwater Horizon Spill quantity is estimated at more than 200 million gallons, and its impact—both economic and ecological—will take years to determine. Restoration will likely take even longer.



Student Thinking

Pollution in the Ocean

Students typically think of point-source pollution entering our ocean. They describe people physically leaving trash on beaches, or can identify particular sources of pollution, such as from a factory or an oil rig that they believe dumps substances directly into the water. Students are less likely to describe nonpoint-source pollution and are also less likely to identify accidental or unintentional pollution. Oftentimes pollution is associated with a "villain" that is intentionally polluting our waters.

Scenario

You are teaching an extensive unit on the ocean to your students and planning to address issues of storm-water and fertilizer runoff. You decide to do a journal activity with your students to assess how much they know about ocean pollution. This will help you determine your starting point for the lessons and concepts that students already understand, as well as ones they do not yet understand. The following are example journal entries you receive from students. Read their ideas and then brainstorm how you would use this information to guide your teaching.

Question

Describe as much as you know about ocean pollution.

Scientific Answer

The ocean is polluted by a variety of sources, some visible and some invisible. This includes microscopic chemicals from fertilizer and storm runoff as well as visible pollutants such as oil and marine debris.

Student Answers

Tony: There is an island in the middle of the ocean that has over 1,000 pounds of pure raw sewage and garbage. Oil comes from the factories over there. Sometimes they spill it.

Alison: People pollute the ocean. They can leave their trash on the beach and then the waves come up and it gets swept into the ocean and then it can get caught on fish or fish can eat it because they think it's something else.

Morgan: People pollute the ocean with oil sometimes. And also with garbage, if people throw their garbage off into the ocean, it's really bad too. It's just a natural instinct if they can't find the garbage can, they just throw it in the ocean.

Jacob: One of the worst things you can do to the ocean is dump waste in it, whether it's petroleum or toxic, or just the every day trash. A lot of things die just because people are careless. A lot of people do it because they make money.

What Would You Do?

1. Think about the sources and types of pollution that students mention. What are they not mentioning? How would you use this information to adjust your teaching plans?
2. Notice that most students mention intentional pollution. What short activity might you include to help student see unintentional pollution that they can control (i.e., oil runoff from driveways, lawn and garden runoff, and so on)?

Teaching Tip

Ask students if they have seen their parents spray anything on a garden or their lawn, and if so, ask them why we spray these things onto plants. If possible, have students examine the labels from different fertilizers and note patterns in the chemicals that are included. Introduce "nitrates" and "phosphates" as key nutrients that spur plant growth and health. If possible considering conducting a lab on the effects of these fertilizers when they enter runoff. See an example at http://pubs.usgs.gov/of/1998/of98-805/lessons/chpt6/act2.htm.

Fertilizers and Harmful Algal Blooms

All across our nation, fertilizers are applied to suburban lawns, golf courses, gardens, and agriculture fields to help keep the plants in these areas growing and healthy. Plants need nitrogen and phosphorous to grow. Fertilizers are designed to provide plants with the needed nitrogen and phosphorous to help them grow large, strong, and healthy and to do so quickly.

As we discussed earlier in this chapter, runoff is a major source of pollution in our ocean. Yet, students may think of runoff as only carrying chemicals from our roadways. However, runoff from farms is a key contributor of pollution. Often, an excess of fertilizer is applied to an area, so that when it rains, the fertilizer that is not absorbed by plants and soil is picked up by the rainwater and then makes its way into the ocean. The runoff of fertilizer can affect the health of the coastal ecosystems and the people that live in these areas. Fertilizer that is not part of runoff may make its way into the groundwater, thereby contaminating drinking water for those who live nearby.

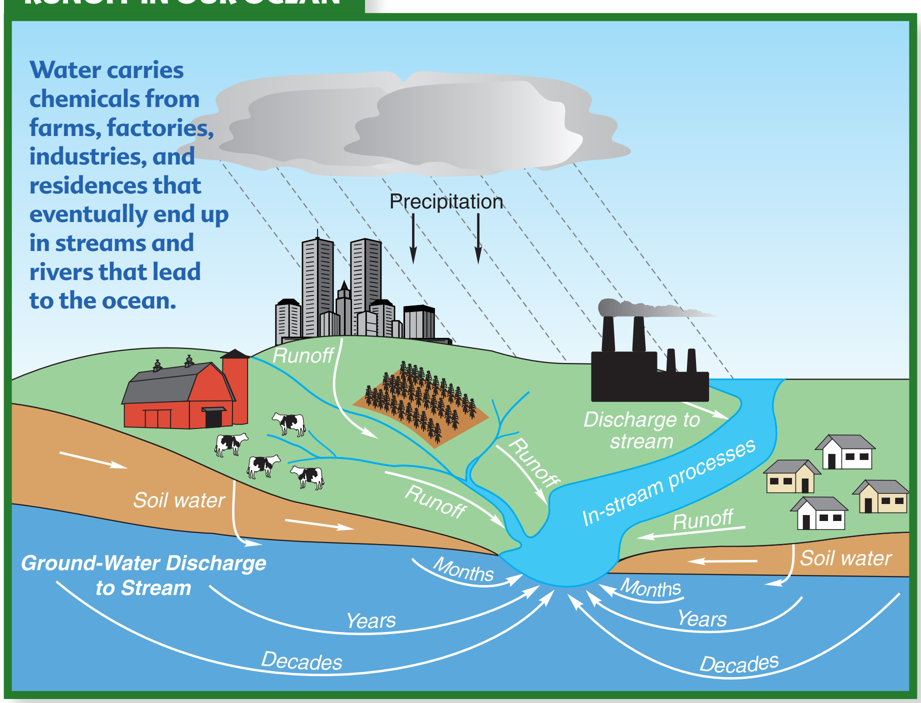
Nitrates and Phosphate Nutrients. As previously mentioned, nitrogen and phosphorous are key elements in fertilizers. When these elements interact with water (as they enter natural water sources), they can become nitrates and phosphates, respectively. A nitrate is a combination of nitrogen and oxygen, or dissolved nitrogen in water. Phosphates are a combination of phosphorous, oxygen, and hydrogen, or dissolved phosphorous in water. Knowing about these elements is important for understanding environmental consequences such as algal blooms.

Algal Blooms. Algae are part of a normal food chain in an aquatic ecosystem because they serve as food, directly or indirectly, for many creatures. Algae are photosynthetic organisms, meaning that they make their own food by converting light energy, water, and carbon dioxide into the sugars they need to survive. During this process, called photosynthesis, oxygen is released as a byproduct as well. One type of algae is called phytoplankton, which are microscopic drifting plant-like organisms.

The buildup of excess nitrates and phosphates in ocean waters can cause abnormally large algal growths, specifically by phytoplankton. Algae that inhabit coastal waters need a normal amount of nitrogen and phosphorous for growth, much like land plants. When there is an excess of these nutrients, algae can grow and reproduce uncontrollably.

In addition to nitrogen and phosphorous, algae need an optimal salinity and temperature for growth. A bloom, or large growth of algae, takes place when all conditions are favorable

RUNOFF IN OUR OCEAN



for the algae. However, when an excess of nutrients is present, large blooms occur, which can have a great impact on the aquatic environments and the organisms that inhabit them. This excessive growth of algae combined with low oxygen concentration in water (and often low pH) is called eutrophication, and it can take place in lakes, streams, estuaries, and coastal areas. These blooms will last as long as the nutrients are available to them in the water. For example, if there is a small area where fertilizer runoff has entered the ocean, an algae bloom may grow but only as long as the nutrients from the fertilizer stay in the area.

Effects of Algal Blooms on the Environment. When algae grow excessively, they can almost look like a large, green "mat" on top of the water. This mat prevents light from getting through the water column and down to the plants and other algae that live below the surface. This can potentially kill them and also affect the populations of organisms that live off of them.

Additionally, although these algae normally undergo photosynthesis, which releases oxygen during the nighttime, because there is no sunlight, the algae are undergoing cellular respiration, and not photosynthesis. This process of cell respiration takes in oxygen from the water, which causes low levels of dissolved oxygen in the water. This can result in massive fish die-offs because they rely on oxygen for survival. When these algae die and decompose, the decomposers use oxygen to break down the algae, further depleting the waters. When an area has little-to-no oxygen available it is called hypoxic (hyp = less, oxic = of oxygen) or anoxic (an = no). If an area is subject to repeated blooms and long-term hypoxic or anoxic conditions, it becomes what is known as a dead zone in the ocean

MAKING OF A DEAD ZONE

HOW THE DEAD ZONE KILLS

1 Fertilizer and other compounds empty from the Mississippi River into Gulf waters.

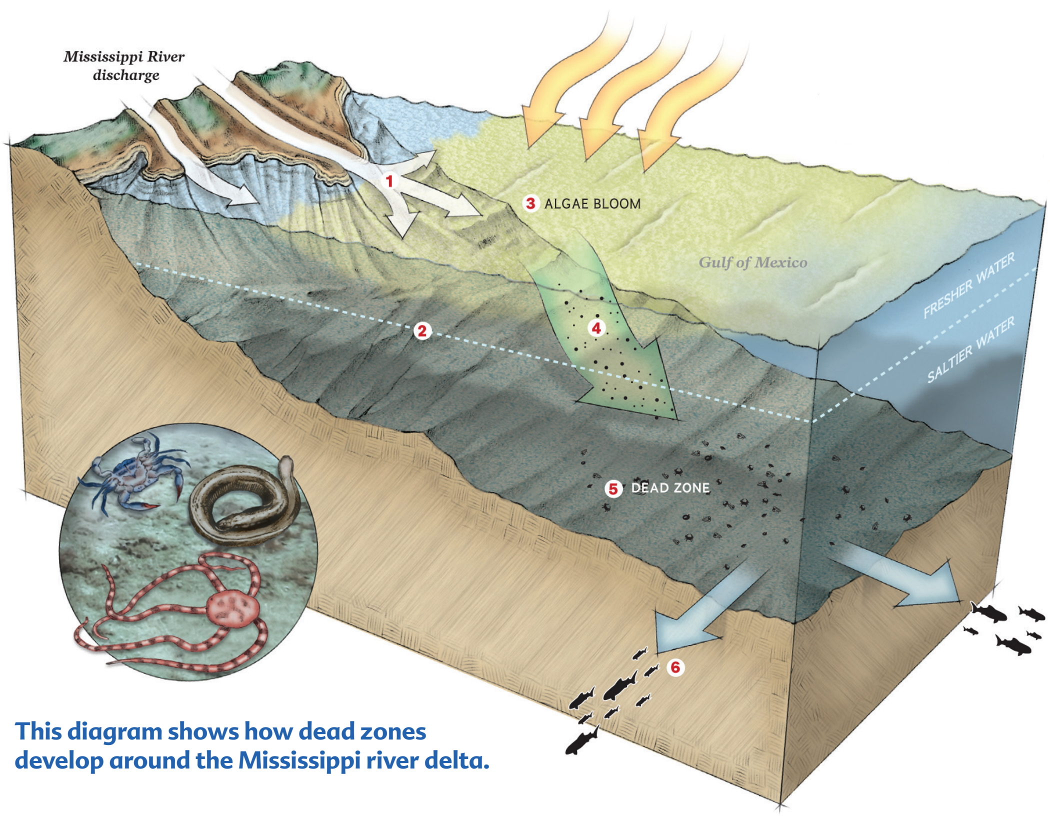
2 In spring, freshwater runoff creates a barrier layer, cutting off the salt water below from the oxygen in the air.

3 Problem: Various fertilizers and the warming waters cause an algae bloom.

4 Dead algae sink to the bottom and are decomposed by bacteria, depleting the oxygen in deep water.

5 Marine animals that live at depths that are depleted of oxygen suffocate and die.

6 Some fish and other fast movers are able to escape the growing dead zone.



This diagram shows how dead zones develop around the Mississippi river delta.

Algal blooms on the Volga River in Russia have become a common sight, due to agricultural pollution.

because very little life can survive there without oxygen.

The number of dead zones in the ocean is growing. First identified in the 1960s, scientists recognize more that 400 dead zones the world over. Some dead zones are seasonal, while others persist year-round. Dead zones are not irreversible, however. After Hurricane Katrina cleared out the Mississippi river delta, the long-standing dead zone in the Gulf of Mexico disappeared for a while. Concentrated efforts to reduce runoff have helped to eliminate or reduce other dead zones. For example, improvements in Los Angeles sewage treatment led to the elimination of the dead zone in Santa Monica Bay.

Harmful Algae Blooms (HABs). Some algal blooms are characterized as harmful algal blooms, or HABs. During a HAB, the species of phytoplankton that is blooming releases toxins that can injure or kill wildlife and make humans quite sick. On the west coast of the United States, at least five major HABs have been documented. A common term for a HAB is a red tide, though this term can be misleading. Traditionally, a red tide refers to a bloom of algae whose coloration leads to the ocean looking red. Many species of algae have this red coloration—some harmful, some not. Other HABs in California are green algae. However, on the east coast of the United States, the red tides are so commonly indicative of a HAB that the two terms have become almost synonymous. During these HAB events, the toxins of the algae have killed fish in large numbers and have debilitated shellfish economies because it makes these organisms unsafe to eat. If toxic shellfish are consumed, it can cause paralytic shellfish poisoning (PSP), as well as other disorders and illnesses. PSP is a debilitating condition that affects the nerves in humans and can cause muscular or respiratory paralysis.

The presence of red tide HAB in coastal waters can also affect the respiratory system of people in the general area of the bloom. The airborne toxins from these growths can cause coughing, wheezing, itchy and red eyes, and in some cases, chronic respiratory issues. It is important to note that not all algae blooms are harmful. In fact, seasonal blooms are critical for supporting food webs. Anecdotal evidence suggests that HABs have been occurring for at least hundreds of years; Native Americans along the West Coast were well aware of PSP and its effects. The state of California introduced a program to prevent PSP in 1927 (Horner, Garrison, and Plumley 1997). Though HABs are naturally occurring, increased nutrient loading, and other ocean stressors have resulted in some types of HABs becoming more common throughout the years (Anderson, Gilbert, and Burkholder 2002).

Pesticides and Other Chemicals. Agricultural and urban runoff contain more than fertilizer. Commonly, the runoff waters from farms contain high levels of pesticides and herbicides. Pesticides are designed to kill insects that prey upon our food species. Runoff from residential areas may carry chemical used to treat lawns, parks, and golf courses. The herbicides are used to keep weeds and plant species of non-agricultural importance from growing in fields. One commonly used herbicide, atrazine, is implicated in the falling populations of frogs and other amphibians, and may be harmful to human health as well (UC-Berkeley 2010). Its impact on marine species is unknown.

Hormones, antidepressants, antibiotics, and other chemicals, including fire retardants and toxic cleansers (i.e., chemicals of emergency concern), are also making their way to the ocean. While some are coming through the watershed, the majority are entering the ocean through sewage treatment processes. The chemicals pass through humans and are expelled in our urine. Consumers also flush these chemicals down the toilet or dispose of them through their drains. Many sewage treatment centers cannot filter these chemicals out, so, when they release their treated water, they are releasing these chemicals as well. As the chemicals are not naturally occurring, the natural system does not effectively break them down. The long-term impact of many of these chemicals is unknown, but scientists are already seeing some impacts. Fish, snails, and other species are experiencing something known as feminization. The chemicals and hormones in the environment are keeping the males from sexually maturing fully. While it may be up to scientists to develop a way to remove or remediate these chemicals in the environment, everyday people can help. By disposing of everyday excess household chemicals, paints, and even old prescriptions at local household hazardous-waste collection events, everyone can help reduce the amount of chemicals entering the ocean.

Bioaccumulation

Before we discuss bioaccumulation, it is important to understand the concept of biotoxins, which are poisonous substances produced by an organism. In **harmful algae blooms** (HABs), page 98, we discussed how some types of algae can produce toxins that can make other organisms sick or even kill them. The toxins that are released by the algae during a HAB are known as **biotoxins.** These toxins may accumulate in any organism that feeds on the algae that produce them.

As defined by the U.S. Geological Survey (USGS), bioaccumulation is "a general term for the accumulation of substances, such as pesticides or other organic chemicals in an organism or part of an organism. The accumulation process involves the biological sequestering of substances that enter the organism through respiration, food intake, epidermal (skin) contact with the substance, and/or other means."

In other words, bioaccumulation is when a chemical builds up in an organism's body. The more of a certain chemical the organism encounters, the greater the level in its body.

Biotoxins in the Pacific Ocean. A wide range of biotoxins exist throughout the Pacific Ocean. The temperate waters of the Pacific can harbor species that produce the toxins responsible for paralytic shellfish poisoning (PSP), as discussed. **Dinoflagellates** and diatoms are responsible for these biotoxins in the temperate waters of the Pacific. As most shellfish are filter feeders, they consume these phytoplankton, and therefore, the toxin becomes concentrated in the tissues of the shellfish.

In the more tropical waters of the Pacific, (mainly in Hawaii and the U.S. territories American Samoa and Guam), the coral-dwelling, benthic (bottom-dwelling) dinoflagellates are responsible for ciguatera fish poisoning (or tropical fish poisoning) caused by eating reef-dwelling fish.

Health Effects of Biotoxins on Humans. Bioaccumulation of toxins in shellfish and fish is a worldwide health issue. Some toxins, even in very small amounts, can make people quite sick. If a person eats fish or shellfish that has bioaccumulated toxins, the toxins can kill a healthy adult in some cases. One of the biggest problems associated with algal blooms in the Pacific has been with paralytic shellfish poisoning, which has been known about for nearly 200 years.

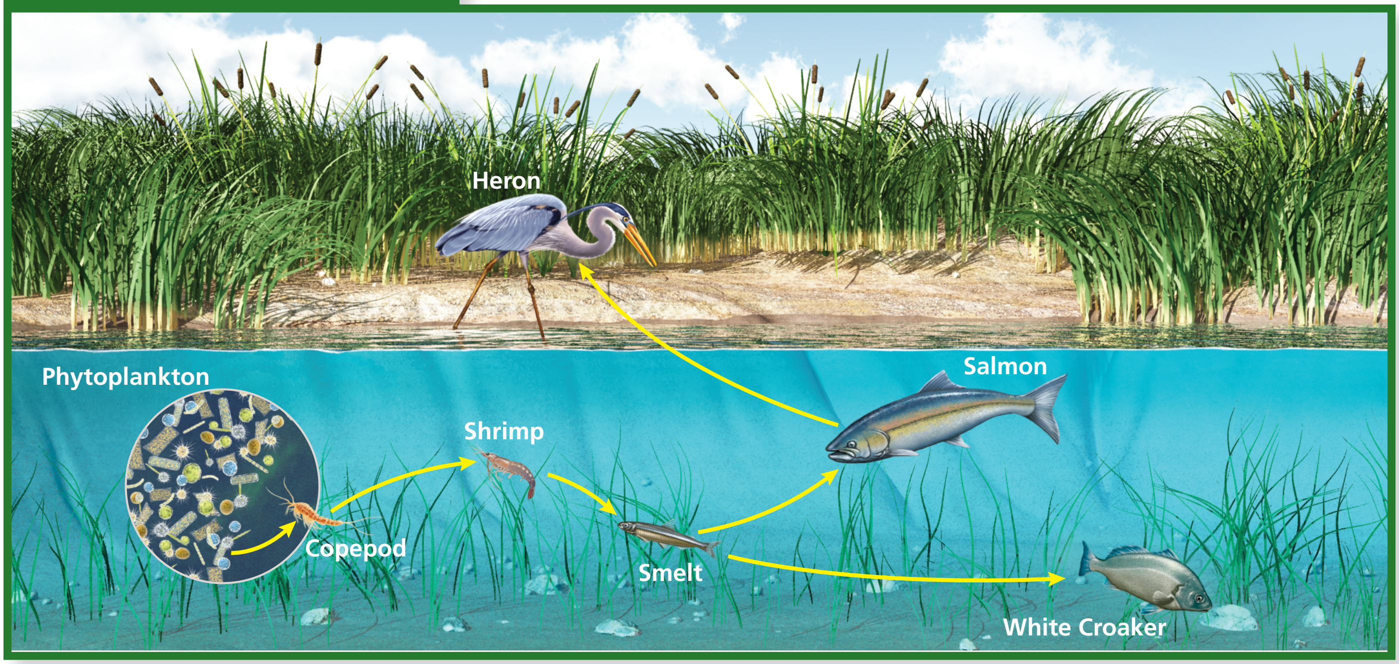
Domoic acid, which is released by a marine diatom, has caused the poisoning of shellfish and fish along the west and east coasts of the United States. The consumption of the fish and shellfish that have bioaccumulated this acid can cause permanent nerve damage and has even killed people. In Monterey Bay, California, in 1991, there was a large die-off of seabirds that had consumed anchovies. Anchovies are filter feeders and had bioaccumulated the domoic acid in their bodies. When analyzed, these birds had high levels of domoic acid in their stomach contents due to consuming the anchovies. Because it affects the nervous system, domoic acid can cause strange behavior in animals including seabirds and mammals. For example, sea lions have been observed walking down city streets and gulls flying into buildings as a result of domoic acid poisoning.

In addition to impacts on the health of both wildlife and humans, the accumulation of biotoxins in fish and shellfish can be detrimental to the fisheries of an area. Often, areas that are known to be experiencing a HAB are shutdown, preventing the area's use for recreation or fisheries, which directly

Teaching Tip

Students may have heard the phrase "only eat shellfish in months ending in *R*" from their parents or grandparents. This bit of folk advice is related to red tides or HABs that can cause PSP and other disorders. The species that can cause the disorders traditionally rarely bloom in the colder waters of the months ending in *R* (i.e., September, October, November, December). Connecting to this folk advice, or other student experiences, may help students better understand when and how algal blooms happen.

MERCURY BIOACCUMULATION



As mercury is introduced into the water system, it travels to other water sources and leaves traces of its presence along the way. Mercury or other substances can enter the food chain at many points but often enter at lower-level organisms such as producers, and then make their way up to higher-order consumers through the food chain.

affects the economy of the coastal area.

Mercury Bioaccumulation. Mercury is an element that can be found in three main forms in the environment: as an element, as inorganic mercury, and as methylmercury. In this section, we will explore the role of mercury in marine environments, and we will see how mercury can affect the health of aquatic organisms and the humans that consume them.

Ocean-dwelling bacteria can secrete biotoxins into the environment that can potentially harm wildlife and humans who consume the contaminated seafood. Bacteria, both in the sediment and in ocean waters, take in inorganic mercury and convert it to other forms of mercury. Through methylation, bacteria convert inorganic mercury into methylmercury (CH_3Hg), which is a highly toxic form of this element. This methylmercury can be released into the atmosphere or into the water and can be absorbed by plants or taken up by plankton. The plankton can then be consumed by other organisms and make its way up a food chain.

The toxic methylmercury, as it makes its way up the food chain, bioaccumulates in the organisms. Animals tend to accumulate this toxin faster than they can get rid of it. In many types of fish, methylmercury will accumulate mainly in muscle tissues; in marine mammals, it will accumulate mainly in the liver, with younger marine mammals having higher concentrations of this toxic element than the adults. Invertebrates, such as bivalves, can also accumulate methylmercury in their tissues but in a much lower concentration than fish or marine mammals.

Mercury originating from human activities such as mining, chemical manufacturing, and use of power plants also affects ocean organisms, particularly in coastal waters.

Biomagnification of Mercury. As methylmercury makes its way up a food chain, and bioaccumulates in the tissues of the organisms, biomagnification is also taking place. This means that the organism at the lowest level of the food chain has the lowest concentration of methylmercury in its tissues, and as you go further up the food chain, the concentration of this element at each successive level increases within the individual organism. These longer living species of fish (such as predatory fish) higher up the food chain (e.g., sharks, swordfish, and tuna), therefore, have higher levels of mercury in their tissues. This has important implications on humans who consume top-level consumers because they are the organisms with the potentially highest level of toxic mercury in their muscle tissues.

Implications of Biomagnification on Human Health. Because methylmercury bioaccumulates in the muscle tissues of the fish we consume, it is nearly impossible to cook the mercury out of fish prior to eating it. Therefore, if we consume fish that have accumulated mercury in their bodies, it could cause severe health implications. However, it is important to understand that the severity of the effect of methylmercury consumption will be affected by the dose consumed, how often it was consumed, and also the current health of the person.

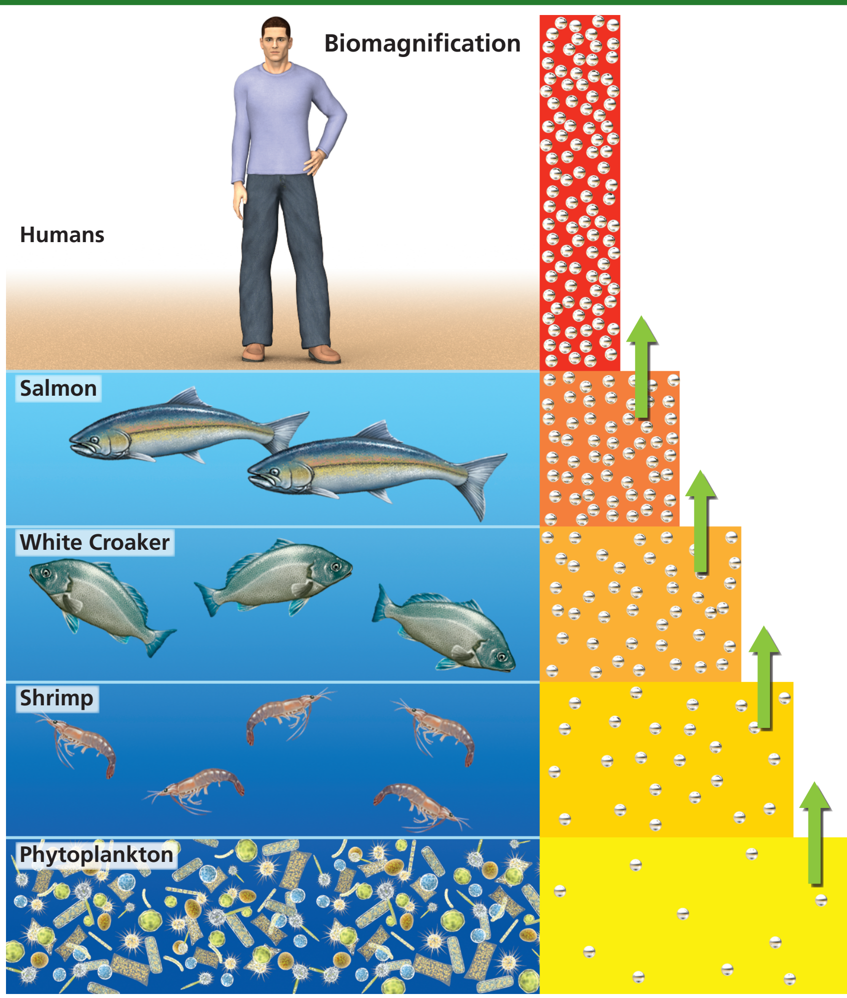
Among humans, mercury has been known to directly affect the central nervous system and possibly cause brain damage. Additionally, high levels of mercury can cause a decrease in motor skills, affect normal sensations, result in muscle weakness, and cause impaired vision. Consumption of toxic fish can also greatly affect the health of an unborn child if the mother consumes these toxic fish during pregnancy. Attention, thinking, and fine motor skill problems have been found in children that were exposed to methylmercury as a developing fetus. Pregnant women, therefore, are advised to limit consumption of predatory fish species.

Pharmacy From the Sea

Humans have looked to the ocean for their needs since the dawn of civilization—for food, transportation, and medicine. Traditional medicines have included whale blubber, ambergris (a waxy substance eliminated by sperm whales), algae, and other ocean-derived products. But human use of ocean-derived products did not end sometime in the distant past. Just like some scientists are combing forests for plants that produce complicated chemicals that can be used for medicines, so too do others look to the algae and animals of the sea. Many marine organisms produce toxins for protection. These toxins might stop a heart, kill a fungus, or keep a virus from reproducing. If they can be harvested or synthesized in adequate amounts, they have promising implications for human health and medical treatment for a variety of disorders. Sponges have yielded the powerful anti-virals Acyclovir and AZT, medicines integral in the treatment of HIV/AIDS and other viruses. Other species of sponges and corals yield chemicals that are being explored for their anti-cancer and anti-inflammatory properties. The blood of the humble horseshoe crab (*Limulus polyphemus*), called a living fossil because this genus predates the dinosaurs, is harvested to analyze medicines for bacteria and fungal contamination, among other things. Many other organisms are used to study processes that affect human health, such as sea urchins for zygotic development and sea slugs for neurological function. When we look at the potential cures and treatments it may contain, conservation of the ocean is a selfish act.

The health of humans is inextricably connected to the health of the ocean. People rely on the ocean for food, transportation, recreation, medicines, and even the oxygen we breathe. More than one billion people rely on the ocean for their daily protein. Scientists estimate that 60–70 percent of the oxygen we breathe is produced by phytoplankton in the ocean. It is important for students to realize and understand how tightly coupled their health is to that of the ocean. In Chapter 6, we will look at ways students can make a difference in helping to protect the ocean.

BIOMAGNIFICATION



Each step of the food chain results in increased levels of a toxin. That is, an animal at the top of the food chain collects a greater concentration of the chemical than organisms lower in the food chain.

Pictures of Practice

Biomagnification

The public is faced with a large variety of threats to their health and well-being, some unknown and some known. When people know about these threats and how they occur, they can be empowered to make decisions about their health. Bioaccumulation and biomagnification are two concepts intimately tied to human health and difficult ones to comprehend. There are many chemicals and toxins that can bioaccumulate in organisms and biomagnify through the food web, including DDT, PCBs, mercury, and algal biotoxins, to name a few. Students may have heard of some of these substances before, and they may even be aware that certain marine organisms contain chemicals that could potentially be harmful to humans when consumed in large proportions.

Students: Grade 5

Location: Laguna Niguel, California (a coastal community)

Goal of Video: The purpose of watching this video is to see an example activity for teaching biomagnification and to find out what students do and do not learn from the activity.

Classroom Context

The biomagnification video shows a classroom activity on biomagnification taught to students at the end of their unit on ocean food webs. Ms. Reimer added this activity because she wanted her students to make connections between environmental problems, ocean food webs, and their own health. Through an interactive activity in which students role-played organisms in a marine food web, students traced the buildup of toxins in higher trophic levels. Ms. Reimer used small stickers to represent toxins moving through the food web. The activity started with many producers with few stickers. By the end of the activity, students saw that a smaller number of higher-order consumers accumulated more and more stickers.

Video Analysis

Ms. Reimer's goal is that students learn that toxins travel from organism to organism in a food web, and higher-level consumers build up more and more toxins at the top of the food webs. This process is called biomagnification, not bioaccumulation. Bioaccumulation describes buildup of toxins within organisms and biomagnification describes increasing levels of toxins at higher levels in the food chain. At this age level, students should be able to trace toxins through food webs, just as they trace food moving from organism to organism. They may struggle with understanding that these toxins are actually found in all parts of the organism, and that when eaten, the toxins pass on to the next organism. These toxins are not easy to get rid of, which is why they remain inside the organisms. Students easily grasp the concept that the toxins (represented by stickers) build up through the food chain. Leah, however, describes the toxins as located on the skin, or exterior, of organisms. How does this compare to where toxins are typically located? Think about whether her confusion is about the concept of biomagnification or whether this confusion resulted from the classroom activity itself.

Reflect

How could you teach biomagnification to your own students?

Think about the activity you observed and what students learned from it. Would you use a similar or slightly modified version of this activity? Why or why not? What additional activities might you include to go into more depth on biomagnification?

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Teaching Resources

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

Environmental Protection Agency Pollution Activities:: http://water.epa.gov/learn/kids/runoff/kids_index.cfm

NOAA Oil and Chemical Spill Resources:: http://response.restoration.noaa.gov/oil-and-chemical-spills

Activities related to algal blooms: http://serc.carleton.edu/microbelife/topics/redtide/education.html

Ocean Research & Conservation Association: http://www.oceanrecon.org/cfiles/home.cfm

National Geographic Oil Spill Resources: http://news.nationalgeographic.com/news/gulf-oil-spill-news/5

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.

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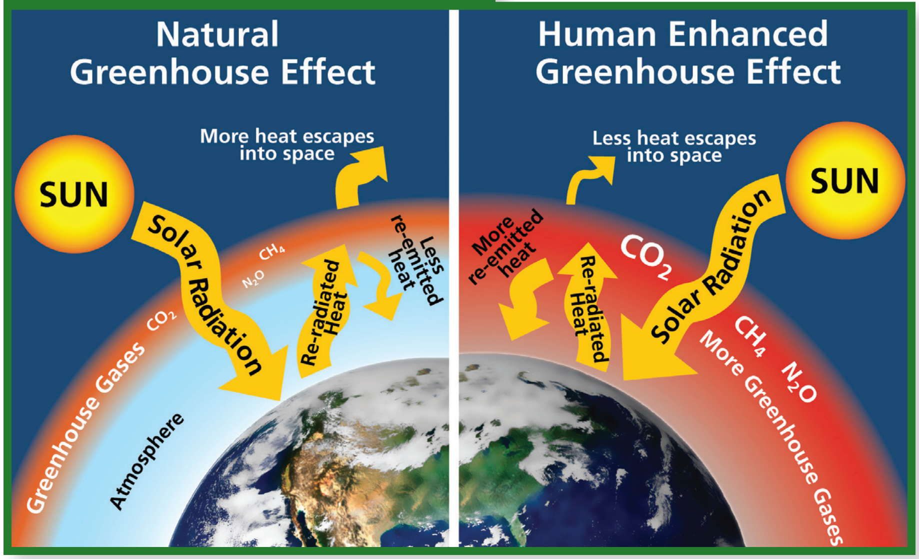
Student Thinking Climate and the Ocean 114

ENHANCED GREENHOUSE EFFECT



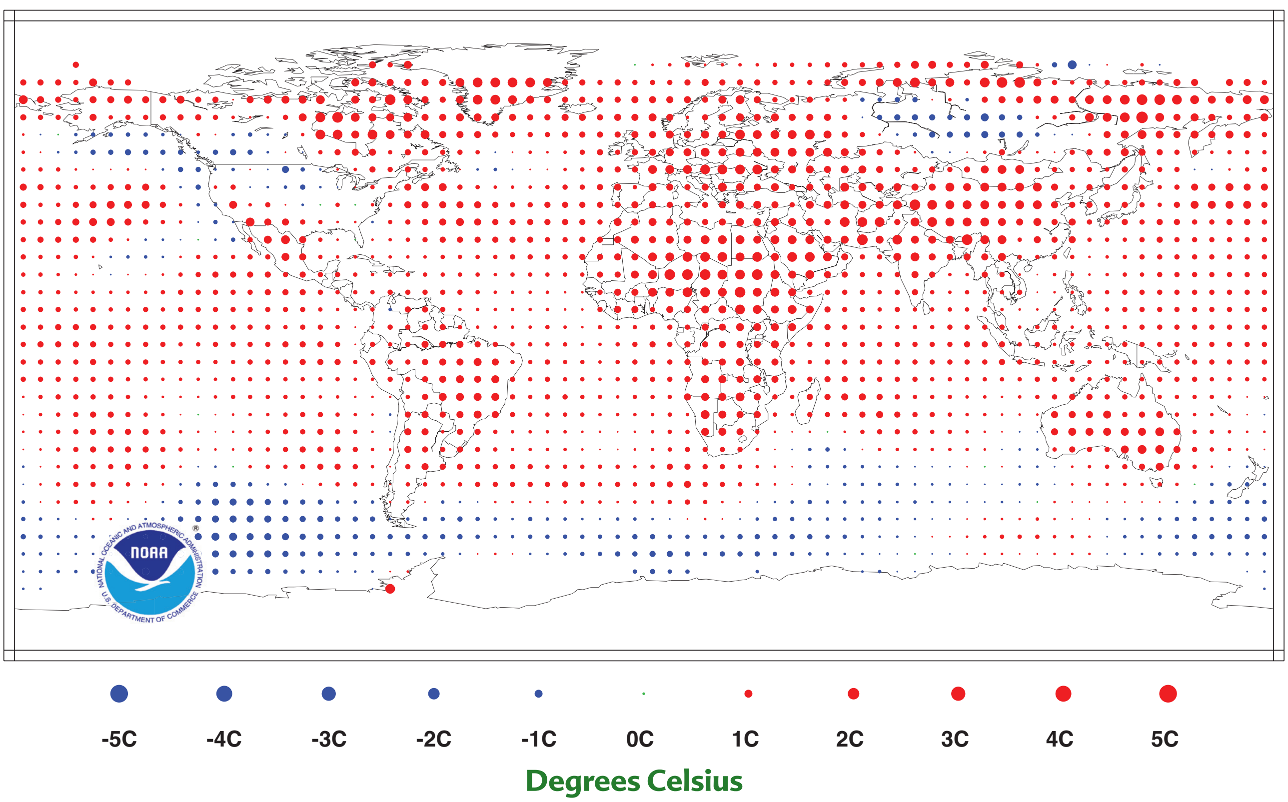
The increased amounts of GHGs, such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) from increased fossil fuel use, are trapping more and more of the sun's heat in our atmosphere.

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.

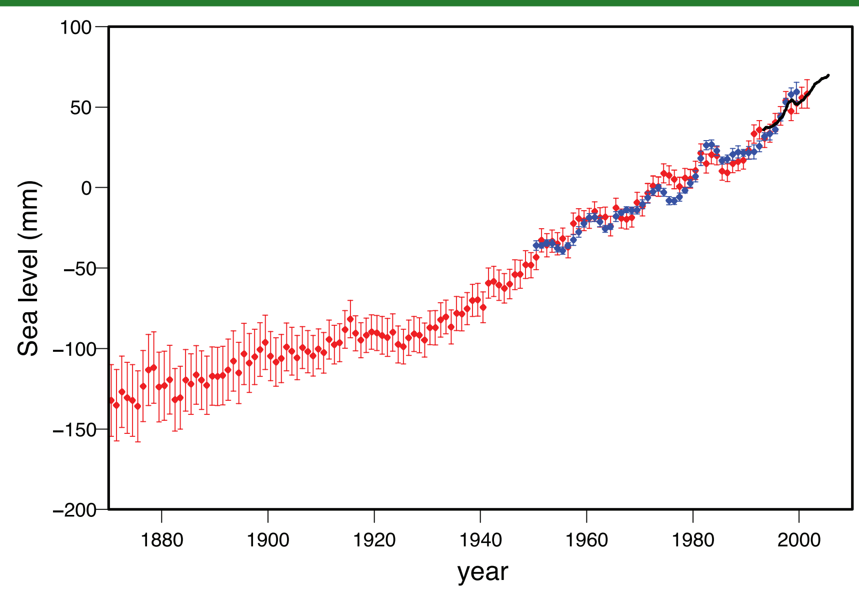
The ocean has also experienced changes in salinity, or saltiness. As discussed in Chapter 1, temperature

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.

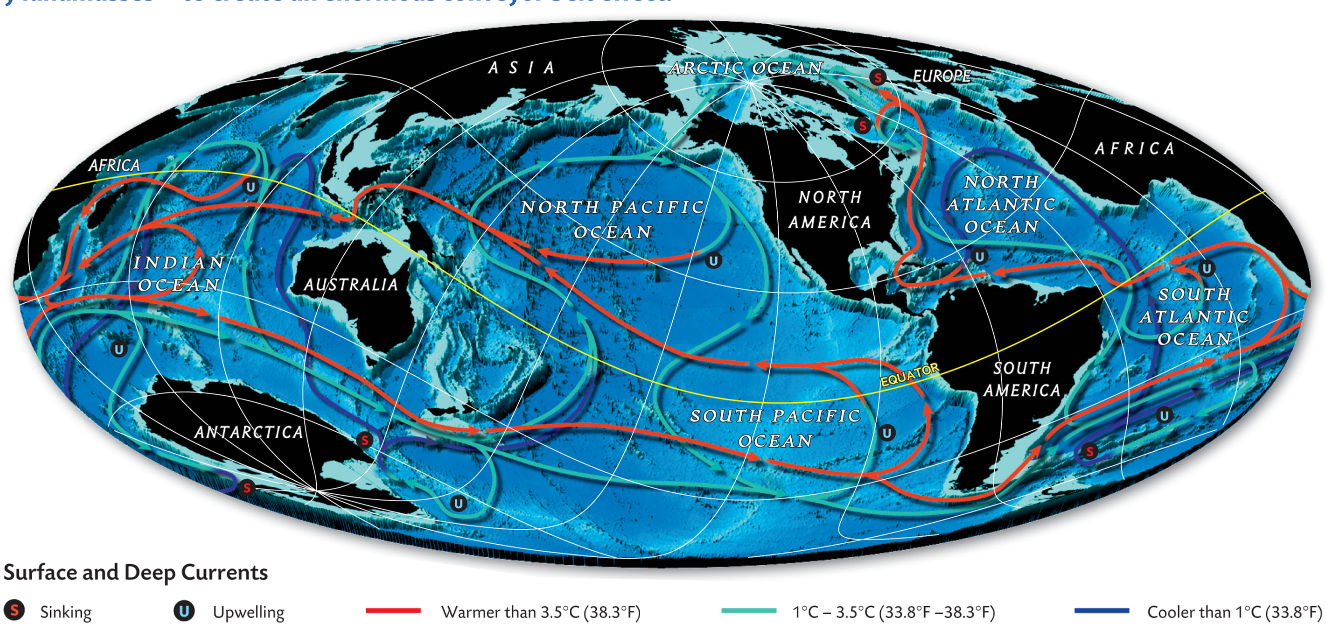
Scientists are also concerned about how changes in the ocean will affect other aspects of the climate system. Higher SSTs, for example, could lead to stronger hurricanes because these storms draw energy in part from warmer waters. Models suggest that higher maximum wind speed combined with higher maximum 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.



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.)

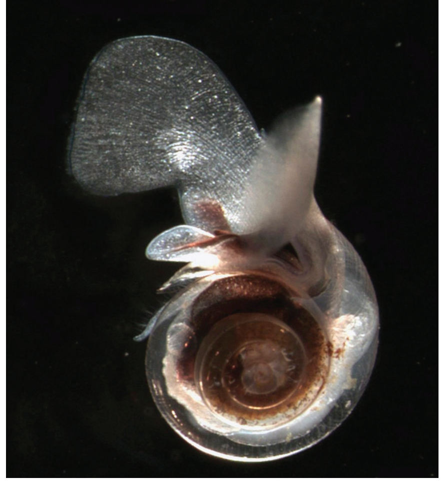
pH SCALE

	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 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).



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

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."

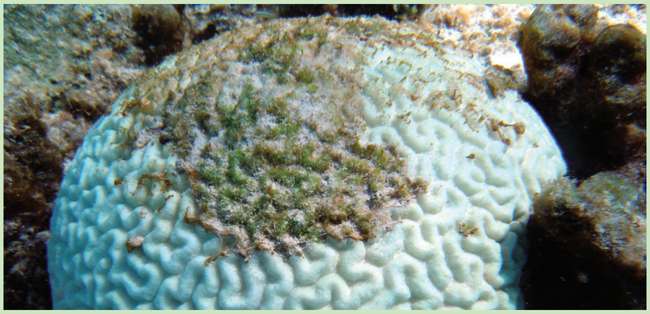
Reefs provide a variety of economic benefits, including recreational activities, tourism, coastal protection, habitat for commercial fisheries, and preservation of marine ecosystems.

"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/

7 Solutions for Our Ocean

by E. Tucker Hirsch

Most of this guidebook has focused on students' perceptions of the ocean and science phenomena. However, what we leave to the next generation depends upon our actions and understanding of the ocean today. For adults, the ocean can bring out the same wonder and excitement as it does in children, underlining its fascinating characteristics, and importance on our planet. Part of our responsibility to our children is to help them better understand the ocean and all the services it provides to us, and to Earth. While environmental problems in the ocean do happen, and the outcomes of these problems may be uncertain, we do not want to share only the negative impacts humans have on these environments.

Students should understand that people have choices about how they interact with the ocean and that history has shown that people can take measures to protect the ocean. Students should also be aware that they—the next generation of voting citizens—will become the scientists and engineers that find solutions. As citizens, they will choose to make decisions when they vote, and also when they buy products in a store. Students should be empowered to do something to protect our ocean. While they may not be able to vote at the polls or with their own dollars, they will take home what they learn at school and through their parents, they will indeed cast a vote for the ocean if prepared to do so.

This chapter focuses on our relationship with the ocean today and what we are doing to the ocean. The focus then shifts to what the ocean provides us and what we can do—children and adults alike—to ensure the ocean provides for us for generations to come.

Relationship With the Ocean

The ocean fascinates both adults and children. When exploring tide pools, people are amazed at the diversity of the critters, and many people ask the same

GRADE	STANDARD	EEI UNIT
Grade 3	3.2.1 3.4.1-2 3.5.3	California's Economy—Natural Choices
Grade 4	4.5.3	
Grade 5		
Grade 6	6.6.b	Energy and Material Resources: Renewable or Not?
Grade 7		
Grade 8	8.3.6	

basic questions. Where does the hermit crab's shell come from? What eats a sea star? Walking through an aquarium, an adult pauses to take a picture of his teenage son with a ten-foot sand tiger shark in the background. Moments later, a five-year-old points up, mouth agape, and yells, "Look at the big fish!" as the same sand tiger shark swims overhead. It is no wonder that the ocean can engage citizens of any age.

Sometimes we see that children's and adults' knowledge of the ocean does not vary greatly. As we saw in the first chapter, student perceptions of currents, tides, and waves are varied and unclear. Similarly, in *A Private University*, researchers showed that Harvard University graduates are often unclear of the difference in these phenomena, as too are many professional, educated adults. The ocean is vast, and with its sheer size comes the misconceptions that our actions cannot possibly influence such a large system. Could we ever really run out of fish from the ocean? Could coral reefs actually disappear? While children and adults may recognize the negative impacts we have on the ocean, they likely do not realize the severity of these impacts or the urgency for response or may not be aware of actions that can be taken both individually and as a collective citizenry (Belden, Russonello, and Stewart 1999; The Ocean Project 1999).

Many people recognize that we can make choices to support ocean health, but are unsure what to do (The Ocean

CHAPTER OVERVIEW

Our lives and livelihoods are intimately connected to the ocean. While prior chapters in this guide have discussed the ocean system and impacts human activities have on that system, this chapter will explore solutions to the ocean issues we currently face.

Solutions may include mitigation strategies, such as international, national, or local policies to regulate what humans put into, and take out of, the ocean. Solutions may also include innovative technologies to make human activities more efficient and less harmful to the ocean ecosystem. While governments and large corporations and industries should be involved in these solutions, individual people can take actions to help protect the ocean. Individuals can engage as voters to pass laws to protect our ocean and as consumers to buy products that are sustainable. Even given all these actions, human communities will still need to adapt to changes in our ocean—changes that will affect our everyday way of life.

This chapter will explore the range of solutions, including mitigation, innovation, adaptation, and actions that individuals can take. We will take a closer look at actions already taken—where they have succeeded and where they have fallen short—in order to better understand where we must go in the future to protect our ocean.

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People can make a positive impact on the ocean environment through simple acts such as purchasing sustainable seafood.

Project, 2009). Do you think about sustainable seafood when you buy fish at your grocery store? Do you think about ocean acidification as you drive your car to work or leave lights on at your home? Do we buy imported shrimp, which is on sale at the grocery store, or choose a more sustainable alternative? These are choices we need to think about each and every day and choices that your students will also be making more and more as they age.

While these issues are urgent and we need an educated citizenry to think more about the ocean, we cannot let "doom and gloom" stories paralyze adults and children from taking action. Science and social-studies educators are uniquely positioned to affect real change among our future voting population. Yes, there is a lack of understanding among children and adults about the ocean. As educators, we not only need to improve understanding of the ocean, but we also need to educate about solutions and actions that have already been taken and can be taken in the future. How can we encourage behaviors that will provide a healthy future for our youth and a healthy future for the ocean?

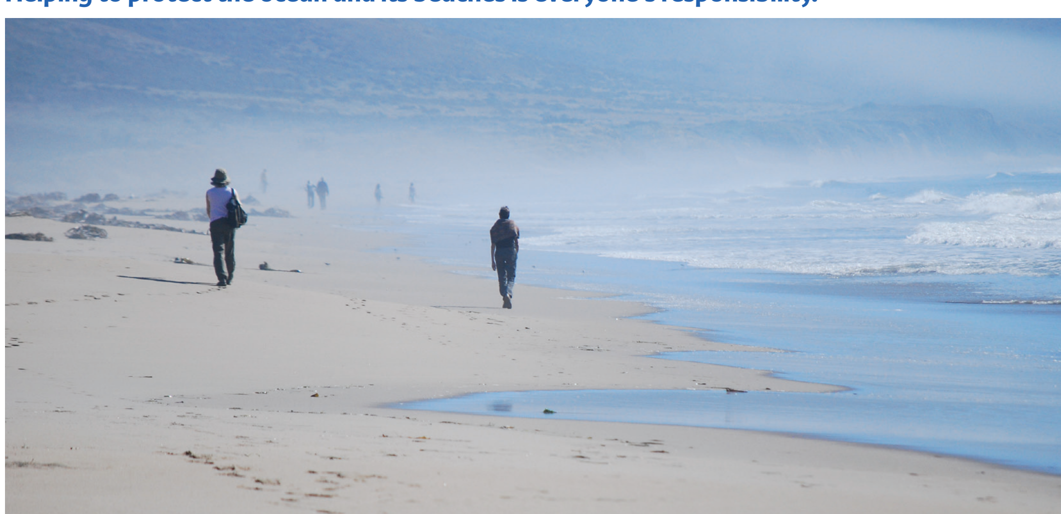
In this chapter, we will discuss **mitigation** and adaptation techniques for a changing ocean, as well as new, innovative ideas and advances in technology for dealing with ocean issues. We will also look at past and current ocean policies, where these policies fall short, what beneficial changes came about through the policies, and what these actions tells us about future solutions.

Who Protects the Ocean?

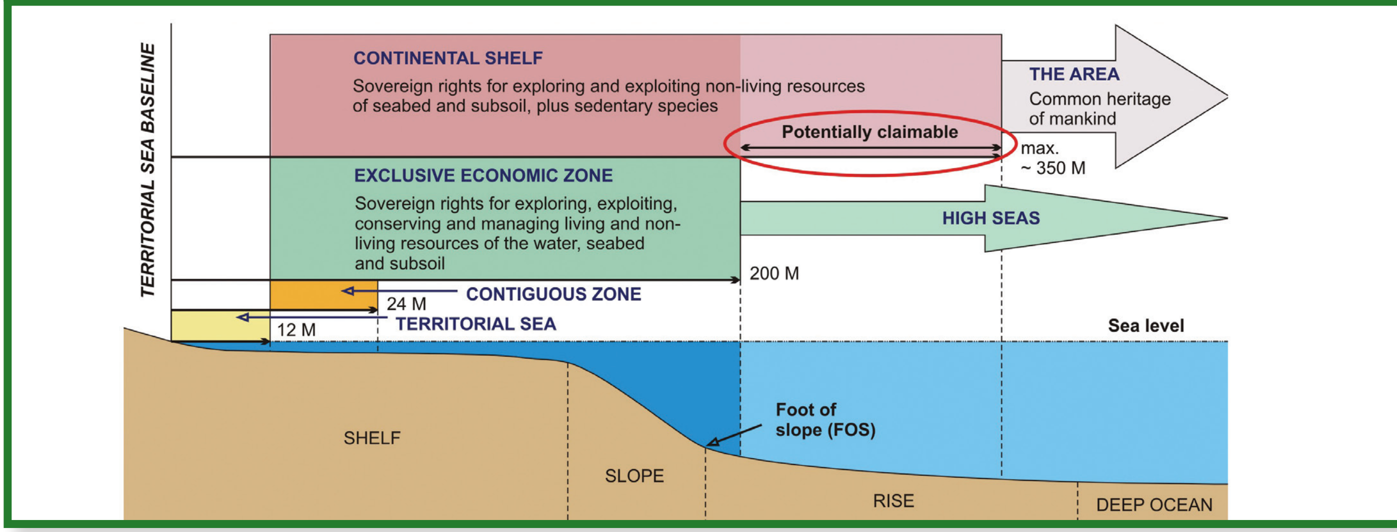
Once considered the "high seas," the open ocean was a place of piracy, warfare, and uncharted waters with land to explore and discover. It is only relatively recently that countries have been making more claims on and, therefore, are having greater impacts on, the ocean. Students may not even know that countries own parts of the ocean. So why is it so difficult to simply make a law that protects the ocean? One drawback is that international law is not set in stone and can be hard to pass in the first place. Nationally, different states have different regulations, and municipalities within a state may have varying regulations. Following is an introduction to the different ruling agencies and bodies that can lay claim to and protect the ocean.

The Law of the Sea. The UN Nations Convention on the Law of the Sea is the treaty that establishes international law for the sea beyond national territories. In 1994, after the sixtieth country ratified the treaty, it went into effect. Prior to the Law of the Sea, the open ocean was considered the high seas and was owned by no country but was free for all countries to utilize. Slowly, individual countries started to take an interest in the resources available in the ocean and began to extend their territorial bounds to include larger swatches of the ocean adjacent to their coastline. As claims and interest grew, it became evident to the international community that there was a great need to regulate the use of ocean resources, both for the protection of the ocean, and for fairness to the countries with smaller or no coastlines.

Helping to protect the ocean and its beaches is everyone's responsibility.



MARINE JURISDICTION



The Law of the Sea and other laws specify rules and regulations to govern how humans interact with the ocean. For example, 321 kilometers (200 miles) from the coastline is the Exclusive Economic Zone. Each nation has exclusive rights to resources within this area. Courtesy of Federal Institute for Geosciences and Natural Resources (BGR). Adapted from Symonds et al. 1998)

The Law of the Sea established, among other items, an **exclusive economic zone** (EEZ) for countries, extending to 320 kilometers (200 miles) from a country's coast, within which a nation may take resources from the ocean but other countries may not without consent. The Law of the Sea also established rules and regulations for scientific research in and on the ocean, seabed exploration, and mining policies as well as traffic and transit regulations. This law was implemented by a variety of international organizations, such as the International Whaling Commission and the International Maritime Organization.

The Law of the Sea, with its large scope and strong international policies, is wonderful in that it is widely accepted. More than 150 countries have ratified the Law of the Sea, signifying an accord among the international community. The caveat with international policies is that they have little or no official standing and can be difficult to enforce. One country cannot simply sue another country for violation of the law. Countries can be brought to international court, but on a basic level, they must be invited, and offenders must accept. It is extremely difficult to monitor and enforce international laws—politically, logistically, and economically. Finally, international laws are not mandatory nor are they necessarily binding. The United States has signed, but not ratified, the Law of the Sea.

Other international regulations exist to help regulate ocean activity. For example, MARPOL (short for marine pollution), or International Convention for the Prevention of Pollution From Ships, was a monumental international regulation passed in the 1970s to help protect the ocean from **abiotic pollutants,** as well as introduced species. The International Convention for the Regulation of Whaling and its ruling body, The International Whaling Commission (IWC), were established in the mid-20th century to ensure the health of whale populations worldwide. The Migratory Bird Treaty Act of 1918 helps to protect waterfowl—many of which are seabirds that migrate through the territories of different countries—by making the taking, death, sale, or transport of them illegal.

These are just a handful of historically monumental international laws to protect and preside over the ocean. Countries and even individual states or regions can also have their own **jurisprudence,** so have your students explore their state and local regulations.

Teaching Tip

Using maps of local or nearby coastlines, have students explore how far off shore the United States actually extends. See if they can measure the 321 kilometers (200 miles) of the exclusive economic zone. For comparison, can they measure the 4.8 kilometers (3 miles) offshore that each state is responsible for?

Many state, national, and international organizations manage ocean resources, such as oil and wildlife.

The United States: Alphabet Soup. In the United States, there are many different agencies tasked with the care and protection of our ocean. Almost every activity occurring on, in, adjacent to, or in someway connected to the ocean requires a permit or license, and many activities require the signature of more than one agency.

For example, offshore oil drilling, and other abiotic **natural resource exploitation,** is under the jurisdiction of the Bureau of Ocean Energy Management (BOEM), the Bureau of Safety and Environmental Enforcement, and the Office of Natural Resources Revenue, all of which are part of the U.S. Department of the Interior. However, the oil drilling, platform, refinement, and transport must conform to the regulations established by the Environmental Protection Agency (EPA). New projects planned for national waters must be acceptable under the National Environmental Protection Act (NEPA), administered by the Council for Environmental Quality (CEQ), and only after an Environmental Impact Statement (EIS) is written. The process is often bypassed in the name of national security, and projects performed by the Department of Defense (DoD), such as testing submarines in the Channel Islands, California, in marine mammal habitat, may be exempt from completing an EIS.

The point of this example is to convey the difficulty of regulating a wide variety of activities in a vast area. However, regulations do exist that work, most often effectively, to protect our ocean nationally. Some examples include

- The Endangered Species Act—Passed in 1973, it protects those species at risk of extinction due to activities related to economic growth and development. It sets rules and regulations regarding impacting those species and requires plans to be developed that will help their populations to recover.
- The Marine Mammal Protection Act—Passed in 1972, the MMPA makes it illegal to take (harass, capture, hunt, or kill), import, export, or sell a marine mammal or any part of a marine mammal in the United States or in its waters. U.S. citizens can be held accountable for breaking this law while outside of the United States as well.
- The Ocean Dumping Act—Passed in 1988, effective January 1, 1992, this act prohibits all dumping of municipal

Explore More

For more information on these acts, visit the following resources:

- The Endangered Species Act: http://www.nmfs.noaa.gov/pr/laws/esa/
- The Marine Mammal Protection Act: http://www.nmfs.noaa.gov/pr/laws/mmpa/
- The Ocean Dumping Act: www.epa.gov/lawsregs/laws/mprsa.html
- The Magnuson Stevens Fishery Conservation and Management Act: http://www.nmfs.noaa.gov/sfa/magact/
- The Oil Pollution Act: http://www.epa.gov/oem/content/lawsregs/opaover.htm

The continued survival of the brown pelican (Pelecanus occidentalis) was at risk in the 1970's due to DDT use. Protection by both the Migratory Bird Act Treaty of 1918 and the Endangered Species Act of 1973 helped the species recover, but this species is still threatened by human impacts, like oil spills.

sewage sludge and industrial waste into the ocean.

- The Magnuson-Stevens Fishery Conservation and Management Act—Originally passed in 1976, this act created laws and national policy requiring an integrated fisheries management.
- The Oil Pollution Act—Passed in 1990 in response to the Exxon Valdez Spill of the previous year, this act created laws that require companies involved with oil and the ocean to have comprehensive plans to prevent oil spills and detailed containment and cleanup plans should a spill occur.

Any of these laws may be good examples to discuss with your students. In addition to these, both the Clean Air Act and Clean Water Act are very important to keeping our ocean clean and healthy. The Clean Air Act limits the amount of air pollution allowed in an area. Suspended particles and chemicals that commonly make up air pollution make their way to the ocean as precipitation picks them up and carries them through the water cycle. The Clean Water Act protects waters from point-source pollution (see Chapter 5) and also from nonpoint-source pollution by holding local governments accountable for dumping from their communities. The Clean Water Act considers storm-water runoff as point-source pollution but agricultural runoff as nonpoint-source pollution.

It should be noted that the U.S. Coast Guard is the major agency charged with ensuring maritime safety, security, and stewardship. Along with the U.S. Navy, the U.S. Coast Guard is in charge of ensuring maritime law enforcement in both domestic and international waters. These two agencies are the enforcers for most, though not all, marine-related laws in U.S. federal waters. Two other federal agencies that play a major role in the protection of the marine environment and enforcement of laws relating to them are

- The U.S. Fish and Wildlife Service—A bureau within the U.S. Department of the Interior, it is the major agency tasked with taking care of U.S. natural living resources, including fish, wildlife, and habitats.
- The National Oceanic and Atmospheric Administration—NOAA is a scientific agency within the U.S. Department of Commerce; the agency that predicts and tracks weather, ocean conditions, and overall climatological trends, is responsible for ensuring the sustainable use of marine and coastal resources; the National Marine Fisheries Service is a branch of NOAA.

It is easy to see how, with so many different agencies and organizations involved, the stewardship and conservation of our marine resources can be difficult. On the other hand, with so many different groups involved, it is hoped that one of them will always be there to make sure the ocean is protected. Because of the number of

Teaching Tip

Students often have a hard time relating to legislation, as it seems so disconnected from their day-to-day lives. The next time you have students research an animal or plant, have them expand their research to see if that organism is protected by any state or federal laws as well. Understanding the laws and how they might impact an organism they care about can help make the organism more real and comprehensible for students.

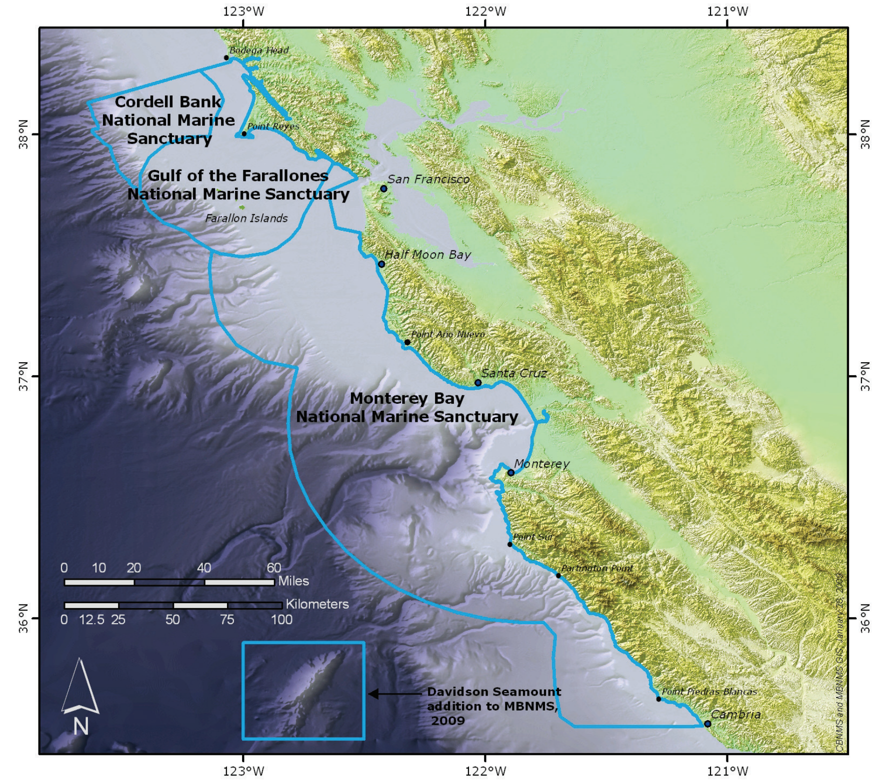
organizations, it is important to talk about the roles of each of these groups with your students.

Marine Sanctuaries. In the 1970's, scientists and citizens alike began to recognize that many of our natural resources were at risk. This lead to the passing of many of the acts already mentioned. It also led to the passage of the 1972 Marine Protection, Research and Sanctuaries Act, which allows for the creation of national **marine sanctuaries** in areas of special conservation, recreational, ecological, historical, research, educational, or aesthetic resources. For the first time, an entire habitat or ecosystem was protected, along with all the organisms that call it home. The Secretary of the Department of Commerce can create these marine sanctuaries, or the president can establish a special marine protected area known as a Marine National Monument. There are National Marine Sanctuaries and Marine National Monuments in diverse places throughout U.S. territories, including in the Great Lakes, Florida Keys, Gulf of Mexico, and American Samoa. The largest marine protected area in the National Marine Sanctuary System is the Papahanumokuakea Marine National Monument in the northwest Hawaiian Islands. California is home to four National Marine Sanctuaries: Channel Islands, Monterey Bay, Cordell Bank, and Gulf of the Farallones.

Fisheries Management. The commercial fishing industry started its boom around the beginning of the 20th century, and individual states started managing fisheries around the same time. In California, the task fell upon the shoulders of the California Department of Fish and Game. Many of the early regulations had the same targets as present-day regulations: prohibition from catching certain species, seasonal openings based on spawning, limitations on the size, sex, or age of a fish, catch-method limitation, net-size minimum limits, and, in some instances cordoning off areas altogether.

Later, fisheries management began to evolve around the same time that the country was discovering environmentalism. In 1976, shortly after the fall of the Pacific mackerel fishery, the Magnuson-Stevens Act transformed fisheries management to focus on actual data from the fish stock itself, rather than setting arbitrary limits. The federal act required national and regional fishery

MARINE SANCTUARIES IN CALIFORNIA



Marine sanctuaries include ocean gardens, coastal coral reefs, whale-migration corridors, deep-sea canyons, and even underwater archeological sites.

Fisheries must comply with state and federal policies regarding seasons, catch limits, catch sizes, and so on.

management plans created by regional groups in order to protect the future of fish stocks. In 1996, the Magnuson-Stevens Act was amended to include the Sustainable Fisheries Act, which shifted the focus of fisheries management to conservation and sustainable practices, from the previous practice of trying to manage the fishery in such a way that maximized catches, year after year.

Only recently have fisheries managers considered both recreational and commercial fishers together when drafting management plans. For years, the two fishing sectors blamed each other for increased competition of fish stocks, for being at fault for depleting certain populations, and for decreasing water quality. In some cases, science and collection data can point to either recreational or commercial fisheries as the cause for the crash of a fishery, but more often many other facts, including habitat destruction and polluted runoff into the ocean, are responsible for declines in fish stocks. Management of commercial and recreational fisheries in California resides with many state and federal organizations including NOAA's National Marine Fisheries Service (through the regional fishery management councils) and the Department of Fish and Game. All agencies must now work together to create comprehensive and integrated fisheries management plans. Newer management strategies include **individual transferable quotas** (ITQs). ITQs can be sold or traded as long as they are below the set quota ceiling. Fisheries, managers set a total allowable catch (TAC), and then fishers can buy and sell their shares.

State Jurisdiction: California Coastal Commission. Many states delegate a government committee to oversea marine affairs, regulations, and policies. In California, the Coastal Initiative established the Coastal Commission in 1972. In 1976, the Coastal Act made the committee a permanent establishment. Because states only have jurisdiction up to 5.5 kilometers (3 nautical miles) offshore, a lot of the focus of states' ocean committees is on coastal-zone management. The goal of the California Coastal Commission (CCC) is to conserve and restore California's coast for the enjoyment of citizens and visitors and for the health of the ecosystem. With some specific exceptions, any new development along the coast that would impact the coastal system must receive a permit from the Coastal Commission. New buildings along the state's beaches must be approved, as well as, for example, a new parking lot adjacent to a wetland that connects to the coast.

The Coastal Commission is also responsible for maintaining access to the beach for the general public. In the 1987 landmark court case, *Nolan v. the California Coastal Commission,* the U.S. Supreme Court ruled that the state may forcibly buy property, via eminent domain, to maintain easement to the beach for public beachgoers. This ruling underlines the value we place on our coasts for our enjoyment as well as our livelihood.

Fishing boats docked in Puerto Penasco, Mexico.

The California Coastal Commission is one of the many agencies responsible for keeping California's coasts safe for future generations.

Case Study

The Recovery of the California Brown Pelican

Sitting on a California beach, you see a flock of birds flying just above the cresting waves in perfect V-formation. As they scan the waters below for fish, the leader glides upward, then turns and dives into the surf below. In quick succession, the rest of the flock shoots into the water, resurfacing moments later.

In what might have been an uncommon sight only a few decades ago, these birds, the California subspecies of the brown pelican *(Pelecanus occidentalis californicus),* have recovered from the brink of extinction.

Their success story is tied to the life and work of one of nature's most passionate protectors, biologist Rachel Carson.

In the 1940s and 1950s, scientists thought they had finally found the solution to one of the biggest problems to plague humanity—mosquitoes. The insect with the incessant buzz does more than just annoy you and leave the occasional itchy red bump on your arm. Mosquitoes and other insects carry diseases, including malaria, that cripple and kill thousands of people every year. Other insects kill crops and devastate agricultural yields. Chemical advances in the early 20th century provided new and powerful insecticides to battle against these pests.

One insecticide widely used on everything from forests to parks, beaches to bedrooms, was DDT (dichlorodiphenyltrichloroethane). DDT was purported to be safe, without any side effects. Over time, its claim of safety was shown to be untrue. DDT bioaccumulates, or builds up, in the fatty tissues of creatures that come into contact with it, either in their environment or their food.

As it progresses up the food chain, DDT biomagnifies, resulting in higher predators having greater amounts of the chemical in their tissues. In birds, in particular, this biomagnification has dire consequences. It causes a thinning of eggshells. Parent birds actually crush their eggs while incubating them.

The loss of songbirds and other species was brought to the attention of Carson, who had worked for the U.S. Fish and Wildlife Service. She was upset about this phenomenon and motivated to inform the public about what was happening to our wildlife.

With the 1962 publication of Carson's book *Silent Spring,* the issue of thinning eggshells and the loss of birds was brought to the attention of the public in a major way.

Larry Schweiger, the president and CEO of the National Wildlife Federation, believes Carson's work was a turning point for birds, including the brown pelican.

"My personal view is that Rachel Carson's book really woke up the public to what scientists had been saying for some time and that was the decline of certain bird species including the California brown pelican," he says.

Schweiger says *Silent Spring* helped influence the creation of the Environmental Protection Agency in 1970, the ban on DDT in 1972, and the Endangered Species Act in 1973. The Endangered Species Act ordered the creation of a Species Recovery Plan and extreme protection of any species listed. The brown pelican was one of the first species to be protected.

"What [Carson] did do was she sparked an awakening that swept across America, and that awakening triggered an upwelling that really took several years after her death [in 1964] to come to fruition," Schweiger says.

As a result of the DDT ban, careful species management, and protection, the brown pelican has recovered. In 2009, the U.S. Fish and Wildlife Service removed the brown pelican from the federal list of endangered species, and the California Fish and Game Commission removed the subspecies from the state's list.

Today, the U.S. Fish and Wildlife Service estimates that 650,000 brown pelicans exist globally, and a healthy breeding population of more than 140,000 birds thrives along the Pacific coast.

Case Study

The Gray Whale: Past, Present, and Future

The gray whale is the official California marine mammal, having edged out the sea otter for the position in 1976. There were once three stocks of gray whales—one in the Atlantic Ocean, long extinct; one in the western Pacific; and a third in the eastern Pacific.

The species makes well-documented seasonal migrations north and south along the state's coast and beyond, from the warm, shallow waters of Mexico to the nutrient-rich waters of Alaska. During their 19,300-kilometer (12,000-mile) journey, gray whales are often spotted from shore, making them a favorite of whale-watching companies. They are easily identified by their dark gray color, lumpy back, heart-shaped spout, and absent dorsal fin. They grow up to 15 meters (49 feet) long.

Gray whales are known to feed on at least 85 different species. They specialize in bottom feeding, focusing on amphipods—small, shrimp-like organisms that live in tube structures in mud. They also ingest other mud-dwelling invertebrates, including tube worms and mollusks.

To feed on these creatures, whales suck in water and mud and separate food morsels using their broom-like baleen plates. They then push the excess water and mud back into the ocean by using their tongue to scrape food from the baleen.

As bottom feeders, gray whales prefer shallow waters and, therefore, migrate near the coast. Mothers birth one calf at a time, nursing them in the warm, shallow waters near Baja California, Mexico.

Unfortunately, some of these characteristics of gray whales nearly led to their demise.

Alisa Schulman-Janiger is the gray whale census director for the Los Angeles, California, chapter of the American Cetacean Society. She says the hunting of gray whales in Baja California lagoons during the late 1800s and early 1900s was devastating.

"The single biggest thing is that gray whales were targeted in their nursing lagoons," she says. "So the whalers would go into the lagoons and kill the pregnant mothers, the nursing mothers, and the calves would die also."

Eastern Pacific gray whales were hunted to near extinction in the mid-1800s and again in the early 1900s. Their blubber produced oil used for lamps. The animals were easily accessible to whalers because they remained close to the coast. The species became overhunted in southern California and Mexico. As populations rebounded in the 1920s, whalers used "floating factories" to process the whales out at sea.

Today, Pacific gray whales are protected by international organizations and several government agencies. The International Whaling Commission (IWC) was established in 1946 to regulate whaling throughout the world's oceans. Gray whales received protections from the IWC in 1947. In the United States, the animals are further protected by the Marine Mammal Protection Act and Endangered Species Act. Mexico transformed some of Baja California's major breeding and nursing lagoons into a protected refuge zone.

Limited whaling is still practiced by indigenous peoples in Alaska, Canada, and Mexico. There have also been some reports of illegal whaling by nations that do not accept IWC treaties.

After being near extinction in the 1950s, the gray whale population in the eastern Pacific has rebounded to an estimated 19,000 animals—considered to be a healthy stock. In 1994, the gray whale was "de-listed," or removed from the Endangered Species List.

Unfortunately, gray whales in the western Pacific, vulnerable to whalers from Japan and Russia, have not fared as well—their population remains at just less than 100 animals.

"The steps that they [the IWC] took in the case of the western gray whale mostly weren't taken soon enough," Schulman-Janiger says. "For the eastern Pacific gray whales, those steps plus other laws that were passed by the United States to protect them along their migratory route has really, really helped tremendously."

Habitats within an MPA are healthier and more diverse.

California and Its Regional Coast: Marine Protected Areas (MPAs). Over time, people have recognized that our haphazard and uncoordinated attempts to protect species or habitats have been unsuccessful, or less successful than we had hoped. A new paradigm for conservation has taken hold over the past 20 years or so and that is one of creating coordinated areas that are protected, conserving delicate species and habitats together. Scientists have also discovered that, if you cannot protect an entire area, protecting a series of small patches within the bigger area can help. Deciding how to delineate these areas can no longer be arbitrary as well—the how and the why for protecting an area or a series of areas needs to be based upon scientific knowledge.

On land, the data and studies are being used to better create parks. While underwater, they are being used to create Marine Protected Areas, or MPAs. Marine Protected Areas are regions in the ocean that are protected at a variety of different levels, including some National Marine Sanctuaries and Marine National Monuments described on page 122. Some MPAs, usually called Marine Reserves, are the strictest kind and are no-take zones prohibiting the take or removal of any items, whether they be sea stars or clams by beachgoers or fish by fishers. Some Marine Protected Areas limit take by species or by commercial fishing or sportsfishing. In most MPAs, kayaking, surfing, swimming, SCUBA diving, and boating are permitted.

In areas where MPAs have been created, studies tend to show that the ecosystem approach of protection is very effective, especially when no-take zones are a part of the model. In protecting the whole habitat, all organisms in the area are given the opportunity to return to normal, healthy populations. Because all organisms are linked to others within their habitat, protecting the entire ecosystem has been more effective in protecting threatened or endangered species than those efforts that focused on the species alone. As a result, overall biodiversity increases in MPAs. Also, in MPAs, especially in Marine Reserves, individual organisms are able to grow much larger than they can outside of protected zones. This is important for fish because large females are able to produce more eggs and, therefore, more young than smaller females, thereby helping populations of fish species increase. As the population grows, areas outside of the MPA see a spillover effect, which occurs when the overcrowded population leaves the MPA in search of more food or an unoccupied territory; therefore, MPAs can help protect and improve more than just the area covered.

In the United States, the National Marine Sanctuaries are a type of MPA being used to protect the ocean but were designated with different goals than those of the Marine Life Protection Act (MLPA). The National Marine Sanctuaries program is run and financed by the federal government under the auspices of NOAA. The program is concerned with classifying waters that touch either U.S. soil, or the soil of U.S. interests, as marine reserves. Alternatively, the Marine Life Protection Act is a California state law and is, therefore, funded by the state. This law mandated a reorganization of the protected areas along California's coast and the waters that touch its soil—as a result, some of these areas are labeled as reserves, while others are classified differently. Through the passage of the Marine Life Protection Act in 1999, the state of California began the process of creating a comprehensive network of MPAs along the coast using scientific data to help determine the placement and size of MPAs. The California-coast network of MPAs was completed in 2012. The process of creating the network of MPAs involved scientists, government agencies, fishers, environmental groups, divers, kayakers, and other concerned citizens. The end result is a system of MPAs from the Oregon border to the Mexico border, protecting delicate habitats and the numerous species that call the California coast home.

Student Thinking

Protecting Our Ocean

When students are asked about what they can do to protect the ocean, a teacher may get a list of answers such as the ones shown in **In the Classroom: Solutions From People**, page 135. Some of these solutions require obvious actions that even young children can understand and practice. For example, "don't litter" and "obey fishing rules" are obvious solutions. But not all the solutions are straightforward. What about solutions such as, "don't spill oil anymore." This solution requires actions that students may not be able to identify readily. Oil drilling is driven by widespread need for oil-based products such as gasoline and plastics. Our society cannot simply stop drilling for oil. This solution requires reducing energy use, carpooling, bicycling, buying fuel-efficient cars, electing political leaders that will support alternative energies, and so on. Unlocking solutions such as this one will require additional instructional time compared to more obvious solutions that students may mention.

Scenario

Your students have just returned from an assembly in the school about how they can be stewards for the environment, especially the ocean. You ask students what they learned during the presentation and receive the following answers.

Question

What can you do to protect the ocean?

Scientific Answer

People can follow the four *R*'s: Reduce, Reuse, Recycle and Rot (see **Actions: Protecting Our Ocean Everyday,** page 132) to guide their everyday actions. Being smart consumers is important, especially reducing consumption of products that harm the ocean (e.g., unsustainable seafood, plastics, such as plastic bags and packaging).

Student Answers

Kate: We need to stop polluting! That will kill animals. We need to wash our cars on the grass so it doesn't go in the gutter and not leave trash on the ground. Leave nothing on the beach that can be harmful.

Bridger: What I can do is stop littering because the water running around can swift the litter into a drain and go into the ocean.

Tamara: What I can do make sure oil doesn't get in the streams.

Reagan: I can help adults tell people what and where you can fish, so the food chain stays balanced, and they all [all the organisms] stay healthier.

What Would You Do?

1. Although all these answers are correct, they are not very complex. How would you guide the rest of this class discussion to elicit more sophisticated answers from your students?
2. How could you make sure students can identify large-scale efforts in marine conservation, while still emphasizing the practical and useful actions they can take as young citizens?

Pictures of Practice

The Aquarium Trade

As consumers, we make many choices about the products we buy. We make choices whether to spend more to get exactly what we want or whether to buy more affordable options. Sometimes these choices support large-scale industries that harm the environment, and sometimes the choices support industries or small-scale businesses that engage in sustainable practices. With respect to ocean products, one of the most obvious decisions consumers make is the choice about purchasing seafood. Given the wealth of attention devoted to this issue and the websites and resources made available to help in this decision-making (i.e., Seafood Watch guides, and so on.), right and wrong choices about seafood are easier to make. But what about choices regarding jewelry, decorations, and pets that come from the ocean?

Students: Grade 7

Location: Carpinteria, California (a coastal community)

Goal of Video: The purpose of this video is to see students learn about and discuss the trade-offs of the aquarium trade and whether this trade is good or bad.

Classroom Context

Previously, Ms. West taught a series of lessons on coral reefs to her students. Although her students live in a costal community, coral reefs are not a habitat close to home. Students studied coral reefs located in Oceania and learned about historical and modern-day resources we get from coral reefs.

Video Analysis

During Ms. West's lesson, she starts a class discussion about what people get from coral reefs. Jacob brings up jewelry, decorations, and aquarium fish. This question leads to a discussion of the aquarium trade and buying other marine products and whether these purchases are good or bad. The aquarium trade is an industry that involves international trading of live marine organisms, including fish and corals. Millions of marine organisms are captured and traded each year. Most of these organisms come from reefs in Southeast Asia, and up to half of the buyers are from the United States. Fishers in poor communities are attracted to the aquarium trade because it can be a relatively lucrative business compared to fishing. It is also an industry that is unregulated. In the United States, the Marine Aquarium Council has developed a voluntary system for certification that can help label products as eco-friendly, but this system is not widely used. The UN Environment Programme (UNEP) also maintains an information website on the trade of marine species (http://www.unep-wcmc.org/biodiversity-series-17_108.html). Although students did not go into great depth regarding this industry, they completed short small-group and whole-group discussions about whether this industry is good or bad. You will hear students describe that taking live animals is acceptable, but taking live animals and killing them for decorations is not acceptable. One student proposes artificial replicas of marine organisms.

Reflect

How would you teach a controversial ocean topic to your students?

Remember, some students may be consumers of aquarium trade products, such as owning a tropical fish tank. How would you address potentially controversial topics in your classroom, including conclusions that may contradict student practices outside of school, such as owning fish tanks and buying unsustainable seafood? Which topics would you teach and why?

Innovation: New Ways of Interacting With the Ocean

As available technology advances, we are finding more ways that the ocean can provide for society, as well as new ways that we can live that decrease the stress on the ocean. The ocean has many solutions to help us meet our need and demand for energy. However, when considering renewable energy sources, we must remember that all alternatives, such as traditional nonrenewable sources, have advantages and disadvantages. An alternative energy source must be economically and technologically feasible, socially and politically acceptable, and environmentally sound for the long run.

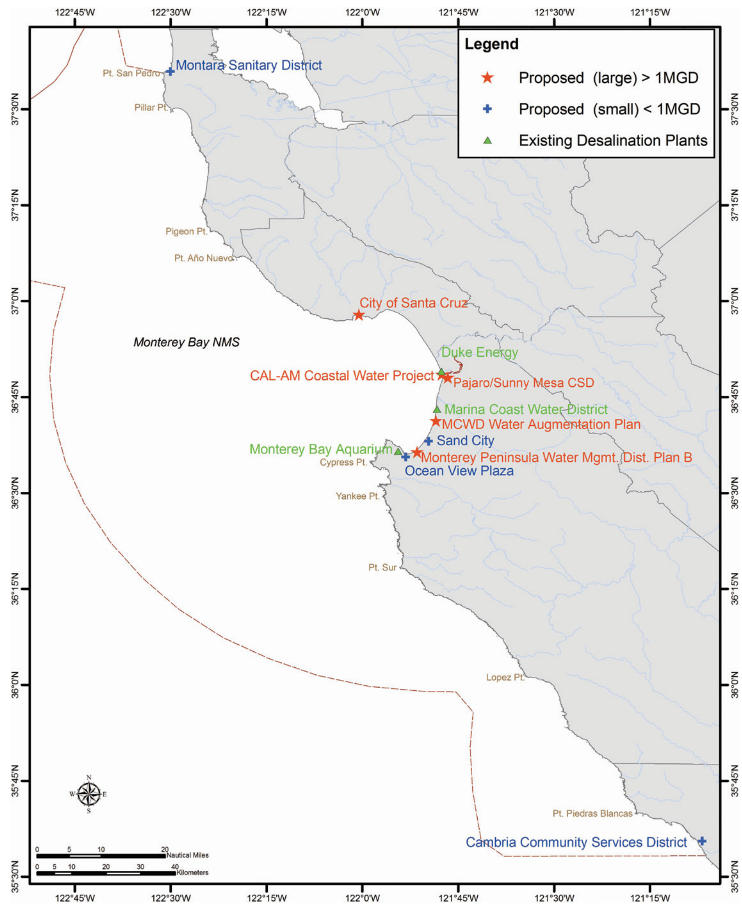
Desalination and Power Plants.

In the *Rime of the Ancient Mariner,* Samuel Coleridge's character remarked of the ocean, "water water everywhere and not a drop to drink." Less than 1 percent of all freshwater on Earth is available to humans for drinking, showering, and other everyday use. Fortunately, we are now able to utilize the ocean's salt water for freshwater uses, through the **desalination** process. Removing salt from ocean water provides freshwater for human consumption and for irrigation. However, there are many environmental drawbacks to desalination that you may want to discuss with your students. One downside to desalination is the intake of organisms with the water being brought into the desalination plant. Many organisms, large and small, can be sucked into the pipes that bring water into the plant, or caught in the screens meant to keep them out—this is called **entrapment.** Another downside is that removing salt and minerals from ocean water requires large amounts of energy and produces the waste of those salts and minerals. Some of the salts and minerals may be utilized (as table salt, for example), but they are often dumped back into the ocean, creating an area of higher-than-normal salt concentration called brine. As discussed in previous chapters, many organisms have specific salinity requirements, and changing the salinity can affect their chances of survival. Furthermore, the process of desalination is energy intensive. This energy use contributes to GHG emissions, and while it may provide more water, contributing to climate change could make water scarcity an even bigger problem on an even larger scale.

In the past, desalination plants were sometimes coupled with an existing power plant. As the plant brought in water to cool the generators or reactors, the water was transferred to the desalination plant. Nowadays, these two systems are less likely to be coupled. California, for example, is phasing out "once-through power plants" because of the Clean Water Act. Once-through power plants try to reuse water repeatedly to cool their generators or reactors. Desalination plants are now being built on their own.

Some people worry that expansion of desalination plants in California and other coastal areas will lead to two major problems—killing ocean wildlife during the pumping process and changing the marine environment when brine is discharged. However, the benefits of desalination would be protection of freshwater resources and the wildlife that live in aquatic habitats, as well as developing plans for future water security.

PROPOSED DESALINATION PLANTS AROUND MONTEREY BAY



Three desalination plants already exist in this region of California, but several more are proposed for future consideration.

There are a variety of techniques used for desalination, including vaccum distillation, multistage flash distillation, and **reverse osmosis.** Vacuum distillation is when a facility boils salt water at a low atmospheric pressure, which means the water boils at lower temperatures. In this method, less energy is required. Multistage flash distillation, a widely used method, removes salt and minerals by turning water into steam throughout a series of heat exchangers. The steam is then collected and cooled. Reverse osmosis is another popular desalination method that filters water by applying pressure to one side of a membrane, using the membrane to remove larger particles. Many of these techniques are energy intensive.

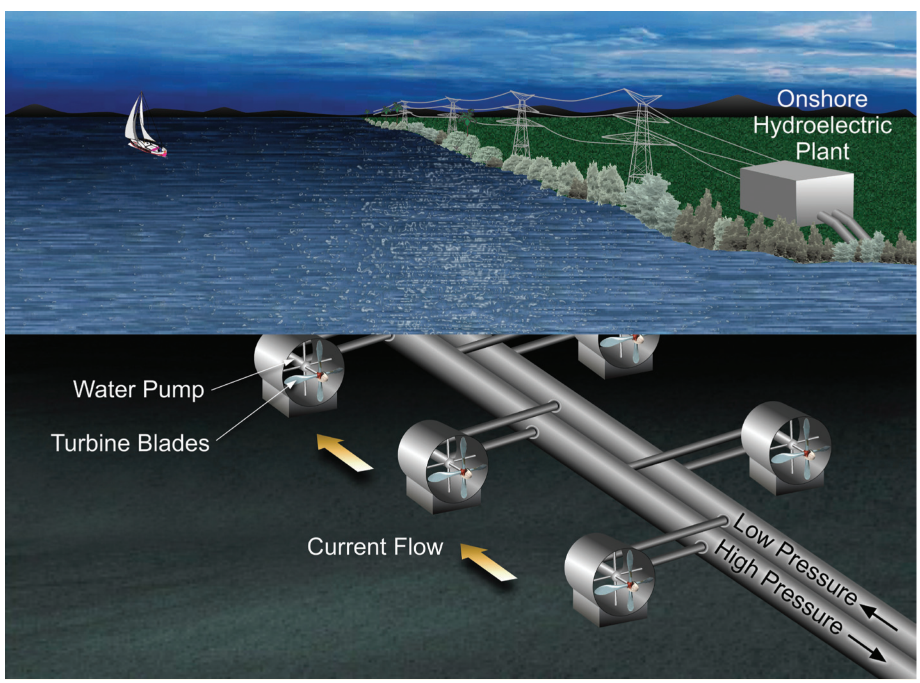
Research is ongoing for alternative methods that require less energy, increase water output, and decrease environmental impact. Some scientists are looking at natural systems for inspiration on methods of desalination. As mentioned in Chapter 2, as water infiltrates, or percolates, through layers of soil, it is cleaned. The water moves on its own, with no need for power. The possibility of creating a desalination plant that mimics infiltration on a large scale is one that scientists are currently exploring. All of these, methods, however, still involve the entrapment of marine life when water is brought in. Until this issue is overcome, desalination still impacts the ocean in a very negative way. The best way to create water is to conserve it, reducing or eliminating the need for such involved and intensive procedures.

Wave and Tidal Energy. Humans have utilized water's power for centuries. The earliest of these technologies was in the form of a water wheel to help grind grain, move paddleboats, and perform other preindustrial processes. Dams have provided huge sources of hydroelectric power. Recently, scientists and engineers have begun planning for wave-and-tidal–energy facilities. These facilities would provide electricity from the natural surges in the ocean. While the practice of harnessing energy in this manner is in its infancy, the Federal Energy Regulatory Committee has started issuing preliminary, three-year wave-energy permits. These permits are part of the testing of wave and tidal energy: and FERC, scientists, and private energy companies are working together to make the most out of the new technology. Early implementation and tests are showing promising results with these systems.

Wave- and tidal-energy is a clean, renewable source of energy with no by-products and a relatively consistent source. However, environmentalists are concerned about the impact on marine animals and the environment. New construction, whether offshore or coastal, could change animals' habitats and migration patterns, similar to the impact of dams on salmon. Tidal-and-wave-energy units can be large and unseemly, marring coastlines, which can make them unpopular with nearby residents and in communities whose economy is based on having a scenic coastline. Furthermore, the energy must be transferred from the coast or ocean to the preexisting electrical grid. As energy is moved, some of it is lost. The farther the energy is transferred, the more energy is lost by the time it reaches its destination.

Wind Energy. Wind energy is most effective when there is a lot of consistently blowing wind. The ocean meets this criteria because in some areas the wind will constantly and

A contra-rotating marine turbine is ready to be installed.



The movement of water causes the underwater turbine blades to rotate, which send high-pressured fluid to turn turbines in an onshore hydroelectric power plant.

predictably blow for weeks. Wind energy is another clean, renewable resource. Scientists and engineers have been building wind turbines for decades and transferring the energy to the electrical grid. However, wind turbines in the ocean are relatively new.

Environmentalists, scientists, engineers, and energy companies are trying to find a balance between wind energy and the environment. The energy must be transported to the electrical grid, and, the farther offshore the turbines are, the more energy is lost in the transport. However, turbines close to land are considered an eyesore by some coastal communities, can produce a great deal of noise, and can be harmful to migrating birds. The turbines are also costly to build and install, and the lifecycle and end-of-life disposal must be considered. We need to ensure that we have a way to dispose of broken or old turbines at the end of their lifespans that is not detrimental to the environment. These and other factors must be taken into consideration when planning to utilize alternative energy sources.

Students may think wind turbines on the ocean are not safe. They learn that electricity and water do not mix. You may need to provide additional explanation about how we can safely harness wind energy from the ocean.

Adaptation: Responding to a Changing Ocean

As we continue to use resources from the ocean, its future seems uncertain. Scientists have made predictions about what will happen if we continue to interact with the ocean as we do currently. Following is one common scenario that you may want to discuss with your students. Your students may have questions about whether this scenario could actually happen. After reading this scenario, look at the following section on actions and think about how you could discuss this scenario with your students.

Can We Run Out of Seafood?

Imagine an ocean with no fish. Some predictions say we will deplete our fisheries of large fish within our lifetime—one report suggests that by 2048 we will have significantly depleted nearly all our fisheries to a point of collapse (Worm 2006). As discussed in Chapter 4, unsustainable fishing practices have greatly impacted the sea. By the early 21st century, we had overfished 90 percent of large fish species—the lions and tigers of the sea—leaving only 10 percent of top predators in the ocean (Myers and Worm 2003). We did not stop with the large fish, however. We have been overfishing small herbivorous fish such as mackerel and sardines as well (see Chapter 4). Over the course of this guide, we have discussed the many ways that different species are interconnected. When we overfish a species or population, the impacts are far reaching. No species disappears without impacting others. Without the small fish to keep them in check, populations of jellyfish could begin to swarm our shores and in fact are already blooming in numbers not seen in the past. While jellyfish are not the most nutritious source of food, without other seafood to eat, and with plentiful numbers, jellyfish could become a more common item on our plates. Anyone interested in a peanut butter and jellyfish sandwich?

Many cultures worldwide depend upon fish as a primary source of protein. Cultural traditions such as paella and lobster boils could be threatened as well. If we cannot get food from traditional sources—such as the ocean—reliably, we may move to other means, such as farming, which often includes clearing vast areas of forests and importing water to desert-like areas that cannot naturally support agriculture on a large scale.

In California, fishing plays an important role in the economy. Annually, commercial fisheries in the state bring in more than $100 million, providing jobs all along the coast (Port of San Diego 2010). If unsustainable practices cause the fisheries to collapse, that means a loss of more than $100 million to the state!

In short, decline of fish populations is not simply a sad tale for an individual fish species. The outcome could be detrimental to different ocean ecosystems—from the decline of species, to toxic blooms of plankton

In northern Myanmar, this fisher propels his boat with his leg, freeing his hands for fishing. This fisher is practicing artisanal fishing.

and jellies—as well as to terrestrial ecosystems as people try to compensate for changes in food sources. Humans have relied on ocean life from their earliest days, and we need to learn to protect and maintain this natural resource in sustainable ways.

Actions: Protecting Our Ocean Every Day

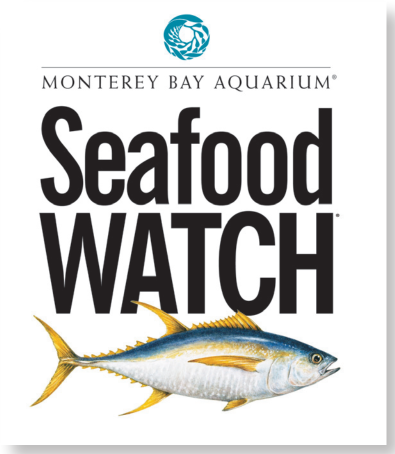
While the ocean has provided society with many great services, it is threatened by humans overutilizing those resources. While the previous section may seem grim, there are precautions we can take to ensure the ocean can provide for us and for generations to come in a healthy, sustainable manner.

Sustainable Seafood. While Marine Protected Areas, Individual Catch Quotas, and other fisheries management plans are helping to ensure the future of our fish stocks and the fishing industry, consumer choices can help as well. In Chapter 4, in the activity **Shop for Solutions!,** page 71, we looked at sustainable and non-sustainable fishing methods. When purchasing seafood, people can be sure to buy fish that is sustainably caught. This means that it is not fished in a style that damages the environment and does not take fish at a rate that depletes the population over time. People can choose aquaculture products that are farmed using techniques that do not degrade the surrounding environment and that are given feed that does not place pressure on other fish stocks. People can avoid products that are caught illegally or are on the protected list. Lastly, many people around the world can also simply reduce their consumption of seafood.

Organizations are working to help us make these choices more easily. Consumer guides are available from many reliable sources, such as the Monterey Bay Aquarium's Seafood Watch program (see http://www.montereybayaquarium.org/cr/cr_seafoodwatch/sfw_recommendations.aspx), and the Blue Ocean Institute's Seafood Guide (see http://www.blueocean.org/seafood/seafood-guide). In California, the Monterey Bay Aquarium Sustainable Seafood Initiative is working throughout the state to increase the number of restaurants that offer sustainable seafood. The Monterey Bay Aquarium has made it easy for seafood eaters to make sustainable choices. They publish a Seafood Watch Guide that they update constantly to tell consumers which fish products are the best choice, which are good alternatives, and which should be avoided. Items are classified by how they are caught or farmed and from what region they are caught or farmed. Shoppers can bring the printed card with them to restaurants and the seafood counter at the grocery store, or they can use the free iPhone application for those times that they forget the card at home. Blue Ocean Institute offers a text-messaging service, available from any cell phone. Simply text *fish* and the species name to 30644 and receive a text back with an assessment of the fish choice and alternatives for environmentally-unfriendly species. Individuals who want to make more of a difference in the seafood industry can become Seafood Watch Advocates and leave friendly, educational cards at restaurants or with fishmongers. With these cards, the advocates can either thank their supplier for providing "Best Choices," or they can inform the supplier of "Avoid" products offered, why the products are detrimental, and what alternative can be provided.

Consumers can also support restaurants and food stores that serve sustainable seafood. Monterey Bay Aquarium partners with many of these restaurants and, through science-based research, helps these restaurants change or plan menus that only offer products off the "Best Choices" and "Good Alternative" lists. Check their website for a restaurant near you that offers sustainable seafood or ask your local servers and restaurant owners where their fish comes from. Greenpeace, the environmental group, ranked common supermarkets with regarding the sustainability of their seafood products. Use guides such as these when going shopping.

Reduce, Reuse, Recycle, Rot. Our ocean is threatened by the amount of trash that ends up in the ocean and along our beaches—about 14 billion pounds per year (Green Guide 2008). As mentioned early in this guide, plastics are threatening entire food webs and ecosystems from purposeful and unintentional littering, and studies show that there is some level of plastic in any seafood that we consume. To help with this problem, we can remember the old adage "Reduce, Reuse, Recycle." The important part of this mantra is the



To get the most up-to-date Seafood Watch pocket guide, log onto Monterey Bay Aquarium's website and print out or request a pocket guide, download the iPhone application, or join their Advocacy team (www.seafoodwatch.org). The Seafood Watch guide provides lists specialized to your region.

order in which we practice our three *R*'s. The first part is to reduce the amount of trash that we create. Avoid buying things that will need to be replaced repeatedly. When you're at a grocery store, consider packaging when choosing a product; avoid using single-use plastic bags and bring reusable bags to the store; use goods and clothes until the end of their life rather than filling landfills with perfectly good, usable products. Donate unwanted items to a thrift store or local charity for household items and clothes that have life left in them. Someone else can reuse your unwanted items.

Many items in our lives have a usable life of minutes but last for years in the environment. It takes energy and raw materials to create things we throw away. This is where reusable items can come in handy. Bring reusable canvas bags or plastic and paper bags back to the store to help you carry purchases. A reusable shopping bag is a small investment that will last you years and keep thousands of single-use plastic and paper bags out of the environment. Reusable water bottles allow you to drink water wherever you go, without the cost of single-use plastic

Support grocers that carry local and sustainable food options. (See http://go.greenpeaceusa.org/seafood/scorecards/scorecard_top20.pdf for more information.)

water bottles. Reusable coffee mugs keep Styrofoam and paper cups out of the environment and can express your personality and be more unique than a coffee-shop cup. Many retailers give you money back for bringing in your own grocery bags or coffee mugs—adding a monetary incentive to the environmental action! Packing your lunch in reusable containers can add variety to your diet and help you to avoid unhealthy processed foods.

Recycle when you can. Paper grocery bags, and now, more frequently, plastic bags may be recycled. Even many electronics can be recycled at a local recycling facility or with the company that made the product. It is important to note that while recycling is less intensive on the environment than buying or using something new, it still requires energy, water and other materials. This is why it comes behind reducing our consumption, and reusing items.

As for the last *R*, *rot*, many paper and food scraps can be composted. This can occur in your backyard, in a community compost, or as is happening in many cities such as San Francisco and Los Angeles, through the local waste-collection company. The less waste we create, the less trash that will end up in the ocean.

If you can't follow the four *R*'s, then it is imperative that all your waste gets disposed of properly. Litter is a top cause of nonpoint-source pollution. Trash that blows on our streets and flows down our storm drains to the ocean has a huge negative impact on the environment. Plastic bags and balloons can look like sea jellies, candy wrappers like small fish, and small plastic pieces called nurdle (small pellets melted by manufacturers to make products) look like fish eggs—all may be ingested by animals in the ocean. Improperly disposing of chemicals, and even waste from our animals, can be detrimental. If you cannot find a way to reduce, reuse, recycle, or rot your trash, at least make sure it ends up in the trash can.

Reduce Emissions. We devoted an entire chapter to climate change, carbon emissions, and ocean acidification

Teaching Tip

After lunch one day, have all students keep their trash. As a class, look at the waste. Have students brainstorm alternatives to a trashy lunch. Ask them to list actions that they would realistically do versus those that they would like to do but probably would not. This can be a great starting point for good discussions about why sometimes people decide to do things that aren't as sustainable as they could be.

because the issues are so important. Reducing our carbon-dioxide emissions can reduce our impact on the ocean from this perspective. Most people know that more-efficient vehicles, carpooling, taking public transportation, and walking or biking can help reduce our emissions and our **carbon footprint** (the amount of carbon dioxide we each produce through our daily action). But sometimes we feel we don't have any other option but to drive, and transportation choice is rarely up to students themselves. Some schools have begun walk-or-bike-to-school groups to help students get outside, get active, and reduce carbon footprints.

There are many other ways to reduce the energy we use. Unplugging electronics when they are not in use is an effective way to reduce energy usage as well as save money. Unplugging the television(s), computer, cellphone chargers, and other appliances when they are not in use greatly reduces the flow of energy that these products draw even when they are turned off. Appliances that still use energy when not in use while plugged in are known as energy vampires, sucking away at energy and money. Turning off the light when you leave a room is a simple activity than anyone can do! Replacing light bulbs with compact fluorescent bulbs (CFLs) also helps to reduce energy use and emissions. Using less water, in general, can also save energy. In California, nearly 20 percent of the state's energy use is spent just on moving water throughout the state (let alone treating it!), more than on any other action. Therefore, the less water we use, the less energy we use.

Another way to reduce emissions is to shop and eat locally. The less distance your food and other products travel to get to you, the less fuel they used to get there and the smaller an impact you are having. It may mean experimenting with new produce recipes or not purchasing the latest fashion, but local farmers and shop owners will appreciate your business. Studies are showing that local food grown in season tends to be more flavorful and vitamin rich too! And buying local means that your money stays in your local economy where it can directly impact your community.

You can also eat lower on the food web or at lower trophic levels. To produce a pound of beef, more than 1,500 gallons of water must be used! (NGM April 2010). This water must be pumped into the farms and processing plants, using fuel to transport it. More energy goes into harvesting grain for the cows, for processing the beef, and in transporting the cattle from the farm to the processing plant to the wholesaler and eventually to your table. If you reduce the amount of meat you eat, you reduce the energy needed to feed yourself and the amount of emissions released in that process. One source reports that, "if all U.S. residents reduced their consumption of animal products by half, we could save the equivalent of the annual flow of 14 Colorado Rivers" (Renault and Wallender 2008). Changing your lifestyle slightly can still have a big impact on our oceans!

Teaching Tip

Students are often unaware of how many resources they use in their daily lives. Having them perform an energy or water audit can help them see how and where they use resources in their lives. One way to expand this lesson to include math skills is to have students each chart their energy use—they can use pie charts to divide how much energy they use in each activity or bar charts to see who in the class uses the most or the least. Additionally, you can challenge your students to reduce their resource use by 10 percent, 15 percent, and so on and have them calculate what the new amount would be. See who in class can reduce his or her impact the most by performing the audit before your lesson as a pre-test and again as a post-test.

In the Classroom Solutions From People

On June 6—8, 2010, the Aquarium of the Bay in San Francisco celebrated World Ocean Day. At the end of their tour through the Aquarium, visitors were invited to see animals that could be affected by climate change, listen to a sustainable-seafood talk, and touch some ocean-animal artifacts. They were also invited to color in a picture of Dr. Seuss's fish and write a message about how the visitors could protect the ocean. Following are some of the visitors' responses:

- Choose to eat sustainable seafood.
- Save energy.
- Save the fish.
- The first thing to do is to clean up the BP oil spill.
- Always use a Seafood Watch Card.
- Don't litter.
- Be eco-efficient.
- Don't drink bottled water.
- Recycle and compost.
- Watch for fish in danger.
- Don't put garbage in the ocean.
- Pick up litter—even if it's not yours.
- Don't support trawling.
- Keep trash out of the water.
- Obey fishing rules.
- Practice catch and release.
- Learn more about the ocean.
- Don't trash the ocean.
- Stop throwing trash and cans.
- Stop throw[ing] bubble gum [in the ocean/on the ground].
- Be aware of what you eat.
- Help clean the ocean.
- Do not pollute.
- Don't spill oil anymore.
- Have pick-up parties where people come and pick up [trash].
- No oil drill[ing] at the ocean.
- Be careful at the beach.

Show the responses to your students and have them group them into major categories. Ask students to explain how the different activities will positively influence and conserve the ocean. After students group and explain the different activities, have them discuss and decide which group of actions will have the most positive impact on the health of the ocean. Tell students that all the actions may have good consequences for the ocean, but students should think about the ones they believe will be most beneficial. Once they discuss their selection, have students share and explain why they believe their chosen action is of highest value for ocean health. As they explain the solutions and talk through their groups and their selections for highest impacts on ocean health, look at where students may have gaps in their knowledge and comprehension.

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Pictures of Practice

Ocean Action

Given the many impacts humans have on our ocean and the extent of these impacts, it can be challenging and a bit overwhelming to make choices about how to reduce the harm done. One might ask, "Does it really matter that I purchase sustainable seafood when millions of people are not doing the same?" Taking action to protect our ocean is important at the individual level, even if it means picking up trash at the beach or choosing to eat at a restaurant that offers sustainable seafood. When these individual actions are aggregated across many people, real change can happen. Students seem to know that the ocean is in danger and that everyday actions impact the ocean, but they do not necessarily grasp the scope of the problem or the scale at which actions need to be taken. They also tend to characterize certain actions as "good" or "bad" without understanding why. Like many adults, children may view ocean-related issues as faraway problems or think that the ocean is so vast that it can handle the pressures put upon it. Other students may be interested in helping but may only focus on visible actions that individuals can take as opposed to collective actions by groups.

Students: Grades 5 and 7

Location: California (coastal communities)

Goal of Video: The purpose of watching this video is to hear student ideas about actions for protecting the ocean and to think about how to use this information to plan instruction.

Classroom Context

Students in this video live near the California coast. The interview clips shown in this video were taken during the spring of the school year after both sets of students learned more about the ocean and ocean biodiversity. The first part of the video shows fifth-grade students describing actions to protect the ocean. The second half of the video shows seventh-grade students answering the same question. Think about the different types of responses you hear from students in the same grade as well as differences between grade levels.

Video Analysis

In the video, students were asked what they can do to protect the ocean. A good answer to this question would not only include answers about reducing litter and pollution, but also would involve answers about choices as consumers. For example, protecting the ocean includes making choices about seafood and not buying too many disposable products such as plastics. However, as you listen to students' ideas, notice that students do not make the connection to consumer choices and actions.

Reflect

How would you help students learn about protecting the ocean?

Think about the obvious actions that students describe in their interviews. What patterns do you see in these responses across grades? How could you help students expand their understanding of ocean conservation and protection to include consumer choices? What concepts would you target?

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Teaching Resources

California Coastal Commission's Waves, Wetlands, and Watersheds Curriculum. www.coastal.ca.gov/publiced/waves/waves_entire.pdf

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

College of Exploration of Oceans. http://www.coexploration.org/ceo/

COSEE-California (Center for Ocean Science Education Excellence – California)http://www.coseeca.net/

MIT designed solar-powered portable desalination system http://web.mit.edu/newsoffice/2010/itw-portable-desalination-1015.html

Monterey Bay Aquarium Seafood Watch. www.montereybayaquarium.org.

National Geographic's Take Action http://www.sylviaearlealliance.org/

Glossary

abiotic pollutantion
(A-bi-ah-tihk puh-LOO-shun)
Harmful substance that is not produced by a living organism, such as heavy metals.

anthropogenic
(an-thruh-puh-JEH-nihk)
Caused by people.

aquaculture
(AH-kwuh-kuhl-cher)
The art and science of cultivating marine or freshwater life for food and industry.

archaea
(AR-kee-uh)
A group of tiny organisms often living in extreme environments, such as ocean vents and salt lakes. (singular: archaeon)

ballast
(BA-luhst)
Heavy material, usually water, used to provide stability for large ships or other oceangoing vessels.

benthic
(BEHN-thihk)
Having to do with the bottom of a deep body of water.

biodiversity
(bi-oh-dih-VEHR-sih-tee)
All the different kinds of living organisms within a given area.

biomass
(BI-oh-mas)
Energy in living organisms.

biome
(BI-ohm)
Area of the planet that can be classified according to the plant and animal life in it.

biotoxins
(BI-oh-tahk-sihn)
Poisonous substances produced by a living organism.

bisphenol A (BPA)
(bi-SFEE-nahl AY)
Chemical used to make some types of plastic that may be unsafe for people, especially infants.

brackish water
(BRA-kihsh WAH-ter)
Salty water, usually a mixture of seawater and freshwater.

bycatch
(BI-kach)
Fish or any other organisms accidentally caught in fishing gear.

calcification
(kal-sih-fih-KAY-shun)
Process by which calcium or calcium salts build up in organic tissue.

carbon footprint
(KAR-bun FOOT-prihnt)
The measurable total impact of one or more people on the environment. Also called environmental footprint.

carbon sink
(KAR-bun SIHNK)
Area or ecosystem that absorbs more carbon dioxide than it releases.

carcinogenic
(KAR-sih-noh-jeh-nihk)
Cancer-causing.

cellular respiration
(SEHL-yoo-lur rehs-pur-AY-shun)
Process by which cells turn nutrients into useful energy.

centrifugal force
(sehn-TRIH-fyoo-gul FORS)
Effect that seems to cause an object moving in a curve to move away from the curve's center.

chemosynthesis
(KEE-moh-sihn-thuh-sihs)
The process by which some microbes turn carbon dioxide and water into carbohydrates, using energy obtained from inorganic chemical reactions.

colonization
(kah-luh-nuh-ZAY-shun)
Spreading of a species into a new habitat or ecosystem and establishing a healthy population there.

commensalism
(kuh-MEHN-suh-lih-zum)
Relationship between organisms in which one organism benefits from the association while not harming the other.

coral bleaching
(KOHR-uhl BLEE-ching)
The unhealthy loss of color in corals.

density
(DEHN-sih-tee)
Number of units in a given area.

desalination
(dee-sal-ih-NAY-shun)
Process of converting seawater to freshwater by removing salt and minerals.

detritus
(deh-TRI-tus)
Nonliving organic material, often decomposing.

dinoflagellate
(di-noh-FLA-juh-lut)
One-celled marine organism that is a major component of plankton.

domoic acid
(duh-MOH-ihk A-sihd)
Toxin produced by some algae.

dredging
(DREHJ-ihng)
The act of removing sand, silt, or other material from the bottom of a body of water.

dynamic equilibrium
(di-NA-mihk ee-kwih-LIH-bree-um)
State in which particles move between substances at a steady rate, resulting in no net change.

eastern boundary current
(EE-sturn BOWN-dree KUR-rehnt)
Shallow flow of water along an ocean's eastern border, carrying cold water toward the Equator.

ecosystem
(EE-koh-sihs-tehm)
Community of living and nonliving things in an area.

El Niño
(ehl NEEN-yoh)
Irregular, recurring weather system that features a warm, eastern-flowing ocean current in the eastern Pacific Ocean.

entrapment
(ehn-TRAP-mehnt)
Process or situation in which an organism or object cannot escape or move out of an area.

eradicate
(ee-RAD-ih-kayt)
To destroy or remove.

estuary
(EHS-choo-wair-ee)
The mouth of a river where the river's current meets the sea's tide.

eutrophication
(YOO-troh-fih-kay-shun)
The buildup of sediment and organic matter in bodies of water, which may cause a change in the productivity of the ecosystem.

exclusive economic zone (EEZ)
(ehks-KLOO-sihv ee-kuh-NAH-mihk ZOHN)
Zone extending 200 nautical miles from a country's coast. A country has the right to explore and exploit the living and nonliving things in its EEZ.

extinct
(eks-TIHNKT)
No longer existing.

fishery
(FIH-shuh-ree)
Industry or occupation of harvesting fish, either in the wild or through aquaculture.

genome
(JEE-nohm)
Set of genes, or chromosomes, that hold all the inherited characteristics of an organism.

Great Pacific Garbage Patch
(GRAYT puh-SIH-fihk GAR-buhj PACH)
An area of the North Pacific Ocean where currents have trapped huge amounts of debris, mostly plastics.

Greenhouse Effect
(GREEN-hows ih-FEHKT)
A phenomenon in which gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape.

greenhouse gas
(GREEN-hows GAS)
Gas in the atmosphere, such as carbon dioxide and ozone, that absorbs solar heat reflected by the surface of the Earth, warming the atmosphere.

halocline
(HA-luh-klin)
Zone in an ocean or other water column in which the salinity changes. Saltier haloclines are usually found in deeper water.

harmful algal blooms (HABs)
(HARM-ful AL-gul BLOOM)
Rapid growth of algae that can threaten an aquatic environment by reducing the amount of oxygen in the water, blocking sunlight, or releasing toxic chemicals.

heat capacity
(HEET kuh-PA-sih-tee)
Amount of heat required to change the tempreature of an object by a given amount. Heat capacity is abbreviated C and is usually measured in joules per kelvin.

hydrocarbon
(HI-droh-kar-bun)
Chemical compound made entirely of the elements hydrogen and carbon.

impervious
(ihm-PUR-vee-yus)
Impenetrable by water.

individual transferable quotas (ITQ)
(ihn-dih-VIH-joo-ul trans-FUR-uh-bul KWOH-tuhs)
Permit allowing an individual or organization to catch or harvest a percentage of an area's fishery. Also called an individual fishing quota (IFQ).

invasive species
(ihn-VAY-sihv SPEE-seez)
Type of plant or animal that is not indigenous to a particular area and can cause economic or environmental harm.

jurisprudence
(JUR-his-proo-dehns)
System of laws, including statutes and court decisions.

La Niña
(LAH NEEN-yuh)
Weather system that includes cool ocean temperatures in the eastern Pacific Ocean.

marine debris
(muh-REEN duh-BREE)
Garbage, refuse, or other objects that enter the coastal or ocean environment.

marine jurisdiction
(muh-REEN jur-his-DIHK-shun)
Power to determine laws and regulations over an area of the ocean.

marine sanctuary
(muh-REEN SANK-shoo-wair-ee)
Part of the ocean protected by the government to preserve its natural and cultural features while allowing people to use and enjoy it in a sustainable way.

mitigation
(mih-tih-GAY-shun)
To lower the severity of a natural or human condition.

mutualism
(MYOO-choo-wuh-lih-zum)
Relationship between organisms of different species, in which both organisms benefit from the association.

natural resource exploitation
(NA-chuh-rul REE-sors ehk-sploy-TAY-shun)
Use and harvest of renewable and nonrenewable natural resources.

nonpoint-source pollution
(nahn-point SORS puh-LOO-shun)
Toxic chemicals that enter a body of water from many sources.

Notothenioidei
(NOH-teh-theh-nee-oy-dee-i)
Group of fish native to the waters surrounding Antarctica.

ocean acidification
(OH-shun uh-sih-dih-fih-KAY-shun)
Decrease in the ocean's pH levels, caused primarily by increased carbon dioxide. Ocean acidification threatens corals and shellfish.

Ocean Gyre
(OH-shun JIR)
An area of ocean that slowly rotates in an enormous circle.

overexploitation
(oh-vur-ehk-sploy-TAY-shun)
Use or harvesting of a renewable resource to the point at which the resource is threatened.

parasitism
(PAIR-ih-sih-tih-zum)
Relationship between organisms in which one organism (a parasite) lives or feeds on the other, usually causing harm.

pelagic
(puh-LA-jihk)
Having to do with the open ocean.

percolation
(pur-kuh-LAY-shun)
Movement and filtration of water through soil or rock layers.

photodegradation
(foh-toh-deh-greh-DAY-shun)
Process by which a substance is broken down by exposure to light.

phylum
(FI-lum)
Grouping that divides organisms by body plan: its symmetry, segments, and limbs.

poikilothermic
(poy-kee-loh-THUR-mihk)
Having a body temperature that changes in response to its surroundings. Also called cold-blooded.

point-source pollution
(POINT SOHRS puh-LOO-shun)
Pollution from a single, identifiable source.

polarity
(poh-LAIR-ih-tee)
Property of having or being attracted to poles, such as positive and negative electrical charges.

polyethylene
(pah-lee-EH-thuh-leen)
Type of plastic that is flexible, easily molded, and used for packaging and insulation.

press disturbance
(PREHS dihs-TUR-buns)
Change in the environment that is sustained after the initial event.

pulse disturbance
(PULSE dihs-TUR-buns)
Change in the environment in which the effects may be long-lasting, but the change is not sustained after the initial event, such as an earthquake or flood.

purse-seining
(PURS SAY-nihng)
Fishing technique that relies upon a large net to catch entire schools of fish.

reverse osmosis
(ree-VURS ahs-MOH-sihs)
Water sanitation process that forces water through plastic sheets in order to remove microscopic pollutants and harmful molecules.

salinity
(say-LIH-nih-tee)
Saltiness.

sessile
(SEH-sil)
Permanently attached, not able to move freely.

surface tension
(SUR-fus TEHN-shun)
Property of the surface of a liquid in which the molecules act like a thin, elastic film, allowing it to resist external forces.

sustainable seafood
(su-STAY-nuh-bul SEE-food)
Fish, shellfish, and other aquatic organisms harvested from fish farms or fisheries that can be maintained without damaging the ecosystem.

symbiotic
(sihm-bee-AH-tihk)
Associating with another organism, not always to the mutual benefit of either species.

thermal expansion
(THUR-mul ehk-SPAN-shun)
Process by which a substance expands its volume as the temperature increases.

thermohaline circulation
(THUR-moh-klin sur-kyoo-LAY-shun)
Ocean conveyor-belt system in which water moves between the cold depths and warm surface in ocean basins throughout the world.

topography
(tah-PAH-gruh-fee)
Study of the shape of the surface features of an area.

transpiration
(trans-puh-RAY-shun)
The evaporation of water from plants.

trawling
(TRAH-lihng)
The act of fishing by dragging a large net along the bottom of the body of water.

watershed
(WAH-tur-shehd)
An entire river system or an area drained by a river and its tributaries.

water cycle
(WAH-tur SI-kul)
Movement of water between atmosphere, land, and ocean.

western boundary current
(WEH-sturn BOWN-dree KUR-rehnt)
Deep, narrow flow of water along an ocean's western border, carrying warm water toward the poles.

Facilitator Questions

Chapter 1

Student Thinking: Movement of Water in the Ocean

1. Order the responses from least to most sophisticated. How did you determine the order of sophistication?
2. What patterns do you see in the responses? What are common mistakes students make in their descriptions?
3. How would your instruction differ if you were responding to Reagan compared to CJ?

Student Thinking: What Causes Tides?

1. How do student experiences reinforce or contradict a scientific explanation of tides? How can you use this information to plan your instruction?
2. How would you reinforce the idea that tidal activity involves the whole ocean and is happening all the time as opposed to a local, coastal phenomena?

Pictures of Practice: Explaining Waves

1. Leah and Reagan use mechanisms that cause tides to explain waves. How do you think the two students developed these ideas, and how would you respond in your instructional planning?
2. Reagan describes *extra water, bulges,* and *tsunami.* What do you think she means by these words?
3. CJ bases his explanation on Earth's tilt (north pointing away) causing waves to move downward. How would you respond to CJ's ideas?
4. Morgan's description says that "waves just form," and Allison identifies both wind and animal movement as causing waves. What concepts would you work on with these students?
5. Jacob seems to have a sophisticated understanding of waves but never identifies a driving mechanism, such as wind. If Jacob shared his idea during a class discussion, what would be your next step?

Chapter 2

Pictures of Practice: Ocean and Water Cycling

1. The first group Ms. Reimer talks with focuses on needing the ocean for food and recreation. Ms. Reimer said that in this situation she wanted to "give" them the answer. What other strategies might Ms. Reimer use to help them elaborate on their ideas?
2. Erica says "stabilize the weather system" means "to not get too hot and burn up." How would you respond to her explanation?
3. Ms. Reimer seems disappointed that her students did not remember more about the ocean-water cycle connection. CJ also expresses uncertainty about this topic in his post interview. Why might these concepts be difficult for students, and how would you support understanding of these concepts?
4. When young students are asked, "Will your rain be salty if you live near the ocean?" many respond yes. How would you adjust your instructional plans to help students understand evaporation?

Student Thinking: Ocean and Water Cycling

1. What do you think Reagan means when she says it's harder for the ocean to take in heat? What does she misunderstand about differential heating of ocean and land?
2. Leah thinks the ocean cools off faster than land, and land heats up faster than the ocean. What would be your next step as Leah's teacher?

3. Both CJ and Leah believe salt is left behind as water evaporates from the ocean. How would you help other students learn this concept?

Student Thinking: Estuary Interfaces

1. Which important aspects of estuaries would you teach to students?
2. What key ideas do students not mention in their answers?
3. How are estuaries connected to the water cycle? How can you help students to strengthen their understanding of these connections?

Chapter 3

Pictures in Practice: Life in the Ocean

1. Students more readily grasp that land plants are photosynthesizers and producers but may not realize that phytoplankton fulfill this role in the ocean. Why do you think students struggle with this concept?
2. Reagan wonders why animals would live near the surface, making them vulnerable to humans. How would you respond to Reagan's question?
3. The focus of Ms. Reimer's lesson was on the euphotic and abyssal zones, but Leah questions how ocean life moves between the zones in the ocean. She also wonders why animals dive for food if they live near the surface where food is abundant. How would you reteach to address Leah's question?

Student Thinking: Animal Life in the Ocean

1. What experiences may cause students to develop personified ideas about ocean life? How can personification be both helpful and harmful when describing ocean ecosystems?
2. How can you help students move beyond iconic ocean species to recognize other essential, but less familiar, species?
3. For many students, fish are just fish. How can you help students see both genetic and species diversity within and between populations of fish?

Pictures of Practice: Marine Food Webs

1. Ms. Reimer describes the leap from food chains to food webs as a challenging one for students. What evidence do you have from your own experience that is similar or different to what Ms. Reimer describes?
2. Food chains and webs use arrows or lines to show connections between organisms. How can you help students see the arrows as representing energy and matter and not just actions such as "eating" or materials like "food?"
3. One group of students thinks that food chains describe land plants and animals, and food webs describe underwater life. How would you respond to this idea if you were the teacher?
4. Both Reagan and Leah said food webs were the most difficult thing they learned during the lessons. Leah also said she thinks sharks would get more energy at the top of the food chain. How can you plan your instruction to help make these concepts easier to understand for students?

Student Thinking: Ecosystem Dynamics and Invasive Species

1. Order student answers from least to most sophisticated. How did you determine your order? What patterns do you see in students' answers?
2. How do students apply human social dynamics to the reef communities? How is this helpful or harmful for reasoning about relationships in marine ecosystems?
3. Some students believe that lionfish would cause other native fish to leave a habitat. How would you respond to this misconception if shared during classroom discussion?

Chapter 4

Student Thinking: Our Fishing Practices

❶ How are Juan and Julie's responses similar? What do these students focus on in their answers?

❷ How are Alan's ideas both similar and different from Juan and Julie? What do you believe Alan knows that Juan and Julie do not yet understand?

❸ What do you think Olivia means when she says, "fish that are good for the environment?" Do you think Olivia believes there are fish that are both bad and good for the environment?

❹ What does Keith understand about habitats? If Keith shared his idea in your classroom, what would be your next step?

Pictures of Practice How We Fish Our Ocean

❶ Ms. West wants students to have a good understanding of trophic levels so that students have a better understanding of how human activities impact marine ecosystems. She elicits several student ideas about the trophic chart. One student explains that higher-level consumers contain fewer organisms due to people hunting them. What would be your next step in responding to this student?

❷ In the post interview, Jacob explains that fishing and other human activities change the trophic chart. Yet artisan and recreational fishing that he describes do not have the impacts of commercial activities. How would you work with Jacob to expand what he knows about the topic?

❸ Alison explains that without trophic levels, it would be hard for animals to survive. What does she mean by this? How can you help Alison better understand trophic charts as a representation?

❹ In preinterviews (not shown in the video), Jacob said that fish are resources humans were meant to have, but Tony is afraid we will run out of fish by 2012 or 2013. How would you plan instruction to deal with these contradictory beliefs?

Student Thinking: Marine Debris

❶ Most students focus on trash discarded at a beach. How can you help students better understand the many origins of marine debris and better understand individual consumer choices that relate to marine debris?

❷ Students may imagine that the Great Pacific Garbage Patch is an "island" of floating trash, but much of the debris is just under the surface. How would you teach this concept?

❸ Why are plastics so common within the Great Pacific Garbage Patch (Pacific Gyre)? How would you help students understand that trash discarded in California communities could make its way to this garbage patch in the ocean?

Pictures of Practice: Marine Debris

❶ Leah and Reagan have very different explanations about the source of debris. Leah describes debris left on a beach, while Reagan describes debris coming from storm drains. How would your instructional plans help both students develop a more complete account of sources of marine debris?

❷ Most students focus on visible litter and trash. What key concepts about marine debris are they missing?

❸ When describing the garbage patch, Jacob describes a mile-long buildup of trash, while Tony describes a mile-high buildup of trash. How would you help both develop a more accurate account of this phenomenon?

❹ The fifth-grade students focus on individual instances of pollution, but the seventh-grade students immediately mention the garbage patch. Why the difference?

Student Thinking: Threats to Ocean Biodiversity

1. How would you teach about both direct impacts on ocean biodiversity, such as overfishing, and indirect effects, such as bycatch?
2. What would be a good way to ensure students understand that fishing affects many organisms in a food web and not just the species caught?
3. How would you teach the difference between turbid waters that seem polluted and actually polluted water?
4. What concepts would you target when teaching about invasive species? How would you respond to questions about what counts as a native versus an invasive species?

Student Thinking: Adjusting to Change

1. Order students' ideas from least to most sophisticated. How did you determine your order?
2. What does Leah seem to understand that CJ and Reagan do not yet understand?
3. How would your teaching be different in responding to Leah as compared to Reagan?
4. No students mention passing genes to offspring, which is normal for students of this age. What concepts would you work on so that students are prepared to understand genes and evolution in future grade levels?

Chapter 5

Student Thinking: Pollution in the Ocean

1. Of the previous responses, what do you see as the most and least sophisticated ideas that students mention?
2. What human-environment interactions do students mention in their descriptions, and how can you capitalize on these ideas to support students' thinking about the complexity of this problem?
3. What sources and types of pollution do students not mention? How can you help students expand their knowledge about pollution?

Pictures of Practice: Biomagnification

1. What concepts do students readily understand after the biomagnification activity?
2. CJ says that driving cars affects the ocean, but he doesn't know how to explain the connection so he moves on to another idea. Most students focus on direct (more visible) impacts of pollution, but how could you take CJ's idea about pollution from cars to teach biomagnifications?
3. Reagan uses the words *get infected.* What do you think she means?
4. Listen closely to Leah's explanation. She described toxins getting on the "skin" of organisms. If Leah shared this idea in class, what would be your next step?
5. CJ associates bacteria with pollution. How would you handle his misconception?

Chapter 6

Pictures of Practice: Melting Ice

1. The impacts of climate change are uncertain. If you were teaching about potential impacts of climate change on our ocean, how would you teach about uncertainty and the range of predictions that scientists have made?
2. In order to understand the difference in melting ice from the Arctic and Antarctica, students must understand basic concepts about volume density. How would you teach about the differences of melting ice in the Arctic compared to melting ice in Antarctica?

3. Burhon is concerned that water and inland climates will change faster than we can adapt. How can you incorporate scenarios for adaptation into your instructional plans?
4. What do you think Hailey means by "a lake might come down and overflow"? What would be your next step to teach Hailey about this topic?

Student Thinking: Ideas About Acids and Bases

1. What are some common themes you see in the logic of the students?
2. How would you explain safety in terms of acids and bases? How can you relate this to everyday life and experiences (e.g., commercials that tout products as "pH balanced")?
3. Students think of harmful, "untouchable" materials when they think of acids. How would you help students see that seemingly small changes in acidity of our ocean may have profound impacts—that the ocean is not going to become the "acid" they think of when they hear the word?

Student Thinking: Climate and the Ocean

1. Why might some organisms benefit from warmer ocean temperatures? How would you teach that climate change could be favorable for some?
2. Natural selection happens over long periods. What would you expect students to struggle with as they learn about organisms surviving climate change?

Chapter 7

Student Thinking: Protecting Our Ocean

1. Order the responses from least to most sophisticated. How did you determine your order?
2. What are the dominant patterns among the responses?
3. What are the glaring omissions from the responses? What actions are not identified by students?
4. Why do students tend to focus on litter? How can you introduce them to other consumer actions that protect the ocean?

Pictures of Practice: The Aquarium Trade

1. Jacob's group decides that live pets are fine to remove from coral reefs, but removing live organisms and killing them for decoration is not acceptable. How would you respond to this group's ideas? What additional concepts about aquarium trading would you need to teach?
2. Some species, such as sand dollars and shells, are taken from the ocean and killed so they can be cleaned and dried for decorations. Several students see this practice as wrong. What would be your next step to help students connect this issue to consumer choices?
3. One girl proposes that artificial coral is a solution for aquariums because "fish aren't that smart." The fish would not know the difference. What does this student not understand about coral's role in ecosystems? How could you support her suggestions for artificial coral, while simultaneously improving her understanding of this species in natural ecosystems?

Pictures of Practice: Ocean Action

1. Compare responses from Allison and Tony. Allison focuses on personal action of not littering and increasing the number of trash cans. Tony focuses on personal actions as well but connects this to keeping a watershed clean. How can you capitalize on both types of actions (both immediate, personal actions and community-level actions) to teach about diversity of solutions?

❷ Jacob realizes that corporations need to change. If Jacob shared this during a class discussion, what would be your next step? How can you help Jacob bring this solution back to consumer choices—choices that give him the ability to act and do not place all the weight on corporations?

❸ CJ shares a sophisticated connection between driving cars and ocean health. How does this compare to Reagan's solutions?

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 3				
Social Studies	3.1.1	Identify geographical features in their local region.	The Geography of Where We Live (e.g., California Connections: California Natural Regions [pp. 42—47 Ocean & Coast])	Chapter 1
	3.1.2	Trace the ways in which people have used the resources of the local region and modified the physical environment.	The Geography of Where We Live (e.g., California Connections: California Natural Regions [pp. 42—47 Ocean & Coast])	Chapter 4
	3.2.1	Describe national identities, religious beliefs, customs, and various folklore traditions.		Chapter 7
	3.4.1	Determine the reasons for rules, laws, and the U.S. Constitution; the role of citizenship in the promotion of rules and laws; and the consequences for people who violate rules and laws.		Chapter 7
	3.4.2	Discuss the importance of public virtue and the role of citizens, including how to participate in a classroom, in the community, and in civic life.	California Economy—Natural Choices	Chapter 7
	3.5.1	Describe the ways in which local producers have used and are using natural resources, human resources, and capital resources to produce goods and services in the past and the present.	California Economy—Natural Choices	Chapter 4
	3.5.2	Understand that some goods are made locally, some elsewhere in the United States, and some abroad.	California Economy—Natural Choices	Chapter 4
	3.5.3	Understand that individual economic choices involve trade-offs and the evaluation of benefits and costs.		Chapter 4, 5, 7
Science	3.1.d	Students know energy can be carried from one place to another by waves, such as water waves and sound waves, by electric current, and by moving objects.		Chapter 1
	3.1.e	Students know matter has three forms: solid, liquid, and gas.		Chapter 2
	3.1.f	Students know evaporation and melting are changes that occur when the objects are heated.		Chapter 2
	3.1.g	Students know that when two or more substances are combined, a new substance may be formed with properties that are different from those of the original materials.		Chapter 2
	3.1.h	Students know all matter is made of small particles called atoms, too small to see with the naked eye.		Chapter 2
	3.3.a	Students know plants and animals have structures that serve different functions in growth, survival, and reproduction	Structures for Survival in a Healthy Ecosystem	Chapter 3
	3.3.b	Students know in different environments, such as oceans, deserts, tundra, forests, grasslands, and wetlands.		Chapter 3
	3.3.c	Students know living things cause changes inexamples of diverse life forms the environment in which they live: some of these changes are detrimental to the organism or other organisms, and some are beneficial.	Living Things in Changing Environments (e.g., California Connections: Sweetwater Marsh National Wildlife Refuge)	Chapter 3, 4, 5, 6
	3.3.d	Students know when the environment changes, some plants and animals survive and reproduce; others die or move to new locations.	Living Things in Changing Environments (e.g., California Connections: Sweetwater Marsh National Wildlife Refuge)	Chapter 3, 4, 5, 6
	3.3.e	Students know that some kinds of organisms that once lived on Earth have completely disappeared.		Chapter 3, 4, 5, 6

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 4				
Social Studies	4.1.4	Identify the locations of the Pacific Ocean, rivers, valleys, and mountain passes and explain their effects on the growth of towns.		Chapter 1
	4.5.3	Describe the similarities (e.g., written documents, rule of law, consent of the governed, three separate branches) and differences (e.g., scope of jurisdiction, limits on government powers, use of the military) among federal, state, and local governments.		Chapter 7
Science	4.2.a	Students know plants are the primary source of matter and energy entering most food chains.	Plants: the Ultimate Energy Resource	Chapter 3, 4, 5
	4.2.b	Students know producers and consumers (herbivores, carnivores, omnivores, and decomposers) are related in food chains and food webs and may compete with each other for resources in an ecosystem.	The Flow of Energy Through Ecosystems	Chapter 3, 4, 5
	4.2.c	Students know decomposers, including many fungi, insects, and microorganisms, recycle matter from dead plants and animals.	Life and Death With Decomposers	Chapter 3
	4.3.a	Students know ecosystems can be characterized by their living and nonliving components.		Chapter 3
	4.3.b	Students know that in any particular environment, some kinds of plants and animals survive well, some survive less well, and some cannot survive at all.		Chapter 3, 4,5, 6
	4.5.c	Students know moving water erodes landforms, reshaping the land by taking it away from some places and depositing it as pebbles, sand, silt, and mud in other places.		Chapter 2
Grade 5				
Science	5.3.a	Students know most of Earth's water is present as salt water in the oceans, which cover most of Earth's surface.	Earth's Water (e.g., Lesson 3: From Fresh to Salt Water)	Chapter 1, 2
	5.3.b	Students know when liquid water evaporates, it turns into water vapor in the air and can reappear as a liquid when cooled or as a solid if cooled below the freezing point of water.	Changing States: Water, Natural Systems, and Human Communities	Chapter 2
	5.3.c	Students know water vapor in the air moves from one place to another and can form fog or clouds, which are tiny droplets of water or ice, and can fall to Earth as rain, hail, sleet, or snow.	Precipitation, People, and the Natural World	Chapter 2
	5.3.d	Students know that the amount of freshwater located in rivers, lakes, underground sources, and glaciers is limited and that its availability can be extended by recycling and decreasing the use of water.	Our Water: Sources and Uses	Chapter 2
	5.3.e	Students know the origin of the water used by their local communities.		Chapter 2
	5.4.a-c	Students know uneven heating of Earth causes air movements (convection currents).		Chapter 2
	5.4.b	Students know the influence that the ocean has on the weather and the role that the water cycle plays in weather patterns.		Chapter 2
	5.4.c	Students know the causes and effects of different types of severe weather.		Chapter 2

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 6				
Science	6.2.b	Students know rivers and streams are dynamic systems that erode, transport sediment, change course, and flood their banks in natural and recurring patterns.	The Dynamic Nature of Rivers	Chapter 2
	6.2.c	Students know beaches are dynamic systems in which the sand is supplied by rivers and moved along the coast by the action of waves.		Chapter 1, 2
	6.3.a	Students know energy can be carried from one place to another by heat flow or by waves, including water, light and sound waves, or by moving objects.		Chapter 1
	6.4.a	Students know the sun is the major source of energy for phenomena on Earth's surface; it powers winds, ocean currents, and the water cycle.		Chapter 1, 6
	6.4.d	Students know convection currents distribute heat in the atmosphere and oceans.		Chapter 1, 2, 6
	6.5.a	Students know energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis and then from organism to organism through food webs.		Chapter 3, 4, 5
	6.5.b	Students know matter is transferred over time from one organism to others in the food web and between organisms and the physical environment		Chapter 3, 4, 5
	6.5.c	Students know populations of organisms can be categorized by the functions they serve in an ecosystem.	Energy: Pass It On!	Chapter 3, 4, 5
	6.5.d	Students know different kinds of organisms may play similar ecological roles in similar biomes.	Playing the Same Role	Chapter 3, 4, 5
	6.5.e	Students know the number and types of organisms an ecosystem can support depends on the resources available and on abiotic factors, such as quantities of light and water, a range of temperatures, and soil composition.		Chapter 3, 4, 5, 6
	6.6.b	Students know different natural energy and material resources, including air, soil, rocks, minerals, petroleum, freshwater, wildlife, and forests, and know how to classify them as renewable or nonrenewable.	Energy and Material Resources: Renewable or Not?	Chapter 7
Grade 7				
Science	7.3.a	Students know both genetic variation and environmental factors are causes of evolution and diversity of organisms.	Shaping Natural Systems Through Evolution	Chapter 3
	7.3.e	Students know that extinction of a species occurs when the environment changes and that the adaptive characteristics of a species are insufficient for its survival.	Responding to Environmental Change	Chapter 3, 4, 5, 6

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 8				
Social Studies	8.3.6	Describe the basic law-making process and how the Constitution provides numerous opportunities for citizens to participate in the political process and to monitor and influence government (e.g., function of elections, political parties, interest groups).		Chapter 7
	8.12.1	Trace patterns of agricultural and industrial development as they relate to climate, use of natural resources, markets, and trade and locate such development on a map	Agricultural and Industrial Development in the United States	Chapter 4, 5
	8.12.5	Examine the location and effects of urbanization, renewed immigration, and industrialization (e.g., the effects on social fabric of cities, wealth and economic opportunity, the conservation movement).	Industrialization, Urbanization, & Conservation Movement	Chapter 4, 5
Science	8.5.d	Students know physical processes include freezing and boiling, in which a material changes form with no chemical reaction.		Chapter 2
	8.5.e	Students know how to determine whether a solution is acidic, basic, or neutral.		Chapter 6
	8.6.a	Students know that carbon, because of its ability to combine in many ways with itself and other elements, has a central role in the chemistry of living organisms.		Chapter 6
	8.8.a	Students know density is mass per unit volume.		Chapter 1
	8.8.b	Students know how to calculate the density of substances (regular and irregular solids and liquids) from measurements of mass and volume.		Chapter 1
	8.8.c	Students know the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid the object has displaced.		Chapter 1
	8.8.d	Students know how to predict whether an object will float or sink.		Chapter 1

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