CHAPTER

5

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 receive 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. In doing so it is possible to develop 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 to environmental problems. Finally, you will design your own solution to a problem.

Engage: Solving a Problem

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"

Process & Procedure

1. 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.
2. Follow your teacher's directions to discuss these questions with the rest of the class.
3. In your group, discuss possible ways of solving the insect problem.
4. Share your group's ideas with the class.
5. In your group, read about the four possible solutions in Handout 5.1-1, "Control Methods."
6. Discuss each solution and make a list of the advantages and disadvantages of each.
7. 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.
8. Follow your teacher's directions to discuss your recommended solution with the class.

Analysis

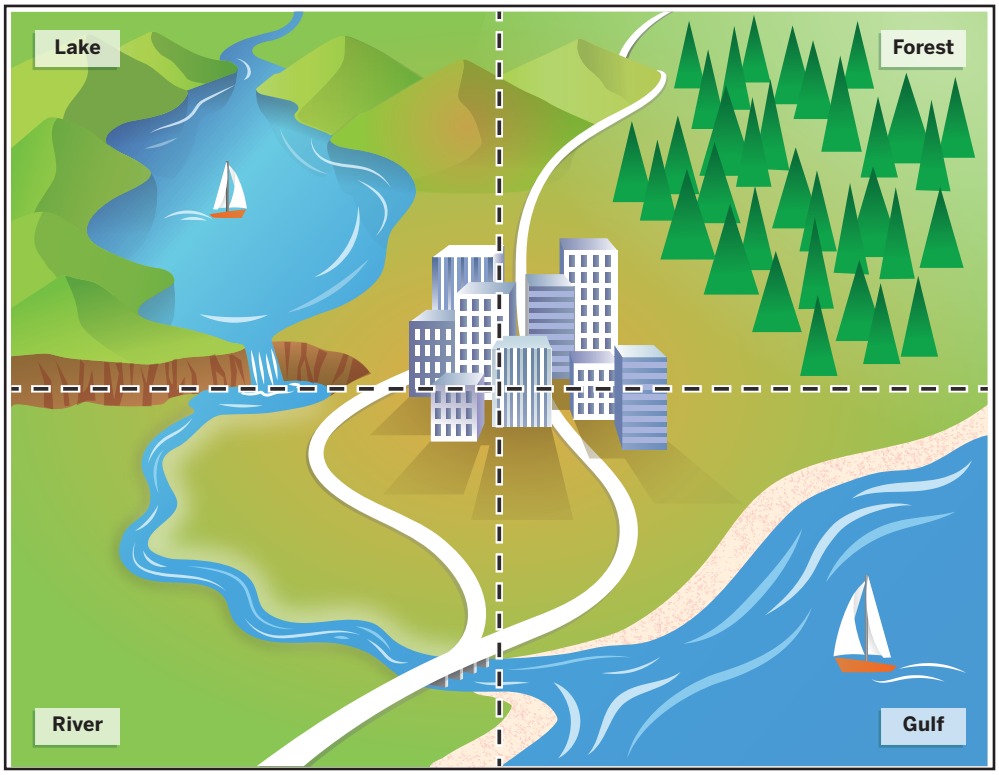
1. What factors did you consider when deciding which solution to recommend?
2. What other information would have been useful when you were examining solutions?

Explore: Stability and Change

As you have seen, people obtain resources and services from ecosystems. By doing this people can affect ecosystems both near and far. When decisions are made that impact ecosystems, there can be consequences for the environment. It can also affect people and the communities in which they live and work. 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 area. You will keep track of the consequences of those decisions. Your goal is to manage your area so that it is in a better condition at the end of the game 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"

Process & 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. Discuss the information on the card and, as a group, make a decision.
5. 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 took in Step 4.
6. Repeat Steps 4 and 5 by having a different player take a Round 1 event card.
7. 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.
8. After four turns using Round 1 event cards, repeat Steps 3 to 7 using the Round 2 event cards.
9. Repeat Step 8 using the Round 3 event cards.
10. In your science notebook, write down your point total at the end of the three rounds.

Analysis

1. List the ecosystem services that your group discussed during the activity.
2. Describe an example of a cause and effect relationship that occurred during the game.
3. Describe any patterns that you saw in the way that the environmental, economic, and social points changed.
4. Explain how an event in one area could affect another area.
5. Do you believe that your area was in a better condition at the end of the game than at the beginning? Explain the reasoning behind your answer.

Explain: Designing a Solution

Throughout this unit you have seen examples of how human activity has 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 student:

- Handout 5.3-1, "Analyzing the Insect Solutions"
- Handout 5.3-2, "Designing a Solution"

Process & Procedure

Part One: Analyzing the Insect Solutions

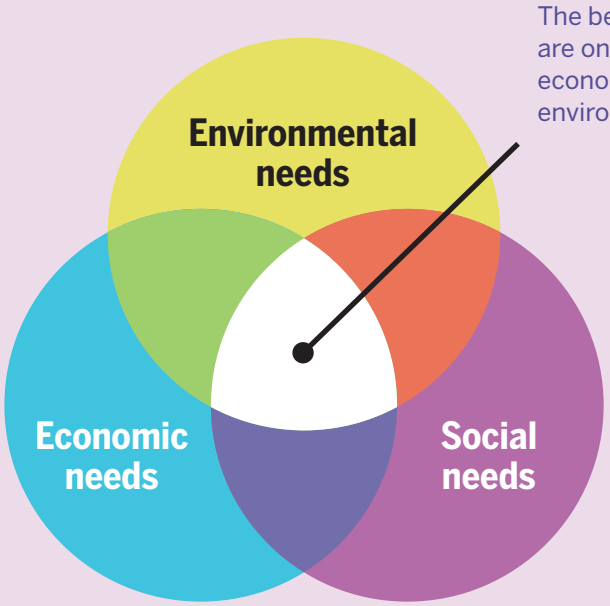
1. Follow your teacher's directions to complete the reading below.

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. For the insect problem in Activity 1, a constraint might be that the family does not have to move away from their home. Such a constraint would mean that Solution B, "Relocate the Farm," would not be acceptable. If another constraint was that no native creatures were harmed, then none of the proposed solutions would work. Criteria can be a little more flexible. Criteria for the insect problem might include that the solution kills the least number of native species. In such a case, estimating the effects on native species could provide the data to help choose the best solution. 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 often 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 often 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 they meet economic, social, and environmental needs.



Designing, or deciding on, the best solution may require making trade-offs between criteria. A trade-off is when something that is a benefit or advantage is given up in return for a different benefit or advantage. For example, an environmental criterion might be to protect all of the land in an area. However, a social criterion might be to provide enough housing for the people living near the area. Since housing requires land, it would be difficult to meet both of these criteria. In such a case, a trade-off might mean that one of the criteria is selected over the other. In another case, maybe one or both of the criteria would need to be changed. With competing criteria, it is not unusual to have disagreements about what is the "best" solution to a problem.

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. As a class, identify the constraints and criteria that should apply to the best insect solution. Discuss any criteria that might need a trade-off.

Part Two: Designing a Solution

6. Follow your teacher's directions to read about the environmental problem described at the end of this activity.

7. In your group, examine each of the possible solutions for how well they meet the criteria and constraints identified by the county government.

8. Use Handout 5.3-2, "Designing a Solution" to design your group's best solution. You may choose several of the possible solutions to implement. Make sure to provide your reasoning to justify why you think a solution or combination of solutions is the best choice.

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

10. 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 were often 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.

The Drought Problem

The southwest of the United States is experiencing a fourth year of drought. In one county there is a small town that is surrounded by many farms. There is a river that flows through the town. This river is home to several species of fish and birds, some of which are unique to this area. About one quarter of the residents in the area make a living through growing crops. A quarter of the population makes a living through local businesses. Many of these local businesses are related to agriculture. The remaining residents work in neighboring cities. Overfarming and population growth have caused dramatic changes to the local ecosystem. New housing developments have been built, along with new schools and roads. The soil on the farmland has too few nutrients and now there isn't enough water for all of the farmland and the people who live in the area. Irrigation on local farms accounts for about 70% of the water used in the area.

The Solution

In looking for a solution, the county began by identifying three constraints and five criteria.

Constraints:

- The increased cost to the county government must not be more than $50,000 per year.
- The increased cost per farm must not be more than $80,000 per year.
- The increased cost to each family must not be more than $1,000 per year.

Criteria:

- **Economic:** Increases in costs should be kept as low as possible.
- **Social:** Everyone should be affected equally.
- **Social:** There should be the least disruption to daily life.
- **Environmental:** There should be as little disruption to native species as possible.
- **Environmental:** The reduction in water use should be as great as possible.

Possible Solutions

Solution	Economic Impact	Social Impact	Environmental Impact
1. No new housing developments.	a) Rent increase of $500/year for some families due to shortage of housing. b) Potential loss of income to local businesses involved in construction, real estate, etc. c) Potential loss of $40,000/year in property taxes to local government.	Insufficient housing for growing population. Some people may have to move away from the area.	a) Preserves existing land. b) No additional water usage.
2. Require new, more efficient irrigation systems for farms.	Average cost per farm of $75,000.	a) Farmers will pay the extra costs. b) No increased expenses for residents of the town.	Reduces water use by 20,000,000,000 liters/year.
3. Charge everyone 50% more for supply of water.	a) Average increase in water cost of $350 per year for each family in the town unless they reduce water use. b) Average increase in water costs of $10,000/year per farm.	People will have to change habits to conserve water.	Estimated to save 50,000,000 liters of water a year. (Equivalent to a reduction of about 500 gallons per person per year.)
4. Farms use crops that need less water but sell at a higher value.	a) Farms will need new machinery at an estimated cost of $50,000. b) Increased profits from new crops of $20,000/year.	a) Farmers will pay the extra costs. b) No increased expenses for residents of the town.	Reduces water use by 25,000,000,000 liters/year.
5. Ban on watering lawns and using swimming pools.	a) Cost of $50,000/year to government for monitoring and enforcement. b) Fines for residents who don't follow the rules.	a) Lawns will not look as nice. b) No place to go swimming.	Estimated to save 50,000,000 liters of water per year. (Equivalent to a reduction of about 500 gallons per person per year.)
6. Build an additional water pumping station.	Increased taxes for everyone in the county. Estimated to cost each family an average of $600/year.	More water for residents in the town.	a) Estimated to use 25,000,000 liters of water per year. b) Wildlife in and around the river will lose habitat.
7. Farms leave 25% of their fields with no crops.	a) Less income from crops. Estimated loss per farm of $25,000 per year. b) Each family spends an extra $250/year on increased produce costs.	a) Farmers pay most of the increased costs.	a) Reduces water usage by 15,000,000,000 liters/year. b) Soil begins to recover and becomes more productive. c) Less fertilizer used.

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 also 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"

Process & 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.
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.

Hint

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

Analysis

1. Describe how your criteria were similar to that of the other group who had the same environmental problem.
2. Describe how your criteria were different from that of the other group who had the same environmental problem.
3. Can environmental problems be solved by technology alone? Explain your answer.

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 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 km^2) 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.

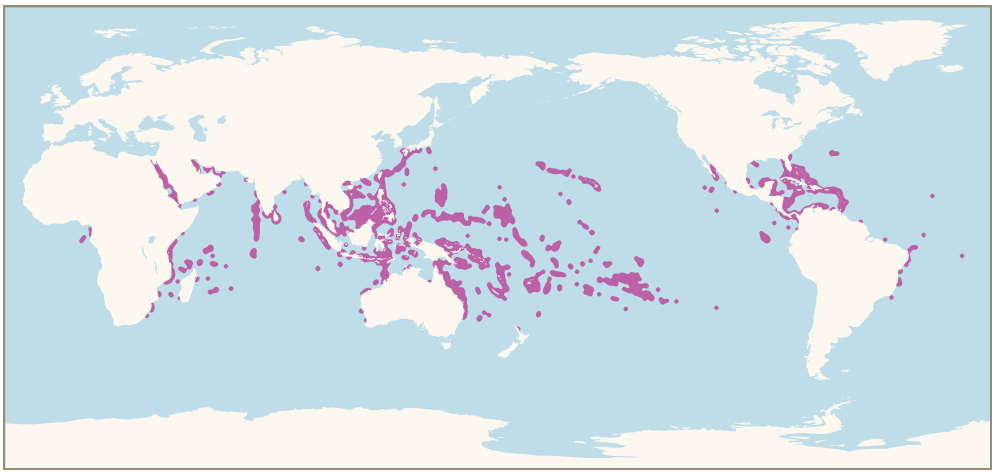
Environmental Problem 4

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.

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?

Process & Procedure

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

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 worldwide problem, such as climate change?

Threats to Coral Reefs

Coral reefs are made up of millions of tiny invertebrate animals called polyps. The 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 in the sea-water to make a hard structure around them in which they live. 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 makes them places that appeal to fishermen. However, overfishing can 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 fishermen 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

An unhealthy coral reef.

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.