Disruptions in Ecosystems

Ecosystem Interactions, Energy, & Dynamics

Middle School Unit Aligned with the Next Generation Science Standards

AMERICAN MUSEUM ᴼ NATURAL HISTORY

THE LAWRENCE HALL OF SCIENCE
UNIVERSITY OF CALIFORNIA, BERKELEY

Student Book

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Moving Next Generation Science Standards Into Practice:
A Middle School Ecology Unit and Teacher Professional Development Model

A project led by the American Museum of Natural History in collaboration with the SEPUP (Science Education for Public Understanding Program) group at the Lawrence Hall of Science and funded by the National Science Foundation Grant DRL 1418235.

PROJECT TEAMS

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Wolves in Yellowstone

Imagine you could travel back in time a thousand years. What differences would you notice in the animals and plants in the area where you live? What kind of animals might you see? Bears, wolves, and eagles used to live where New York City now stands. Today, coyotes, deer, and peregrine falcons can sometimes be found in the city. In many places in the world, the populations of plants and animals have changed as human populations have grown. In some places the changes haven't been as extreme. In Rocky Mountain National Park in Colorado there used to be wolves, black bears, and grizzly bears, but now there are only black bears. What do you think caused such changes? What effects do you think these changes have had on the other animals and the plants that live in the area? What do you think would happen if some animals, like bears, were brought back to live in these environments?

In this chapter you will focus on the relationships between living things and the non-living things in the environment. You will investigate the effects of disruptions— events that change environments—caused by human populations and their actions. As you study scientific questions, you will engage in scientific practices—the things scientists do to understand and explain the world. For example, scientists analyze the data they collect to develop explanations for how things work. Scientists also construct arguments about which explanation makes the most sense. You will develop scientific explanations about relationships and changes in the environment. You will learn how to use your explanations to construct scientific arguments about the ways humans affect the environment, and whether people should try to reduce disruptions.

Engage: People and Animals Interacting

More than 330 million people visited national parks in 2017. One of those parks was Yellowstone National Park—the first national park in America. The park was created in 1872 by the federal government to preserve a large wilderness area. Yellowstone is home to many types of plants and animals, and the majority of the world's geysers.

Figure 1. Location of Yellowstone National Park. While 96% of the park is in the state of Wyoming, 3% is in Montana and 1% is in Idaho.

The animals in Yellowstone include bison, grizzly bears, moose, and wolves. These animals interact with plants and other animals and with non-living things including air, water, and soil. Scientists study the interactions between living and non-living parts of the environment. Over time, they can use this information to tell how disruptions—events that change environments—affect these interactions. In this unit, you will investigate how and why environments get disrupted.

A geyser in Yellowstone National Park. A geyser is a natural hot spring that ejects hot water or steam into the air.

Guiding Question

How do living things interact with living and non–living parts of the environment?

Materials

For each student:

■ Handout 1.1-1, "Video Guide: Wolves in Yellowstone"

Procedure

Part One: Living and Non-Living Parts of a Local Environment

1. Think of an environment with lots of living things, such as a park, field, or garden, near where you live or that you know well. Discuss Steps 1a–f (on the next page) with your group, and then with the class. You will re-visit and develop your ideas about how living things interact with each other and the non-living environment throughout this chapter.

a. Brainstorm a list of living things in that area.

b. How do you think these living things interact with each other?

c. Brainstorm a list of non-living things in that area.

d. How do you think the living things interact with non-living things in the area?

e. How do you think this area has changed over time? What types of events (disruptions) may have caused these changes?

f. How do you think introducing a new living thing into the environment might change the interactions among other parts of the environment?

Part Two: Living and Non-Living Parts of Yellowstone

2. How can the introduction of a living thing change interactions in other parts of an environment? Find out more by watching a video clip on the reintroduction of wolves in Yellowstone and reading the information on the next page. Use Handout 1.1-1, "Video Guide: Wolves in Yellowstone," to guide your understanding.

3. Discuss each of the following questions with your partner, and then with the class.

a. What are some living and non-living parts of Yellowstone? How do living things interact with each other and with non-living things?

b. How do you think the reintroduction of wolves has changed how living things interact with each other and with non-living in Yellowstone?

c. Certain types of events, or disruptions, have caused Yellowstone to change in the past. What types of events do you think might cause it to change in the future?

d. What do you think each of the following groups are likely to feel about the reintroduction of wolves in Yellowstone National Park?

- Tourists who visit the park

- Cattle ranchers (people who raise animals such as cows for meat)

- People who live near the park

- Park rangers (people whose job it is to protect the park)

e. What is your opinion: do wolves belong in Yellowstone? Explain your reasoning.

Wolves in Yellowstone

1872	Yellowstone National Park was created at a time when the U.S. population was increasing. Cattle ranches in Montana and Wyoming helped to meet the growing demand for meat. People killed large animals, such as wolves and bears, because they were worried about their effects on cattle, pets, other wildlife, and human safety.
1930	No wolves remained in Yellowstone National Park.
1973	The Endangered Species Act was passed and the gray wolf was listed as a protected species. Wolves could no longer be killed.
1980s	Packs of gray wolves were living in northwestern Montana, but not in Yellowstone National Park.
1995	Fourteen wolves were reintroduced into Yellowstone National Park.
2017	There are approximately 100 wolves in the park. They travel in packs that average four to nine wolves. These wolf packs move in and out of the park. They hunt small and large animals, including moose, deer, and bighorn sheep.

Figure 2.
Yellowstone National Park Wolf Packs and Their Ranges
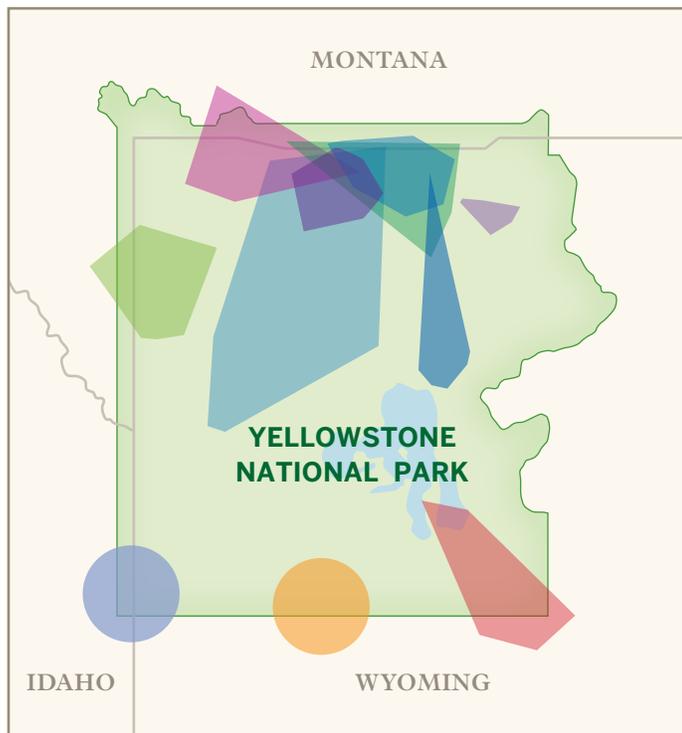
Each colored shape on the map shows the range of one wolf pack.

Analysis

1. As you can see in Figure 2, "Yellowstone National Park Wolf Packs and Their Ranges," wolf packs can move and hunt outside the park.

   a. Think of some animal species that may be found within the park. Do you think these animals are likely to stay within the park boundaries? Explain your reasoning.

   b. How might the movement of animals into and out of the park affect how ranchers and other people in the area feel about wolves?

2. What questions do you have about the interaction of living and non-living parts of the Yellowstone environment? Share your ideas with your class. As a class, record these ideas on your KWL chart.

3. Do you think people should try to restore wild environments (like they have when reintroducing the wolf to Yellowstone)? Why or why not?

Extension 1

National parks can be found all over the country. Jamaica Bay Wildlife Refuge is located in Queens, New York, and is a part of the National Park Service. Over 330 species of migrating birds have been seen there. Other National Park sites include historic buildings, monuments, and battlefields. What National Park sites are located near where you live? How have these sites changed over time?

Extension 2

National parks aren't the only places with interesting ecosystems! State parks, local parks, and even backyards are home to ecosystems that may also change over time. What are some local ecosystems that you would like to know more about? Do you think these places look the same as they did in the past? Find out more about the parks near you by visiting them with your family.

Explore: Ecological Interactions

After studying an environment, scientists may observe patterns in the way that living things interact. For example, they may observe that owls eat lots of mice and that mice eat seeds and insects. Scientists use diagrams to show the feeding relationships among living things. You may know that these relationships can be shown as a single chain (Figure 1a) or as a web that provides a more complete picture (Figure 1b). Arrows point from the thing that is eaten to the thing that eats it. For example, in the chain in Figure 1a, the arrow from the grass to the grasshopper shows that the grasshopper eats the grass.

Figure 1a.
Food Chain
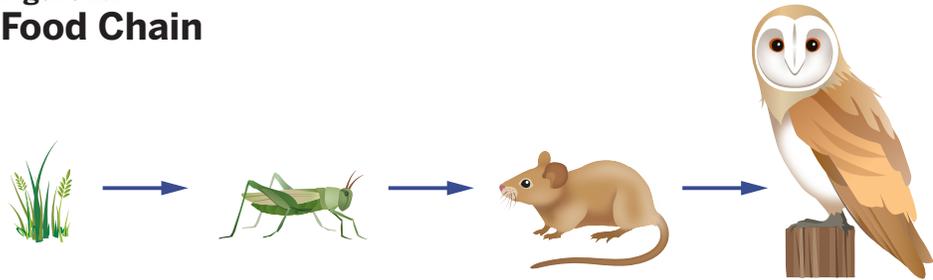
Figure 1b.
Food Web
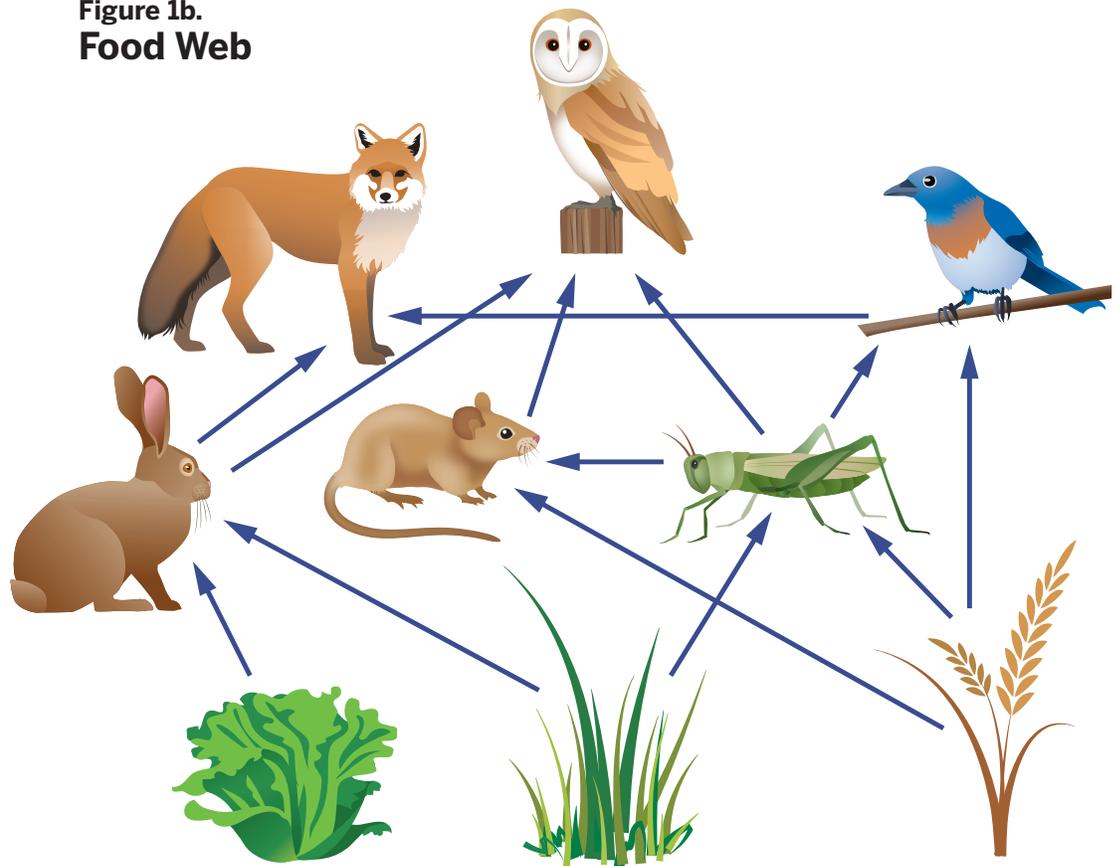
Guiding Question

What effect did the reintroduction of wolves have on the food web in Yellowstone National Park?

Materials

For each group of four students:

■ 1 set of 12 Yellowstone Food Web cards

■ 1 additional Yellowstone Food Web card: Gray Wolf

For each student:

■ Handout 1.2-1, "Yellowstone Food Web Data"

Procedure

Part One: Investigating the Yellowstone Food Web in 1990

1. Work with your group to examine the 12 Yellowstone Food Web cards in your set. Consider which organisms (living things) are familiar to you and which are not.

2. Think about what the organisms on the Food Web cards might eat.

3. Work with your group to sort the cards into groups. Explain how you decided to group the cards.

4. As a group, choose three cards that make a simple food chain. Record your food chain in your science notebook.

5. Work with your group to create a food web using all of the cards in your set.

6. Record your food web. Use a full page of paper to draw your food web. Leave space around the name of each organism so that you have room to draw in arrows. Then draw arrows from the eaten organism to the animal that eats it.

7. Share and discuss your food web with another group of students. How similar or different are your ideas?

Hint

Put organisms with similar eating patterns on the same row of your food web to make it easy to understand (see sample food web in the introduction). If you are having difficulty with making the web, make several food chains and then work to combine them into a single food web.

8. Obtain a copy of Handout 1.2-1, "Yellowstone Food Web Data," from your teacher. Use the information on the handout to revise your food web.

9. In your science notebook:

   a. Record your revised food web.

   b. Identify a card that changed its placement from your original food web. Explain why you placed it in the original location and what you learned that made you move it.

10. Discuss with your group the patterns of interaction among the organisms in your food web:

   ■ Which organisms play a similar role in the food web? Describe these roles.

   ■ What do you predict would happen to the food web if all of the plants died?

Part Two: Reintroducing the Gray Wolf in 1995

11. Your teacher will give you another Yellowstone Food Web card: the Gray Wolf.

12. Use your knowledge about wolves and information learned in Activity 1.1 to add the wolf to your revised food web.

13. Discuss with your group how the reintroduction of the wolf affected your food web.

14. Your teacher will introduce another organism into the food web: bacteria. With your class, discuss the role this organism plays in this environment and where to add it to the food web.

15. As a class, discuss what effect you think restoring wolves to the Yellowstone food web had on each of the following populations in the park. Explain your ideas.

   a. Elk

   b. Small animals

   c. Plants

Part Three: The Role of People and their Animals

16. Add humans and cattle to your food web diagram. Describe how humans and cattle change the food web.

Analysis

1. The Food Web cards were used to model the interactions in an ecosystem.

    a. Did the Food Web cards represent the living or non-living parts of an environment?

    b. Why do you think only these parts are included on the cards?

2. Describe the patterns of interaction among the organisms in your food web:

    a. Which animals eat other animals for food?

    b. Which animals compete for the same food source(s)?

    c. What role did the winter tick play in the food web?

    d. What role did the bacteria play in the food web?

    e. Look again at your food web and Handout 1.2-1. Find an example of a helpful relationship between two animals.

> **Hint**
>
> They do not have to be directly connected in your food web.

3. People often think of grizzly bears as meat-eaters. Grizzlies eat everything, including plants, insects, and other animals. More than 80% of their diet comes from seeds, nuts, and other vegetation. Does a food web address the importance of different food sources in an organism's diet? Explain.

4. Review the list of organisms in a familiar environment that you developed for Part One of Activity 1.1.

    a. Construct a food web for that area.

    b. What similarities do you see between the food web you drew for question 4a and the Yellowstone food web? Share your ideas with your class. As a class, record these ideas on your KWL chart.

Explain: Patterns of Interaction Among Organisms

In an **ecosystem**, living organisms interact with each other and with non-living things in their environment. Ecosystems don't end at park borders. Yellowstone National Park is part of a larger area known as the Greater Yellowstone Ecosystem. The Greater Yellowstone Ecosystem refers to the park and nearby areas with similar plants and animals.

Figure 1. Map of Greater Yellowstone Ecosystem. How does the boundary of Yellowstone National Park compare to that of the Greater Yellowstone Ecosystem?

Greater Yellowstone Ecosystem

MONTANA

IDAHO

WYOMING

In an ecosystem, organisms interact in various ways. One type of organism may eat another, or may be eaten. Organisms can compete for resources such as food, space, or water. Organisms can also interact in other ways that may be helpful to one or both types of organism. In some cases, what is helpful to one can harm the other.

Elk and bison in Yellowstone. What interactions between living organisms do you observe in this photo?

Guiding Question

How do organisms interact with each other?

Materials

For each student:

- Handout 1.3-1, "Types of Interactions"

Procedure

Part One: Types of Interactions

1. How do scientists describe how living things interact with each other? Watch and discuss three video clips describing patterns of interaction between living organisms.

2. Work with your group to create definitions of these patterns of interaction. You may find it helpful to first provide an example of each interaction from the video. Record your responses on Handout 1.3-1, "Types of Interactions," in the columns headed "My Group's Definition" and "Video Examples."

3. Share your definitions and examples with your class.

Part Two: Living Interactions in Ecosystems

4. Read the information on the next page about patterns of interaction between living organisms.

5. Work with your group to revise your definitions and add additional examples from the reading to the last two columns of Handout 1.3-1.

6. Look back at the Yellowstone food web you developed in Activity 1.2, "Ecological Interactions." What patterns of interactions are in the food web? Copy the table below and provide an example of each pattern from this ecosystem.

Examples of Ecological Relationships in Yellowstone

Pattern of Interaction		Example
Predator-prey		
Competition		
Symbiosis	commensalism	
	mutualism	
	parasitism	

Types of Interactions

Predator-prey interactions, competition, and symbiosis are all interactions between living organisms. A **predator-prey** interaction involves a feeding relationship between two animals. The **predator** is the animal that kills and consumes another animal, called the **prey**. In the photo above the bear is the predator and the fish is the prey.

Competition can occur when two or more species require the same limited resources. Competition can cause one or both populations to go down. For example, in 1989 green crabs from Europe ended up in the San Francisco Bay. These crabs started eating up the clams

in the Bay. Local yellow shore crabs now found it very hard to find clams to eat. Since 1989, the yellow shore crab population has gone down 90% in some areas.

Symbiosis includes mutualism, commensalism, and parasitism. These interactions are defined and illustrated on the next page. Many symbiotic relationships have evolved over time. These established interactions do not usually change population sizes. However, if either population were to be affected by living or non-living factors, the other population might be affected in turn.

Type of Symbiosis

Mutualism helps both species involved.

The Nile crocodile allows the Egyptian plover to enter its open mouth. The plover benefits by eating small bits of food left on the crocodile's teeth. The crocodile benefits by having its mouth cleaned, reducing the chance of infection.

Commensalism helps one species, while neither helping nor harming the other.

Groundhogs (woodchucks) are the major hole-digging mammal of North America. Their abandoned burrows are used for shelter by foxes, opossums, raccoons, and skunks.

Parasitism benefits one species (the parasite), which lives in or on the other (the host). The host is usually harmed.

Tapeworms can live in the intestines of animals. They obtain nutrients from food passing through the intestines and harm the host by depriving them of needed nutrients.

Analysis

1. Compare your definitions from Part One of the activity to your revised definitions in Part Two. Think about the changes you made to your definitions. What did you learn that made you make these changes?

2. Identify each of the following as one of the five patterns of interaction being studied and explain your answers:

   a. Mountain lions eat deer

   b. Lice live on a person's head

   c. Hummingbirds feed on plant nectar

   d. Ladybugs eat aphids

   e. Deer and elk browse for shrubs in winter

   f. Vultures eat the remains of an animal killed by a mountain lion

   g. Roundworms live in the intestines of dogs

   h. Gophers dig tunnels and expose insects to nearby birds

   i. Bees gather nectar and pollinate flowers

3. Give an example of how humans interact with another species in each of the following ways:

   a. Predator-prey

   b. Competition

   c. Mutualism

4. Explain the impact of humans on the food web in and near Yellowstone National Park during each of the following time periods. Use the scientific terms you have learned in this chapter (such as predator-prey, competition, symbiosis) to explain the interactions between humans and other organisms.

   a. From the late 1800s to 1994 (Yellowstone was established in 1872)

   b. From 1995 (when wolves were brought back to Yellowstone) to the present

Extension

There are many examples of how living organisms interact with each other in various ecosystems. Go online to look for examples of patterns of interaction that can be found in your local ecosystem. Revisit Analysis item 4 in Activity 1.2 and label the types of interactions in that food web. Are there some interactions that are not shown in your food web? If so, do you think those relationships can be found in that ecosystem?

Explain: Living and Non-Living Factors in Ecosystems

So far in this chapter, you have focused on the living organisms in an ecosystem and their interactions. Various factors can affect ecosystems. In some cases, living factors, such as a predator or competition with another type of organism, can affect population size. In other cases, non-living factors, such as temperature, rainfall, or even the amount of pollution, can affect a population. The diagram below illustrates some living and non-living factors in Yellowstone.

| Living Factors | ECOSYSTEM | Non-Living Factors |
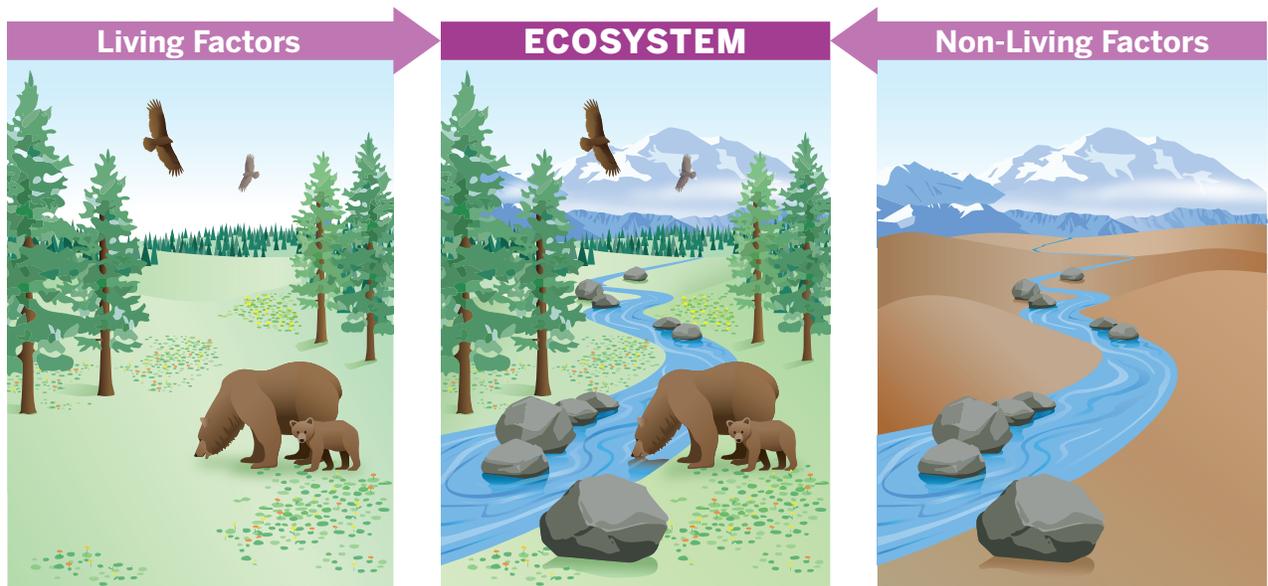
Figure 1. Living and Non-Living Factors in the Greater Yellowstone Ecosystem. What similarities and differences do you observe among the pictures? How does this help you understand living and non-living factors?

Changes in the living and non-living parts of an ecosystem often affect the populations of organisms that live there. For example, several years of heavy snow can weaken animals, or kill the plants they rely on for food. Graphing these measurements helps to reveal patterns. The graph on the next page shows a relationship between a deer population and average snowfall. During the very heavy snowfall of years 7-10, the deer population begins to decline.

Figure 2.

Deer Population and Average Snowfall
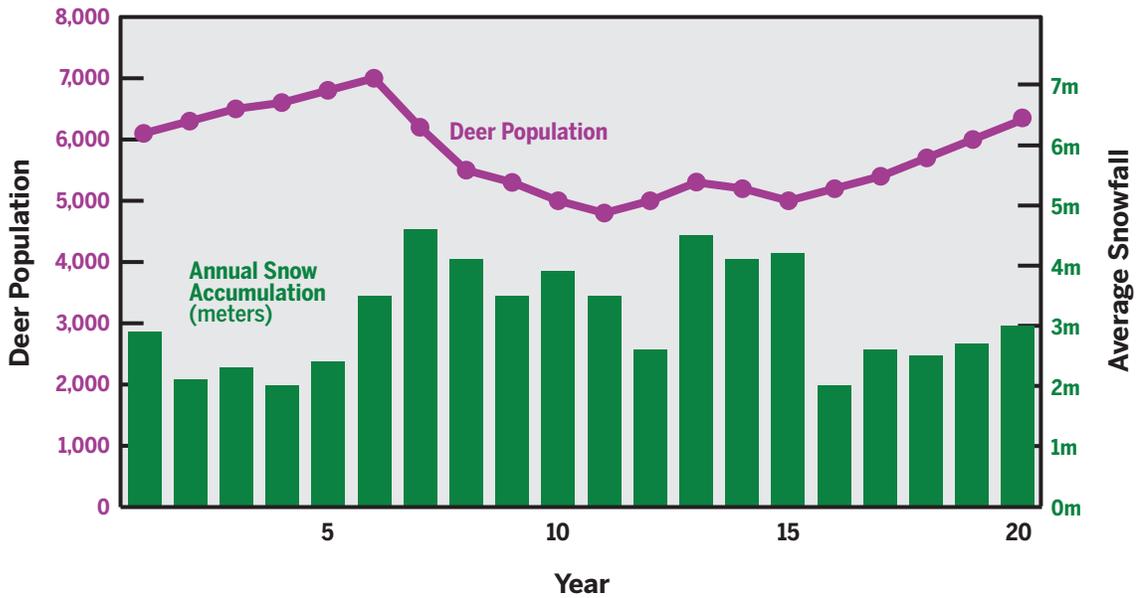
Guiding Question

What effects do living and non–living factors have on populations?

Materials

For each student:

■ Handout 1.4-1, "Predicting Predator-Prey Interactions"

■ 2 colored pencils

Procedure

Part One: Living Factors Affecting a Population

1. Examine the graph of a predator population and the start of a graph for the prey population on Handout 1.4-1, "Predicting Predator-Prey Interactions." With your group, discuss the relationship between the population of predators and prey over time:

   ■ What happens to the number of prey when the number of predators *increases*?

   ■ What happens to the number of prey when the number of predators *decreases*?

2. Record your ideas about predator-prey interactions on Handout 1.4-1.

   a. Complete the pattern of the *predator* line.

   b. Predict what will happen to the prey population over time by drawing the rest of the *prey* population line.

3. Read about the wolves and moose on Isle Royale below.

Wolves and Moose on Isle Royale

One of the longest studies of predator-prey interactions is that of the wolves and moose on Isle Royale, Michigan. Isle Royale is an isolated island in Lake Superior. Wolves are the only large predators on the island. Moose eat plants. Isle Royale and smaller nearby islands are part of Isle Royale National Park.

Figure 3.
Wolf and Moose Populations in Isle Royale National Park 1960-2015
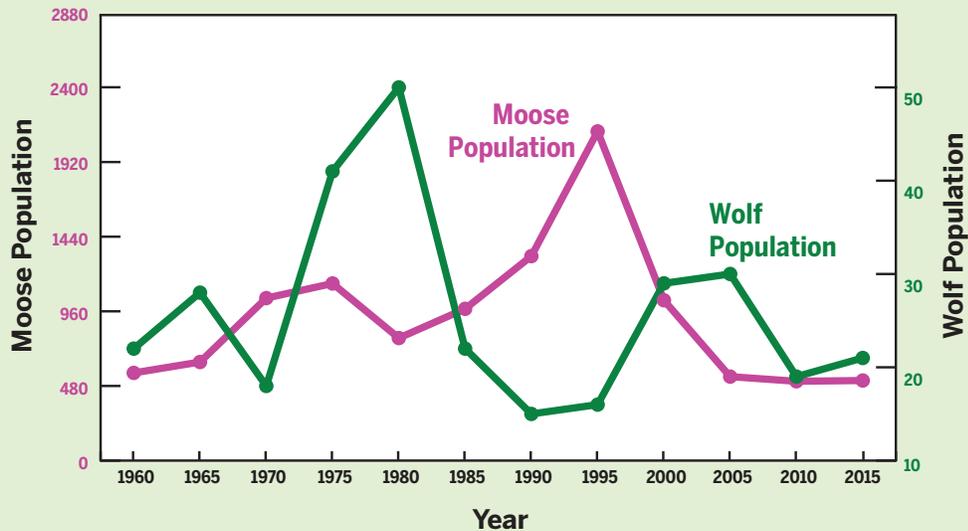
4. Discuss Figure 3, "Wolf and Moose Populations in Isle Royale National Park, 1960-2015," with your group, and then with your class:

- What happens to the number of prey when the number of predators *increases*?

- What happens to the number of prey when the number of predators *decreases*?

- Does there appear to be a relationship between the populations of the predators and the prey?

- What other factors could affect these predator and prey populations?

5. Figure 3 shows real data about a specific population of wolves and moose. Ecologists have used such information to create a graph showing the general pattern of interaction between predator and prey populations. Your teacher will help you record this predator-prey pattern on Handout 1.4-1.

Part Two: Non-Living Factors Affecting a Population

6. Read the following information about patterns of interaction between an organism and a non-living factor.

Sonoran Pronghorn

One endangered species found in the Arizona desert ecosystem is the Sonoran pronghorn, the fastest land mammal in North America. They eat a variety of desert plants. Droughts have been increasingly frequent in the western United States, even in desert ecosystems. Young pronghorns, called fawns, are especially sensitive to drought conditions.
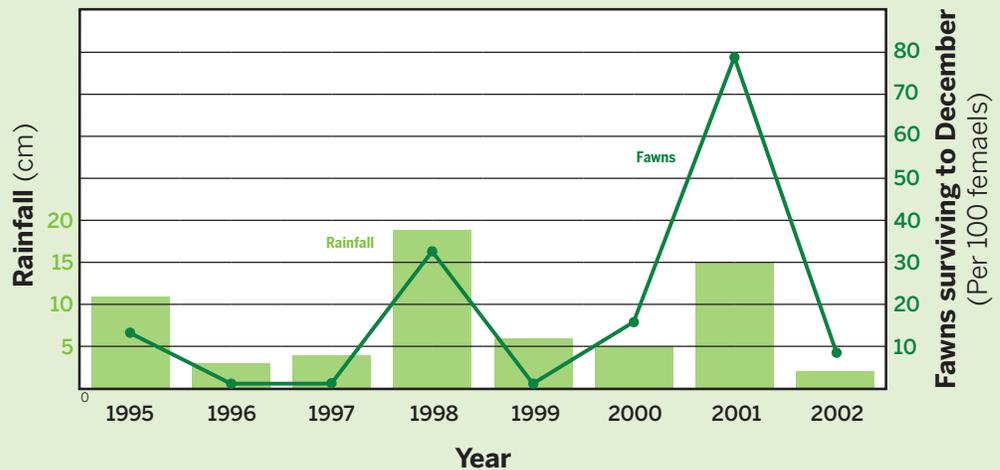
7. Discuss Figure 4, "Rainfall and Fawn Survival, 1995–2002," with your group, and then with your class:

   ■ Describe how the amount of rain changed over time.

   ■ Describe how the survival rate of fawns changed over time.

   ■ Does there appear to be a relationship between rainfall and fawn survival? What is it?

- What effect could these changes have on the pronghorn population?

- What other factors could be affecting the survival rate of fawns?

Analysis

1. Look again at the graph of wolves and moose on Isle Royale, Michigan.

   a. Describe the pattern the graph shows in the interaction between wolves and moose on Isle Royale, Michigan.

   b. What do you think might cause this pattern?

   c. What other living factors could affect the size of the moose population?

   d. What non-living factors could affect the size of the moose population?

   e. Looking at Figure 1, what do you predict will happen to the size of the wolf and the moose populations over the next 10 years? Explain your reasoning.

Hint

Think about your Yellowstone food web.

2. Look again at the graph of Sonoran pronghorn antelope and rainfall.

   a. Describe the pattern in the relationship between Sonoran pronghorn antelope and rainfall.

   b. What do you think might cause this pattern?

   c. What other non-living factors could affect the survival rate of fawns?

   d. What living factors could affect the survival rate of fawns?

   e. What do you predict would happen to the survival rate of fawns if rainfall levels stayed high? Explain your reasoning.

3. Pigeons are native to Europe, Asia, and northern Africa. They originally nested on cliffs and ledges. Their diet included seeds, grains, and some fruit and insects. Their predators included large birds, such as hawks, and mammals, such as raccoons and foxes. Pigeons are one of the few animals that are very successful in urban ecosystems with dense human populations.

   Why are pigeons successful in urban ecosystems? Use what you know about living and non-living factors in your answer.

Elaborate: Analyzing Patterns in Ecosystems

O rganisms in an ecosystem interact with both living, or **biotic**, and non-living, or **abiotic**, factors. For example, squirrels in a city park are affected by biotic factors, such as the availability of food. Abiotic factors, such as water shortages, could also affect the population size. Scientists observe and gather information about ecosystems. They use the information to create explanations. For example, an explanation of why a squirrel population in a park has decreased over time could include an increase in the predator population and the loss of parkland. Understanding such an explanation would require knowledge of predator–prey interactions and the role of abiotic factors in an ecosystem.
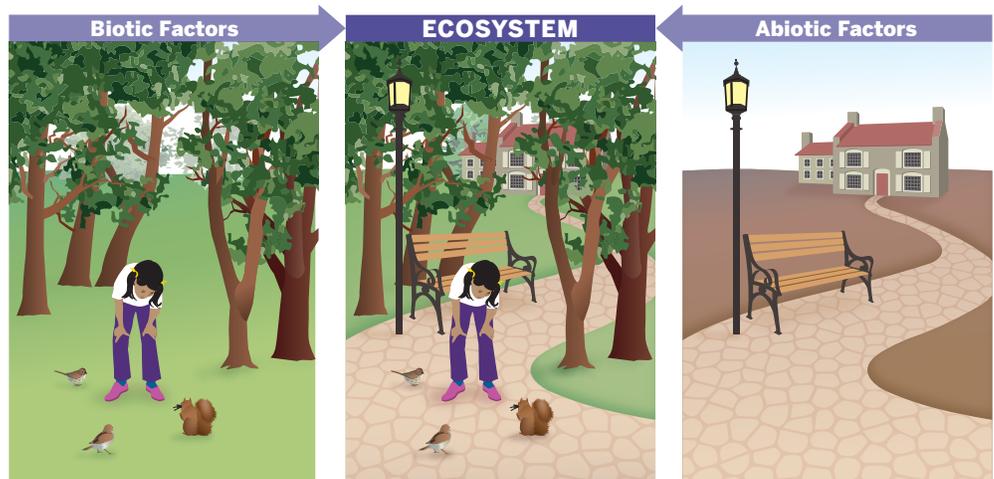
Figure 1. Biotic and abiotic factors in a local ecosystem. What similarities and differences do you observe among the pictures?

Guiding Question

How do biotic and abiotic factors affect patterns of interaction among organisms?

Materials

For each student:

- Handout 1.5-1, "Patterns of Interaction"

- Explanation Tool

Procedure

1. Read the six scenarios described below. Each one describes an interaction between a population and an abiotic or biotic factor.

SCENARIO 1: Freshwater Lake Fish

Rainbow smelt are a freshwater fish that can survive in a wide range of lake environments. When rainbow smelt were introduced to Crystal Lake in northern Wisconsin, they quickly changed ecological interactions in the lake. For example, they ate up much of the food preferred by other fish. They have nearly eliminated the yellow perch, another type of fish.

SCENARIO 2: Scaleworms and Ocean Temperatures

Scaleworms live on sea stars in shallow ocean waters of the Pacific northwestern U.S. The population of the worms increases when water temperatures drop in winter, and then the population decreases as water temperatures rise through the summer.

SCENARIO 3: Insects in Fields and Orchards

Insects are a pest in crop fields, orchards, and other farmland. Evidence suggests that the introduction of a parasitic wasp can cause the populations of certain insect pests in farm fields to decline.

SCENARIO 4: Phosphorus and Algae Growth

Phosphorus is an abiotic substance needed by plants and algae to grow. When phosphorus levels in water rise due to sewage waste, the population of algae increases.

SCENARIO 5: Canadian Lynx and Snowshoe Hare

The Canada lynx is a member of the cat family, not much larger than a house cat. In northern Canada, the lynx prefers to eat snowshoe hare. When the snowshoe hare population decreases, the lynx kittens are often unable to survive.

SCENARIO 6: Oxygen and Fish Populations

Investigations of a fish population in a lake showed that it was able to survive some decrease in oxygen. But as oxygen levels continued to drop, the fish population decreased rapidly.

2. Work with your group to examine the patterns of interaction illustrated by the graphs on Handout 1.5-1, "Patterns of Interaction." Describe what is happening to each line on the graph and how it relates to the other line.

3. Work together to match each scenario to one or more graphs. Record the graph(s) that match the scenario.

4. If the interaction is biotic, discuss with your group what pattern of interaction may be occurring (predator-prey, competition, mutualism, commensalism, or parasitism). Record this information on Handout 1.5-1, making sure to explain your reasoning.

5. With your group, discuss what you think might happen to the organisms on each graph over time.

6. Your teacher will model the use of an Explanation Tool. This tool will help you construct a scientific explanation.

7. Your teacher will assign your group to focus on one of the six scenarios. Review why you think the graph you selected matches this scenario.

8. Using the Explanation Tool, construct a scientific explanation about the pattern of interaction in your scenario. Use the steps below to guide you as you use the Explanation Tool.

- **Question:** Record the question "Which graph best represents the pattern of interaction described in your scenario?"

- **Evidence:** Examine the data in the graph(s) that you matched with your scenario. What patterns do you notice? Describe these patterns to use them as evidence.

- **Science Concepts:** List any science concepts that are connected to the evidence and might help answer the question.

- **Scientific Reasoning:** Describe the scientific reasoning that connects the evidence and science concepts to the question you are trying to answer.

- **Claim:** Based on the evidence of patterns in the data and on your scientific reasoning, state your claim about the patterns of interaction in your scenario.

Analysis

1. Think about the Yellowstone ecosystem.

   a. What pattern of interaction resulted from the reintroduction of wolves to Yellowstone?

   b. What do you think a graph showing Yellowstone wolves and elk populations over time would look like? Sketch out your ideas. Discuss your sketched graph with your class.

   c. Would a graph showing Yellowstone bears and elk populations over time look similar or different to the graph you created in Question 1(b)? Explain your reasoning.

2. What happens when humans disrupt ecosystems? Think about the ways in which humans cause change in the living and non-living parts of environments. Share your ideas with your class. As a class, record these ideas on your KWL chart.

Evaluate: Disrupting Ecosystems with Wolves

As you have seen, changing biotic and abiotic factors can affect an ecosystem in many ways. For example, the number of elk in the Greater Yellowstone Ecosystem increased greatly after the wolves were gone. The reintroduction of wolves to Yellowstone contributed to a smaller elk population, as shown in Figure 1 below. Other factors, including disease, severe winter weather, drought, and hunting, also played a role in decreasing elk populations.

In many parts of the United States, white-tailed deer populations are at very high levels. Is it time to reintroduce a predator such as the wolf?

Figure 1.
Wolf and Elk Populations, 1994–2014
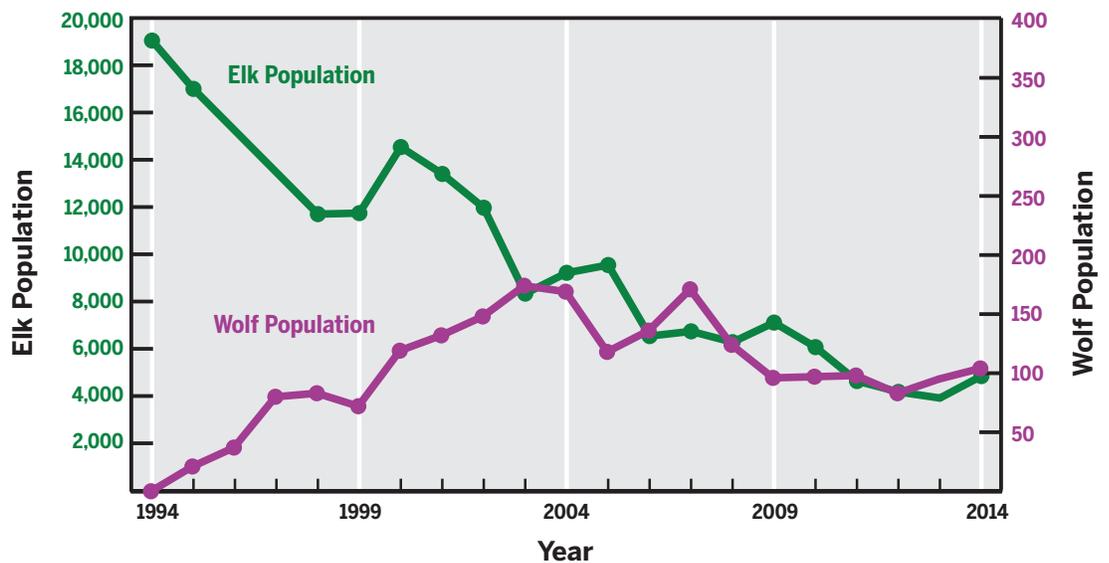
Figure 1. Wolves were reintroduced into Yellowstone in 1995, and they have been counted every year since. Elk counts were made in and near the northern border of the park during the winter. There are no elk data for 1996 and 1997 because of weather.

Guiding Question

Should wolves be reintroduced into the northeastern United States?

Materials

For each student:

- 1 Handout 1.6-1, "DART: Reading Support for Activity 1.6"
- Explanation Tool

Procedure

Part One: Interactions between Deer and Wolves

1. Use Handout 1.6-1, "DART: Reading Support for Activity 1.6," with the reading on the following pages.

Part Two: Developing an Explanation

2. Use information from the reading and the Explanation Tool to construct a scientific explanation answering the question "What effect does a large population of deer have on an ecosystem?" Use the steps below to guide you as you use the Explanation Tool.

   - **Question:** Record the question "What effect does a large population of deer have on an ecosystem?"

   - **Evidence:** Examine information and data from the reading.

   - **Science Concepts:** List any science concepts that are connected to the evidence and might help answer the question.

   - **Scientific Reasoning:** Describe the scientific reasoning that connects the evidence and science concepts to the question you are trying to answer.

   - **Claim:** Based on the evidence of patterns in the data and on your scientific reasoning, state your claim about the effect of a large population of deer on an ecosystem.

Part Three: Using Evidence

3. Use information from the reading, what you have learned in this chapter, and your Explanation Tool to decide:

   - Should wolves be reintroduced into the northeastern U.S. Adirondack ecosystem? Why or why not?

4. Participate in a walking debate with your class to see what others think about this issue. Discuss your points of view, supporting your ideas with scientific evidence from this unit. You may also want to add ideas to your class KWL chart.

Populations of Deer

In this chapter, you have closely examined the Greater Yellowstone ecosystem. People often think of the animals in this ecosystem as living only in the western U.S. At one time, many of these animals existed in large numbers in other parts of the U.S. For example, bears, wolves, elk, and moose were found across the northern states. Today, black bears and moose can still be found in upstate New York and other northeastern states.

One species that thrives in much of the U.S. is deer. White-tailed deer in particular have been successful in the absence of predators. You may have heard of white-tailed deer because it is a host animal for the blacklegged tick, also known as the deer tick. This tick sometimes carries Lyme disease, which can be transmitted to humans when they are bitten by an infected tick. Lyme disease is a growing problem, especially in the Northeast and upper Midwest.

The white-tailed deer population was estimated to be over 30 million a few hundred years ago. Deer, as well as the wolves that ate them, were hunted almost to extinction in the early part of the 20th century. Deer populations recovered when wildlife protections were put into place and predator populations remained low. Today, large deer populations mean that hunters can apply for licenses to kill deer during certain times of the year.

Figure 2.
Number of Deer Intentionally Killed by People, 2000–13
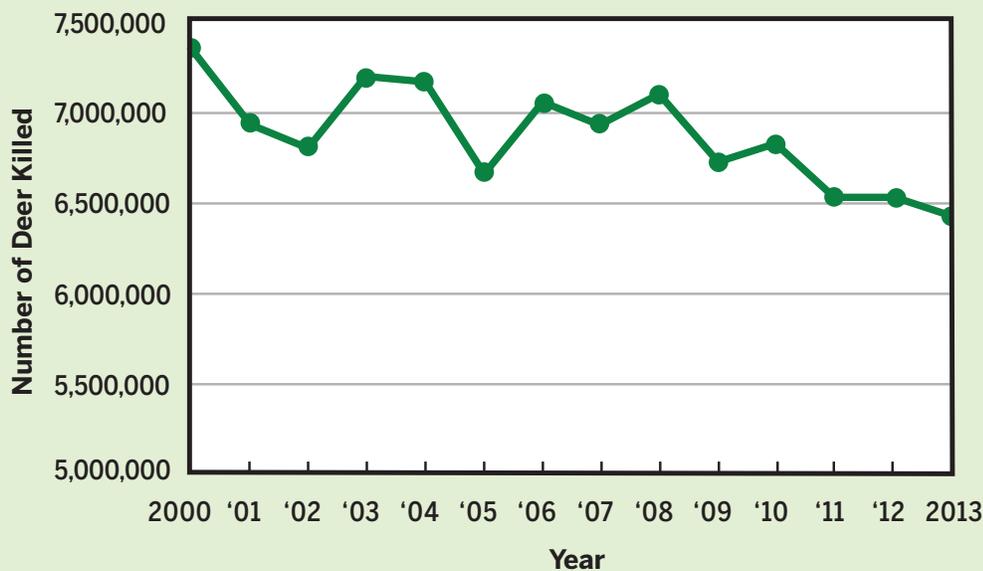
Figure 2 shows that the number of deer killed in 2000 was over 7 million, which dropped to just under 6.5 million in 2013. This represents a 12.6% drop in killed deer.

Deer Within an Ecosystem

Today, white-tailed deer are found throughout North America, from Canada to Mexico. In the northeast, bobcats, coyotes, and black bears eat deer, usually scavenging dead deer. Bobcats and coyotes also hunt them in the winter when the deer are tired and slowed by deep snow. However, these interactions are not enough to reduce deer populations.

White-tailed deer usually live at the forest edge, and are often found in fields and grasslands during summer months. They eat

Trillium

plant leaves, twigs, buds, nuts, and fruits and vegetables. They do not eat grass. The deer scatter seeds in their droppings, spreading certain plant species like *Trillium* (at left) up to 3 kilometers from their original site.

White-tailed deer eat about 3% of their body weight per day, which can be 1–5 kilograms (2–10 pounds) of plant material a day. When large numbers of deer are concentrated in an area, their feeding can affect the local ecosystem, reducing the diversity of plants and small animals. As you can see in the photos below the healthy forest (on the left) has new plant growth on the forest floor as well as on the lower layers of the forest. The forest on the right shows signs of overgrazing. Numerous studies have shown that this can occur when large numbers of herbivores such as deer are feeding in one area.

The healthy forest at left has typical plant life on the forest floor. The overgrazed forest at right lacks young trees, shrub, and other plants typical of a healthy forest.

Deer can also affect the number of songbirds in a forest. Some songbird populations eat or nest in the same trees and shrubs that are consumed by deer. One study found that bird counts across the U.S. showed that high populations of deer correlated with declining populations of certain songbird species.

People and Deer

Hungry deer are not restricted to wild ecosystems. Urban and sub-urban areas with high deer populations routinely have problems with deer eating flowers, vegetables, shrubs, and other neighborhood plants. It is estimated that they cause about $250 million in damage to these environments, as well as another $100 million in damage to cropland.

By far the greatest damage results from collisions between deer and cars. On average, over one million such collisions occur each year. This can sometimes result in human injury or death as well as the death of the deer. Damage to cars involved in deer collisions is estimated to be 1-4 billion dollars a year.

Controlling Deer Populations

Hunting is one way to control deer populations. White-tailed deer are one of the most commonly hunted species in the U.S., with approximately six million deer killed each year. In most cases, the dead animals are used for food.

In addition to hunting to reduce deer populations, some people have proposed reintroducing wolves into areas such as the Adirondacks in upstate New York. The Adirondacks are a

mountainous area inside Adirondack Park, the largest preserve in the lower 48 states and considerably larger than Yellowstone National Park.

The park contains mountains, lakes, rivers, forests, and many types of plants and animals. The park covers about 6 million acres, of which 45% is protected public land. Much of the private land is used for agriculture, forestry, and open space. There are 105 towns and villages within the park, and over 60 million people live within a day's drive of the park.

Analysis

1. In this activity, you investigated the question, "Should wolves be reintroduced into the northeastern U.S. Adirondack ecosystem?" Some students may have argued that wolves should be reintroduced, while other students may have argued that wolves should not be reintroduced. As a class, discuss:

   a. What scientific evidence supports each side of this debate?

   b. Discuss the quality and strength of the evidence that supports each side.

2

Ecosystem Models

In Chapter 1 you studied interactions between organisms, and developed food webs to model feeding relationships. Why do organisms need food? What does food provide? What else do organisms need to live, grow, and reproduce? And what happens to an organism when it dies? In Chapter 2 you will take a closer look at the roles of producers, consumers, and decomposers in the overall function of an ecosystem. The crosscutting concepts of energy and matter will be critical to thinking about interactions among organisms and between organisms and the abiotic parts of the environment.

You will use the scientific practice of developing and using models to understand and explain the movement of matter and energy in ecosystems. Scientists use models to show how things work, to construct explanations for why things happen, and to make predictions. You will use models to represent the movement of energy and matter in ecosystems. These models will help you describe, explain, and predict how ecosystems are affected by disruptions, such as forest fires or volcanic eruptions.

Engage: Energy and Matter for Ecosystems

I n the previous chapter, you developed food webs to model the feeding interactions in the Greater Yellowstone ecosystem. In this activity and this chapter, you will look more deeply at the interactions between organisms and the abiotic environment. You will develop scientific models to represent these interactions and explain how matter and energy move in ecosystems. Later in the unit, you will use your models to explain how ecosystems are affected by natural disasters.
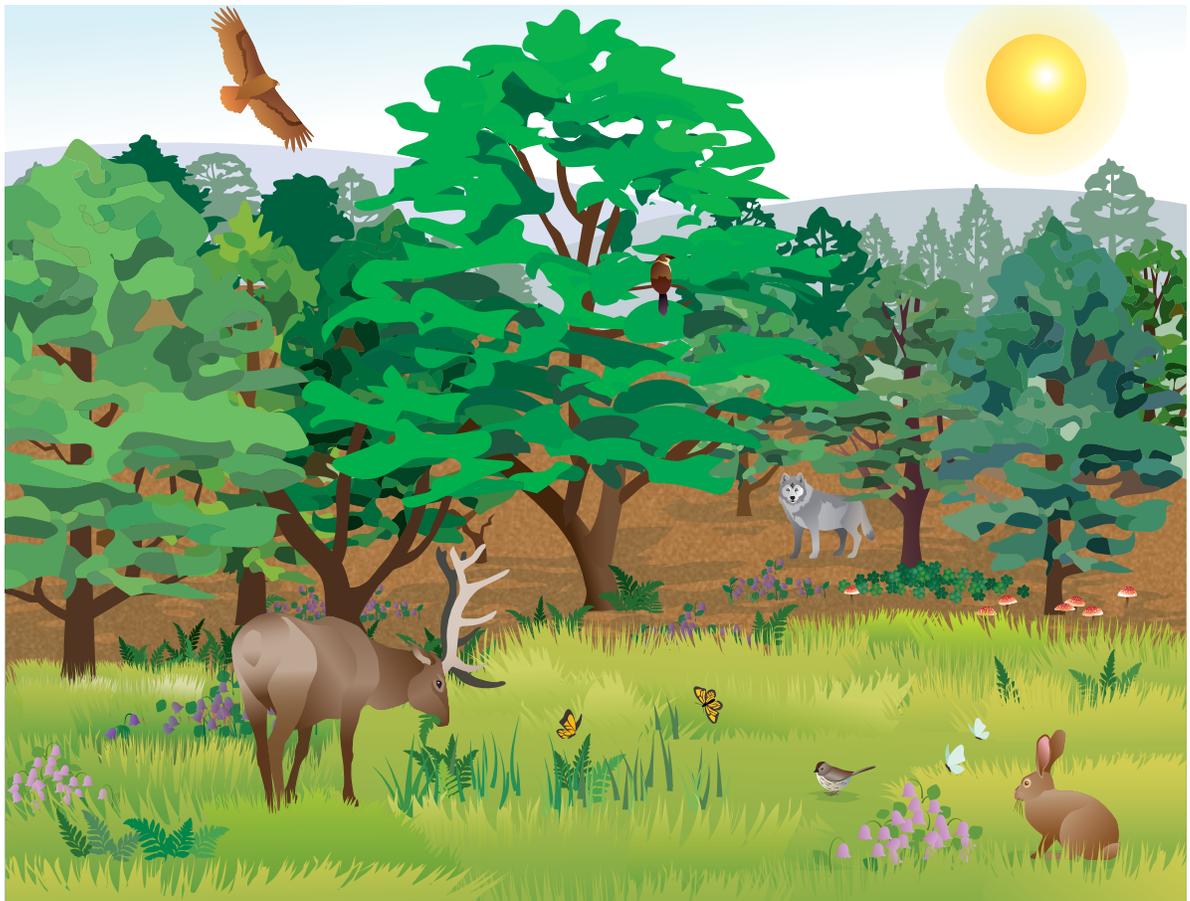
Guiding Question

How do organisms get matter and energy?

Procedure

Part One: Thinking About Ecosystems

1. Examine the illustration on the facing page of a forest and meadow in the Yellowstone Ecosystem. Discuss the following questions with your group of four students.

   a. How do the plants in the illustration:

   ■ get the energy they need to live, grow, and reproduce?

   ■ get the matter (stuff) they need to grow?

   b. How do the animals in the illustration:

   ■ get the energy they need to live, grow, and reproduce?

   ■ get the matter (stuff) they need to grow?

   c. When a plant or animal dies, what happens to it? Where does the matter it's made from go?

2. Record your group's ideas in your science notebook. You will have a chance to revise and add to these ideas throughout the chapter.

Part Two: What Happens to Dead Organisms and Wastes

3. Watch as your teacher sets up a compost bag with leftover plant material.

4. Discuss with your group:

   ■ What do you predict will happen to the material in the bag in the next few days?

   ■ What do you think will cause this to happen?

Analysis

1. How do you think a major disruption, such as a forest fire, would affect the ability of animals in a forest ecosystem to get matter and energy?

Extension

Set up a home compost bin, following your teacher's instructions. Safety note: Do not put any animal products in your bin. Compare the results of your bin with the class bin.

Explore: Life and Death in an Ecosystem

In the previous activity, you began to think about how organisms get the matter and energy they need to live, grow, and reproduce. You also began to think about what happens to dead organisms and to the wastes organisms produce. In this activity, you will explore further the movement of matter and energy within food webs, and between food webs and the abiotic components of an ecosystem.
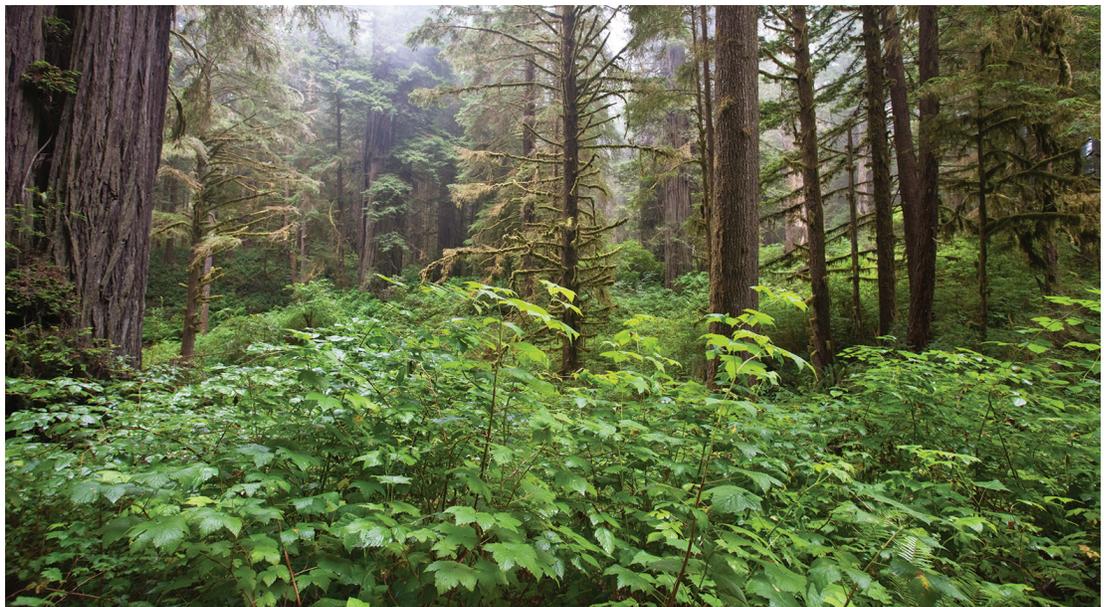
Guiding Question

How do life and death affect the movement of matter and energy in ecosystems?

Materials

For each group of four students:

- 1 set of 13 Yellowstone Food Web Cards from Activity 1.2
- 1 badger card
- 1 bald eagle card

Procedure

1. Spread out the Yellowstone Food Web Cards. With your group of four students, create a food web that includes two additional animals—a badger and a bald eagle.

   ■ Badgers eat smaller animals such as hares.

   ■ Bald eagles eat badgers, beavers, and hares.

2. Work with your group of four to select four cards that you can arrange in a food chain with four levels.

3. In your science notebook, begin a simple diagram (drawing) of the food chain you just created. To make your diagram:

   a. Use a full sheet of paper for your diagram.

   b. Title the diagram "Yellowstone Ecosystem Model."

   c. Put the plant near the bottom of the page, and arrows to the organisms that eat them going up the page.

   d. Label the organisms on the diagram.

4. Certain bacteria, shown in the picture at right, can feed on dead organisms and wastes. Add bacteria to your diagram.

5. Discuss the following with your group. Then add your ideas to your diagram. Use labels and captions to help explain your thinking. You will have a chance to revise and add to your ideas throughout this chapter.

   ■ Where does each organism get the matter it needs to grow?

   ■ What happens to the matter in each organism when it dies?

   ■ Where does each organism get the energy it needs to grow?
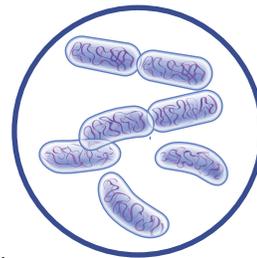
Analysis

1. What do you think would happen to your ecosystem if a disease killed all the plants? Explain your thinking.

2. What do you think would happen to your ecosystem if there were no bacteria? Explain your thinking.

Explain: Matter in Ecosystems

Y ou have used food webs to show feeding relationships between organisms in an ecosystem. These food webs are examples of scientific models.

A scientific **model** is a representation that can be used to explain and predict what happens in the natural world. Scientists use models to ask questions and develop explanations for how a system works. They also use them to communicate ideas and predict how a change in one part of a system might affect another part of the system. A model might be presented in a diagram, an arrangement of physical objects, a mathematical equation, or even a computer program.

In the previous activity, you added your ideas about the movement of matter and energy in ecosystems to your Yellowstone ecosystem model. In the next three activities, you will add to and revise your model as you learn more about matter and energy.

Plants (A) and decomposers (B) each play important roles in the movement of matter in ecosystems.

A.

B.

Guiding Question

How does matter move between biotic and abiotic parts of an ecosystem?

Materials

For each group of four students

- ■ Chart paper
- ■ Colored markers

For each student

- ■ Handout 2.3-1, "Anticipation Guide: Matter and Energy in Ecosystems"
- ■ Handout 2.3-2, "Making Sense of Scientific Findings"
- ■ Explanation Tool

Procedure

Part One: Your Ideas About Energy and Matter in Ecosystems

1. Read the statements on Handout 2.3-1, "Anticipation Guide: Matter and Energy in Ecosystems."

   a. In the "Before" column, mark whether you think each statement is correct (+) or incorrect (−). You will have a chance to revise your answers after reading Part Two, "The Movement of Matter in Ecosystems."

   b. Pick one statement from the handout that you think is incorrect. Write one sentence explaining why you think the statement is incorrect.

Part Two: Scientific Findings About Matter in Ecosystems

2. Scientists have found out many things about matter and energy in ecosystems. Review each of the scientific findings on the following pages and discuss with your group what each finding tells you about the where matter comes from and where it goes in an ecosystem.

Scientific Findings

A. Living things are made mostly of substances, like proteins, carbohydrates, and fats, that contain carbon.

Substances in organisms	Main building blocks in the substance
Carbohydrates	carbon, hydrogen, oxygen
Proteins	carbon, hydrogen, oxygen, nitrogen, sulfur
Fats	carbon, hydrogen, oxygen

B. A scientist named Van Helmont weighed some soil and planted a willow tree in the soil. Over five years, the willow tree gained 74 kg (164 pounds). The soil lost only 0.05 kg (0.025 lb).

C. Plants can be grown without soil in the presence of sunlight with only air and water containing some dissolved minerals.

These plants are growing without soil.

D. All organisms—including plants, animals, and bacteria—conduct a process called cellular respiration. They must do this all the time in order to use the energy stored in food. In this process, the organisms take in oxygen and use it to break down sugars and other substances in food. They give off carbon dioxide and water.

Cellular Respiration

Inputs		Outputs
sugars + oxygen	All Organisms	carbon dioxide + water
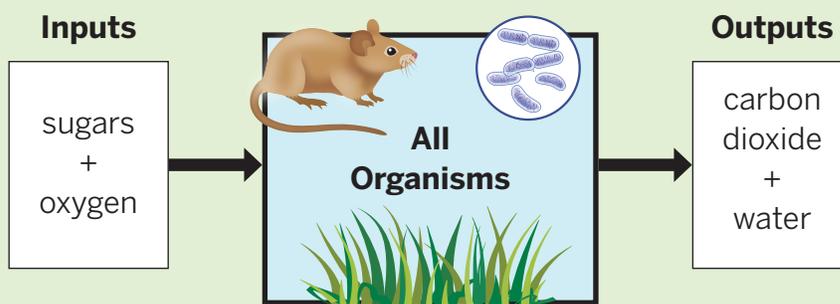
E. Plants conduct photosynthesis to make their own food. When they do this, they use carbon dioxide and water as the source of matter they need to make sugars. Plants that live on land get water from the soil, and carbon dioxide from the air. Plants that live in water use carbon dioxide that is dissolved in the water.

Photosynthesis

| carbon dioxide + water | → | **Plants** | → | sugars + oxygen |
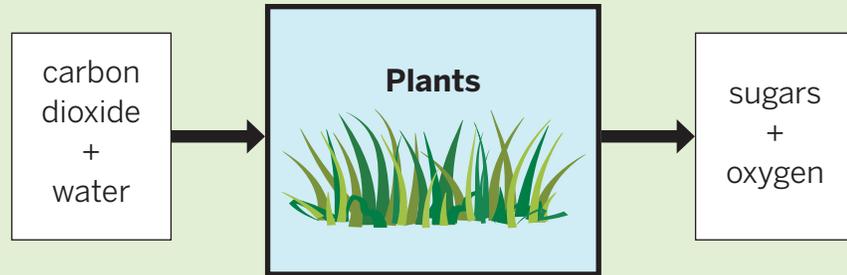
F. Following your teacher's instructions, examine the contents of the compost bag that was set up in Activity 2.1. Record your findings in your science notebook.

G. Decomposers get food by consuming dead animals and plants. For example, scientists have shown that compost piles are full of many kinds of bacteria that break down the compost for matter and energy. At the same time, they release thermal energy to the environment. This transfer of thermal energy is called heat.

Left: A compost pile. Right: Bacteria viewed through a powerful microscope.

H. Dead organisms and their wastes will only rot if decomposers are present. For example, if food is sterilized to kill all decomposers it will not rot.

The berries on the left were treated to kill decomposers. The berries on the right were not treated.

3. Use Handout 2.3-2, "Making Sense of Scientific Findings," to record your ideas about what each finding tells you.

4. Work with your group of four students and use the chart paper provided to develop a model for the movement of matter in an ecosystem. Use blue arrows to show the movement of matter. You can base your model on the diagrams you created for Activity 2.2, but be sure to add the details you have learned about in this activity. You will continue to revise this Yellowstone ecosystem model in the next two activities.

5. Discuss with your group how your ideas about matter in ecosystems have changed. Be prepared to share your ideas with the class.

Analysis

1. An animal dies. Explain:

    a. What happens to the matter the animal was made of?

    b. What happens to the energy stored in the animal?

2. Using the Explanation Tool, construct a scientific explanation that answers the question: What substances provide the matter a plant needs to grow, where does the plant get those substances, and how does the plant use the substances to grow? Use the steps below to guide you as you use the Explanation Tool.

- **Question:** Record the question "What substances provide the matter a plant needs to grow, where does the plant get those substances, and how does the plant use the substances to grow?"

- **Evidence:** Examine the data in the findings that help to answer this question. Include data (with units) as evidence to support your answer.

- **Science Concepts:** List any science concepts that are connected to the evidence and might help answer the question.

- **Scientific Reasoning:** Describe the scientific reasoning that connects the evidence and science concepts to the question you are trying to answer.

- **Claim:** Based on the evidence and on your scientific reasoning, state your claim about where plants get the matter they need to grow.

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3. Complete the "After" Column for statements 1–3 on Handout 2.3-1, "Anticipation Guide: Matter and Energy in Ecosystems."

    a. In the "After" column, mark whether you think each statement is correct (+) or incorrect (-).

    b. Under each statement, explain how the activity gave evidence to support or change your ideas. Cite specific evidence from the scientific findings that you used.

Explain: Energy Flow in Ecosystems

You have been learning that many ecological interactions are related to food. You have learned that food provides the matter that all organisms need to grow, survive and reproduce. Plants make their own food, while animals and decomposers get their food by eating other organisms, living or dead. You have discovered that all the matter that supports the ecosystem is present within the boundaries of that system because it keeps cycling throughout the biotic and abiotic components.

But what about energy? Without energy, animals wouldn't be able to grow muscles, digest food, or move. Plants wouldn't be able to produce leaves, move the sugars they make or make their own food in the first place. No organism would be able to reproduce. How do organisms get the energy they need? Where does it come from? Where does it go?

Guiding Question

How does energy flow in an ecosystem?

Materials

For each group of four students

- colored markers
- chart paper

For each student

- Partially completed Handout 2.3-1 from previous activity

Procedure

Part One: Sources of Energy

1. As you learned in the previous activity, plants make their own food through the process of photosynthesis. In order to carry out this process, plants require energy.

   a. Discuss in your group: Where do plants get the energy for photosynthesis?

   b. Record your preliminary ideas in your science notebook.

   c. Follow your teacher's instructions for discussing your preliminary answer to this question.

   d. After the discussion, record your revised answer to this question.

2. Discuss in your group: Where do animals and decomposers get the energy they need for life processes?

   a. Record your preliminary ideas in your science notebook.

   b. Follow your teacher's instructions for discussing your preliminary answer to this question.

   c. After the discussion, record your revised answer to this question.

3. Return to your Yellowstone Ecosystem Model from the previous activity. Based on your current understanding, add red arrows to your model to show how you think energy is flowing in the ecosystem.

4. Read the following information to prepare you to check your model and revise it if necessary.

Photosynthesis

Plants need sunlight in order to make food. Plants are able to transform the energy in sunlight into chemical energy in sugar through photosynthesis. Plants use the sugar as food. Without light energy from the Sun, the plants would be unable to make sugar. For a while, they would use the food they have stored, but eventually they would die. This is because the food that plants make provides the chemical energy for their life processes.

Abiotic Environment

Sunlight

ENERGY

Carbon Dioxide + Water

MATTER

Biotic Environment

The leaf makes and stores sugars.
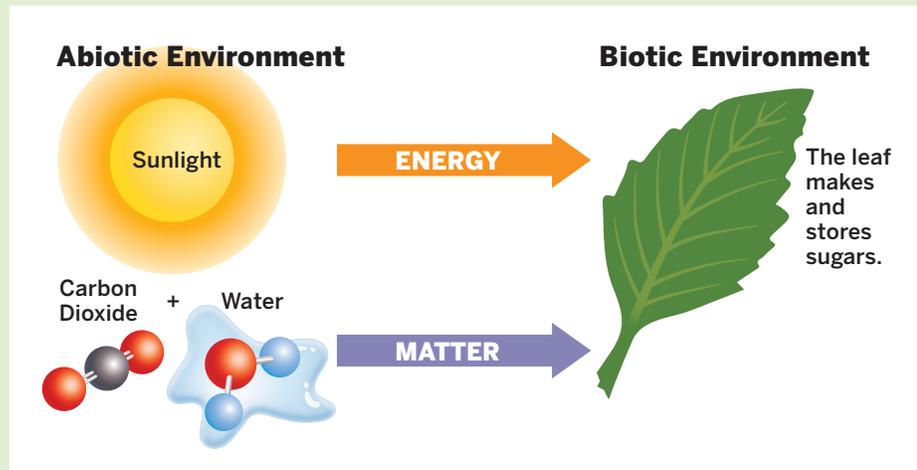
The energy that flows from the Sun and is transformed by plants is the source of energy for nearly all life on Earth, whether on land or in water. If all the plants died, the organisms in the rest of the food web that rely on them for food would die too. This is because the chemical energy stored in the food of plants is the only source of energy for plant-eating animals.

While all organisms require water and other substances, such as minerals (plants and animals) and vitamins (animals), these substances do not provide energy for organisms. Only substances that contain carbon (carbohydrates, proteins, and fats) can provide the kind of chemical energy needed by living organisms. They use this energy to move, grow, and carry out all of their activities.

Chemical energy only flows from the producers to the consumers and decomposers. It cannot flow in the other direction. At each level of a food chain, organisms use some of their energy for their own maintenance and growth. When these organisms are eaten, chemical energy stored in the organisms moves to the next level. Plants never get energy from animals. Even Venus fly traps, which capture insects in their leaves, do not get energy from those animals, only other kinds of substances like minerals.

5. Revisit question 1a: Where do plants get the energy for photosynthesis?

    a. Follow your teacher's instructions for discussing your revised answer to this question.

    b. After the discussion, record your final answer in your science notebook.

6. Revisit question 2: Where do all animals and decomposers get the energy they need for life processes?

    a. Follow your teacher's instructions for discussing your final answer to this question.

    b. After the discussion, record your revised answer in your science notebook.

7. Make any necessary adjustments to your Yellowstone Ecosystem Model to show how energy is flowing in the ecosystem.

Part Two: Energy Tracking

8. Based on what you know so far, which of the following models is the best for describing the flow of energy among the biotic components in an ecosystem? Record your initial answer along with your reasoning in your science notebook.

A.

B.

C.

D.
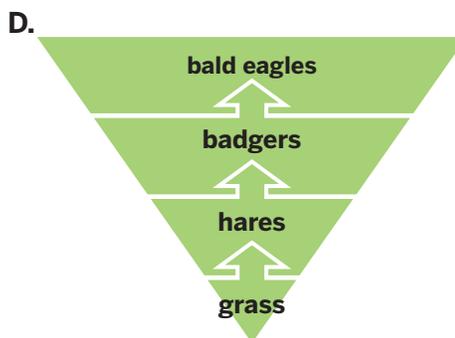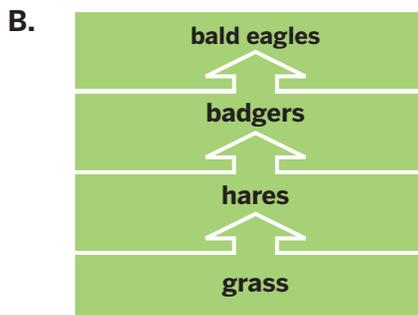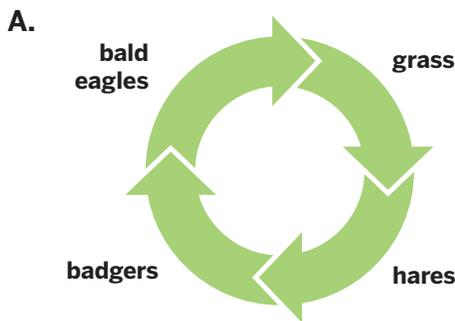
9. Read the following scientific findings.

- Thermal energy, light, and energy stored in food are all forms of energy.
- Thermal energy is released to the environment when plants, animals, and decomposers break down sugars in cellular respiration.
- Plants cannot reuse or recycle the thermal energy that flows to the environment. They can only use only light energy to make food during photosynthesis.

10. Review your choice of models in step 8 and explain whether your initial ideas are supported or you need to revise them based on the scientific findings.

    a. Record your revised explanation in your science notebook.

    b. Follow your teacher's instructions for discussing your explanation with others.

11. Read the additional scientific information below and discuss what it means with your group.

While energy flows up the food web or food chain from one level to the next, at each level of the food web, about 10% of the energy taken in by organisms is stored within the organism's body as chemical energy, while about 90% is transformed into thermal energy as the organism conducts activities like digesting food, respiring, growing, and moving. This thermal energy transfers into the abiotic environment as heat, and cannot be used by organisms in higher levels of the food chain.

12. Return to your Yellowstone Ecosystem Model and revise it to show how energy flows among the biotic and abiotic components in the ecosystem.

Analysis

1. Use your revised model to explain why sunlight is essential for the flow of energy throughout the ecosystem.

2. Explain what happens to the energy in an animal:

   a. while it is alive?

   b. when it is eaten by another animal?

   c. when it dies, but isn't eaten by another animal?

3. Do you think there could be 10 levels in a food chain or food web? Why or why not?

4. Scientists describe the movement of energy with the word "flows" and the movement of matter with the word "cycles." Why do they use these two different words to describe the movement of energy and matter?

5. Complete the "After" Column for statements 4–8 on Handout 2.3-1, "Anticipation Guide: Matter and Energy in Ecosystems."

   a. In the "After" column, mark whether you think each statement is correct (+) or incorrect (-).

   b. Under each statement, explain how the activity gave evidence to support or change your ideas. Cite specific evidence from the reading and anything you learned while revising your Yellowstone Ecosystem Model.

Elaborate: Disruptions and Food Webs

You have learned that matter cycles throughout an ecosystem, moving between biotic and abiotic components. You have also learned that energy only flows from the sun to producers and then to consumers and decomposers. Energy never flows back to the producers. You have been making and revising a Yellowstone Ecosystem Model to explain these phenomena.
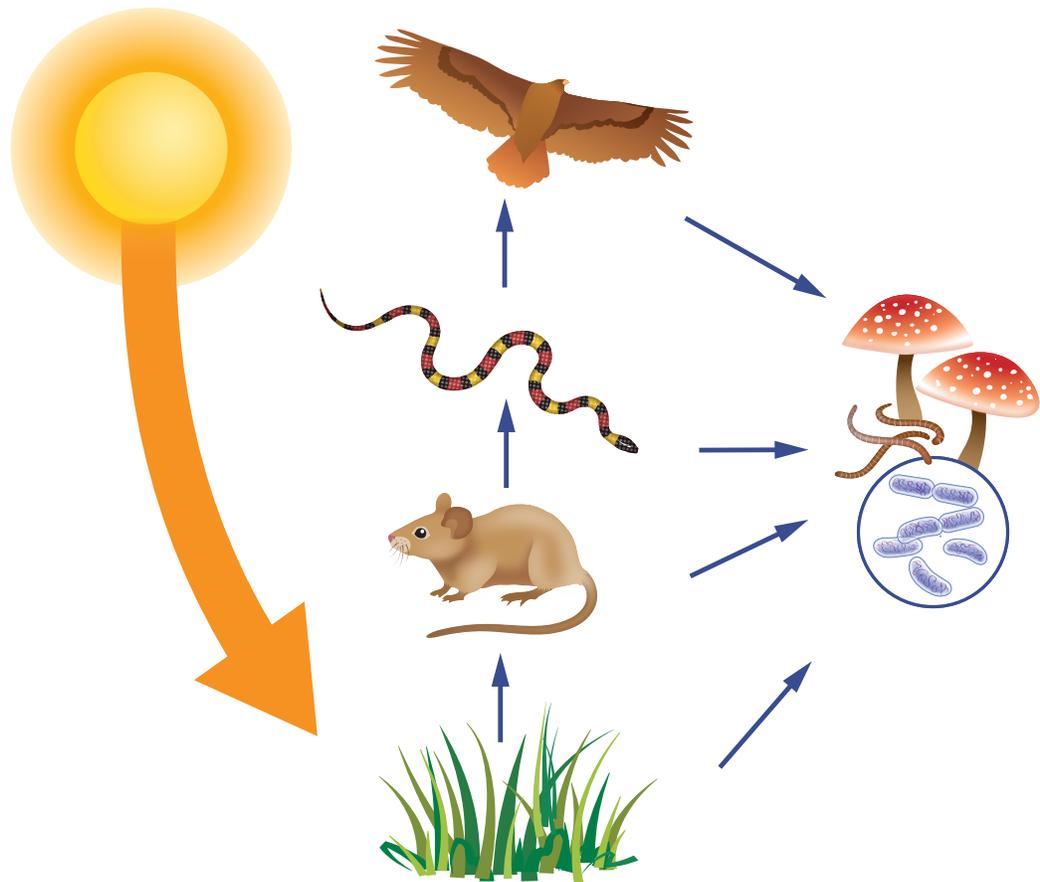
So far you have examined a stable Yellowstone ecosystem. But what happens to all of the energy and matter when an ecosystem experiences a large disruption?

Guiding Question

How does a disruption affect the flow of energy and cycling of matter in an ecosystem?

Materials

For each group of four students

- 1 set of six Forest Change cards

For each student

- Handout 2.5-1, "Changes Due to Fire in a Forest Ecosystem"

Procedure

Part One: Types of Disruptions

1. Examine the photographs and read the captions for the four disasters described below.

A. A severe drought is caused by several years of very little rainfall.
B. A landslide covers a hillside and meadow with mud and debris.
C. An area is flooded, and as it recedes, it washes away soil and plants.
D. A violent tornado tears a 1.5 mile wide path through the forest.

2. Your teacher will assign your group of four to discuss one of the four disasters. With your group, discuss the following questions.

   a. How do you think the disruption you discussed would affect the ability of organisms to get the energy they need to live?

   b. How do you think the disruption you discussed would affect the ability of organisms to get the matter they need to live?

3. With the class, discuss the question: What similarities and differences are there in the effects of the four disasters on the ecosystems?

Part Two: Fire in Yellowstone

4. Another kind of major disruption that can affect some ecosystems, especially Yellowstone, is fire.

   a. What effects do you think a fire would have on the abiotic (non-living) parts of the Yellowstone ecosystem?

   b. What effects do you think a fire disaster would have on the biotic (living) parts of the Yellowstone ecosystem?

   c. Would any organisms be killed by the disaster? If so, what do you think would happen to these dead organisms?

5. Carefully examine the six Forest Change cards. They show a forest and a meadow at the forest's edge in the Yellowstone ecosystem before and after a fire. With your group, use words to:

   a. identify or describe the plants and animals on the cards.

   b. describe the abiotic factors in the forest.

6. The Forest Change cards show changes in a forest ecosystem. Discuss how the drawings are similar to and different from a real forest ecosystem.

7. Which card shows the forest ecosystem that has existed for the longest time? Place it as the first card in your timeline.

8. Determine what happened in this forest over time. Place the remaining five cards in the order you think they happened. Record your sequence in your science notebook, skipping a few lines between the letter for each card.

9. Next to the letter for each card, write a brief description explaining:

   a. why you placed the card where you did.

   b. what is happening to the ecosystem in the card.

10. With your class, discuss the order of the cards and try to reach agreement on the order.

11. Use Handout 2.5-1, "Changes in a Forest Ecosystem," to write a caption describing what is happening to the matter and energy in the forest in each diagram.

Analysis

1. Explain how fire helps matter cycle through the biotic and abiotic parts of an ecosystem.

2. Which type of organism is the last to return to an ecosystem after a major disaster? Explain your answer in terms of matter and energy.

3. Do you think large fires in national parks should be put out or left to burn? Explain your thinking.

Extension 1

Review the series of illustrations below of change in a pond ecosystem. Compare how change occurred in the forest and the pond. Be sure to describe similarities and differences in the causes and effects of the changes in the two ecosystems.

A.

B.

C.

D.

E.

F.

Extension 2

What kinds of disruptions happen in your local environment or in your region? Do these disruptions happen frequently, occasionally, or rarely? Go online to look for information from sources like your local newspaper or news station, or from government research groups like the U.S. Geological Survey (USGS.gov) or your state's geological survey.

Evaluate: Modeling Energy Flow and Matter Cycling in an Ecosystem

So far in this chapter, you have worked to develop models to explain the movement of energy and matter in the Yellowstone Ecosystem. In this activity, you will construct a model of your local ecosystem to predict how the flow of energy and cycling of matter might be affected by various disruptions.

Challenge

How can a model be used to represent and make predictions about an ecosystem?

Materials

For each group of four students

■ A variety of materials, supplied by your teacher

For each student

■ Explanation Tool

Procedure

1. You will work with your group to construct a model of your local ecosystem. Your teacher will explain the materials available to you as you make your model.

2. Brainstorm organisms that live in your area, and use them to develop a food web that includes at least:

   ■ 2 producers

   ■ 2 consumers that eat producers

   ■ 2 consumers that eat other consumers or a combination of consumers and producers

   ■ 1 consumer from the top of the food chain

   ■ 1 decomposer

   ■ the ultimate source of energy for your ecosystem

   You may include more organisms if there are available materials and you have enough time.

3. Gather the materials you need to create your model.

4. Record your food web in your science notebook. Be sure to include arrows showing what eats what.

5. Construct a model of an ecosystem. Use the materials to:

   a. label producers, consumers, and decomposers.

   b. show the cycling of matter between the biotic and abiotic parts of your ecosystem.

   c. show the flow of energy between the biotic and abiotic parts of your ecosystem.

d. include a key if needed.

6. Present your model to the class, making sure to:

    a. describe what happens to the total amount of matter within your ecosystem.

    b. describe what happens to energy after it enters the ecosystem.

Analysis

1. Imagine that a science museum is making a very large version of your model for a museum display. Write three captions explaining the model for members of the public who will view the display. The captions should describe:

    a. interactions between living organisms.

    b. the cycling of matter between abiotic and biotic parts of the ecosystem.

    c. the source, flow, and loss of energy from abiotic and biotic parts of the ecosystem.

2. Using the Explanation Tool, construct a scientific explanation for the following. A disease kills off the consumers in the top level of the Yellowstone ecosystem. Predict how the flow of energy and the cycling of matter would be affected both in the short term and in the long term. Use the steps below to guide you as you use the Explanation Tool.

■ **Question:** Record the question "What would happen to the flow of energy and cycling of matter if a disease killed off the top level of the Yellowstone ecosystem?

■ **Evidence:** Use evidence from this chapter that helps you to answer this question.

■ **Science Concepts:** List any science concepts that are connected to the evidence and might help answer the question.

■ **Scientific Reasoning:** Describe the scientific reasoning that connects the evidence and science concepts to the question you are trying to answer.

■ **Claim:** Based on the evidence of patterns in the data and on your scientific reasoning, state your claim about the effects of the ash cloud on matter, energy, and organisms in the ecosystem.

Interactions Between Populations and Resources

You have learned in previous chapters that all organisms need resources to live and grow. For example humans breathe oxygen, eat food, drink water, and do many other things that require resources of one type or another. Although some resources are available in large quantities, all are limited.

In this chapter you will investigate cause and effect relationships as you examine how resources are affected by populations of organisms. You will analyze and interpret data as you look at how populations are affected by the resources available to them. You will also learn about some ways that humans' use of resources is managed to prevent overuse. Finally, you will construct arguments supported by evidence for how increases in the human population impact Earth's systems.

Engage: Shopping for Fish

Sara and her mother were shopping for groceries one day. Sara had asked if they could have fish for dinner, because she knew fish was really good for her. They stopped by the fish counter to see what looked good. Sara was hoping they would have her favorite, orange roughy, but she hadn't seen it for sale in the store in a really long time. They looked at the fish in the case and the first thing she noticed was that there was no orange roughy, so she started looking a little more carefully to see if there were any others she liked.

Once Sara started looking more carefully, she saw that a lot of the fish had colored labels. Some were red, some yellow, some green. Sara also noticed that some of the fish were pretty expensive, including the red snapper (another fish she likes). Some of the fish that were less expensive were ones she didn't like as much. She wondered why one fish would cost so much more than another, and if it was worth it to pay more for the fish she really liked.

Fish are an important source of protein and a large part of the diet for many people. Over the last several decades, many fisheries have had problems with catching fewer and fewer fish. Many fish populations around the world have become overfished. If a fish population is **overfished** it means that so many are being caught that the population cannot reproduce fast enough to maintain itself. Fewer fish caught means fewer jobs for fishers, and less income for the fishers that are still fishing.

Red snapper (left) and orange roughy (right) are two fish often sold in fish markets.

Guiding Question

What factors should you consider when purchasing fish to eat?

Procedure

1. With your class, review what you already know about fishing.

2. With your partner, review the information in the table below.

Fish Name	Cooking Notes	Cost per Pound	Label Color
Red Snapper	Mild, "nutty," sweet flavor, low in fat	$$	Yellow
Atlantic Salmon	Mild flavor, medium fat	$	Red
Coho Salmon	Medium-mild flavor, low to medium fat	$$$	Green
Albacore Tuna	Medium flavor, medium to high fat	$$	Red

3. With your partner discuss the following:

   a. Why do you think there are differences in the cost and label colors for the fish?

   b. What do you think the label colors mean?

   c. Based only on the information in the table, which fish would you buy?

   d. If you could get more information about the fish before deciding, what other questions would you have about the fish?

4. Discuss your answers to Step 3 with your class.

Analysis

1. How might the health of a fish population affect the ecosystem where the fish lives?

2. Is it important to monitor the health of fish populations? Why or why not?

3. What factors do you think are important to consider when deciding what fish to purchase? Explain your answer.

Extension

Go to your local grocery store, butcher, or seafood store and look for any labeling similar to the label color described in this activity. If you don't see any, or if you don't understand the labels, consider asking the person behind the meat or fish counter what they know about the meat or fish they sell.

Explore: Going Fishin'

As you have learned, one major cause of ecosystem disruption is human activity. In aquatic ecosystems, one way that humans often disrupt the ecosystem is by overfishing. Preventing a resource, such as a fishery, from being overused is not always easy, and can involve making difficult decisions.

The resource in this activity is the fish in Blue Bay. Blue Bay is a marine ecosystem, with two main species of fish (orange and yellow). Many people fish in Blue Bay, both to feed their families and to earn a living. In this activity you will investigate fishing limits as a possible method to help prevent overfishing.

Guiding Question

Can fishing limits prevent the overuse of an ecosystem?

Materials

For each group of four students:

- 100 fish crackers (orange)
- 30 fish crackers (yellow or color other than orange)
- tray or dish
- set of 4 Game A Character Cards
- set of 4 Game B Character Cards
- set of 4 Ecosystem Disruptions Cards
- timer that beeps

For each student:

- Handout 3.2-1, "Populations Over Time"
- 1 pair of chopsticks
- cup
- paper towel

Procedure

Part A: No Fishing Limits

1. Place 25 orange fish and 5 yellow fish in the tray in the center of your table. This represents Blue Bay and the fish in it. Each person will use a set of chopsticks to fish in the bay.

2. Use the flowchart on the next page for instructions on how to play the game.

3. In Game A you will have no fishing limits. Predict what you think will happen to the fish populations in Blue Bay. Write your prediction in your science notebook.

4. Begin playing. At the end of each round record your data for Game A on Handout 3.2-1, "Populations Over Time," and then empty your cup onto your paper towel. After four rounds, stop, and finish recording the data for Game A on your student sheet.

⚠ Safety

Don't eat the crackers; many people have handled them. If you have any severe food allergies, such as a nut allergy, alert your teacher before handling the materials to ensure the materials will not harm you.

```
              Pick a
          character card.
               │
               ▼
          Read it aloud.                    The fish reproduce!
               │                            Double the amount
               ▼                            of orange & yellow fish
          Set the timer                     left on the tray.
          for 15 seconds.  ◄──────────┐            ▲
               │                       │     Record all results
               ▼                       │      in your table.
          Start fishing!                             ▲
        (One fish at a time)           Sell the rest of your fish
               │                       at $1 per orange fish and
               ▼                       $2 for each yellow fish.
          Stop fishing                               ▲
        (after 15 seconds)              Set aside two fish
        and count your fish.             for your family.
               │                               ▲
               ▼                               │
            Did you        YES ───────────────┘
          catch at least
          two fish?
               │
               ▼
                    NO ──►  Sorry! You are not
                            able to continue.
```

5. After the fourth round, discuss, as a group, what happened in Game A. Record your responses in your science notebook. Be sure to answer the following questions:

- How did your fishing limit affect your behavior?

- What is the condition of the fishing community (did everyone catch enough to survive, did everyone earn some extra money)?

- What is the condition of Blue Bay (are there fish left, will there be enough for the next generation)?

- Were your predictions from Step 3 correct?

- If the fishing limits were lower, do you think the fish populations in Blue Bay would be different at the end of the game? Why or why not?

Part B: Set Fishing Limits

6. Play the game again, following the same rules as before. Repeat Steps 3 - 5, using Character Cards for Game B. In Game B there are strict fishing limits.

Part C: Changing Ecosystem Disruptions

7. Play the game again, following the same rules as before, using Character Cards for Game B. Start with the same number of fish. Before you begin each round select an Ecosystem Disruptions Card and follow the instructions during that round. In Game C the limits are the same as Game B, but several ecosystem disruptions occur.

8. As a group, discuss what happened in your game. Record your responses in your science notebook. Be sure to include the following questions:

   ■ How did the conditions of the ecosystem change the results of the game as compared to Game B?

   ■ Were your predictions accurate?

   ■ How did each person do (did they catch enough to survive, did they earn extra money)?

   ■ What is the condition of the fishing community (did everyone catch enough to survive, did everyone earn some extra money)?

   ■ What is the condition of Blue Bay (are their fish left, will there be enough for the next generation)?

Analysis

1. Describe the three games and what happened to the two fish populations over time in each game.

2. How did the reproduction of the fish (adding one fish for every live fish at the end of each round) affect fish population levels? Explain.

3. How was the effect of humans modeled in this activity?

4. What is missing from this model?

Explain: Three Fisheries

In the previous activity, you saw how fishing limits and ecosystem conditions affect the health of a fish population and the fishery that catches those fish. The word "fishery" includes all the people and organizations that catch a certain species of fish to eat or sell. You tracked data on the fishery and the fish population, including reproduction. Often scientists do not have population data, but they do have other data such as how much of a particular fish is caught during the year. Scientists use this data to monitor the health of the fish populations. In this activity you will learn about three fisheries that have managed their fish populations in different ways.

These scientists are collecting data on a small, live shark. This data will help them monitor the health of the shark population and the ecosystem the shark lives in.

Guiding Question

What effect have humans had on the health of fisheries?

Materials

For each student

■ Argument Tool

Procedure

Part A: Managing Different Fisheries

1. With your partner, discuss what effect you think humans have had on the health of different fisheries. Discuss if you think the effect has been the same on all fisheries. Write down your ideas.

2. With your partner, examine the graph below. "Total catch" refers to all fish of that species caught by commercial fishers in that year. Discuss any patterns you see in the data.

Catch Data, Species A
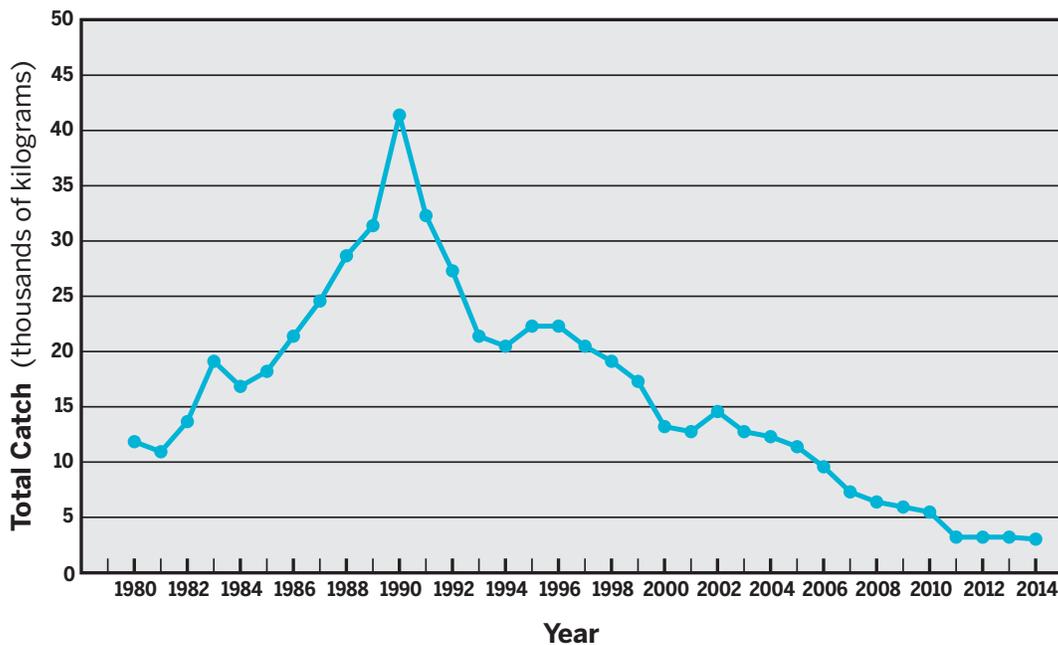
3. Repeat Step 2 for fish species B using the graph below.

Catch Data, Species B
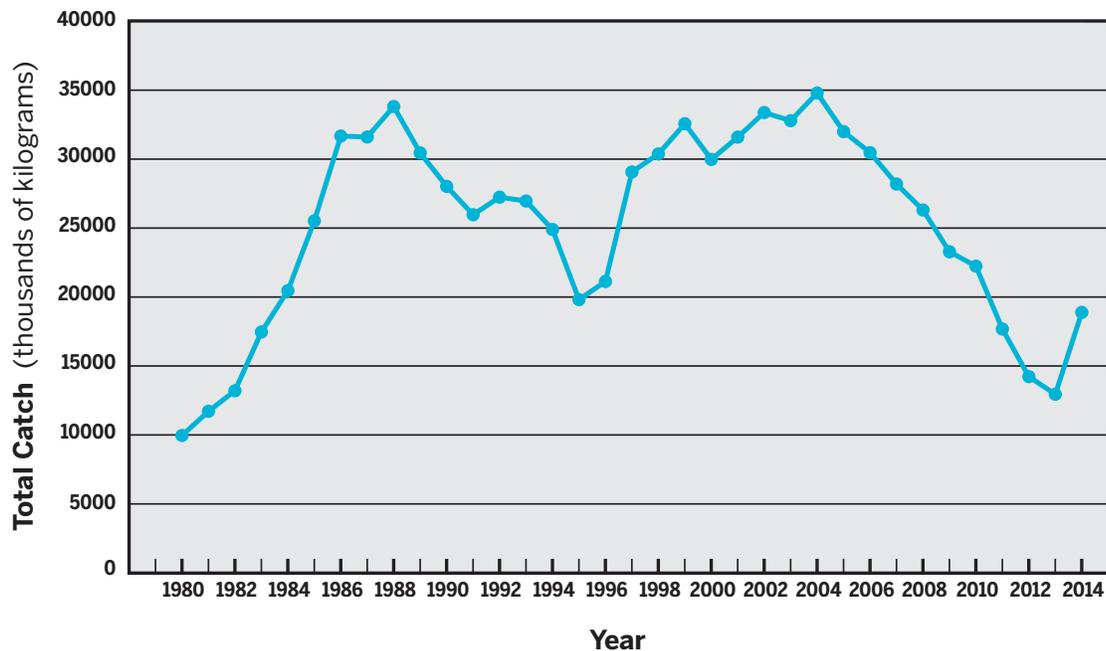
4. Repeat Step 2 for fish species C using the graph below.

Catch Data, Species C
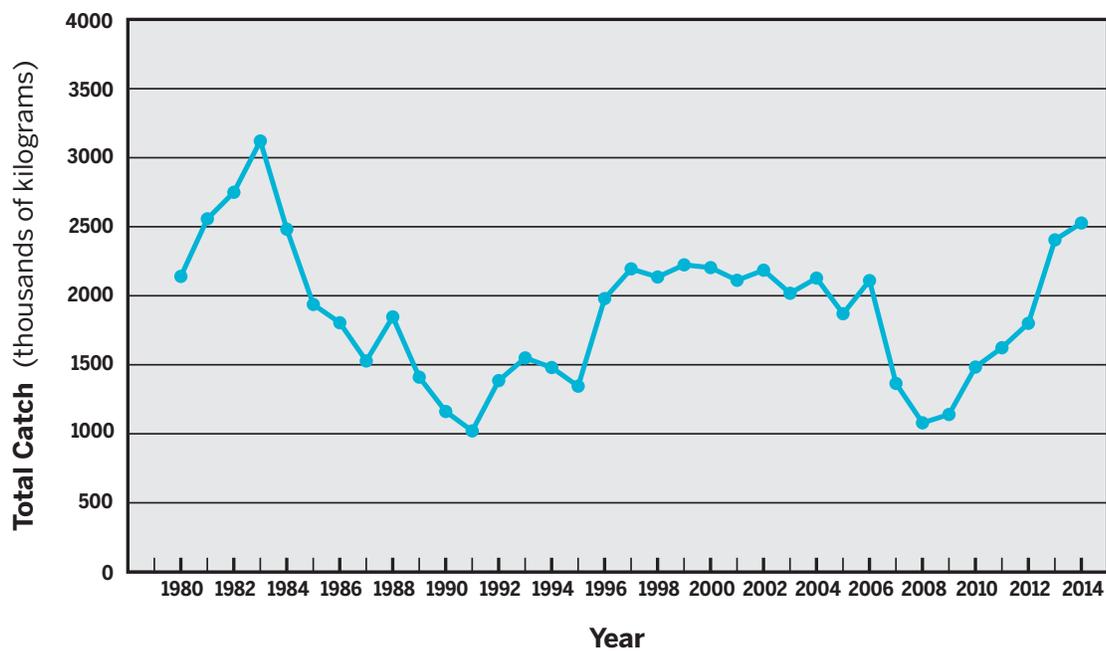
5. With your partner, read the three fisheries descriptions below. Decide which fishery you think matches the graphs above for fish species A, fish species B, and fish species C.

Three Fisheries

Pacific Halibut

The Pacific halibut fishery is known for maintaining a healthy population of Pacific halibut. The fishery is carefully monitored, and each year scientists make new recommendations on where and how many fish can be caught. The entire fishery adopts these limits, and they are carefully enforced.

Red Snapper

The red snapper has been fished in the Gulf of Mexico since at least the 1840's. As fishing technology has improved, more and more snapper have been caught. By the 1990's, up to 15 million pounds of red snapper were being caught in the Gulf of Mexico each year. The snapper population was being severely overfished. In 2007 fishers and the government worked together to set new regulations for the fishery. They used scientific studies of the snapper population levels to determine the number of fish each fisher is allowed to catch during the year. The limits are evaluated every year and changed as needed.

Orange Roughy

The orange roughy was not fished for many years. They live on the bottom of the ocean, in very deep waters, and for a long time were rarely caught. That all changed with modern fishing techniques and equipment allowing fishers to find and catch fish more effectively, even deep on the bottom of the ocean. Because orange roughy tend to sit in groups on the ocean floor, they were easy targets for fishers. To make matters worse, orange roughy grow and reproduce very slowly: they don't even start to reproduce until they are 20 years old! There were no limits on orange roughy catches until the mid-1990's, and only in some areas where the orange roughy is fished.

6. With your partner, based on what you have learned in previous activities and this activity, decide what level of health you think each of the fish species populations should be labeled: red, yellow, or green.

7. Follow your teacher's instructions to discuss with your class how humans affect different fisheries.

Part B: Pacific Halibut Fishery: More Information

Different fisheries manage their populations differently. Some fisheries, such as the Pacific halibut fishery, collect more data than just the amount of fish caught.

8. The following graph shows the average mass of male and female Pacific halibut at various ages. The data lines indicate the data for three years when data was collected: 1975, 1995, and 2014. With your group, examine the graph and answer the following:

   a. What patterns do you notice in the data?

   b. What do the patterns in the data tell you about the health of the fishery?

Average Mass of Male and Female Halibut Over Time
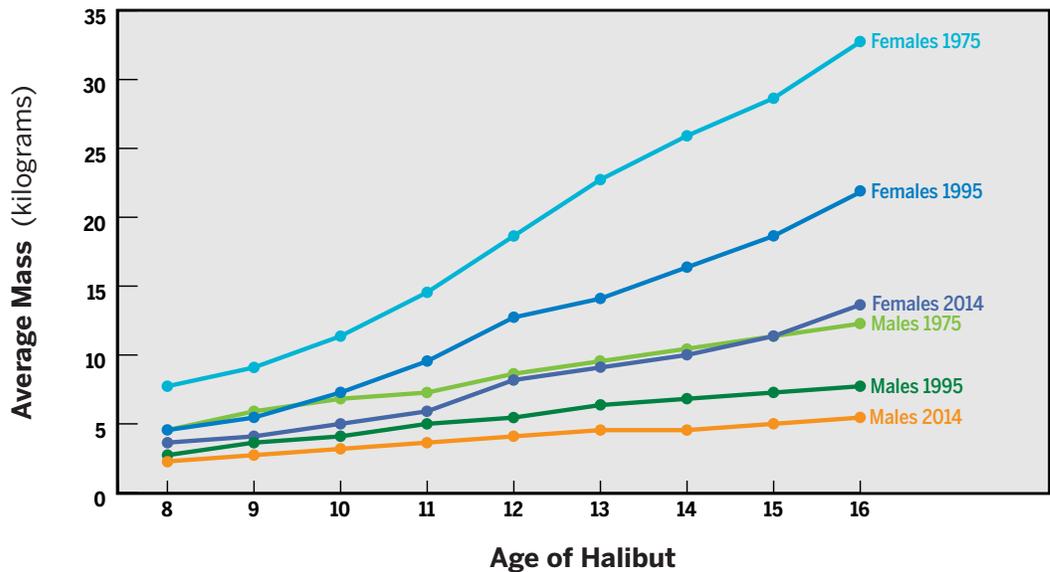
9. Using the Argument Tool, construct a scientific argument about the health of the Pacific halibut fishery in 2014. Use the list below to guide you as you use the Argument Tool.

- **Question:** Record the question "Was the Pacific halibut fishery healthy in 2014?"

- **Claim:** Record the two possible claims that could be made in response to the question

- **Evidence:** What evidence supports each of the two claims?

- **Science Reasoning:** For each claim, critique the quality and strength of evidence that supports the claim.

Analysis

1. Give two examples of criteria scientists might use to determine if the Pacific halibut fishery is healthy.

2. Why might scientists want to look at more than one type of data to determine the health of a fishery?

Extension

Investigate other types of natural resources and their industries, like agriculture and forestry, to learn more about how people impact those environmental resources. Contact your state departments of agriculture, forestry, fisheries and/or natural resources to learn about industries near you. Ask them to explain current environmental issues involving those industries.

Elaborate: Dead Zones

Catching fish is just one way that humans impact fisheries and aquatic ecosystems. Humans can also affect fisheries by disrupting other biotic and abiotic factors. In this activity you will learn about an extreme case of human-influenced ecosystem disruption—dead zones—which have had a major impact on shrimp and other fisheries in the Gulf of Mexico, one of the most important areas for fisheries in the United States.

In aquatic ecosystems around the world, scientists have recorded an increase in the number and size of dead zones. A **dead zone** is an area in a body of water where the water at the bottom has little or no dissolved oxygen. Scientists are concerned about the increase in dead zones because very few organisms can survive in dead zones.

One of the main causes of the increase in size and number of dead zones is fertilizer run-off. Fertilizer contains nutrients like nitrogen, which plants need to grow. Farmers apply fertilizer to plants to help them grow. If extra fertilizer is given to plants, when it rains the extra washes away into streams and rivers. This is called fertilizer run-off.

Dead zones happen when large amounts of nutrients are added to a body of water. If there is a lot of fertilizer run-off, the nutrients in the run-off help phytoplankton grow. Populations of phytoplankton increase quickly. When the plankton die and sink, they feed the bacteria (decomposers) on the bottom of the ocean. The bacteria population increases, and uses up the oxygen in the surrounding water, leaving no oxygen for other organisms. The organisms have to leave that part of the ecosystem or they die.

All of the streams and rivers in the Mississippi Watershed (the green shaded area) connect to the Mississippi river. One area that has a very large dead zone is the Gulf of Mexico, where the Mississippi river flows into the ocean.

How do humans affect the size of dead zones?

Materials

For each student:

■ Explanation Tool

Procedure

1. With your class, watch the video segment "The Gulf of Mexico Dead Zone."

2. Discuss the video segment with your class.

3. With your group, examine the graph below. Discuss the following:

   ■ What patterns do you notice?

   ■ What do you think explains the patterns?

   ■ What pattern do you expect to see in the size of the dead zones in the Gulf of Mexico? Explain why you expect to see these patterns.

Nitrogen Input and Water Flow from the Mississippi Basin to the Gulf of Mexico
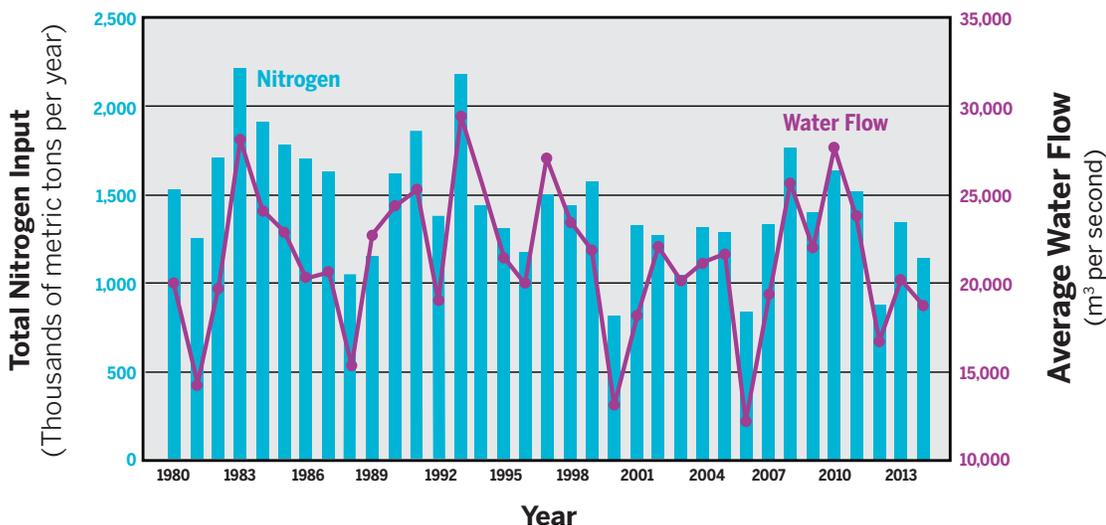
This graph shows the amount of nitrogen input and water flow from the Mississippi Basin into the Gulf of Mexico from 1985 to 2014

**4.** Using the Explanation Tool, construct a scientific explanation about why the total nitrogen in the Gulf of Mexico correlates to the water flow from the Mississippi Basin. Use the steps below to guide you as you use the Explanation Tool.

- ■ **Question:** Record the question "Why does total nitrogen in the Gulf of Mexico correlate to water flow from the Mississippi Basin?"

- ■ **Evidence:** Examine the data in the graph and information from the introduction. What pattern do you notice in the nitrogen input and water flow data? Describe these patterns. Include data (with units) as evidence from the graph to support your description.

- ■ **Science Concepts:** List any science concepts that are connected to the evidence and might help answer the question.

- ■ **Scientific Reasoning:** Describe the scientific reasoning that connects the evidence and science concepts to the question you are trying to answer.

- ■ **Claim:** Based on the evidence of patterns in the data and on your scientific reasoning, state your claim about the effect of water flow from the Mississippi Basin on total nitrogen input in the Gulf of Mexico.

5. With your group, examine the graph below. Discuss the following:

a. What patterns do you notice?

b. Do the data in the graph match the prediction you made in Step 3 about patterns in the size of dead zones in the Gulf of Mexico?

Size of Dead Zones in the Gulf of Mexico
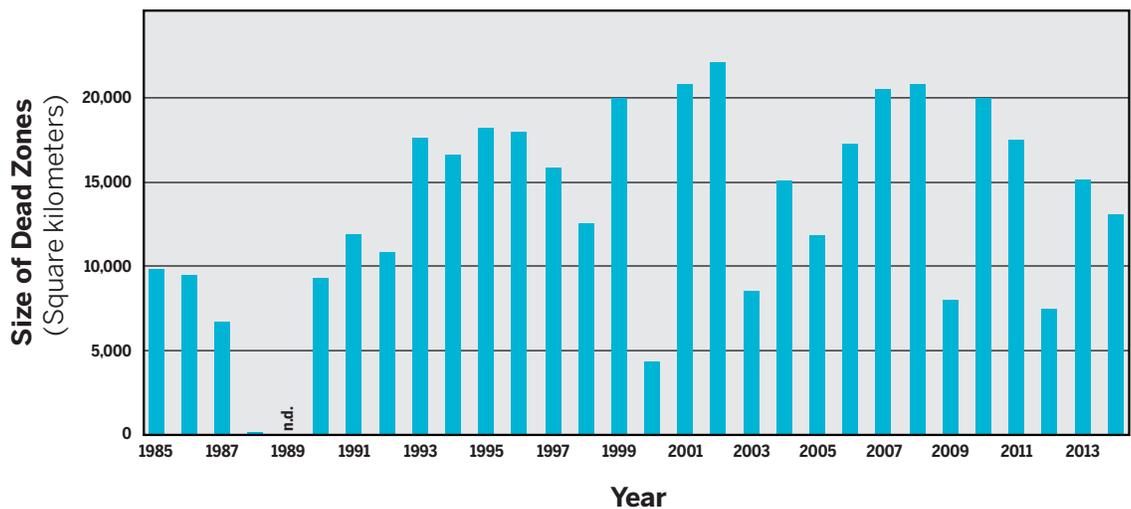
This graph shows the size of dead zones in the Gulf of Mexico between 1985 and 2014.

6. Complete the following reading.

Gulf of Mexico Dead Zone

The Gulf of Mexico is one of the largest and most important areas for fisheries in the United States. The area where the Mississippi River drains into the Gulf waters is the location of the largest recorded dead zone in the United States. This dead zone reappears nearly every summer, and has been as large as 21,576 km² (8,400 mi²).
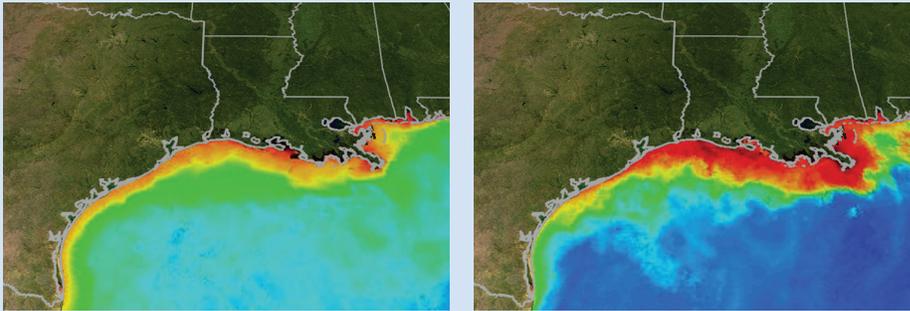
These maps show the dead zone in the Gulf of Mexico in winter (left) and summer (right). The colors indicate how much plankton is present. Red represents high levels of plankton. Orange is slightly less plankton, yellow is less than orange, etc..

The Mississippi drains nearly 41% of the land in the United States, and a lot of the land is farmland where fertilizers are used. Scientists estimate that 65% of the nutrients that drain into the Gulf of Mexico come from farms and livestock production along the Mississippi. Scientists measure nitrogen to help determine the presence of nutrients in water.

Source of Nitrogen	% Total Nitrogen from Source
Fertilizer & treated soil	50
Animal manure	15
Other (atmosphere, ground water, erosion, runoff, etc.)	24
Factories and other buildings	11

Scientists are concerned about the effect of this increasing dead zone on the fisheries in the Gulf, especially because several of the fisheries are already considered overfished or in danger of becoming overfished.

7. With your class, debate the question "Should fertilizer use be limited to help prevent dead zones?"

Analysis

1. What are the abiotic and biotic factors that are affected in a dead zone? How do they differ from a healthy ecosystem?

2. How might an increase in the size of the dead zone in the Gulf of Mexico affect the red snapper fishery, or other fisheries in that area?

3. Draw a diagram with four panels showing the main stages in the creation of a dead zone. The panel below is an example of what the fourth panel in your diagram might look like. Include a caption for each panel that explains what is happening in the diagram.

- Nutrients
- Plankton
- Bacteria
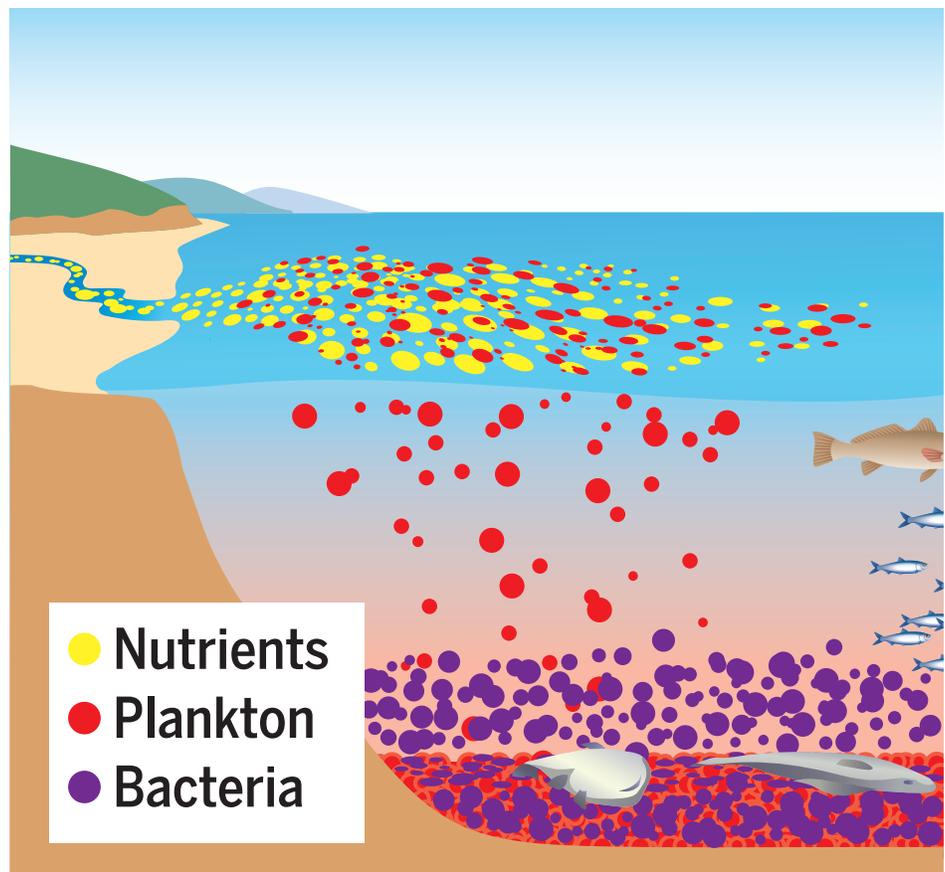
Extension 1

Investigate other types of natural resources and their industries, like agriculture and forestry, to learn more about how people impact those environmental resources. Contact your state departments of agriculture, forestry, fisheries and/or natural resources to learn about industries near you. Ask them to explain current environmental issues involving those industries.

Extension 2

Are there local water quality problems where you live? If so, what might be causing them or contributing to them? Try to answer these questions by looking up your local water district or checking EPA.gov.

Evaluate: Chesapeake Bay Oysters

Eastern Oysters are one of the most important organisms in the Chesapeake Bay ecosystem. The oysters are part of the food web, and they filter the water of the Bay. The oyster fishery is also very important to the area's economy. One hundred years ago Chesapeake Bay was the world's largest oyster-producing area, with fishers harvesting more oysters than all other countries combined. However, the oyster population has been overfished and the amount of oysters available to harvest has decreased dramatically. In this activity you will investigate how this has affected the Chesapeake Bay ecosystem.

Guiding Question

How do increases in the human population affect the resources available to organisms?

Materials

For each student:

■ Argument Tool

Procedure

Part A: Oysters in Chesapeake Bay

1. With your partner, examine the graph below of the harvests of oysters in the Chesapeake Bay. Discuss what this information suggests about what has happened to the oyster population over time.

Oyster Harvests in Chesapeake Bay
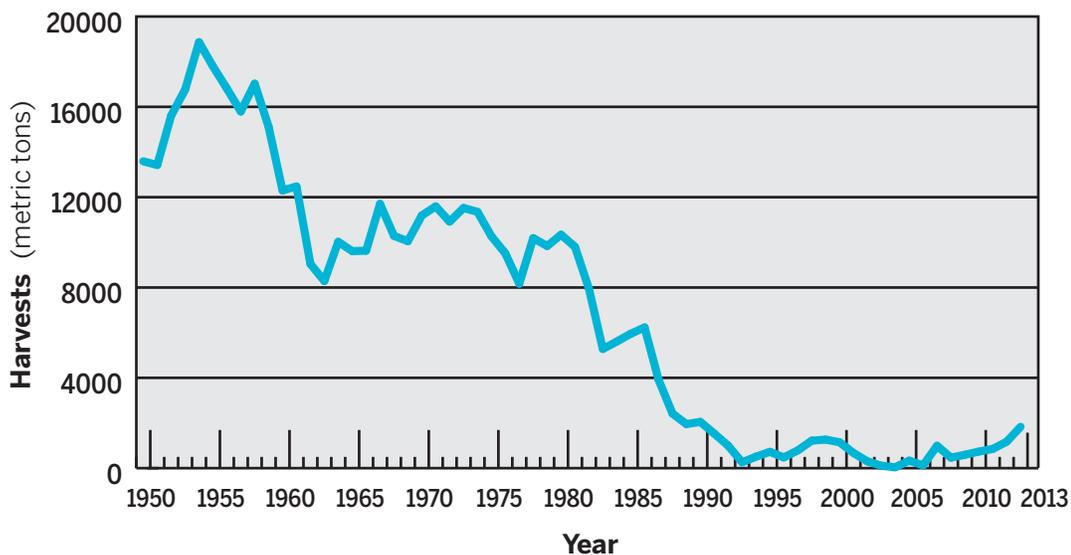
2. Using the food web below, identify two organisms that compete with the Eastern Oyster for resources in the Chesapeake Bay ecosystem.
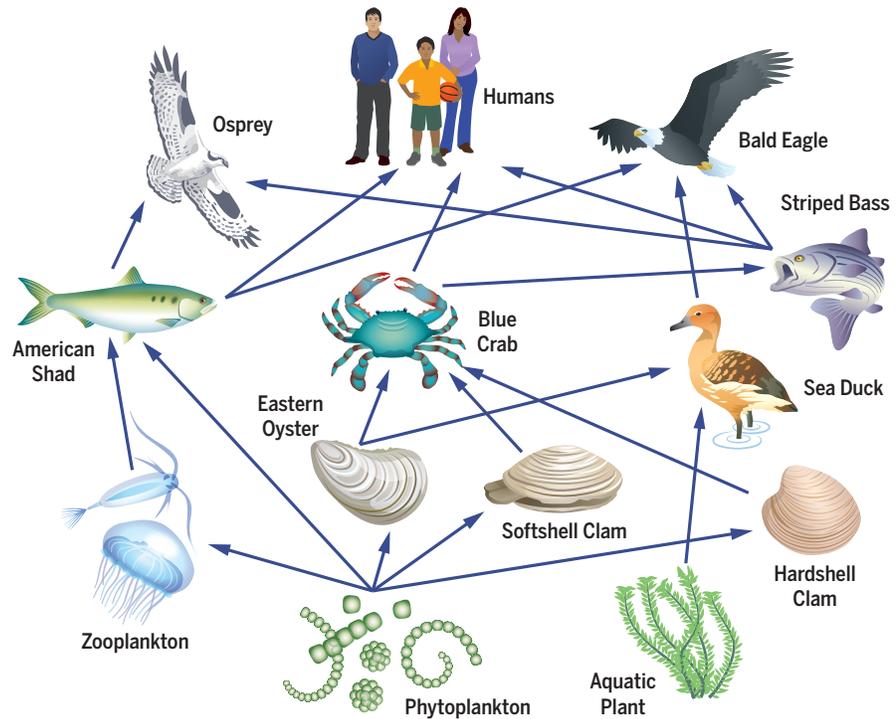
3. With your partner, discuss the following:

- How might the changes in the oyster population affect other organisms in the ecosystem?

- How might this affect the rest of the ecosystem?

4. Follow your teacher's directions to share your discussion with your class.

Part B: Changes in the Chesapeake Bay Ecosystem

One of the important roles of the oysters is to filter the water in the Bay. As they filter the water they remove nutrients and other matter. One of the biggest challenges for the Chesapeake Bay ecosystem in recent years is the appearance of dead zones. There are farms surrounding the Bay, and the run-off from these farms is the primary source of nutrients that cause phytoplankton populations to increase. This can lead to an increase in the size of dead zones. In general, as the human population increases, so will the number of farms and the amount of fertilizer that becomes run-off.

5. With your partner, examine the following three graphs. For each graph identify and discuss any patterns or trends you see in the graphs.

Annual Nitrogen Run-off in Chesapeake Bay
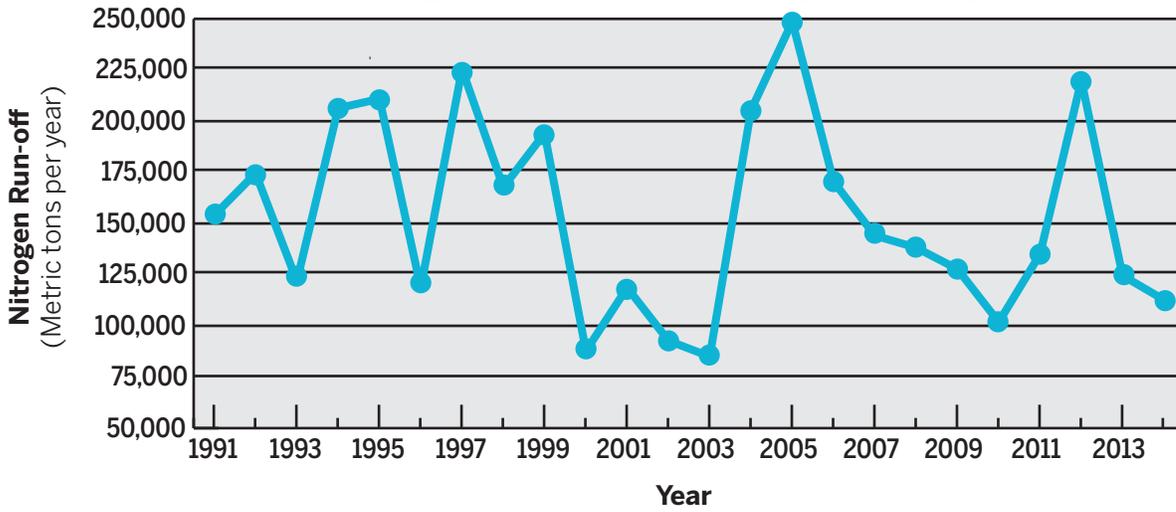
Total Size of Dead Zones in Chesapeake Bay
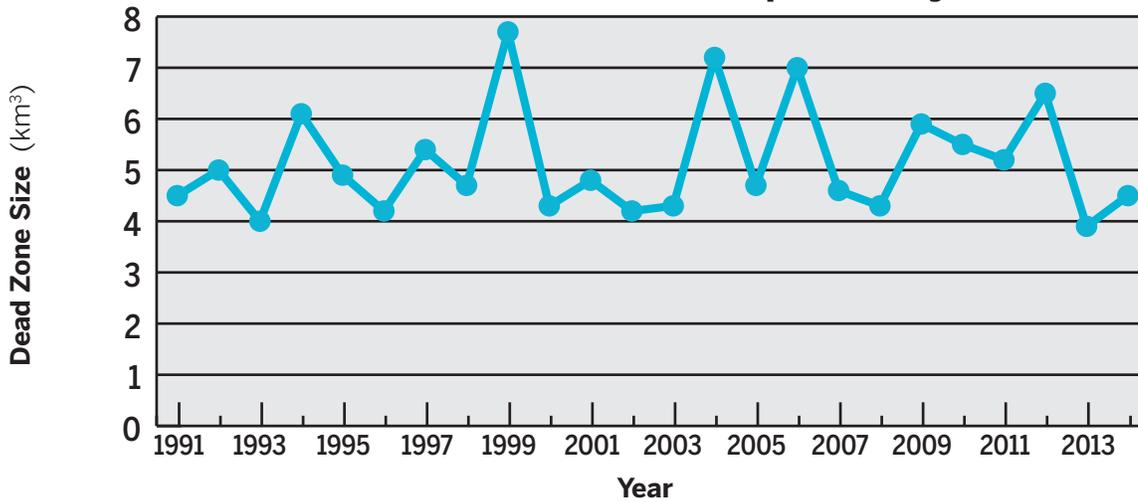
Annual Oyster Harvests in Chesapeake Bay
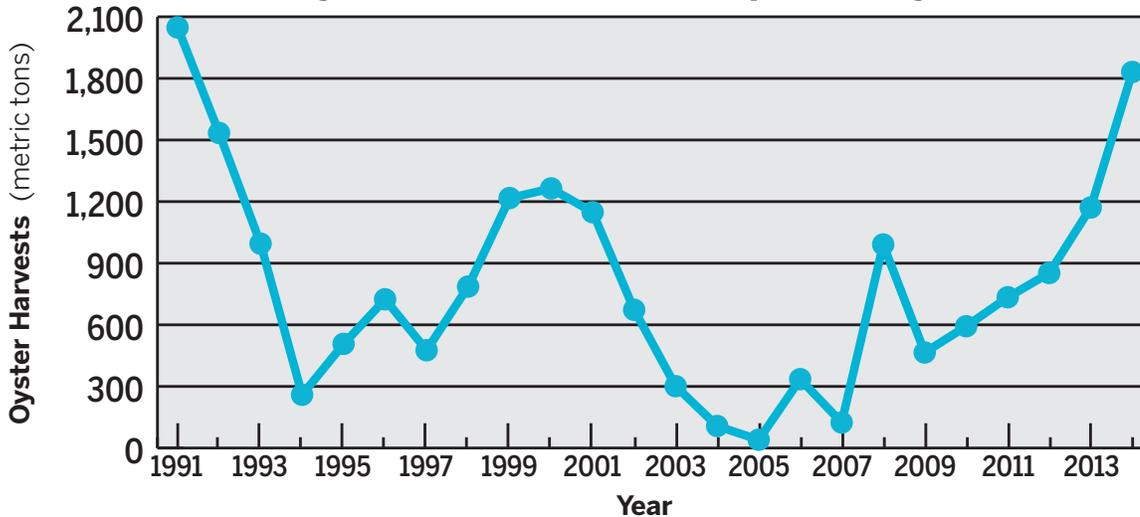
6. Using the Argument Tool, construct a scientific argument about whether an increasing human population in the Chesapeake Bay area is affecting the number of oysters in the Bay. Use the list below to guide you as you use the Argument Tool.

- **Question:** Record the question "Is an increase in the human population in the Chesapeake Bay area affecting the number of oysters in the Bay?"

- **Claims:** Record the two possible claims that could be made in response to the question.

- **Evidence:** What evidence supports each of the two claims?

- **Science Reasoning:** For each claim, critique the quality and strength of evidence that supports the claim.

Analysis

1. Suppose two species of fish that live in the Chesapeake Bay only reproduce during July. For the fish eggs to mature properly and hatch, there must be at least 2 mg/L of oxygen in the water. Based on the diagram below, answer the following:

   a. Which resources will the two species of fish have to compete for in order to breed successfully?

   b. What effect might this competition have on the populations of the two fish, both long- and short-term?

Fish Species 1 Breeding Zone

Fish Species 2 Breeding Zone
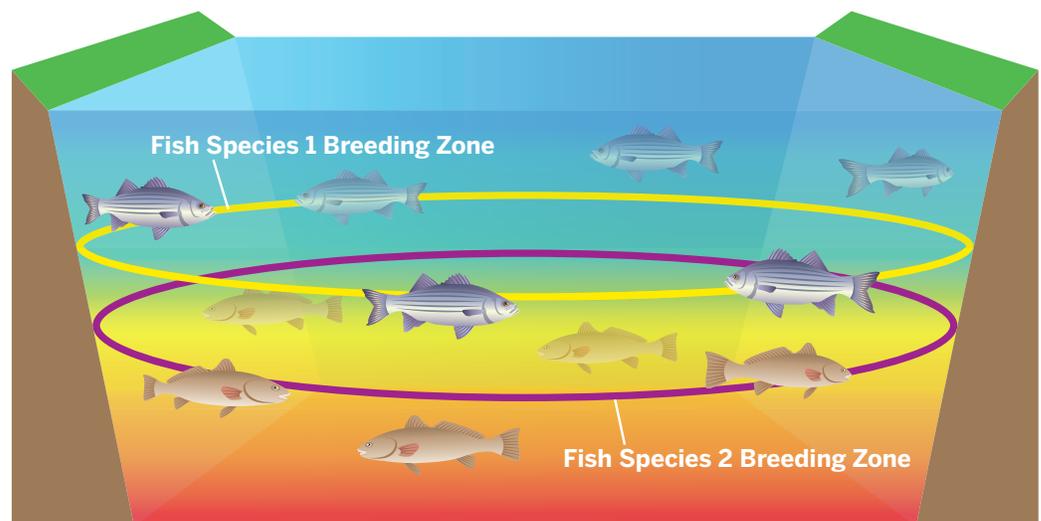
Oxygen in Water (mg/L)

| 0-0.2 | 0.2-1.9 | 1.9-5 | 5-8 | 8-10 |

Zebra Mussels

Imagine you took a fish from the Amazon River in South America. If you let it go in the Hudson River, it would die because the Hudson is too cold. But what if you took a fish from another cold river in North America, like the Colorado River, and let it go in the Hudson. Could the fish survive? What would the fish need in its new environment in order to survive? How might the fish affect the other animals in its new environment?

In this chapter you will learn what happens when an organism that is native to one ecosystem is introduced to another ecosystem. You will analyze and interpret data as you investigate how ecosystems change when new organisms are introduced. You will develop explanations and construct arguments supported by evidence about how the introduction of new organisms affects ecosystems.

Engage: Hudson River Ecosystem

There are many different ecosystems in the world. You have already learned about several, including the Gulf of Mexico. You have also learned about some of the challenges faced by ecosystems. One challenge is the introduction of new species to an ecosystem. If a new species survives and its population increases, it can disrupt the ecosystem. This can affect the health of the ecosystem. In this activity you will learn about the zebra mussel, a species that has been introduced to the ecosystems of the Great Lakes and the Hudson River. You will predict what effect the zebra mussel might have on the health of these ecosystems.

Guiding Question

How might the introduction of the zebra mussel affect the health of the Great Lakes and Hudson River ecosystems?

Materials

For each pair of students:

- 1 set of 9 Hudson River Ecosystem cards
- 1 additional Hudson River Ecosystem card: Zebra Mussel
- 1 Handout 4.1-1, "Ecosystems Comparison"

Procedure

Exploring a Dynamic Ecosystem

1. With your class, review what you already know about the Gulf of Mexico, Great Lakes, and Hudson River.

2. Watch the video clip, "The Problem."

3. As a group, based on the information your class has discussed and the video clip, fill in as much as you can of Handout 4.1-1, "Ecosystems Comparison."

4. With your group examine the 9 Hudson River Ecosystem cards.

5. With your group create a food web using all of the cards in your set.

6. Record your food web in your science notebook. Use a full page of paper to draw your food web. Leave space around the name of each organism so that you have room to draw in arrows. Then draw in arrows from the eaten organism to the animal that eats it.

7. Discuss with your group the patterns of interaction among the organisms in your food web:

    ■ Which organisms play a similar role in the food web? Describe these roles.

    ■ What changes might occur in this dynamic ecosystem based on the patterns of interaction among the organisms?

    ■ What do you predict would happen to the food web if a new organism that consumes plankton was introduced?

8. Your teacher will give you another Hudson River Ecosystem card: Zebra Mussel.

9. Add the zebra mussel to your food web.

10. Discuss with your group how the introduction of this species might affect your food web.

Analysis

1. How do you predict the introduction of the zebra mussel will affect each of the following in the Hudson River ecosystem:

    a. the flow of energy.

    b. the location and cycling of matter.

Explore: Introducing a New Species

When scientists realized that zebra mussels were likely to show up in the Hudson River, they were in a unique position to investigate the impact of the invasion. Scientists don't usually have data about a lake or river until after the new species appear. However, scientists began collecting data on the Hudson River's ecosystem in 1986. They started studying the whole Hudson River ecosystem to see how was changing. Ecosystems are constantly changing for many reasons. You have learned that ecosystems have many interactions between living organisms and between biotic and abiotic factors. Because of these interactions, a change in one factor can cause other changes in an ecosystem. Both natural and human-caused disturbances can cause changes in ecosystems. Scientists use the phrase **dynamic ecosystem** to describe this phenomenon because dynamic means constantly changing.

In this activity, you will explore the Hudson River ecosystem and predict how this dynamic ecosystem might be affected by the introduction of the zebra mussel.

Fish

Zooplankton

Bacteria

Rooted Plants

Phytoplankton

Watershed Nutrients from Organic Matter
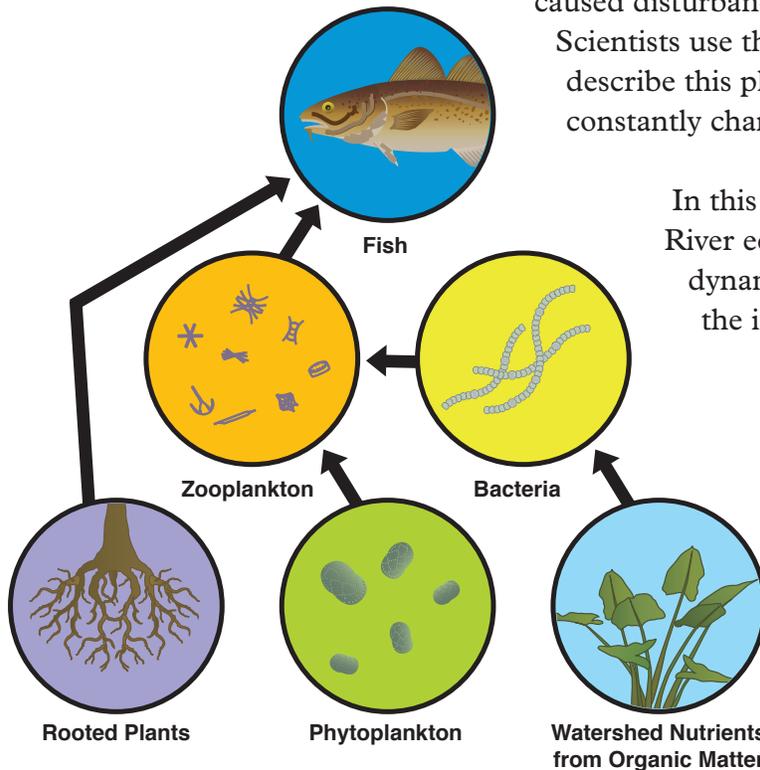
Guiding Question

What biotic and abiotic factors are affected when a new species is introduced to an ecosystem?

Materials

For each student:

■ Handout 4.1-1, "Ecosystems Comparison" (from Activity 4.1)

Procedure

Part A: Comparing Ecosystems

1. Use the Read, Think, and Take Note strategy as you complete the following reading.

<div>

Read, Think, and Take Note: Guidelines

As you read, stop at least three times to write one of the following:

■ Explain a thought or reaction to something you read.

■ Note something in the reading that is confusing or unfamiliar.

■ Identify a word that you do not know.

■ Ask a question about the reading.

■ Draw a diagram or picture of an idea.

</div>

An Unwelcome Newcomer

Invasion of the Zebra Mussels

The zebra mussel is a small freshwater animal with two shells like a clam. It is named for its striped shell. This tiny creature may look harmless, but it can cause big problems. The zebra mussel is not native to North America but arrived in this part of the world about thirty years ago.

Zebra mussels cling to any hard surface—including native mussels and other animals with shells. This can cause these animals to die
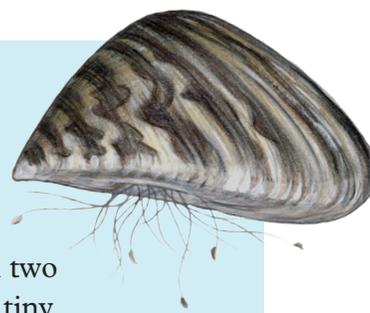
because they can't eat. Zebra mussels are filter feeders. They pump water through their gills and strain out microscopic animals and plants called plankton. Zebra mussels can quickly clear the plankton from huge bodies of water, leaving little food for the native mussels and other animals.

Zebra mussels can also cause millions of dollars in damage. The mussels clog water pipes to businesses and power plants. They damage boats, docks, and other structures.

The Great Lakes Invasion

The Great Lakes System includes Lakes Superior, Michigan, Huron, Erie, Ontario, and the smaller Lake St. Clair.

The Great Lakes are a system of connected freshwater lakes and waterways in northeastern North America, between Canada and the United States. It is the largest group of freshwater lakes on Earth, and holds about 20% of the world's fresh water. In many places, if you stand on the shore of one of the Great Lakes you cannot see to the other side. Zebra mussels were first discovered in a small lake in the Great Lakes system, Lake St. Clair, in 1988. Scientists believe the mussel was introduced by one of the large ships that travel across the Atlantic Ocean carrying cargo between countries. Soon scientists were finding zebra mussels in other areas of the Great Lakes systems and rivers connected to the Great Lakes, such as the Mississippi and Ohio Rivers. Even today, scientists continue to find new zebra mussel invasions in ecosystems as far away from the Great Lakes as Texas and California.

How do these mussels spread so quickly? A single female can produce up to one million eggs each year. The young mussels float along water currents and eventually attach themselves to hard surfaces like rocks on the riverbeds and the bottom of boats. They form dense colonies, with as many as 10,000 mussels in a single square foot.

Zebra mussels

The Hudson River Invasion

The Hudson River flows south through New York State, from the mountains to New York City. Because the river is connected to the Great Lakes, scientists predicted it would not be long before the zebra mussel would arrive in the Hudson.

The Hudson River's ecosystem is very different from the Great Lakes. Lake water settles into layers, with cool water near the bottom and warm, clear water above. In the Hudson River water flows from the mountains to the Atlantic Ocean. The last 150 miles of the Hudson River is significantly affected by water from the Atlantic Ocean. The salt water from the ocean mixes with fresh water from the river. The tides from the ocean mix the water from top to bottom. This area of mixed salt and fresh water is called an **estuary**. In the estuary, tides also stir up material from the riverbed, making the water cloudy. Little sunlight can pass through the water. Less sunlight means fewer plants and phytoplankton.

Scientists wondered how zebra mussels might affect the ecosystems of the Great Lakes and the Hudson River. They also wondered if different biotic and abiotic factors in the ecosystems might lead to different effects from the zebra mussels. Soon they would find out.

2. As a group, based on the reading and the information your class has discussed, add what you have learned to Handout 4.1-1, "Ecosystems Comparison."

3. With your group, discuss what you still want to know about these ecosystems. In your science notebook, write down four of your group's questions.

Part B: Predicting Changes in Biotic and Abiotic Factors

4. With your class, watch the video clip, "Observation."

5. With your partner, review the abiotic factors in the table below. Choose one abiotic factor you think might be affected by the zebra mussels that you would like to investigate further.

Abiotic Factors
Water Temperature: Temperature affects an organism's metabolism—the internal chemical reactions that affect its health and growth.
Dissolved Oxygen: Oxygen dissolves in water. Both producers and consumers (like zebra mussels) take up oxygen during respiration. Producers also give off oxygen.
Water Clarity: Scientists use a Secchi disk to measure how clear water is. The disk is lowered into the water until the pattern on its surface can no longer be seen. The clearer the water, the deeper the pattern can be seen.
Suspended Solids: The solid particles suspended in water affect its clarity and quality. These particles can be both biotic (like phytoplankton) and abiotic (like silt and clay). Zebra mussels consume huge amounts of biotic suspended solids, clearing large bodies of water.

6. With your partner, choose two organisms (biotic factors) from your food web that you think might be affected by the zebra mussels that you would like to investigate further. Have your teacher approve your choice of factors.

7. Following your teacher's directions, develop a testable question and a prediction for how each factor you selected will change after the zebra mussels' arrival in the river. Write down why you chose these factors and your prediction for each factor.

Analysis

1. Explain how the Hudson River is an example of a dynamic ecosystem. Use information from the activity to support your answer.

2. Think about the differences and similarities between abiotic and biotic factors in the Hudson River, the Great Lakes, and the Gulf of Mexico. Do you think the zebra mussels will spread to the Gulf of Mexico? Explain why or why not.

3. How do you think the zebra mussel will change the Hudson River ecosystem?

4. Suppose a group of scientists wants to monitor the effect of zebra mussels on an ecosystem. What data about the ecosystem might scientists collect to investigate this question?

Extension

Are there invasive species around where you live? Are they causing problems for either biodiversity or people? Investigate one of these species and share what you find with others.

Explain: Changing Ecosystems

In May 1991, a few years after they were first found in the Great Lakes, zebra mussels appeared in the Hudson River. Within a year scientists estimated the zebra mussel population had reached 500 billion! If you had a huge balance and put zebra mussels on one side, they would outweigh all the other consumers in the ecosystem combined: all the fish, zooplankton, worms, shellfish, and bacteria. Scientists wondered how the zebra mussels would affect the river ecosystem.

One measurement scientists use to monitor ecosystem health is the biodiversity in the ecosystem. **Biodiversity** is the diversity of life at every level, including variation within a species, variation between species, and variation between populations of species. For example, if an area has many healthy populations of a range of organisms scientists say it has more biodiversity than a region with a smaller number of healthy populations of organisms. The biodiversity of an ecosystem is affected by biotic and abiotic factors. Over time, the biodiversity of a particular ecosystem may change depending on the health of the ecosystem.

To measure the biodiversity of the Hudson River ecosystem scientists count the number of different species and how large their populations are.
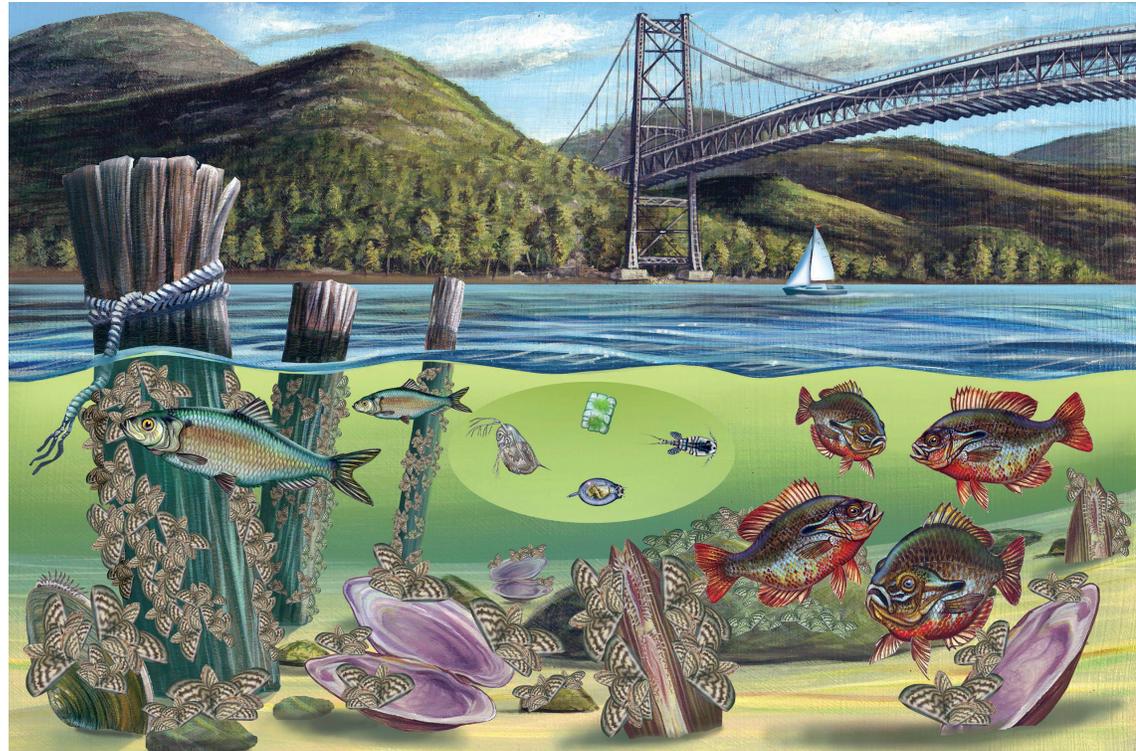
In the previous activity, you chose three factors to investigate further. In this activity you will compare data for those factors collected by scientists in the years before and after the arrival of the zebra mussel. From the data and a reading you will learn more about how the zebra mussel affected the ecosystem health and biodiversity of the Hudson River in the first eight years after its arrival.

Guiding Question

How did the zebra mussel initially affect the health and biodiversity of the Hudson River ecosystem?

Materials

For each pair of students:

■ computer with Internet access

For each student:

■ Handout 4.1-1, "Ecosystems Comparison" (from Activity 4.1)

Procedure

Investigating Zebra Mussel Impact

1. With your partner, review the testable questions and predictions you developed for your three chosen factors from the previous activity.

2. With your partner, go to the "Overview" page of the "Graph the Data" section of the River Ecology website:

   ◂ https://www.amnh.org/education/resources/rfl/web/riverecology

3. You will examine data from the Kingston location. Select "Over Time" and use the map to choose the Kingston location.

4. Set the first parameter to "Zebra mussel" and set the second parameter to one of the factors that you chose in the previous activity. Use the table below to determine which parameter matches with the factors you chose.

Factor	Graph Parameter
Alosa: Fish	Alosa (pelagic fish)
Bacteria	Bacterial abundance
Centrarchidae: Fish	Centrarchidae (littoral fish)
Cladocera: Zooplankton	Cladocera
Copepods: Zooplankton	Copepods
Dissolved Oxygen	Dissolved oxygen
Phytoplankton	Chlorophyll a
Rotifers: Zooplankton	Rotifers
Sphaeriidae: Freshwater Mollusks	Sphaeriidae
Suspended Solids	Total suspended solids
Unionidae: Freshwater Mollusks	Unionidae
Water Clarity	Secchi depth
Water Temperature	Temperature

5. Examine the section of the graph from 1988 to 1996. Look for any patterns and record your observations.

6. Repeat Procedure Steps 4 and 5 for each of the other two factors you chose.

7. With your class, watch the video segment "Results."

8. Return to your Handout 4.1-1, "Ecosystems Comparison," from Activity 4.1 and add any new information you have learned.

9. Complete the reading on the next page, following your teacher's instructions to answer the "Stop to Think" questions.

Zebra Mussels Invade

What Makes a Good Invader?

There are many characteristics of the zebra mussel that help them thrive in North American lakes and rivers. Zebra mussels can reproduce when they are less than a year old. Just one female can lay up to 1 million eggs every year. Zebra mussels will eat most types of plankton and will attach to nearly any hard surface. They can grow in water as cold as 3°C and as warm as 30°C.

Zebra mussels are sensitive to several abiotic factors, which limit their spread. They can only live in fresh water or water that has very little salt (less than 0.4%). They cannot survive in water with low oxygen levels. They also are not found in water that moves faster than about two meters per second, so you won't find them in fast-moving streams or rivers. They will only reproduce if the water is 14-16°C or warmer.

Stop to Think

What characteristics of zebra mussels make them likely to live in a variety of river ecosystems?

In the Hudson River and Great Lakes, the conditions for a zebra mussel invasion were just right. There were lots of plankton for the zebra mussels to eat, many hard surfaces for the mussels to attach to, and in spring and summer the temperatures were just right for zebra mussels to reproduce. This means that once the zebra mussels were introduced, it was easy for them to spread out.

Lake Michigan Zebra Mussel Density

These maps show how the distribution of zebra mussels changed over time in Lake Michigan, one of the Great Lakes.

Stop to Think

What do the patterns in the data on the map tell you about the density of zebra mussels in Lake Michigan between 1994-95 and 2000?

Changes Caused by Zebra Mussels

By 1992, there were so many zebra mussels in the Hudson River that scientists estimate they were filtering a volume of water equal to all of the water in the estuary every 1-4 days during the summer. In the years right after their arrival, phytoplankton fell by 80-90 percent. Zooplankton (which eat phytoplankton) declined by half.

The plankton populations in the Great Lakes also dropped dramatically. Some research showed the zebra mussels were rejecting certain types of harmful blue-green algae as food. This meant the blue-green algae population increased, while other plankton decreased, causing changes in the biodiversity and the food availability for other filter feeders.

Hudson River Chlorophyll Levels Over Time
(Sampled from Kingston, NY)
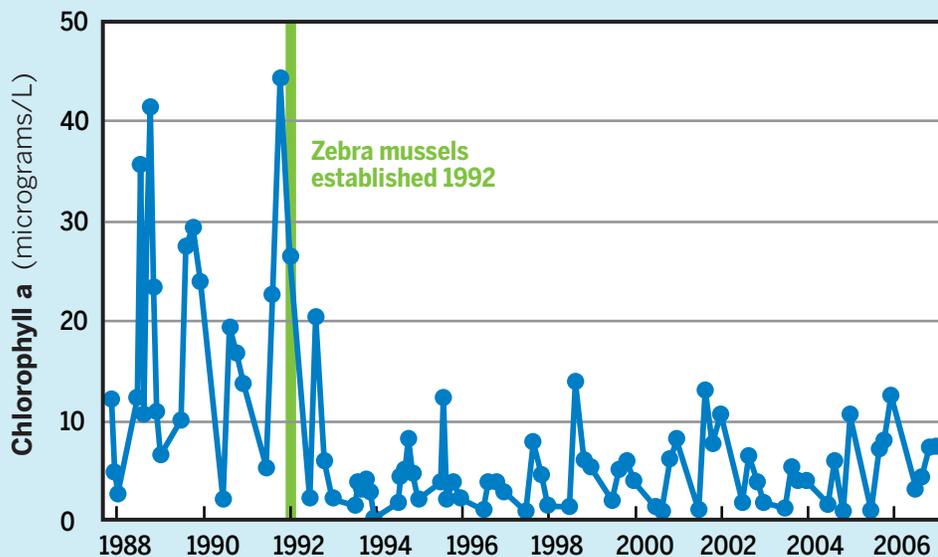
Stop to Think

Why did the introduction of one species, the zebra mussel, cause changes to so many of the other populations in the Great Lakes and Hudson River?

In both locations the populations of native mussels, also filter feeders, shrank dramatically. Native mussels could not compete with the zebra mussels, and their populations dropped as the plankton populations dropped. In the Hudson, native mussel populations fell from more than one billion to almost none. Many fish species also eat plankton. With the decline in plankton populations, there were fewer—and smaller—fish in the open river as well as the open lakes. The biodiversity of the Hudson was changing.

But some populations in the Hudson River increased—likely due to the change in the river's water clarity. With far less phytoplankton, the water got clearer. During the summer, visibility went from 3-4 to 4-8 feet from the surface. Since sunlight reached deeper into the water, rooted aquatic plants increased by up to 40 percent. Populations of fish living in these shallow weeds increased, and they were also found further upriver than before the invasion. Another surprising result was that dissolved oxygen in the river fell by about 15 percent. Scientists think the enormous zebra mussel populations were consuming a lot of oxygen very quickly. At the same time, the mussels were removing the phytoplankton that produce oxygen.

In the Great Lakes, most of the species that increased after the zebra mussel invasion were considered "nuisance" or even harmful species, like the blue-green algae. The zebra mussel increase also seemed to cause an increase in the bacteria that produces botulism toxin, and more than 52,000 waterbird deaths due to botulism toxin occurred between 2002 and 2006.

Effect on Ecosystem Services

The organisms living in the Hudson River and the Great Lakes are not the only organisms depending on those ecosystems. Humans depend on, and benefit from, these two ecosystems in many ways. When humans benefit from an ecosystem, scientists call these benefits ecosystem services. For example, a lake might provide people with drinking water, fish to eat, and a place to go sailing and relax. All of these benefits are **ecosystem services**. When scientists study the effect of a non-native species, like the zebra mussel, they study how it affects the ecosystem in all ways, including how it affects ecosystem services.

In both the Great Lakes and the Hudson River, the zebra mussels have affected many ecosystem services. One effect has been on power plants and water treatment facilities built on the shores of large lakes and rivers. These facilities have large pipes to take in and release water. The zebra mussels attach to the pipes and other equipment. The number of mussels that attach to the pipes is so great that the pipes become clogged, causing large increases in maintenance and repair costs. Another effect is that the blue-green algae that increased

after the zebra mussel invasion releases harmful toxins into the water in the Great Lakes, causing beaches to be closed and preventing people from going swimming. Also, several fisheries, including the Lake Whitefish, have declined dramatically due to the zebra mussel invasion, causing people to lose income and jobs. However, some fisheries on the Hudson River that rely on littoral fish have increased.

The Hudson River provides many ecosystem services to the nearby communities, including a place for recreation.

Stop to Think

Why might people be concerned about the effects of zebra mussels on ecosystem services?

Questions about the long-term impact

Once scientists had a clear picture of the invasion's immediate impact, they started to wonder about long-term effects the zebra mussels might cause in these two ecosystems. Would the systems continue to change, or would they recover? Would native species eventually tolerate or even feed on the zebra mussel? Perhaps another species might arrive that would change the effects of the invasion? Should people try to control the zebra mussel invasion or see if the ecosystem would eventually stabilize? Only continued studies would allow scientists to determine how the zebra mussel might change these ecosystems in the long term.

10. With your group, update the information on Handout 4.1-1, "Ecosystems Comparison."

11. Follow your teacher's directions to debate the question "Has the zebra mussel had a positive or negative effect on the Hudson river ecosystem?" Use words from the class word wall to help you form your discussions during the debate.

Analysis

1. For each factor you examined, do the data show stability or change in the Hudson River ecosystem? Explain your answers.

2. In Activity 4.2, Hudson River Ecosystem, you made predictions about how each of the three factors would be affected by the introduction of the zebra mussels. Describe whether the data supported your predictions.

3. Your observations covered data that spanned from a few years before to a few years after the zebra mussels arrived in the Hudson River. Predict what the data might show about the biodiversity and health of the Hudson River ecosystem 20 years or more after the introduction of the zebra mussels. Explain the reasons for your prediction.

4. An invasive species is a species that is brought from its native area to a new place where it causes harm to the environment, the economy, or human health. Scientists consider the zebra mussel an invasive species in North America. What evidence supports this?

Elaborate: The Zebra Mussel Problem: 20 Years of Data

Ecosystems are dynamic places that can change over time. The introduction of zebra mussels changed the Great Lakes and Hudson River ecosystems by altering their food webs. Over time, further changes occurred in both ecosystems. Sometimes an ecosystem can recover from a change and return to a stable state similar to before the change, or a new stable state. Other times the changes are too great.

In the last two activities, you learned how the zebra mussel affected the ecosystem in the Hudson River. The data you investigated covered a period of eight years. When scientists monitor ecosystem health, this amount of time is considered short-term. Looking at short-term data can give scientists important information about the early effects of a change. In this activity, you will look at the same factors you investigated before, but you will analyze the data in terms of long-term ecosystem health.

Scientists want to understand what happens when ecosystems, such as the Hudson River, have a new species introduced.

Guiding Question

What are the long-term effects of the zebra mussel invasion of the Hudson River?

Materials

For each pair of students:

- computer with Internet access

For each student:

- Explanation Tool

- Argument Tool

Procedure

Part A: Constructing Another Explanation of the Impact

1. In this activity you will examine long-term data for the same factors you studied in Activity 4.3. With your partner, review your predictions from activity 4.3. Decide with your partner if you want to change your prediction or keep it the same.

2. With your partner, go to the "Overview" page of the "Graph the Data" section of the website.
   - https://www.amnh.org/education/resources/rfl/web/riverecology/

3. Select "Over Time" and use the map to choose the Kingston location to study.

4. In the box below the map, select "Split Date."

5. Use the pop-up calendar to set Split Date #1 to August 15, 1990. This represents average data from before the zebra mussels arrived in the Hudson River.

6. Set Split Date #2 to August 15, 2000. This will split the remaining data into two periods—one soon after the zebra mussels arrived and the other more recent.

7. Set the first parameter to "Zebra mussel" and set the second parameter to the first factor you investigated in Activity 4.3.

8. Examine the three pairs of bar graphs that are produced. Look for any patterns and record your observations.

9. Repeat Procedure Steps 6 and 7 for the second and third factors you investigated in Activity 4.3. Make sure the first parameter is always "zebra mussel."

10. With your class, watch the video clip, "Going Further."

11. Using the Explanation Tool, construct a scientific explanation about the long-term interactions between zebra mussels and the biotic or abiotic factor you chose. Use the steps below to guide you as you use the Explanation Tool.

■ **Question:** Record the question "What is the long-term effect of zebra mussels on the factor you chose?"

■ **Evidence:** Examine the data in the graphs you created. What pattern do you notice in the zebra mussels over time? What pattern do you notice in the factor you chose over time? Describe these patterns. Include data (with units) as evidence from the graph to support your description.

■ **Science Concepts:** List any science concepts that are connected to the evidence and might help answer the question.

■ **Science Reasoning:** Describe the scientific reasoning that connects the evidence and science concepts to the question you are trying to answer.

■ **Claim:** Based on the evidence of patterns in the data, state a claim about the relationship between the zebra mussels and the factor you chose.

12. Complete the reading below, following your teacher's instructions to answer the "Stop to Think" question.

Long Term Changes

In 2005, 14 years after the first sighting of zebra mussels in the Hudson River, Cary Institute scientists noticed an unexpected change in the river: zooplankton had returned to the same levels as before the invasion. The scientists also observed a change in the zebra mussels they were collecting from the river. Scientists group zebra mussels by three sizes: small (less than 10 mm), medium (10–20 mm), and large (more than 20 mm). While there were still many zebra mussels in the Hudson River, they were on average much smaller. Populations of the largest—or oldest— mussels were in decline. Zebra mussels can live six or seven years, but now it seemed that most were dying after only one or two years. If there were fewer older and larger zebra mussels, it made sense that there was more zooplankton. That's because large zebra mussels feed on bigger

food particles like zooplankton. Smaller zebra mussels can eat only smaller particles like phytoplankton and bacteria.

These changes started to affect the rest of the food web. As zooplankton increased, so did native mussels and clams. Scientists anticipated some fish species would increase too as their food supply increased. Scientists didn't know all the factors that caused the decline in large zebra mussels, but they did know blue crabs were starting to eat the zebra mussels.

Over time, blue crabs have begun to eat zebra mussels and are one significant factor in the decrease of zebra mussels.

By monitoring several aspects of the Hudson River over many years, Cary Institute scientists are beginning to answer their original question: How might a zebra mussel invasion affect the Hudson River ecosystem? Early on during the invasion, zebra mussels thrived and had a huge impact on the ecosystem's food web—just as scientists had predicted. However, about 20 years later the number of zebra mussels has greatly declined. Parts of the ecosystem, such as the number of zooplankton, native mussels, and clams, have started to increase. But is this the end of the story? Or have we just seen the first two stages of an invasion that might have three, four, or more stages?

As their data sets grow, the scientists are able to track changes in the river—whether from pollution, weather, invasive species, or human activity—and to pose new questions. This broad approach puts scientists in a unique position to investigate future changes to the Hudson River ecosystem.

13. Review your Explanation Tool from Procedure Step 11. Revise or add to your student sheet as needed, based on the passage you just read.

14. Using the Argument Tool, construct a scientific argument about whether the zebra mussel has had a positive or negative effect on the Hudson River ecosystem. Use the following list to guide you as you use the Argument Tool.

■ **Question:** Record the question "Has the zebra mussel had a positive or negative effect on the Hudson River ecosystem?"

■ **Claims:** Record the two possible claims that could be made in response to the question.

■ **Evidence:** What evidence supports each of the two claims?

■ **Science Reasoning:** For each claim, critique the quality and strength of evidence that supports the claim.

Analysis

1. Explain why it is important to monitor ecosystems over long periods of time.

2. How do the effects of zebra mussels in the Hudson River relate to stability and change in ecosystems?

3. The graph below shows water clarity over time in the Hudson River. The bars indicate how far scientists are able to see into the river from the surface of the water. What do the patterns in the data tell you about the effect of zebra mussels on water clarity?

Water Clarity Over Time in Hudson River

Distance from surface (cm) — y-axis: 0 cm, 30, 60, 90, 120, 150

Zebra mussels established 1992

Year — x-axis: 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996
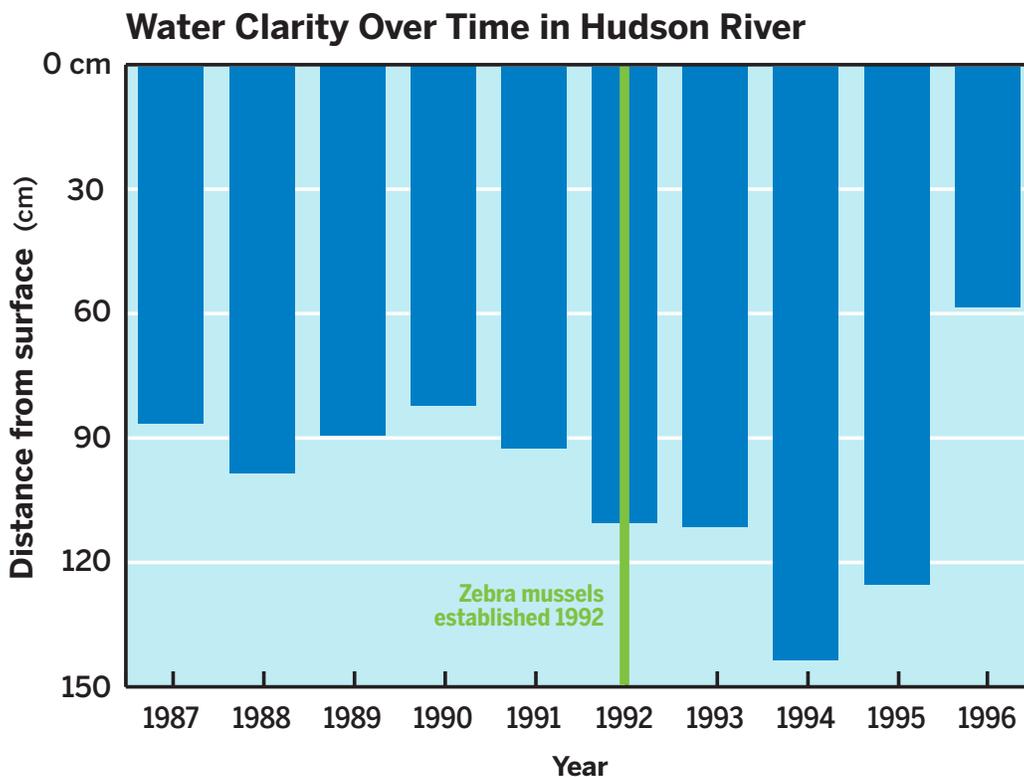
4. Consider the statement: "A small change to one factor can lead to large changes in an ecosystem." If the introduction of one species is considered a "small change," do you think this statement is accurate? Explain your answer.

Evaluate: A New Mussel in Town

Q uagga mussels are an invasive species closely related to the zebra mussel. They arrived in the Great Lakes region a few years after the zebra mussels. Quagga mussels are now found in all of the Great Lakes.

In this activity you will examine data on the spread of the quagga mussel and compare it to data on the zebra mussel populations in one of the Great Lakes, Lake Michigan. You will compare this information to other data about biotic and abiotic factors in Lake Michigan and how those factors have changed as the quagga mussel has spread.

Guiding Question

Has the quagga mussel had a positive or negative effect on the Lake Michigan ecosystem?

Materials

For each student:

- Argument Tool

Procedure

Constructing an Argument

1. Using data from the information items that follow, the concepts you have learned in this chapter, and the Argument Tool, construct a scientific argument about whether the quagga mussel has had a positive or negative effect on the Lake Michigan ecosystem. Use the list below to guide you as you use the Argument Tool.

> - **Question:** Record the question "Has the quagga mussel had a positive or negative effect on the Lake Michigan ecosystem?"
>
> - **Claims:** Record the two possible claims that could be made in response to the question.
>
> - **Evidence:** What evidence supports each of the two claims?
>
> - **Science Reasoning:** For each claim, critique the quality and strength of evidence that supports the claim.

The Next Invasion: Quagga Mussels

Quagga mussels and zebra mussels share many characteristics, but they also have important differences. They are both filter feeders, and can filter up to a liter of water per day. Both species produce up to a million eggs per mussel per year. Both species will attach to hard surfaces, and can clog water pipes and equipment at water treatment and power generation facilities. Zebra mussels can survive being out of water for longer than quagga mussels. However, quagga mussels can also live on sandy and muddy river and lake bottoms. They can live in deeper water and in a much wider temperature range than zebra mussels.

The quagga mussel's ability to live in deeper water allows them to filter the plankton from the water at the bottom of deep lakes. Scientists believe that the quagga mussels are competing for food with another species, diporeia. Diporeia are a small, shrimp-like organism that used to cover the bottom of many of the Great Lakes. Scientists used to find up to 20,000 diporeia per meter on the bottom of Lake Michigan. Now in some areas there are almost no diporeia left. Diporeia are an important food source for many fish in the Great Lakes, including the Whitefish, chubs, and smelt. Chubs and smelt are prey for trout and salmon. Trout, salmon, and Whitefish fisheries are important sources of income for many people.

The graph below shows how the water clarity has changed over time in Lake Michigan. The bars indicate how far scientists are able to see into the lake from the surface of the water.

Water Clarity Over Time in Lake Michigan

10-year average depth: 16.4 ft

10-year average depth: 19.6 ft

10-year average depth: 28.4 ft

Distance from surface (ft)

Year
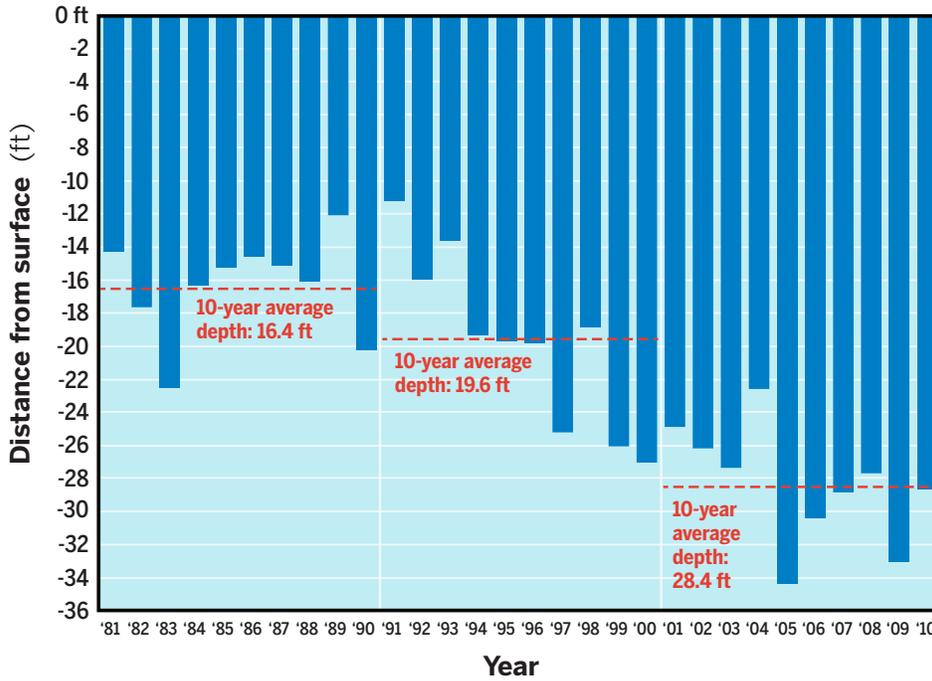
The maps below show how the distribution of zebra mussels, quagga mussels, and diporeia has changed over time in Lake Michigan, one of the Great Lakes.

Lake Michigan Zebra Mussel Density

1994-95   2000   2005   2010

10^5
10^4
10^3
10^2
10^1
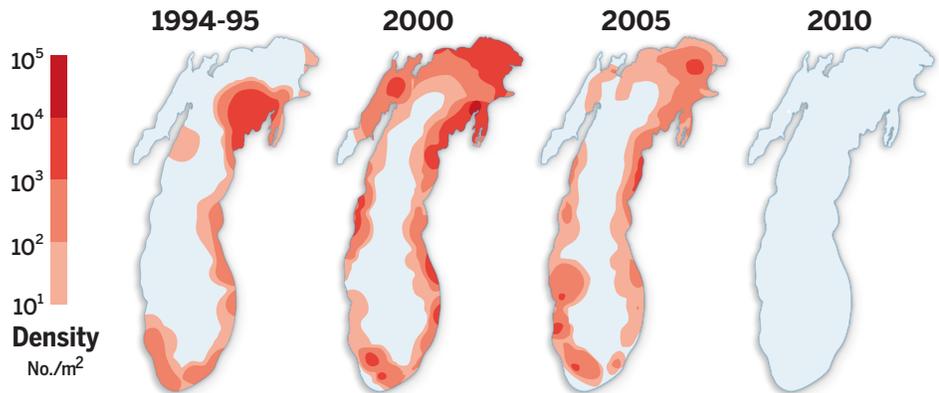
Density
No./m^2

Lake Michigan Quagga Mussel Density

1994-95   2000   2005   2010

10^5
10^4
10^3
10^2
10^1
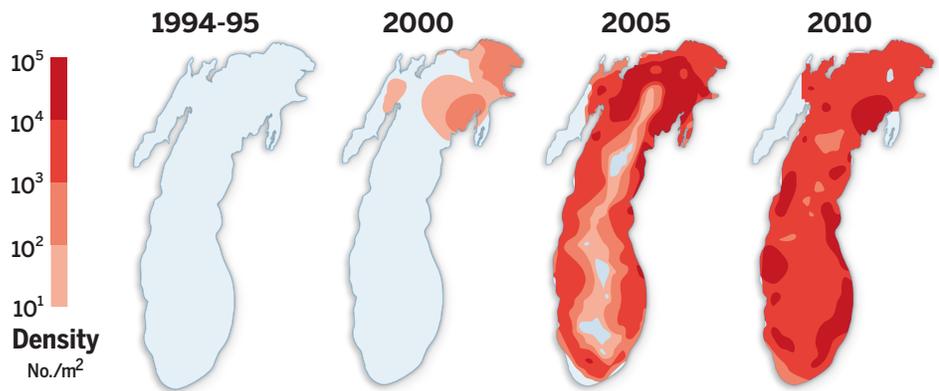
Density
No./m^2

Lake Michigan Diporeia Density

1994-95   2000   2005   2010

15
12
9
6
3
0

Density
No. /m^{2}x10^3
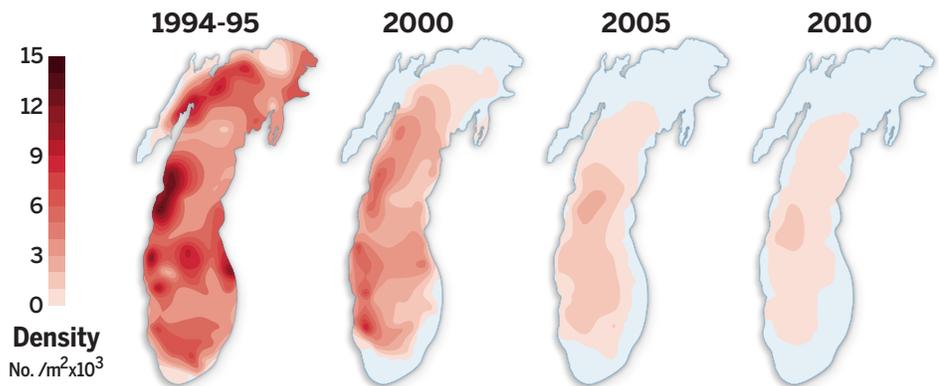
Analysis

1. What additional information would have been useful to know in developing your argument?

2. Compare the change in distribution of the zebra mussels in Lake Michigan to that in the Hudson River over the last 20 years. Do you think that the changes have occurred because of the same reasons? Explain.

Extension

Are there any existing or new invasive species that your local community is worried about? Contact your local park or government officials to ask them if they are concerned about any existing, new, or potentially invasive species.

Designing Solutions

In this unit you have seen many ways in which humans interact with ecosystems. For example in chapter 4 you learned that we use ecosystem services, such as food, water, and recreation. Throughout the unit you have also learned that humans can cause disruptions to ecosystems. Many disruptions create a threat to the biodiversity of the ecosystem. Although humans cause environmental problems, we also have the ability to solve them. Scientists work to make sense of phenomena. Engineers use this understanding to design solutions to lessen the negative impact that humans have on the earth.

In this chapter you will examine more environmental problems. However, this time you will make decisions. You will consider cause and effect relationships as the decisions you make have environmental consequences. You will also act as engineers. As engineers you will develop and use criteria to evaluate solutions for environmental problems. Finally, you will design your own solution to an environmental problem.

Engage: Solving a Problem

Throughout this unit you have encountered various environmental problems. In this chapter you will continue to look at such problems, but you will also consider what can be done about them. The first problem to solve involves environmental damage by insects, as described in the story below.

Holly sat in the shade and watched her parents talking. She couldn't hear everything that they said but she knew what they were talking about. In all the years that she had lived on the farm, she had never seen them so worried. She turned to look at the fields that surrounded the house. Holly felt sad as she saw the large areas where the crops were damaged or dead. She knew that her parents were discussing what they could do about the insect that was damaging the crops. Holly's parents had bought the farm when she was five years old. Now that she was in middle school, it seemed that she had lived on the farm all her life. Jumping to her feet, Holly moved towards her parents to join in the discussion.

Guiding Question

What are some of the ways to deal with an insect problem?

Materials

For each student:

- Handout 5.1-1, "Control Methods"

Procedure

1. Read Holly's story at the beginning of this activity.

2. In your group, brainstorm a list of questions that Holly might ask her parents to learn more about the insect problem affecting the family farm.

3. Follow your teacher's directions to discuss these questions with the rest of the class.

4. In your group, discuss possible ways of solving the insect problem.

5. Share your group's ideas with the class.

6. In your group, read about the four possible solutions in Handout 5.1-1, "Control Methods."

7. Discuss each solution and make a list of the advantages and disadvantages of each.

8. As a group, recommend the solution that you believe is the best one for Holly's family. Make sure that each person in your group can explain why you chose this solution.

9. Follow your teacher's directions to discuss your recommended solution with the class.

Analysis

1. What factors did you consider when deciding which solution to recommend?

2. What other information would have been useful when you were examining solutions?

3. Holly's story is based on a real-life problem. Your teacher will give you more information about the problem and the solution that was tried. Describe how the solution relates to an environmental problem that you have studied in this unit.

Explore: Stability and Change

In the previous activity you discussed an environmental problem on a farm. Insects were destroying crops which meant that the family was losing money. The family was unhappy with the situation and needed to decide on a solution. The decision on dealing with the insect problem had many effects. Some of the effects were unexpected. In this activity you will play the role of managers of connected environmental areas. In your groups you will make decisions about changes to the areas. Your decisions will affect the stability of the areas through both expected and unexpected effects. You will keep track of how your decisions affect the environment, money, and how people feel. Your goal is to manage your area so that it is in a better condition at the end of the activity than it was at the beginning.

Guiding Question

How can we balance human needs with those of the environment?

Materials

For each group of 4 students:

- set of Round 1 event cards

- set of Round 2 event cards

- set of Round 3 event cards

- map

For each student:

- Handout 5.2-1, "Score Sheet"

Procedure

1. As a group, decide who will manage each of the four areas on the map—Forest, Lake, River, and Gulf.

2. On Handout 5.2-1, circle the area that you manage.

3. Choose a player to begin and have that player take a card from the Round 1 event card stack.

4. One person in your group should read aloud the Action item at the top of the card.

5. The other members of the group should discuss and predict how each decision would change the environmental, money, and happiness scores.

6. As a group, make a decision on which action to take.

7. In the row labeled "Round 1, Turn 1" of the table on Handout 5.2-1, "Score Sheet," write down the new number of points in each column after adding or subtracting points based on the decision you made in Step 6.

8. Repeat Steps 4 to 7 by having a different player take a Round 1 event card.

9. Continue to have each player in your group take a Round 1 event card and add or subtract the points in each column each time.

10. After four turns using Round 1 event cards, repeat Steps 3 to 9 using the Round 2 event cards.

11. Repeat Steps 3 to 9 using the Round 3 event cards.

12. In your science notebook, write down your point total at the end of the three rounds.

Analysis

1. Describe an example of a cause and effect relationship that occurred during the game.

2. Describe any patterns that you saw in the way that the environmental, money, and happiness points changed.

3. Explain how an event in one area could affect another area.

4. Do you believe that your area was in a better condition at the end of the game than at the beginning? Explain your reasoning.

5. How difficult was it to balance human needs with those of the environment? Explain your answer using examples from the activity.

Explain: Designing a Solution

Throughout this unit you have seen examples of how human actions have had an impact on the health of the environment. In the previous activity you modeled making decisions that affected communities across different but related ecosystems. Sometimes you tried to agree on solutions to problems such as relieving traffic congestion, restoring low fish stocks, and building more housing. A good solution works for people and for the environment. It also does not create problems in the future. In this activity you will use a framework to examine and design solutions to environmental problems.

Guiding Question

What factors should be considered when choosing or designing a solution to an environmental problem?

Materials

For each group of four students:

■ 1 set of two Insect Solution cards

For each student:

■ Handout 5.3-1, "Analyzing the Insect Solutions"

■ Handout 5.3-2, "Designing a Solution"

Procedure

1. Follow your teacher's directions to complete the reading below.

Designing a solution to an environmental problem

Engineers design solutions to problems. However, the aim of engineering is not just to design a solution, but to design the best solution. Before designing a solution, engineers will identify criteria and constraints. **Criteria** are the desired features of the solution. **Constraints** are limits that apply to solving the problem. A solution can have many criteria and constraints. This can make designing the solution complicated.

As you saw in the previous activity, it can be difficult to satisfy the needs of people and those of the environment. When considering criteria related to people, it is useful to look at the social and economic impacts. **Economic** impacts are related to money. They can be positive, such as earning more money. They can also be negative, such as reduced income or higher costs for people in an area. **Social** impacts are related to the quality of life. They can include factors such as the health and safety of residents, the standard of living, and opportunities for work and leisure. An important social consideration is whether a solution is fair to different groups of people. One way of analyzing solutions to environmental problems is to consider how well the solutions meet economic, social, and environmental needs.

The best solutions are ones that meet economic, social, and environmental needs.
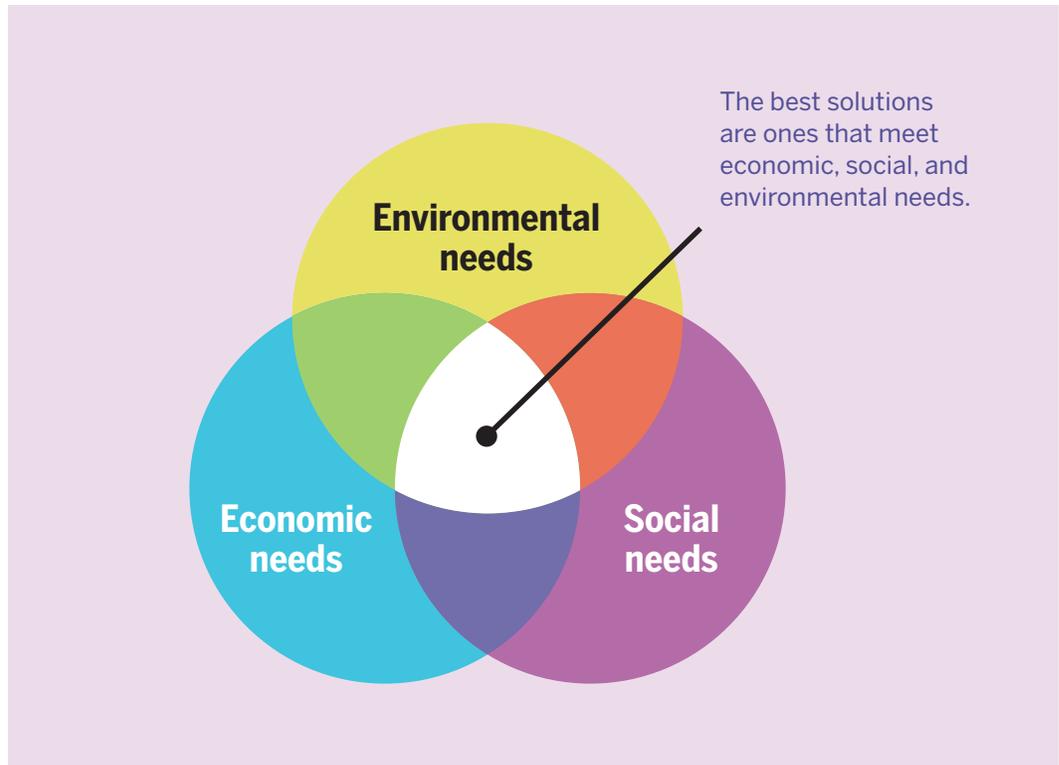
2. Your teacher will assign your group one of the proposed solutions to the insect problem from Activity 1 of this chapter. Complete your row of Handout 5.3-1 by identifying possible economic, social, and environmental impacts of your assigned solution.

3. Meet with another group that was assigned the same solution. Compare the impacts that you recorded on Handout 5.3-1.

4. Follow your teacher's directions to share the discussion that you had with the other group. Use the information from other groups' reports to complete the other rows on Handout 5.3-1.

5. One pair of students in your group should read Insect Solution card A. The other students in your group should read Solution card B.

6. Discuss the criteria and constraints listed on the card with your partner.

7. Select the insect solution that best fits the criteria and constraints on your card.

8. Tell the other students in your group which solution you selected. Make sure to explain why you chose that solution.

9. As a group, discuss how the criteria and constraints affected the choice of solution.

10. Use Handout 5.3-2, "Designing a Solution" to design your group's solution to the insect problem. Make sure to provide your reasoning to justify why you think a solution or combination of solutions is the best choice.

11. Follow your teacher's directions in sharing your solution and your reasoning with the class.

12. As a class, discuss how to make a better solution. Include any changes that you would make to the criteria or to the proposed solutions.

Analysis

1. How do criteria and constraints affect the development of a solution?

2. Which types of criteria might be in competition with one another? Suggest reasons why.

3. Scientific knowledge is valuable when making decisions because it can describe the consequences of actions. However, science is not usually the only consideration when making a decision. Explain why, using an example from a problem that has affected your own community.

Elaborate: Evaluating Solutions

Humans rely upon ecosystems in many ways. They supply us with resources such as food, shelter, energy, and even the oxygen that we breathe. They also provide enjoyment and income for people. Using resources can threaten the health of the ecosystem. In some cases a problem can become so bad that the environment will not recover by itself. In such cases, a solution is needed. Ideally, engineers would design solutions that preserved biodiversity and ecosystem services. After a solution is put in place it must be monitored to see if it is working. In this activity, you will examine several environmental issues and evaluate possible solutions.

Guiding Question

How can we evaluate solutions to decide how well they might work?

Materials

For each group of 4 students:

- Handout 5.4-1,"Possible Solutions"

Procedure

1. As a group, examine the environmental problem assigned by your teacher.

2. In your science notebook, write down the cause of the problem and describe its effects.

3. Brainstorm a list of possible solutions with your group members.

4. Identify any constraints and criteria that you wish to apply to your solution.

5. Rank your list of solutions from best to worst.

6. Meet with the other group that has been assigned the same environmental problem. Compare your lists of possible solutions.

7. Explain your criteria, constraints, and ranking to the other group.

8. Your teacher will give your group Handout 5.4-1, "Possible Solutions," which includes possible solutions for your environmental problem. Discuss the solutions and evaluate them against your criteria and constraints.

Hint

You may find Handout 5.3-2 "Designing a Solution" to be useful.

9. As a group, make a recommendation for a solution. You may use one of the solutions provided by your teacher, one of those suggested by your group, or a combination of different solutions.

10. Meet with the other group again to discuss the solution that you chose. Make sure to explain the reasoning behind your choice.

11. Follow your teacher's directions to share your discussions with the class.

Environmental Problem 1

Coral reefs are very important to the health of the oceans as they are home to almost 25% of all marine organisms. They are also important to communities as they provide protection from erosion from storms. They provide ecosystem services such as food, recreation, and employment. One threat to coral reefs is the crown-of-thorns sea star, a large starfish that preys on hard coral. It is native to coral reefs in the Indian and Pacific Ocean regions. Some coral species grow quickly and others grow slowly. When the crown-of-thorns feeds on the faster growing coral it provides an opportunity for the slower growing species to establish itself. This increases the biodiversity of the coral reef. During the warmer months each female crown-of-thorns starfish can produce millions of eggs. Predators of the adult crown-of-thorns include several species of fish. In some coral reefs, overfishing of these predators has led to large increases in the numbers of crown-of-thorns starfish. When this occurs, much more of the reef is eaten by the starfish. In some cases up to 90% of a reef can be destroyed by the crown-of-thorns starfish.

A crown-of-thorns starfish (bottom left) on a reef.

Environmental Problem 2

    In a corner of an island in Southeast Asia, there is a village next to a lake. Near to the lake is a large area containing mountains and forest. Although not a national park, the land in this area is protected from development. Most of the people in the village are farmers. There are few employment and educational opportunities. Most people have little money. The lake is used for drinking water and for electrical power generation for the region. The fish in the lake are an important and inexpensive food source for families in the region. Recently, villagers have been going into the protected area to hunt animals and cut down some of the trees. The wood from the trees can be used for fuel and can be sold. Some of the farmers in the village have also cut down trees in the protected area so that they can expand their farms to grow more food. All of these actions have led to a decrease in the biodiversity of the forest. The removal of the trees has also led to increased erosion of the soil in the forest. The soil is being washed into the lake which is increasing the sediment there. This is affecting the food web of the lake and also the quality of the drinking water.

The area in front of the picture used to be a forest until the trees were cut down and removed.

Environmental Problem 3

Yellowstone Lake is the largest body of water in Yellowstone National Park. It is a very large (350 km²) freshwater lake with an average depth of 42 m. More than 140 rivers and streams flow into Yellowstone Lake. The Yellowstone River is the largest outflow of water from the lake, eventually reaching the Missouri River. At the present time, no zebra mussels have been spotted in Yellowstone Lake but they have reached neighboring states. Scientists are concerned that one day they might arrive in Yellowstone.

Zebra mussels are an invasive species that first appeared in the Great Lakes in the 1980's. Ever since then they have been spreading around the country. They spread easily partly because each female can lay millions of eggs. Young mussels float along the water currents. Eventually they attach themselves to hard surfaces like rocks and the bottom of boats. Colonies can become very dense with as many as 10,000 mussels per square foot. Zebra mussels also cling to native mussels and other shelled animals. These animals die because they can't feed. Zebra mussels disrupt ecosystems by eating microscopic animals and plankton. This reduces the food available for the native invertebrates and small fish. They also disrupt ecosystem services by clogging water pipes to businesses and power plants. They damage boats, docks, buoys, and other structures.

Yellowstone Lake in northwestern Wyoming.

Environmental Problem 4

Chesapeake Bay is the largest estuary in the country. Over 100,000 rivers and streams from six states, including New York, drain into the bay. Over 16 million people live close to these streams and rivers. It used to be the world's largest oyster-producing region. However, this century the oyster harvest is only about 1% of what it was 100 years ago. The reasons for this large decline include destruction of habitat, overharvesting, disease, and reduction in water quality. The decrease in oysters has had a major effect on the environment and the local economy. Without large numbers of oysters, the water in the bay is not filtered well. The water quality is made worse by runoff into the streams and rivers that feed into the bay. The runoff is rich in nutrients. This has increased algae growth in the bay. When the algae die, they sink to the bottom of the bay where bacteria decompose them. The presence of large numbers of bacteria reduces the oxygen content of the water, causing dead zones. Very few organisms can survive in these zones. Some of the organisms that are mobile, such as crabs and fish, can move out of the dead zone. Other organisms that cannot move as freely, such as oysters, are more likely to die in dead zones.

An oyster catch in Chesapeake Bay.

Analysis

1. Describe how your criteria were similar to those of the other group who had the same environmental problem.

2. Describe how your criteria were different from those of the other group who had the same environmental problem.

3. Can environmental problems be solved by technology alone? Explain your answer.

Extension

What environmental problem is your community facing, and what are they doing to try to fix the problem or prevent the problem from getting worse? Check online resources like your local parks department or water district. Many communities also have local groups working to restore habitat or help with other environmental problems. Research what local environmental projects are happening in your area.

Evaluate: Coral Reefs

Coral reefs make up a tiny fraction of the ocean floor but are home to about one million species. It is estimated that about one quarter of all marine organisms live in or near coral reefs. Reefs are important for more than their biodiversity. They help protect coasts from tropical storms, reducing erosion. They are breeding grounds and nurseries for many marine organisms. They also contribute billions of dollars to local economies through ecosystem services such as fishing, tourism, and recreation. However, coral reefs are fragile. Over the past 50 years more than a quarter of the world's reefs have been destroyed. The threats to coral reefs are many and varied. In this final activity you will look at some of these threats as you design and evaluate potential solutions.
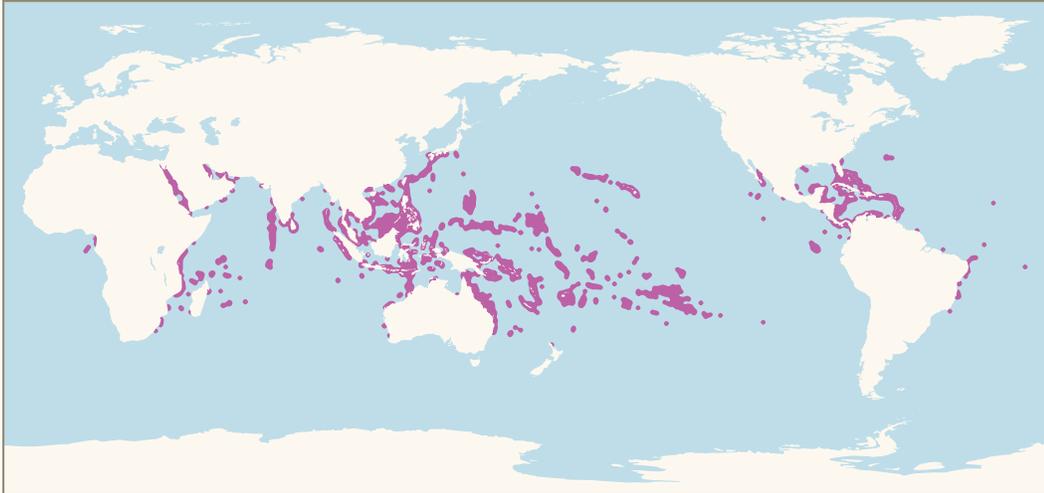
Coral reef distribution

Guiding Question

How can the negative impact of humans on coral reefs be reduced?

Procedure

1. Use the Read, Think, and Take Note strategy as you complete the following reading on coral reefs.

Read, Think, and Take Note: Guidelines

As you read, stop at least three times to write one of the following:

- Explain a thought or reaction to something you read.

- Note something in the reading that is confusing or unfamiliar.

- Identify a word that you do not know.

- Describe a connection to something you learned or read previously.

- Make a statement about the reading.

- Ask a question about the reading.

Threats to Coral Reefs

Coral reefs are made up of millions of tiny invertebrate animals called polyps. Polyps rely on algae for their survival. The algae live inside the tissues of the polyps and are producers, capturing the energy of the sun. Most polyps use chemicals from the sea water to make a hard structure around them that they live in. It is these hard cases that make up coral reefs. Healthy coral reefs are full of color and life with many organisms making their homes in or near the reef.

A healthy coral reef

Coral reefs are also easily damaged and are under threat in many parts of the world. On a global level, climate change is causing some parts of the ocean to be warmer. It is also causing some parts of the ocean to become more acidic. These increases in temperature and acidity can damage or even kill the coral reefs. These global threats can be very difficult to address, because they require so many people all over the world to work together.

On a local level there are also a number of threats to coral reefs. These threats can often be addressed by the people living in the communities near the coral reefs. The large number and types of fish that live in coral reefs attract fishers. However, overfishing can

An unhealthy coral reef

cause the number of fish to go down. It can also cause the average size of the fish that are caught to decrease, as fish are caught at a younger age. In order to catch enough fish to feed their families and to sell, some people turn to destructive fishing techniques. One such technique is dynamite fishing, where explosives are thrown into the water. Both the explosion and the shockwaves kill or stun the fish in the blast area. This allows the fishers to collect a large number of fish in a short period of time. The explosion also causes great damage to the coral in the reef. In the end this reduces the amount of coral and the number of fish and other organisms in the area. Even when non-destructive fishing techniques are used, reefs can be harmed. If one or more species is overfished, the food web can become unbalanced. You read about one example of this in the last activity, with the crown-of-thorns sea star.

The beauty of coral reefs makes them an attractive destination for many people. The presence of tourists is important to the local economy as it benefits businesses, such as tour companies, hotels, and restaurants. Unfortunately, tourism can also cause problems for the reef ecosystem. When swimmers and divers stand on or even touch a reef, the coral can be damaged. This is even more of a problem when boats drop their anchors onto the reef. Boats can also

cause pollution with the gasoline and oil that they use. Development of the coast causes an indirect threat to reefs that are nearby. As roads, hotels, and other buildings are constructed, debris and sediment can wash into the ocean and smother the reef. Sediment can also reduce the clarity of the water, which affects the ability of the algae to capture the energy of the sun. Nutrients from substances such as fertilizer can be washed from coastal developments into the ocean. This can cause weed-like algae to grow quickly and overgrow a reef. An increase in the nutrients in the water also allows more of the young crown-of-thorns sea stars to survive and become adults.

2. With your group, select one of the threats affecting coral reefs.

3. Write a paragraph that summarizes the threat and why it is important to develop a solution.

4. In your group, design a method to stop or reduce the threats to coral reefs. In your design, make sure to include the following:

   ■ The environmental, economic, and social aspects of your proposed solution.

   ■ The criteria and constraints that apply to your solution.

   ■ The evidence that you would need to see in order for you to feel that your solution had worked.

5. Follow your teacher's directions to present your solution to the class.

6. Listen to the presentations of other groups and evaluate each of the proposed solutions against the chosen criteria and constraints.

Analysis

1. Some of the causes of threats to the health of coral reefs are local and some are global. How does the challenge of designing and applying a solution differ when the cause is a global problem, such as climate change?

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