**UNIVERSITY HIGH SCHOOL**
*A Nationally Recognized Exemplary School*
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Website: http://www.universityhigh.org

Welcome 2018-2019 AP Environmental Science Students!

This course is designed to be the equivalent of an Environmental Science course taken during the first year of college. AP Environmental Science is a *full year college level laboratory course*. Students will examine environmental issues from an economic, scientific, sociological and historical point of view. The goal of this course is to provide students with the scientific principles, concepts and methodologies required to understand the interrelationships of the natural world, to identify and analyze environmental problems both natural and human-made, to evaluate the relative risks associated with these problems, and to examine alternative solutions for resolving and/or preventing them.

**The book that we will be using is:**
Title: **Environmental Science for AP ***
Authors: Andrew Friedland et. al
ISBN: 9780716738497 or 071673849X

This text will be available for check out in the library at the beginning go the school year for those that do not want to purchase the text. Advantages to purchasing your own copy of the text include: the ability to highlight the text as you actively read, annotating the figures, and retaining the text as a reference for college. Because the exam is in May, we require that students complete summer reading requirements before the start of school. This is necessary to ensure that all topics are addressed to fully prepare you for the AP exam. The assignment you will be responsible for this summer is listed below. You will have a test during the first or second week of school on the material covered in the summer assignment. Good Luck!! You may contact us during the summer at JenniferBartlau@iusd.org or MeganLewis@iusd.org if you have any questions.

**Summer Assignment:** You can find the link to the summer assignment on the UNI homepage. The assignment below is due the second week of class.

1. Read/study chapter 1 and chapter 2.
   ***Hand write*** an outline that includes but is not limited to:
   a. All vocabulary terms with definitions.
   b. Answers to the CHECKPOINT questions embedded throughout the chapter.
   c. Hand draw three of the tables/graphs presented throughout the chapter and write a new caption (at least one sentence) for each.
   d. Answer the two Free-Response Questions at the end of each chapter (4 total).
   e. Answer the multiple choice questions at the end of Chapters 1 and 2.
2. Read two current events and then complete two current event summaries. (Google Doc)
3. Go on a scavenger hunt to explore important environmental science topics and create a document to share with the class first week of school. This should be fun! (Google Slides)
4. Complete the basic math skills practice.
5. **OPTIONAL:** You will be required to do field work for this course, if you would like, you can complete some of your field hours prior to the beginning of the school year when you have more time. (Google Doc)

We are looking forward to a great year! Enjoy your summer.

Sincerely,
Jennifer Bartlau and Megan Lewis
AP Environmental Science Instructors

## Part Two: Current Events Digital Tables and Presentation

### Introduction

AP Environmental Science is a fantastic course for increasing science literacy with regards to the media. An environmental issue is referenced up to 20 times in every edition of every newspaper every day in the United States and these stats are similar on the international scale. Environmental issues are multifaceted and relate to all aspects of each of our lives. Many issues may not touch our lives personally, but are noteworthy human issues such as social crisis or worldwide epidemics. The articles you choose for this assignment must have a clear connection to Environmental Science. You can preview the chapters in the text to get an idea of appropriate topics, or email either of us.

Current events will be ongoing throughout the year, so you will receive further instructions at the beginning of the year. For now, what you need to do is complete the following table for two current events related to environmental science. These current events **MUST BE PUBLISHED AFTER JUNE 1 2018**. They will not be given credit if they are from a date prior to that. Your initial introduction to the course content will be Chapter 1 of the textbook so refer to the chapter to connect your current event to the course content.

Articles should be from sources that are science oriented or reputable such as Scientific American, Nature, Discover, and Science. Other appropriate sources include Grist, TreeHugger, The New York Times, Washington Post, LA Times, NPR, The Atlantic, Slate, Time, Newsweek, Orion Magazine, The Economist, The Wall Street Journal and National Geographic.

*You can either recreate the table below or go to this link and make a copy:* *https://bit.ly/2LOh4pU* . Your completed table should be between 1 and 2 pages.

**APES Current Events Summary Table -** The summary table below should be done using complete sentences in a narrative style. The narrative should flow from one cell to the next. The order of the components can be modified however, the bibliographic information can come first and your opinion must come last (you could move stakeholders earlier in the table for example). You will complete this assignment in a Google Doc.

| | |
|---|---|
| **Include** bibliographic information including title, date, author, source, and a link. | |
| **Include a** clear, thorough summary about the content of the article. Be sure to identify the 'Ws' (the Who, What, Where, When, and Why). | |
| **Discuss** the environmental/scientific, economic, and social/political implications of the article. | All three must be addressed, environmental, economic and social. |
| **Identify and Discuss** the stakeholders in the article and describe how each is affected by the issue. This includes humans and other organisms. | |
| **Identify and Explain** the content in chapter one and two that this article relates to. Include and highlight as many vocabulary words as possible. For each item explain HOW the article relates to it. This can be a bulleted list of sentences. | |
| **Present** your take on the issue. How does it apply to your life? (It does!) Do you think it should be resolved in some way? Provide reasons/ evidence that support your perspective. **Use the given sentence starters.** | This issue relates directly to my life because…<br><br>This issue relates indirectly to my life because…<br><br>I believe that…<br><br>This issue should….because… |
| Include an image for each article that you think represents the article, the issue, or your stance. | |
| **Copy and paste the original article below.** | |

## Part Three: Summer Scavenger Hunt

Make a Google Slideshow to share what you did/saw this summer related to environmental science. This should be fun! The purpose is for you to start engaging with the content over the summer to better prepare you for the school year. Environmental science is all around you; this project should help you become aware of the fact.

### On each slide, be sure to include the following:

1. Label the slide as the category being displayed. (Lithosphere, Species Interactions, Forest, etc.…)
2. Photo of the item with you in it. (Selfie?)
3. Photo caption naming the specific object. (Igneous Rock, Mutualism, Native Tree, etc.…)
4. An explanation as to why you chose the item. How does it relate to environmental science or your current ideas regarding environmental science?
5. Date photo was taken.
6. Location – be specific. (Irvine, California or Arches National Park, Utah)

**Choose twenty items from the following list and make a slide for each item you choose. Your slide show will have 21 slides, one slide per item and one cover slide (name, date, and period). Be prepared to show your finished product with the class.**

| *#* | *Category/Identification* | *Ideas/Criteria/Guidelines* | *Also Include* |
|---|---|---|---|
| 1 | **Lithosphere** | Igneous rock, sedimentary rock, metamorphic rock, non-native rock, | Name of Rock |
| 2 | **Hydrosphere** | Ocean, bay, flowing or standing water, watershed | Name of water body |
| 3 | **Atmosphere** | Clouds, smog, fog, etc. | Name of cloud type or smog type |
| 4 | **Biogeochemical Cycles** | Nitrogen, Carbon, Water, Phosphorus | Where the element is, has come from and is going. |
| 5 | **Energy Flow** | Carnivore consuming, Herbivore consuming, photosynthesis happening | Names of participating species. |
| 6 | **Biodiversity** | Native, threatened or endangered animal in its habitat. Non-native animal in its habitat. | Name of species. |
| 7 | **Species Interactions** | Mutualism between two plants, two animals or between a plant and animal. | Name of each species and how each species benefits. |
| 8 | **Species Interactions** | Competition, Parasitism, Predation | Name of each species and how they impact each other. |
| 9 | **Population Growth** | A human less than 1 year old. A human less than 2 years old. A human less than five years old. | Name of the human and a photo caption. |
| 10 | **Forest** | Native tree you can't reach more than one quarter of the way around. Native tree you cannot reach more than halfway around. Non-native tree you cannot reach more than half way around. | Name of species. |
| 11 | **Biodiversity Preserve** | National park system unit. State park system unit. County or city park system unit. | Name of Park |

| | | | |
|---|---|---|---|
| 12 | **Food Crops** | Food crop being grown on a farm. Food crop being grown in a garden. Food crop being processed or retailed. | Name of food crop. |
| 13 | **Meat** | Animals being raised for food in a farm or CAFO. Animals being raised for food in a household. Meat being retailed. Animals at a ranch. | Name of animal. |
| 14 | **Fishing** | Commercial fishing operation. Recreational fishing. Fresh fish being retailed. | Name of fish. |
| 15 | **Water Resources** | Agricultural irrigation system. Man-made dam. Man-made reservoir. | How the water you observed is being used. |
| 16 | **Water Pollution** | Wastewater treatment facility. Source of water pollution. Polluted water or solid water pollutant. | Type of water pollution observed. |
| 17 | **Air Pollution** | Stationary, point source emitting pollution. Mobile source emitting pollution. Air pollution without identified source. | Type of air pollution. As specific as possible. |
| 18 | **Renewable Energy** | Renewable power generation plant (solar, wind, geothermal…) Renewable residential or commercial generator. Renewably powered appliance. | Type of renewable energy. |
| 19 | **Water Resources** | Water transport system. Water storage system. Water delivery and use. | Where water comes from and where it goes. |
| 20 | **Fossil Fuels** | Fossil fuel production or processing (mine, well, refinery…). Non-gasoline fossil fuel use or retail. Gasoline retail. | Name of fossil fuel. |
| 21 | **Solid Waste** | REDUCING waste generation (instead of reusing, recycling or discarding). REUSING potential waste (instead of recycling or discarding). RECYCLING potential waste (instead of discarding). | Potential waste that is being averted. |
| 22 | **Urbanization** | LEED platinum or gold building. LEED silver or certified building. Other "green" building. | Name of or occupants of building. Description of "green" features. |
| 23 | **Urbanization** | New development previously natural habitat. New development on previously rural land. New development on previously urban land. | What was the land used for before? What will the land be used for in the future? |
| 24 | **Transportation** | Riding public mass transit. Public mass transit. Private mass transit. | Destination and ride commentary. |
| 25 | **Politics and Economics** | University building, from which the environment is studied. Community college building from which the environment is studies. Commercial or public building from which the environment is worked with. | Name of someone who works there, and hopefully a quote from him or her about the environment. |

| | | | |
|---|---|---|---|
| **26** | **Politics and Economics** | Worker in an environment-related profession. Volunteer in environment related work. Environmental aware person. | Name and environmental role of person and a quote from the person. |
| **27** | **Beauty** | A non-human "thing" in the environment that you find extraordinarily beautiful. | What it is and why it is beautiful? |
| **28** | **Anthropogenic** | Take a picture of something man made. | Comment on the impact of the use of your chosen object on the environment. |
| **29** | **Choice.** | Anything relevant to the environment. | Relate what you take a picture of to environmental science. |

## CREDIT

1. Full credit is the expectation. Follow all guidelines, and full credit is easy to achieve.
2. Clarity and quality of imagery is important.
3. Accuracy and thoroughness of documentation are important.
4. Creativity and entertainment value are way better than no creativity or entertainment value; they can compensate for minor deficiencies, but not for major deficiencies.
5. Evidence of trespassing, obstruction of traffic, violation of laws, jeopardizing safety or compromising integrity will cost credit. Photoshopping or other image manipulation to gain advantage constitutes an absolute abandonment of integrity.

## SUGGESTIONS

### Have fun with it; it's not supposed to be "work."

Build it gradually throughout the summer. Saving it all for the last day would make it "work".
If you have no imaging device, you can borrow one from a friend or family member.
Please email and let us know at the beginning of the summer if you do not have access to a camera.

## Part Four: Basic Math Skills

Some basic math skills such as algebraic computation, unit conversions, graph interpretation, and rate calculations are required in the course. Perform the following calculations WITHOUT a calculator (you will not be allowed on the AP exam)! If you do not know how to do these calculations go online and reteach yourself. These problems have been set up with numbers that multiply and divide evenly to produce whole number answers, just like you would find on a typical APES exam.

1. 14000 millimeters = ? meters ________________
2. 6544 liters = ? milliliters ________________
3. 0.078 kilometers = ? meters ________________
4. 17 grams = ? kilograms ________________

5. Expand the following:

a. $2.96 \times 10^{7}$

b. $6.02 \times 10^{-3}$

c. $6.67 \times 10^{-11}$

d. $9.8 \times 10^{5}$

6. Put the following in scientific notation:

a. 0.025

b. 1150000

c. 0.0000550

d. 6070

7. Perform the following calculations without a calculator and write the answers in scientific notation:

a. $(2.96 \times 10^{7}) + (1.0 \times 10^{7})$ ________________

b. $(6.0 \times 10^{6}) \div (3.0 \times 10^{4})$ ________________

c. $(2 \times 10^{5}) \times (3 \times 10^{10})$ ________________

d. $(8 \times 10^{12}) - (1.2 \times 10^{12})$ ________________

8. Perform the following calculations without a calculator and write the answers in scientific notation:

a. $(2.96 \times 10^{7}) + (1.0 \times 10^{8})$ ________________

b. $(6.0 \times 10^{6}) \div (3.0 \times 10^{-4})$ ________________

c. $(2 \times 10^{5}) \times (3 \times 10^{-10})$ ________________

d. $(8 \times 10^{12}) - (1.2 \times 10^{11})$ ________________

9. Perform the following calculations without a calculator (but show some work) and write the answers in scientific notation:

a. $(2.96 \times 10^{7}) \div (3.7 \times 10^{8})$ ____________________________

b. $(6.8 \times 10^{6}) \div (1.7 \times 10^{-4})$ ____________________________

c. $(2.1 \times 10^{5}) \times (3.1 \times 10^{10})$ ____________________________

d. $(9.6 \times 10^{12}) \div 160{,}000$ ____________________________

*Show ALL work for these problems below:*

***Unit Conversions—All APES students should be able to convert from one system of units to another.***

- Use Table 1 to complete the following. Show all of your work, including the cancelling of units.

| | |
|---|---|
| 1 square mile = 640 acres | 1 hectare = 2.5 acres |
| 1 barrel = 42 gallons | 1 liter = 0.3 gallons |
| 1 metric ton = 2000 pounds | 1 kilogram = 2.2 pounds |
| 1 kWh = 3400 BTU | 1 BTU = 250 calories |
| 1 BTU = amount of energy to raise temp of 1 lb water 1°F | |
| Density of water = 1g/ml = 8 lbs/gallon | |

1. A 100 square mile area of national forest is how many acres? How many hectares?
2. A city that uses ten billion BTUs of energy each month is using how many kilowatt-hours of electricity?
3. Fifty eight thousand kilograms of solid waste is equivalent to how many metric tons?
4. If one barrel of crude oil provides six million BTUs of energy, how many BTUs of energy will one liter of crude oil provide? How many calories of energy will one gallon of crude oil provide?
5. For crude oil, if 150 pounds of CO2 is released per million BTUs of energy, how much CO2 is produced by each barrel of crude oil? (use information from previous problem)

***Percentages—All APES students should be able to work comfortably with percentages.***

6. A natural gas power plant is 60% efficient. If one cubic meter of natural gas provides 1000 BTUs of electricity, how many BTUs of waste heat are produced?
7. If 35% of a natural area is to be developed, leaving 500 acres untouched, how many acres are to be developed?
8. Calculate the percentage growth rate for a country with a population of 6 million: in a year in which it had 100,000 births, 70,000 deaths, 30,000 immigrants and 50,000 emigrants.
9. If the concentration of mercury in a water supply changes from 65 ppm to 7 ppm in a ten-year period, what is the percentage change of the mercury concentration?

***Energy—The APES exam always has questions about energy use. Be prepared!***

- Use Table 1 to help you with the conversions.

10. How much energy is required to raise the temperature of 1000 gallons of water by 25°F?
11. By how many degrees Fahrenheit can the temperature of one metric ton of water be raised with the addition of 110 thousand BTUs of heat?
12. If 500 thousand BTUs of energy are available to raise the temperature of a water boiler from 20°F to 100°F, how many gallons of water can be added to the boiler?

## Part Five (Optional): Get a Head Start on Field Hours

Over the course of the year you will complete 8-12 hours of field work in 4 separate experiences ranging from 1-3 hours each. Typically this is arranged so that you complete 2 experiences for each semester gradebook. If you would like to get a head start on your experiences you are welcome to do one this summer. Please email us if you have questions about opportunities as many come up. Copy the link below to access the assignment. You will submit your link through Canvas at the beginning of the school year. Here is the Google Doc: https://bit.ly/2J7WUFp

| | Category Description |
|---|---|
| *You may select from these categories as many times as you like.* | *Open Ocean, Estuary, or Nature Preserve visit*: Whale Watching, Bolsa Chica Wetlands in Huntington Beach, Upper Newport Bay, San Joaquin Marsh in Irvine, Back Bay Science Center, Davey's Locker.<br><br>*Environment Related Organizations and Talks*: Audubon House, California Native Plant Society, Rock Club, Irvine Ranch Conservancy, UCI open seminars, Orange County Society of Conservation Biology, Nix Nature Center at Laguna Wilderness Park, The Ecology Center, Shadetree Nursery, Starr Ranch, Crystal Cove State Park, OC Coastkeeper, Surfrider Foundation.<br><br>*Job Shadowing in an ES field*<br><br>*Any type of environmental remediation work.* |
| *Limited to selecting from this category ONLY ONCE.* | *Aquariums:* Cabrillo Marine Aquarium/Museum, Sea World San Diego, Steven Birch Aquarium at Scripps Institute of Oceanography, Aquarium of the Pacific, Monterey Bay Aquarium.<br><br>*Zoos and Rescue Shelters*: Los Angeles, San Diego, or Irvine Regional Park Zoos. |
| *Limited to selecting from this category ONLY ONCE.* | *Hiking or Camping*: Anything from local general areas to nearby State or National Parks, **must be accompanied by a docent or volunteer + a visit to the visitors center**. |
| *Email us if you have another idea.* | ______________________________________________ |

Following your fieldwork experience you need to submit a **one page (or more)** written summary of your experience describing how it relates to the class and your life. You will use one ongoing document for your fieldwork entries. Use the following checklist to make sure your write up is up to par for submission. A header is included on the following page. Please use this header for your Field Hours document. There should be one paragraph each: a description of what you did for field work , how what you participated in relates to chapter one, and finally your own reflection/opinion about what you did for field work.

- ✓ **Format**: my name is on my paper, the date of attendance is listed, no larger than size 12 font is used, no larger than 1 inch margins are used, one and a half or double space.
- ✓ **Evidence**: Evidence is attached to or included in your write up. This could be a ticket, a picture of you at the event, confirmation email, etc.
- ✓ **What you learned and did**: Summarize what you did and what you learned at the event.
- ✓ **How it relates to the content**: Give a few clear examples of how the things you learned relate directly to the content of our course. Use of specific vocabulary is recommended here. It would be wise to use sentence frames such as: In APES we learned ______________________, this experience relates directly to that content because ______________________.
- ✓ **Personal reflection**: Describe how this experience relates to your own life and experience with nature.

If you do all of the above, you should get full credit on your field hours.

APES 2017- 2018 Field Hours Name

| Experience | Category Selected | Date of Experience | Time of Experience |
|---|---|---|---|
| Ex. | Aquarium of the Pacific | 6/15/2018 | 10:00 – 1:00 |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |

Field Work Experience #1: ___________________________________________________________

# Studying the State of Our Earth

## The Mysterious Neuse River Fish Killer

Over the course of a few days in 1991, roughly a billion fish died in North Carolina's Neuse River. Researchers at North Carolina State University (NCSU), led by Professor JoAnn Burkholder, identified the cause of this disaster as a microscopic free-living aquatic organism in the river water. This particular organism, of the genus *Pfiesteria* (fis-TEER-ee-uh), emits a potent toxin that rapidly kills fish. When members of the research team working with the organism began to develop skin sores and experience nausea, vomiting, memory impairment, and confusion, they became concerned that people using the river for fishing, crabbing, or recreation could also be in danger.

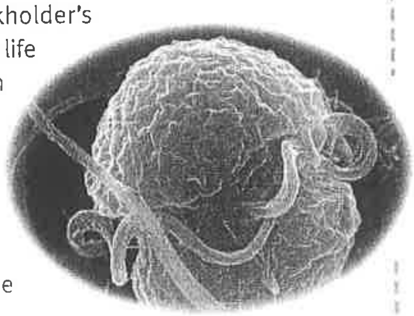
As researchers continued to study *Pfiesteria*, they found that, depending on environmental conditions, the organism could have up to 24 different life stages—an incredibly large number for any organism. They found that under most conditions, swimming *Pfiesteria* fed harmlessly on algae. However, in the presence of high concentrations of nutrients and large populations of fish, *Pfiesteria* rapidly changed into a carnivore. During this carnivorous life stage, *Pfiesteria* emitted a toxin that stunned fish, then burrowed into a fish's body to feed. Once the fish died, *Pfiesteria* transformed into yet another life stage, a free-floating amoeba that engulfed the tissue sloughed off from fish corpses. Finally, when food became scarce, it could develop a protective casing and sink to the river bottom as a cyst, able to remain dormant for decades awaiting a new influx of nutrients.

Burkholder's group deduced that large influxes of nutrients into the Neuse River had triggered *Pfiesteria's* metamorphosis from harmless algae eater into carnivorous fish killer. But where did these nutrients come from, and how did they get into the river? The answer probably lies in human activities along the river's banks. The Neuse flows through a region dominated by large industrial-scale hog farms, agricultural fields, and rapidly growing suburban areas, all of which contribute fertilizer runoff and nutrient-rich waste to the river water. A sudden increase in nutrient concentrations caused by these various human activities apparently started a "bloom," or rapid proliferation, of *Pfiesteria*.

The discovery of *Pfiesteria* in North Carolina rivers created panic among the area's recreation and fishing industries. The organism was subsequently found in many other locations from Delaware to Florida, where it infected fisheries and discouraged tourism. Concern over *Pfiesteria* led to a $40 million loss in seafood sales in the Chesapeake Bay region alone.

The discovery of *Pfiesteria* in North Carolina rivers created panic among the area's recreation and fishing industries.

While the NCSU researchers proceeded with their investigations, other investigators suggested that the "*Pfiesteria* hysteria" was overblown. Studies of humans exposed to *Pfiesteria* along rivers were inconclusive, despite additional anecdotal evidence of the symptoms that the initial researchers had experienced. Some investigators were unable to replicate the findings of Burkholder's team regarding certain *Pfiesteria* life stages. A few researchers even argued that *Pfiesteria* did not produce toxins at all. It wasn't until 2007—16 years after the fish kill that drew so much attention—that other investigators confirmed the identity of the toxin released by *Pfiesteria*. ▶



*Pfiesteria* cell.

◀ Despite the beautiful appearance of North Carolina's Neuse River, shown here, runoff from agriculture and housing development contributed to an environmental catastrophe in 1991.

The *Pfiesteria* story is a particularly good introduction to the study of environmental science. It shows us that human activities—for example, releasing waste material into a river—can affect the environment in complex and unexpected ways. Such unintended consequences of human activities are a key concern for environmental scientists.

The case of *Pfiesteria* also tells us that environmental science can be controversial. Following a new discovery, individuals, commercial interests, and the media may overstate the problem, understate it, or disagree with the initial report. Many years may pass before scientists understand the true nature and extent of the problem. Because the findings of environmental science often have an impact on industry, tourism, or recreation, they can create conflicts between scientific study and economic interests.

Finally, the story shows us that findings in environmental science are not always as clear-cut as they first appear. As we begin our study of environmental science, it's important to recognize that the process of scientific inquiry always builds on the work of previous investigators. In this way we accumulate a body of knowledge that eventually resolves important questions—such as what killed the fish in the Neuse River. Only with this knowledge in hand can we begin to make informed decisions on questions of appropriate policy. ■

*Sources:* P. D. R. Moeller et al., Metal complexes and free radical toxins produced by *Pfiesteria piscicida, Environmental Science and Technology* 41 (2006): 1166–1172; Nicholas Wade, Deadly or dull? Uproar over a microbe, *New York Times*, August 6, 2000.

## Key Ideas

Humans are dependent on Earth's air, water, and soil for our existence. However, we have altered the planet in many ways, large and small. The study of environmental science can help us understand how humans have changed the planet and identify ways of responding to those changes.

After reading this chapter you should be able to

- define the field of environmental science and discuss its importance.
- identify ways in which humans have altered and continue to alter our environment.
- describe key environmental indicators that help us evaluate the health of the planet.
- define sustainability and explain how it can be measured using the ecological footprint.
- explain the scientific method and its application to the study of environmental problems.
- describe some of the unique challenges and limitations of environmental science.

# Environmental science offers important insights into our world and how we influence it

Stop reading for a moment and look up to observe your surroundings. Consider the air you breathe, the heating or cooling system that keeps you at a comfortable temperature, and the natural or artificial light that helps you see. Our **environment** is the sum of all the conditions surrounding us that influence life. These conditions include living organisms as well as nonliving components such as soil, temperature, and the availability of water. The influence of humans is an important part of the environment as well. The environment we live in determines how healthy we are, how fast we grow, how easy it is to move around, and even how much food we can obtain. One environment may be strikingly different from another—a hot, dry desert versus a cool, humid tropical rainforest, or a coral reef teeming with marine life versus a crowded city street.

We are about to begin a study of **environmental science,** the field that looks at interactions among human *systems* and those found in nature. By **system** we mean any set of interacting components that influence one another by exchanging energy or materials. We have already seen that a change in one part of a system—for example, nutrients released into the Neuse River—can cause changes throughout the entire system.

An environmental system may be completely human-made, like a subway system, or it may be natural, like weather. The scope of an environmental scientist's work can vary from looking at a small population of individuals, to multiple populations that make up a species, to a community of interacting species, or even larger systems, such as the global climate system. Some environmental scientists are interested in regional problems. The specific case of *Pfiesteria* in the Neuse River, for example, was a regional problem. Other environmental scientists work on global issues, such as species extinction and climate change.

Many environmental scientists study a specific type of natural system known as an *ecosystem*. An **ecosystem** is a particular location on Earth whose interacting components include living, or **biotic,** components and nonliving, or **abiotic,** components.

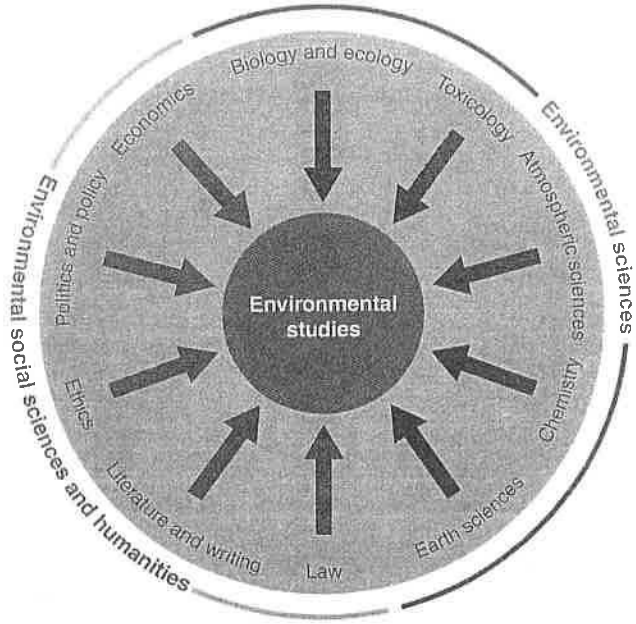



**FIGURE 1.1** **Environmental studies.** The study of environmental science uses knowledge from many disciplines.

It is important for students of environmental science to recognize that environmental science is different from *environmentalism,* which is a social movement that seeks to protect the environment through lobbying, activism, and education. An **environmentalist** is a person who participates in environmentalism. In contrast, an environmental scientist, like any scientist, follows the process of observation, hypothesis testing, and field and laboratory research. We'll learn more about the scientific method later in this chapter.

So what does the study of environmental science actually include? As FIGURE 1.1 shows, environmental science encompasses topics from many scientific disciplines, such as chemistry, biology, and Earth science. And environmental science is itself a subset of the broader field known as **environmental studies,** which includes additional subjects such as environmental policy, economics, literature, and ethics. Throughout the course of this book you will become familiar with these and many other disciplines.

We have seen that environmental science is a deeply interdisciplinary field. It is also a rapidly growing area of study. As human activities continue to affect the environment, environmental science can help us understand the consequences of our interactions with our planet and help us make better decisions about our actions.

**CHECKPOINT**

- What factors make up an organism's environment?
- In what ways is the field of environmental studies interdisciplinary?
- Why is environmental science research important?

## Humans alter natural systems

Think of the last time you walked in a wooded area. Did you notice any dead or fallen trees? Chances are that even if you did, you were not aware that living and nonliving components were interacting all around you. Perhaps an insect pest killed the tree you saw and many others of the same species. Over time, dead trees in a forest lose moisture. The increase in dry wood makes the forest more vulnerable to intense wildfires. But the process doesn't stop there. Wildfires trigger the germination of certain tree seeds, some of which lie dormant until after a fire. And so what began with the activity of insects leads to a transformation of the forest. In this way, *biotic,* or living, factors interact with *abiotic,* or nonliving, factors to influence the future of the forest.

The global environment is composed of small-scale and large-scale systems. Within a given system, biotic and abiotic components can interact in surprisingly complex ways. In the forest example, the species of trees that are present in the forest, the insect pests, and the wildfires interact with one another: they form a system. This small forest system is part of many larger systems and, ultimately, one global system that generates, circulates, and utilizes oxygen and carbon dioxide, among other things.

Humans manipulate their environment more than any other species. We convert land from its natural state into urban, suburban, and agricultural areas (FIGURE 1.2). We change the chemistry of our air, water, and soil, both intentionally—for example, by adding fertilizers—and unintentionally, as a consequence of activities that generate pollution. Even where we don't manipulate the environment directly, the simple fact that we are so abundant affects our surroundings.

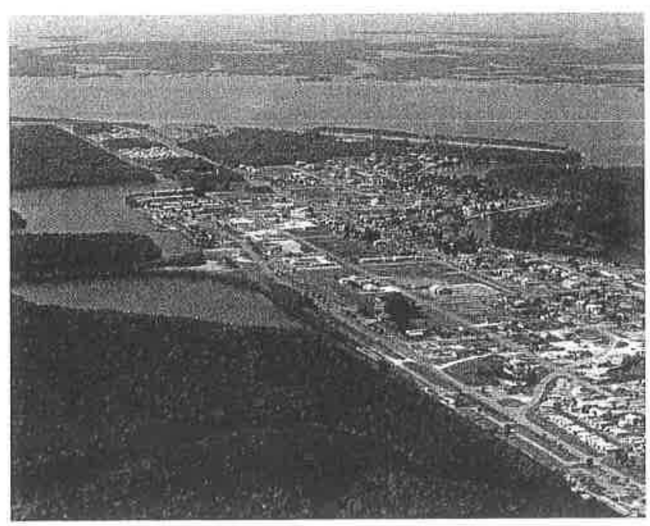


**FIGURE 1.2** **The impact of humans on Earth.** Housing development is one example of the many ways in which humans convert land from its natural state.

(a)

(b)

**FIGURE 1.3 It is impossible for millions of people to inhabit an area without altering it.** (a) In 1880, fewer than 6,000 people lived in Los Angeles. (b) In 2009, Los Angeles had a population of 3.8 million people, and the greater Los Angeles metropolitan area was home to nearly 13 million people.

Humans and their direct ancestors (other members of the genus *Homo*) have lived on Earth for about 2.5 million years. During this time, and especially during the last 10,000 to 20,000 years, we have shaped and influenced our environment. As tool-using, social animals, we have continued to develop a capacity to directly alter our environment in substantial ways. *Homo sapiens*—genetically modern humans—evolved to be successful hunters: when they entered a new environment, they often hunted large animal species to extinction. In fact, early humans are thought to be responsible for the extinction of mammoths, mastodons, giant ground sloths, and many types of birds. More recently, hunting in North America led to the extinction of the passenger pigeon (*Ectopistes migratorius*) and nearly caused the loss of the American bison (*Bison bison*).

But the picture isn't all bleak. Human activities have also created opportunities for certain species to thrive. For example, for thousands of years Native Americans on the Great Plains used fire to capture animals for food. The fires they set kept trees from encroaching on the plains, which in turn created a window for an entire ecosystem to develop. Because of human activity, this ecosystem—the tallgrass prairie—is now home to numerous unique species.

During the last two centuries, the rapid and widespread development of technology, coupled with dramatic human population growth, has increased both the rate and the scale of our global environmental impact substantially. Modern cities with electricity, running water, sewer systems, Internet connections, and public transportation systems have improved human well-being, but they have come at a cost. Cities cover land that was once natural habitat. Species relying on that habitat must adapt, relocate, or go extinct. Human-induced changes in climate—for example, in patterns of temperature and precipitation—affect the health of natural systems on a global scale. Current changes in land use and climate are rapidly outpacing the rate at which natural systems can evolve. Some species have not "kept up" and can no longer compete in the human-modified environment.

Moreover, as the number of people on the planet has grown, their effect has multiplied. Six thousand people can live in a relatively small area with only minimal environmental effects. But when 4 million people live in a modern city like Los Angeles, their combined activity will cause greater environmental damage that will inevitably pollute the water, air, and soil and introduce other consequences as well (FIGURE 1.3).

**CHECKPOINT**

- In what ways do humans change the environment?
- What is the relationship between the development of technology and environmental impacts?
- How does human development have an impact on natural systems?

## Environmental scientists monitor natural systems for signs of stress

One of the critical questions that environmental scientists investigate is whether the planet's natural

**TABLE 1.1 Some common environmental indicators**

| Environmental indicator | Unit of measure | Chapter where indicator is discussed |
|---|---|---|
| Human population | Individuals | 7 |
| Ecological footprint | Hectares of land | 1 |
| Total food production | Metric tons of grain | 11 |
| Food production per unit area | Kilograms of grain per hectare of land | 11 |
| Per capita food production | Kilograms of grain per person | 11 |
| Carbon dioxide | Concentration in air (parts per million) | 19 |
| Average global surface temperature | Degrees centigrade | 19 |
| Sea level change | Millimeters | 19 |
| Annual precipitation | Millimeters | 4 |
| Species diversity | Number of species | 5, 18 |
| Fish consumption advisories | Present or absent; number of fish allowed per week | 17 |
| Water quality (toxic chemicals) | Concentration | 14 |
| Water quality (conventional pollutants) | Concentration; presence or absence of bacteria | 14 |
| Deposition rates of atmospheric compounds | Milligrams per square meter per year | 15 |
| Fish catch or harvest | Kilograms of fish per year or weight of fish per effort expended | 11 |
| Extinction rate | Number of species per year | 5 |
| Habitat loss rate | Hectares of land cleared or "lost" per year | 18 |
| Infant mortality rate | Number of deaths of infants under age 1 per 1,000 live births | 7 |
| Life expectancy | Average number of years a newborn infant can be expected to live under current conditions | 7 |

life-support systems are being degraded by human-induced changes. Natural environments provide what we refer to as **ecosystem services**—the processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced. We often take a healthy ecosystem for granted, but we notice when an ecosystem is degraded or stressed because it is unable to provide the same services or produce the same goods. To understand the extent of our effect on the environment, we need to be able to measure the health of Earth's ecosystems.

To describe the health and quality of natural systems, environmental scientists use *environmental indicators.* Just as body temperature and heart rate can indicate whether a person is healthy or sick, **environmental indicators** describe the current state of an environmental system. These indicators do not always tell us what is causing a change, but they do tell us when we might need to look more deeply into a particular issue. Environmental indicators provide valuable information about natural systems on both small and large scales. Some of these indicators are listed in Table 1.1.

In this book we will focus on the five global-scale environmental indicators listed in Table 1.2: biological diversity, food production, average global surface temperature and carbon dioxide concentrations in the atmosphere, human population, and resource depletion. These key environmental indicators help us analyze the health of the planet. We can use this information to guide us toward **sustainability,** by which we mean living on Earth in a way that allows us to use its resources without depriving future generations of those resources. Many scientists maintain that achieving sustainability is the single most important goal for the human species. It is also one of the most challenging tasks we face.

## Biological Diversity

Biological diversity, or **biodiversity,** is the diversity of life forms in an environment. It exists on three scales: *genetic, species,* and *ecosystem* diversity. Each of these is an important indicator of environmental health and quality.

**GENETIC DIVERSITY** Genetic diversity is a measure of the genetic variation among individuals in a population. Populations with high genetic diversity are better able to respond to environmental change than populations with lower genetic diversity. For example, if a population of fish possesses high genetic diversity for disease resistance, at least some individuals are likely to survive

**TABLE 1.2 Five key global environmental indicators**

| Indicator | Recent trend | Outlook for future | Overall impact on environmental quality |
|---|---|---|---|
| Biological diversity | Large number of extinctions, extinction rate increasing | Extinctions will continue | Negative |
| Food production | Per capita production possibly leveling off | Unclear | May affect the number of people Earth can support |
| Average global surface temperature and $CO_2$ concentrations | $CO_2$ concentrations and temperatures increasing | Probably will continue to increase, at least in the short term | Effects are uncertain and varied, but probably detrimental |
| Human population | Still increasing, but growth rate slowing | Population leveling off Resource consumption rates are also a factor | Negative |
| Resource depletion | Many resources are being depleted at rapid rates. But human ingenuity frequently develops "new" resources, and efficiency of resource use is increasing in many cases | Unknown | Increased use of most resources has negative effects |

whatever diseases move through the population. If the population declines in number, however, the amount of genetic diversity it can possess is also reduced, and this reduction increases the likelihood that the population will decline further when exposed to a disease.

**SPECIES DIVERSITY** Species diversity indicates the number of *species* in a region or in a particular type of habitat. A **species** is defined as a group of organisms that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties. Individuals within a species can breed and produce fertile offspring. Scientists have identified and cataloged approximately 2 million species on Earth. Estimates of the total number of species on Earth range between 5 million and 100 million, with the most common estimate at 10 million. This number includes a large array of organisms with a multitude of sizes, shapes, colors, and roles (FIGURE 1.4). Scientists have observed that ecosystems with more species, that is, higher species diversity, are more resilient and productive. For example, a tropical forest with a large number of plant species growing in the understory is likely to be more productive, and more resilient to change, than a nearby tropical forest plantation with one crop species growing in the understory.

Environmental scientists often focus on species diversity as a critical environmental indicator. The number of frog species, for example, is used as an indicator of regional environmental health because frogs are exposed to both the water and the air in their ecosystem. A decrease in the number of frog species in a particular ecosystem may be an indicator of environmental problems there. Species losses in several ecosystems can indicate larger-scale environmental problems.

Not all species losses are indicators of environmental problems, however. Species arise and others go extinct as part of the natural evolutionary process. The evolution of new species, known as **speciation,** typically happens very slowly—perhaps on the order of one to three new species per year worldwide. The average rate at which species go extinct over the long term, referred to as the **background extinction rate,** is also very slow: about one species in a million every year. So with 2 million identified species on Earth, the background extinction rate should be about two species per year.

Under conditions of environmental change or biological stress, species may go extinct faster than new ones evolve. Some scientists estimate that more than 10,000 species are currently going extinct each year—5,000 times the background rate of extinction. Habitat destruction and habitat degradation are the major causes of species extinction today, although climate change, overharvesting, and pressure from introduced species also contribute to species loss. Human intervention has saved certain species, including the American bison, peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), and American alligator (*Alligator mississippiensis*). But other large animal species, such as the Bengal tiger (*Panthera tigris*), snow leopard (*Panthera uncia*), and West Indian manatee (*Trichechus manatus*), remain endangered and may go extinct if present trends are not reversed. Overall, the number of species has been declining (FIGURE 1.5).

**ECOSYSTEM DIVERSITY** Ecosystem diversity is a measure of the diversity of ecosystems or habitats that exist in a given region. A greater number of healthy and productive ecosystems means a healthier environment overall.

As an environmental indicator, the current loss of biodiversity tells us that natural systems are facing strains

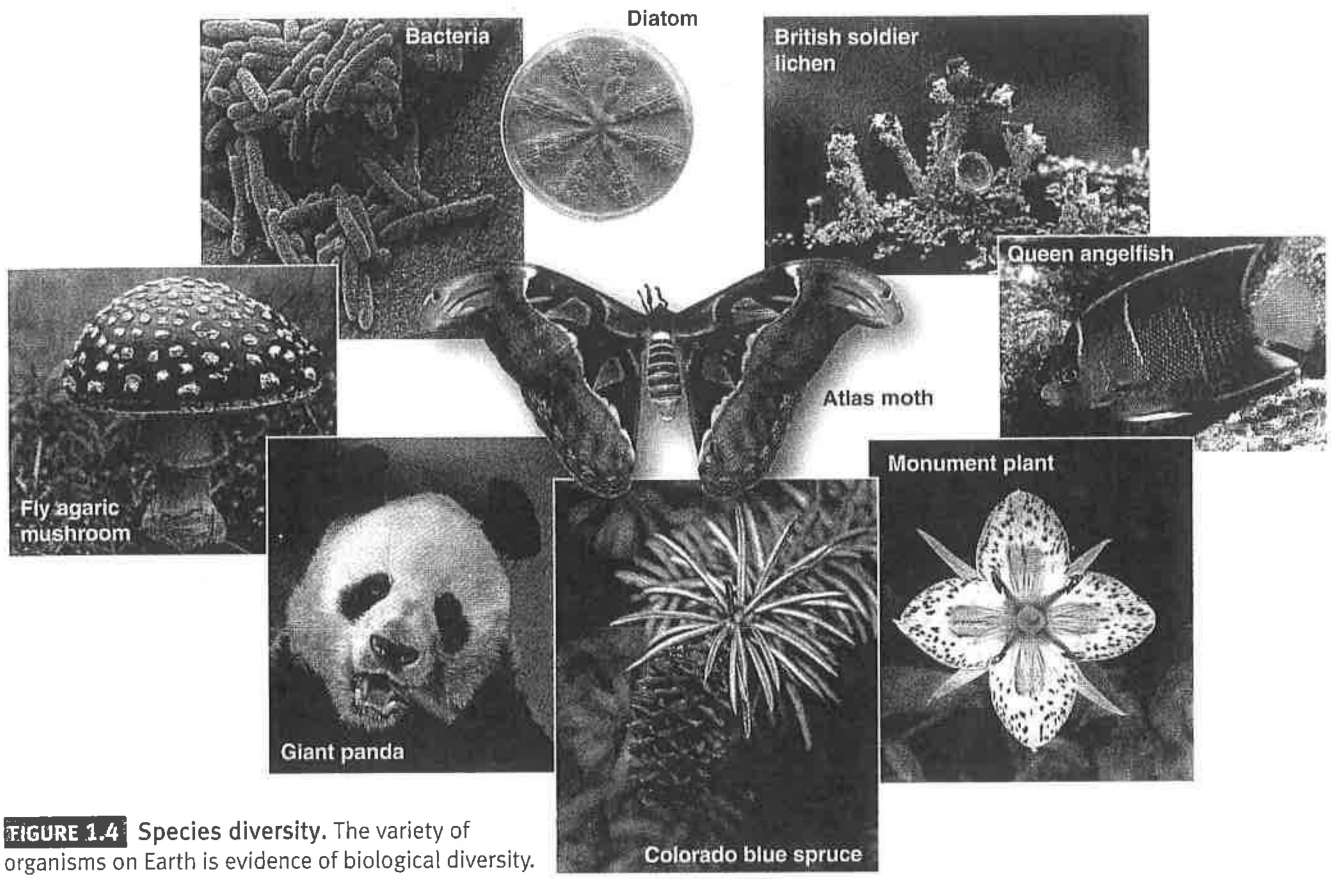



**FIGURE 1.4** **Species diversity.** The variety of organisms on Earth is evidence of biological diversity.

unlike any in the recent past. It is clearly an important topic in the study of environmental science, and we will look at it in greater detail in Chapters 5 and 18 of this book.

Some measures of biodiversity are given in terms of land area, so becoming familiar with measurements of land area is important to understanding them. As Do the Math "What Is a Hectare?" describes, a hectare

**DO THE MATH**

### What Is a Hectare?

Some environmental indicators are expressed in hectares. A hectare is a measure of land area, abbreviated "ha," that represents an area that is 100 meters by 100 meters. In the United States we measure land area in terms of square miles and acres. However, the rest of the world measures land in terms of hectares. Let's see how the two systems compare:

$$1 \text{ mile}^2 = 640 \text{ acres}$$

Given that there are 5,280 feet in a mile:

$$1 \text{ mi}^2 = (5{,}280 \text{ ft})^2 = 27{,}878{,}400 \text{ ft}^2$$

Using this information, we can determine the number of square feet in 1 acre, as follows:

$$\left(\frac{1 \text{ mi}^2}{640 \text{ acres}}\right) \times \left(\frac{27{,}878{,}400 \text{ ft}^2}{1 \text{ mi}^2}\right) = 43{,}560 \text{ ft}^2/\text{acre}$$

So—what is a hectare?

1 ha = 10,000 m²—that is, a square that is 100 m on each side, and 1 kilometer (km) = 1,000 m. Thus:

$$1 \text{ km}^2 = (1{,}000 \text{ m})^2 = 1{,}000{,}000 \text{ m}^2$$

Using this information, we can determine the number of hectares in 1 square kilometer.

$$\left(\frac{1{,}000{,}000 \text{ m}^2}{1 \text{ km}^2}\right) \times \left(\frac{1 \text{ ha}}{10{,}000 \text{ m}^2}\right) = 100 \text{ ha/km}^2$$

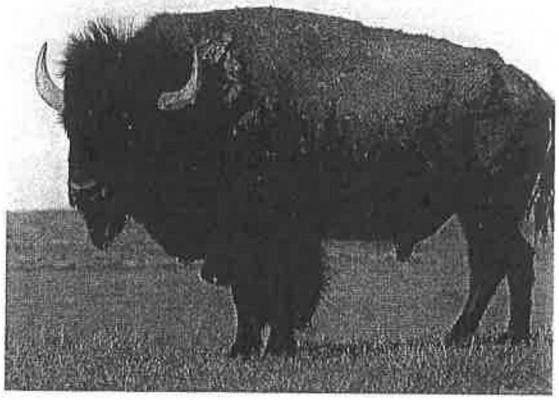
Notice how neatly the metric system handles all these calculations. Everything is in powers of 10—unlike feet, miles, acres, and sections.

How can we compare hectares to acres? To do so, we first need to use common units. Let's convert square kilometers to square feet. If 1 km = 0.6214 mi, then:

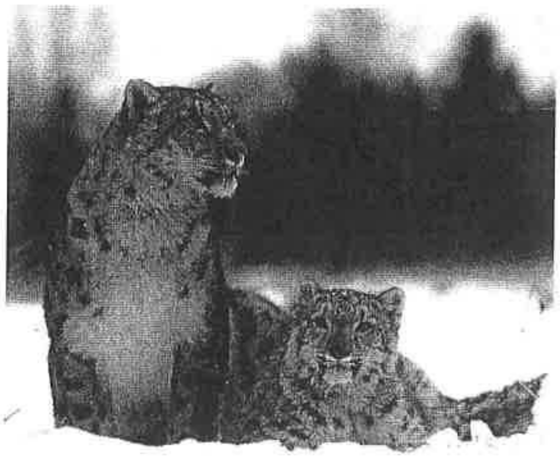
$$1 \text{ km}^2 = (0.6214 \text{ mi})^2 \times \left(\frac{27{,}878{,}400 \text{ ft}^2}{1 \text{ mi}^2}\right) = 10{,}764{,}908 \text{ ft}^2$$

Now, finally, we can determine the number of acres in 1 hectare, as follows:

$$(10{,}764{,}908 \text{ ft}^2/\text{km}^2) \times \left(\frac{1 \text{ km}^2}{100 \text{ ha}}\right) \times \left(\frac{1 \text{ acre}}{43{,}560 \text{ ft}^2}\right) = 2.47 \text{ acres/ha}$$


(a)


(b)


(c)

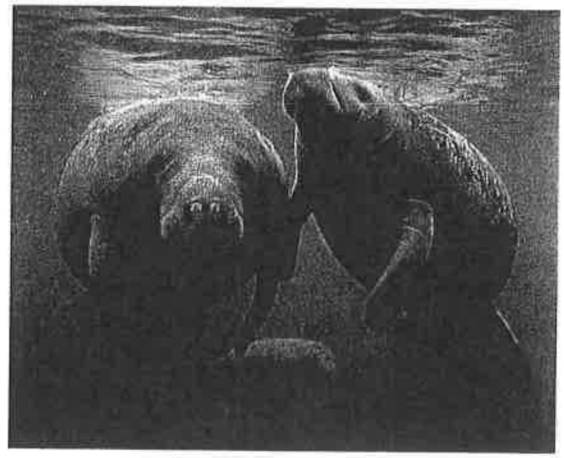

(d)

**FIGURE 1.5** **Species on the brink.** Humans have saved some species from the brink of extinction, such as (a) the American bison and (b) the peregrine falcon. Other species, such as (c) the snow leopard and (d) the West Indian manatee, continue to decline toward extinction.

is a unit of area used primarily in the measurement of land.

## Food Production

The second of our five global indicators is food production: our ability to grow food to nourish the human population. Just as a healthy ecosystem supports a wide range of species, a healthy soil supports abundant and continuous food production. Food grains such as wheat, corn, and rice provide more than half the calories and protein humans consume. Still, the growth of the human population is straining our ability to grow and distribute adequate amounts of food.

In the past we have used science and technology to increase the amount of food we can produce on a given area of land. World grain production has increased fairly steadily since 1950 as a result of expanded irrigation, fertilization, new crop varieties, and other innovations. At the same time, worldwide production of grain *per person,* also called *per capita* world grain production, has leveled off. **FIGURE 1.6** shows a downward trend in wheat production since about 1985.

In 2008, food shortages around the world led to higher food prices and even riots in some places. Why did this happen? The amount of grain produced worldwide is influenced by many factors. These factors include climatic conditions, the amount and quality of land under cultivation, irrigation, and the human labor and energy required to plant, harvest, and bring the grain to market. Why is grain production not keeping up with population growth? In some areas, the productivity of agricultural ecosystems has declined because of soil degradation, crop diseases, and unfavorable weather conditions such as drought or flooding. In addition, demand is outpacing supply. The rate of human population growth has outpaced increases in food production. Furthermore, humans currently use

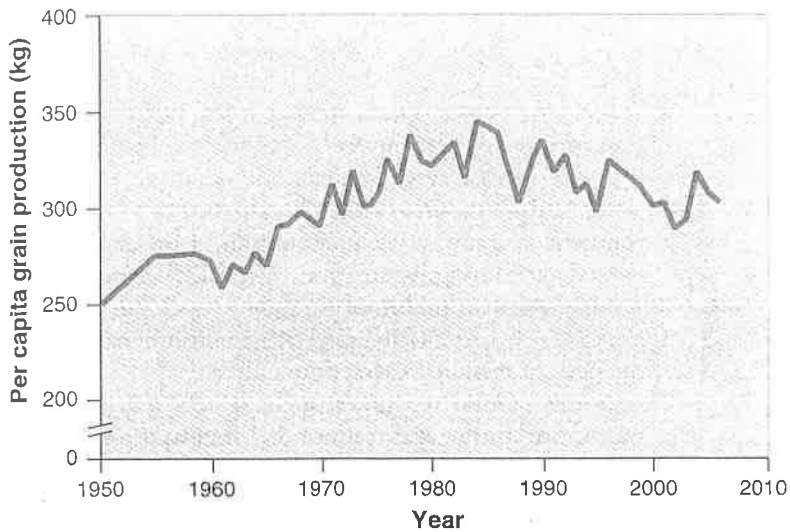



**FIGURE 1.6 World grain production per person.** Grain production has increased since the 1950s, but it has recently begun to level off. [After http://www.earth-policy.org/index.php?/indicators/C54.]

more grain to feed livestock than they consume themselves. Finally, some government policies discourage food production by making it more profitable to allow land to remain uncultivated, or by encouraging farmers to grow crops for fuels such as ethanol and biodiesel instead of food.

Will there be sufficient grain to feed the world's population in the future? In the past, whenever a shortage of food loomed, humans have discovered and employed technological or biological innovations to increase production. However, these innovations often put a strain on the productivity of the soil. Unfortunately, if we continue to overexploit the soil, its ability to sustain food production may decline dramatically. We will take a closer look at soil quality in Chapter 8 and food production in Chapter 11.

## Average Global Surface Temperature and Carbon Dioxide Concentrations

We have seen that biodiversity and abundant food production are necessary for life. One of the things that makes them possible is a stable climate. Earth's temperature has been relatively constant since the earliest forms of life began, about 3.5 billion years ago. The temperature of Earth allows the presence of liquid water, which is necessary for life.

What keeps Earth's temperature so constant? As FIGURE 1.7 shows, our thick planetary atmosphere contains many gases, some of which act like a blanket trapping heat near Earth's surface. The most important of these heat-trapping gases, called **greenhouse gases,** is carbon dioxide ($CO_2$). During most of the history of life on Earth, greenhouse gases have been present in the atmosphere at fairly constant concentrations for relatively long periods. They help keep Earth's surface within the range of temperatures at which life can flourish.

In the past two centuries, however, the concentrations of $CO_2$ and other greenhouse gases in the atmosphere have risen. During roughly the same period, as the graph in FIGURE 1.8 shows, global temperatures have fluctuated considerably, but have shown an overall increase. Many scientists believe that the increase in atmospheric $CO_2$ during the last two centuries is **anthropogenic**—derived from human activities. The two major sources of anthropogenic $CO_2$ are the combustion of fossil fuels and the net loss of forests and other habitat types that would otherwise take up and store $CO_2$ from the atmosphere. We will discuss climate in Chapter 4 and global climate change in Chapter 19.

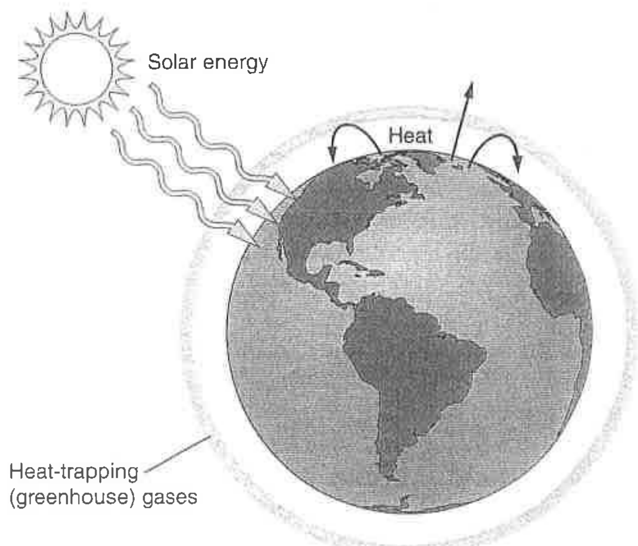



**FIGURE 1.7 The greenhouse effect.** As Earth's surface is warmed by the Sun, it radiates heat outward. Heat-trapping gases absorb the outgoing heat and reradiate some of it back to Earth. Without these greenhouse gases, Earth would be much cooler.

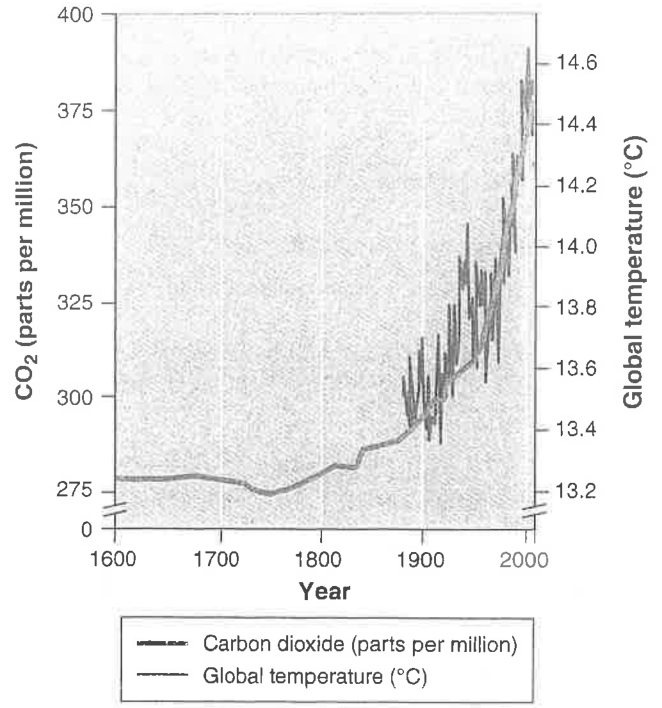



**FIGURE 1.8 Changes in average global surface temperature and in atmospheric $CO_2$ concentrations.** Earth's average global surface temperature has increased steadily for at least the past 100 years. Carbon dioxide concentrations in the atmosphere have varied over geologic time, but have risen steadily since 1960. [After http://data.giss.nasa.gov/gistemp/2008/. http://mb-soft.com/public3/co2hist.gif.]

## Human Population

In addition to biodiversity, food production, and global surface temperature, the size of the human population can tell us a great deal about the health of our global environment. The human population is currently 6.8 billion and growing. The increasing world population places additional demands on natural systems, since each new person requires food, water, and other resources. In any given 24-hour period, 364,000 infants are born and 152,000 people die. The net result is 212,000 new inhabitants on Earth each day, or *over a million additional people every 5 days.* The rate of population growth has been slowing since the 1960s, but world population size will continue to increase for at least 50 to 100 years. Most population scientists project that the human population will be somewhere between 8.1 billion and 9.6 billion in 2050 and will stabilize between 6.8 billion and 10.5 billion by 2100.

Can the planet sustain so many people (FIGURE 1.9)? Even if the human population eventually stops growing, the billions of additional people will create a greater demand on Earth's finite resources, including food, energy, and land. Unless humans work to reduce these pressures, the human population will put a rapidly growing strain on natural systems for at least the first half of this century. We discuss human population issues in Chapter 7.

## Resource Depletion

Natural resources provide the energy and materials that support human civilization. But as the human population grows, the resources necessary for our survival become increasingly depleted. In addition, extracting these natural resources can affect the health of our environment in many ways. Pollution and land degradation caused by mining, waste from discarded manufactured products, and air pollution caused by fossil fuel combustion are just a few of the negative environmental consequences of resource extraction and use.

Some natural resources, such as coal, oil, and uranium, are finite and cannot be renewed or reused. Others, such as aluminum or copper, also exist in finite quantities, but can be used multiple times through reuse or recycling. Renewable resources, such as timber, can be grown and harvested indefinitely, but in some locations they are being used faster than they are naturally replenished. Do the Math "Rates of Forest Clearing" provides an opportunity to calculate rates of one type of resource depletion.

Sustaining the global human population requires vast quantities of resources. However, in addition to the total amounts of resources used by humans, we must consider resource use per capita.

Patterns of resource consumption vary enormously among nations depending on their level of development. What exactly do we mean by *development?* **Development** is defined as improvement in human well-being

**FIGURE 1.9 Kolkata, India.** The human population will continue to grow for at least 50 years. Unless humans can devise ways to live more sustainably, these population increases will put additional strains on natural systems.

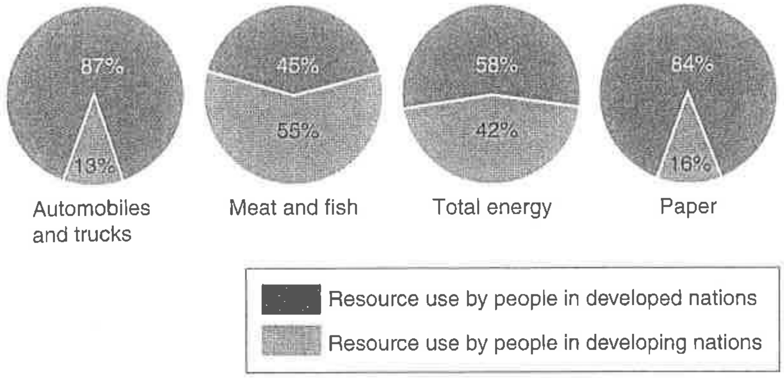



FIGURE 1.10 **Resource use in developed and developing countries.** Only 20 percent of the world's population lives in developed countries, but that 20 percent uses most of the world's resources. The remaining 80 percent of the population lives in developing countries and uses far fewer resources per capita.

through economic advancement. Development influences personal and collective human lifestyles—things such as automobile use, the amount of meat in the diet, and the availability and use of technologies such as cell phones and personal computers. As economies develop, resource consumption also increases: people drive more automobiles, live in larger homes, and purchase more goods. These increases can often have implications for the natural environment.

According to the United Nations Development Programme, people in developed nations—including the United States, Canada, Australia, most European countries, and Japan—use most of the world's resources. **FIGURE 1.10** shows that the 20 percent of the global population that lives in developed nations owns 87 percent of the world's automobiles and consumes 58 percent of all energy, 84 percent of all paper, and 45 percent of all fish and meat. The poorest 20 percent of the world's people consume 5 percent or less of these resources. Thus, even though the number of people in the developing countries is much larger than the number in the developed countries, their total consumption of natural resources is relatively small.

So while it is true that a larger human population has greater environmental impacts, a full evaluation requires that we look at economic development and consumption patterns as well. We will take a closer look at resource depletion and consumption patterns in Chapters 7, 12, and 13.

**CHECKPOINT**

- ✓ What is an environmental indicator and what does it tell us?
- ✓ What are the five global-scale environmental indicators we focus on in this book, and how do they help us monitor the health of the environment?
- ✓ How do human activities contribute to changes in the five global-scale environmental indicators?

**DO THE MATH**

### Rates of Forest Clearing

A Web search of environmental organizations yielded a range of estimates of the amount of forest clearing that is occurring worldwide:

Estimate 1: 1 acre per second

Estimate 2: 80,000 acres per day

Estimate 3: 32,000 ha per day

Convert all three estimates into hectares per year and compare them.

There are 2.47 acres per hectare (see Do the Math "What Is a Hectare?"). Therefore, 1 acre = 0.40 ha.

$$\text{Estimate 1: } 1.0 \text{ acre/second} \times 0.40 \text{ ha/acre} = 0.40 \text{ ha/second}$$

$$0.40 \text{ ha/second} \times 60 \text{ seconds/minute} \times 60 \text{ minutes/hour} \times 24 \text{ hours/day} \times 365 \text{ days/year} = 12{,}614{,}400 \text{ ha cleared per year}$$

$$\text{Estimate 2: } 80{,}000 \text{ acres/day} \times 0.40 \text{ ha/acre} = 32{,}000 \text{ ha cleared per day}$$

$$\text{Estimate 3: } 32{,}000 \text{ ha/day} \times 365 \text{ days/year} = 11{,}680{,}000 \text{ ha cleared per year}$$

The second and third estimates are exactly the same. Both are equivalent to 32,000 ha per day (as seen in the intermediate step of the conversion above).

There is a difference of less than 1,000,000 ha per year, or roughly 9%, between the estimates, suggesting that they are similar in scope.

Why might environmental organizations choose to present similar information in different ways?

## Human well-being depends on sustainable practices

We have seen that people living in developed nations consume a far greater share of the world's resources than do people in developing countries. What effect does this consumption have on our environment? It is easy to imagine a very small human population living on Earth without degrading its environment: there simply would not be enough people to do significant damage. Today, however, Earth's population is 6.8 billion people and growing. Many environmental scientists ask how we will be able to continue to produce sufficient food, build needed infrastructure, and process pollution and waste. Our current attempts to sustain the human population have already modified many environmental systems. Can we continue our current level of resource consumption without jeopardizing the well-being of future generations?

Easter Island, in the South Pacific, provides a cautionary tale (FIGURE 1.11). This island, also called Rapa Nui, was once covered with trees and grasses. When humans settled the island hundreds of years ago, they quickly multiplied in its hospitable environment. They cut down trees to build homes and canoes for fishing, and they overused the island's soil and water resources. By the 1870s, almost all of the trees were gone. Without the trees to hold the soil in place, massive erosion occurred, and the loss of soil caused food production to decrease. While other forces, including diseases introduced by European visitors, were also involved in the destruction of the population, the unsustainable use of natural resources on Easter Island appears to be the primary cause for the collapse of its civilization.

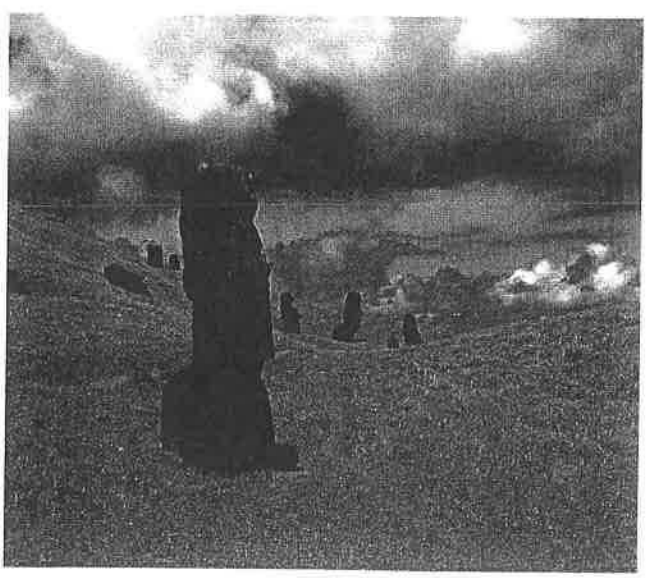


**FIGURE 1.11** **Easter Island.** The overuse of resources by the people of Easter Island is probably the primary cause for the demise of that civilization.

Most environmental scientists believe that there are limits to the supply of clean air and water, nutritious foods, and other life-sustaining resources our environment can provide, as well as a point at which Earth will no longer be able to maintain a stable climate. We must meet several requirements in order to live sustainably:

- Environmental systems must not be damaged beyond their ability to recover.
- Renewable resources must not be depleted faster than they can regenerate.
- Nonrenewable resources must be used sparingly.

**Sustainable development** is development that balances current human well-being and economic advancement with resource management for the benefit of future generations. This is not as easy as it sounds. The issues involved in evaluating sustainability are complex, in part because sustainability depends not only on the number of people using a resource, but also on how that resource is being used. For example, eating chicken is sustainable when people raise their own chickens and allow them to forage for food on the land. However, if all people, including city dwellers, wanted to eat chicken six times a week, the amount of resources needed to raise that many chickens would probably make the practice of eating chicken unsustainable.

Living sustainably means *acting in a way such that activities that are crucial to human society can continue.* It includes practices such as conserving and finding alternatives to nonrenewable resources as well as protecting the capacity of the environment to continue to supply renewable resources (FIGURE 1.12).

Iron, for example, is a nonrenewable resource derived from ore removed from the ground. It is the major constituent of steel, which we use to make many things, including automobiles, bicycles, and strong frames for tall buildings. Historically, our ability to smelt iron for steel limited our use of that resource. But as we have improved steel manufacturing technology, steel has become more readily available, and the demand for it has grown. Because of this, our current use of iron is unsustainable. What would happen if we ran out of iron? Not too long ago the depletion of iron ore might have been a catastrophe. But today we have developed materials that can substitute for certain uses of steel—for example, carbon fiber—and we also know how to recycle steel. Developing substitutes and recycling materials are two ways to address the problem of resource depletion and increase sustainability.

The example of iron leads us to a question that environmental scientists often ask: How do we determine

**FIGURE 1.12** **Living sustainably.** Sustainable choices such as bicycling to work or school can help protect the environment and conserve resources for future generations.

the importance of a given resource? If we use up a resource such as iron for which substitutes exist, it is possible that the consequences will not be severe. However, if we are unable to find an alternative to the resource—for example, something to replace fossil fuels—people in the developed nations may have to make significant changes in their consumption habits.

## Defining Human Needs

We have seen that sustainable development requires us to determine how we can meet our current needs without compromising the ability of future generations to meet their own needs. Let's look at how environmental science can help us achieve that goal. We will begin by defining *needs.*

If you have ever experienced an interruption of electricity to your home or school, you know how frustrating it can be. Without the use of lights, computers, televisions, air-conditioning, heating, and refrigeration, many people feel disconnected and uncomfortable. Almost everyone in the developed world would insist that they need—cannot live without—electricity. But in other parts of the world, people have never had these modern conveniences. When we speak of *basic needs,* we are referring to the essentials that sustain human life, including air, water, food, and shelter.

But humans also have more complex needs. Many psychologists have argued that we require meaningful human interactions in order to live a satisfying life; therefore, a community of some sort might be considered a human need. Biologist Edward O. Wilson wrote that humans exhibit **biophilia**—that is, love of life—which is a *need* to make "the connections that humans subconsciously seek with the rest of life." Thus our needs for access to natural areas, for beauty, and for social connections can be considered as vital to our well-being as our basic physical needs and must be considered as part of our long-term goal of global sustainability (FIGURE 1.13).

## The Ecological Footprint

We have begun to see the multitude of ways in which human activities affect the environment. As countries prosper, their populations use more resources. But economic development can sometimes improve environmental conditions. For instance, wealthier countries may be able to afford to implement pollution controls and invest money to protect native species. So although people in developing countries do not consume the same quantity of resources as those in developed nations, they may be less likely to use environmentally friendly technologies or to have the financial resources to implement environmental protections.

How do we determine what lifestyles have the greatest environmental impact? This is an important question for environmental scientists if we are to understand the effects of human activities on the planet and develop sustainable practices. Calculating sustainability, however, is more difficult than one might think. We have to consider the impacts of our activities and lifestyles on different aspects of our environment. We use land to grow food, to build on, and for parks and recreation. We require

**FIGURE 1.13** **Central Park, New York City.** New Yorkers have set aside 341 ha (843 acres) in the center of the largest city in the United States—a testament to the compelling human need for interactions with nature.

water for drinking, for cleaning, and for manufacturing products such as paper. We need clean air to breathe. Yet these goods and services are all interdependent: using or protecting one has an effect on the others. For example, using land for conventional agriculture may require water for irrigation, fertilizer to promote plant growth, and pesticides to reduce crop damage. This use of land reduces the amount of water available for human use: the plants consume it and the pesticides pollute it.

One method used to assess whether we are living sustainably is to measure the impact of a person or country on world resources. The tool many environmental scientists use for this purpose, the *ecological footprint,* was developed in 1995 by Professor William Rees and his graduate student Mathis Wackernagel. An individual's **ecological footprint** is a measure of how much that person consumes, expressed in area of land. That is, the output from the total amount of land required to support a person's lifestyle represents that person's ecological footprint (**FIGURE 1.14**).

Rees and Wackernagel maintained that if our lifestyle demands more land than is available, then we must be living unsustainably—using up resources more quickly than they can be produced, or producing wastes more quickly than they can be processed. For example, each person requires a certain number of food calories each day. We know the number of calories in a given amount of grain or meat. We also know how much farmland or rangeland is needed to grow the grain to feed people or livestock such as sheep, chickens, or cows. If a person eats only grains or plants, the amount of land needed to provide that person with food is simply the amount of land needed to grow the plants they eat. If that person eats meat, however, the amount of land required to feed that person is greater, because we must also consider the land required to raise and feed the livestock that ultimately become meat. Thus one factor in the size of a person's ecological footprint is the amount of meat in the diet. Meat consumption is a lifestyle choice, and per capita meat consumption is much greater in developed countries.

We can calculate the ecological footprint of the food we eat, the water and energy we use, and even the activities we perform that contribute to climate change. All of these impacts determine our ecological footprint on the planet as individuals, cities, states, or nations. Calculating the ecological footprint is complex, and the details are subject to debate, but it has at least given scientists a concrete measure to discuss and refine.

Scientists at the Global Footprint Network, where Wackernagel is now president, have calculated that the human ecological footprint has reached 14 billion hectares (34.6 billion acres), or 125 percent of Earth's total usable land area. Furthermore, they have calculated that if every person on Earth lived the average lifestyle of people in the United States, we would require the equivalent of five Earths (**FIGURE 1.15**). Even to support the entire human population with the lifestyles we have now, we would need more than one Earth. Clearly, this level of resource consumption is not sustainable.

According to Wackernagel and Rees, if we are to sustain human life, we must ensure that our total consumption leads to an ecological footprint of no more than 11 billion hectares (27.2 billion acres). This number will need to be significantly less if we wish to preserve land for species other than humans. In order to achieve this goal, humans will have some important choices to make.

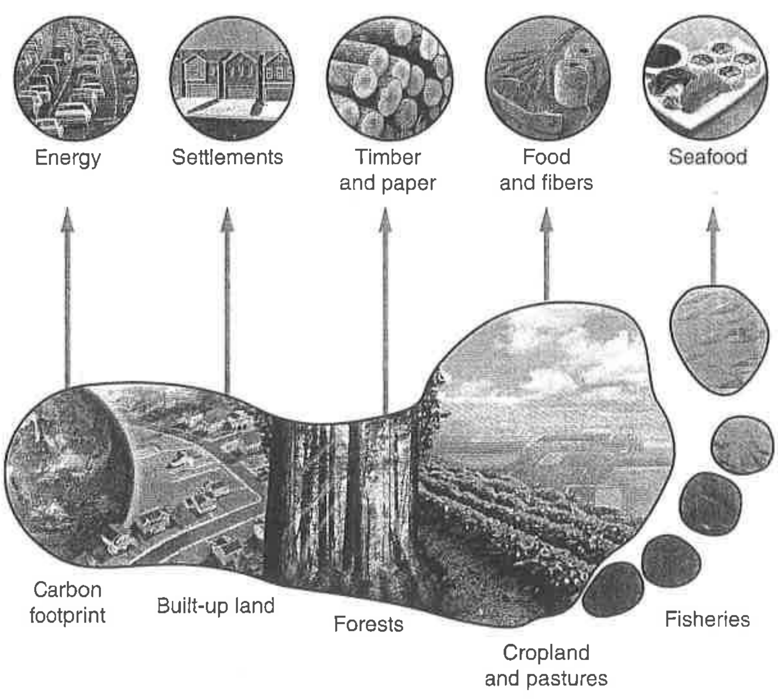



**FIGURE 1.14 The ecological footprint.** An individual's ecological footprint is a measure of how much land is needed to supply the goods and services that individual uses. Only some of the many factors that go into the calculation of the footprint are shown here. (The actual amount of land used for each resource is not drawn to scale.)

**CHECKPOINT**

- ✓ What is meant by basic human needs?
- ✓ What does it mean to live sustainably?
- ✓ What does an ecological footprint tell us? Why is it important to calculate?

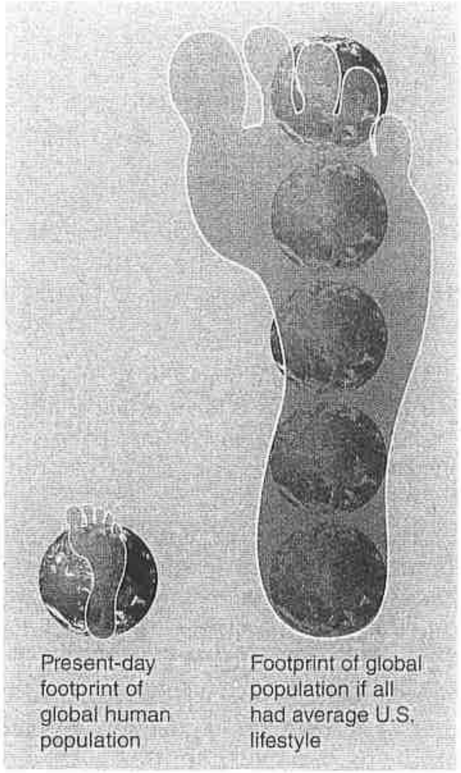



FIGURE 1.15 **The human footprint.** If all people worldwide lived the lifestyle of the average U.S. citizen, the human population would need five Earths to support its resource use.

## Science is a process

In the past century humans have learned a lot about the impact of their activities on the natural world. Scientific inquiry has provided great insights into the challenges we are facing and has suggested ways to address those challenges. For example, a hundred years ago, we did not know how significantly or rapidly we could alter the chemistry of the atmosphere by burning fossil fuels. Nor did we understand the effects of many common materials, such as lead and mercury, on human health. Much of our knowledge comes from the work of researchers who study a particular problem or situation to understand why it occurs and how we can fix or prevent it. We will now look at the process scientists use to ask and answer questions about the environment.

### The Scientific Method

To investigate the natural world, scientists like JoAnn Burkholder and her colleagues, who examined the large-scale fish kill in the Neuse River, have to be as objective and methodical as possible. They must conduct their research in such a way that other researchers can understand how their data were collected and agree on the validity of their findings. To do this, scientists follow a process known as the *scientific method*. The **scientific method** is an objective way to explore the natural world, draw inferences from it, and predict the outcome of certain events, processes, or changes. It is used in some form by scientists in all parts of the world and is a generally accepted way to conduct science.

As we can see in FIGURE 1.16, the scientific method has a number of steps, including *observations and questions, forming hypotheses, collecting data, interpreting results,* and *disseminating findings.*

**OBSERVATIONS AND QUESTIONS** JoAnn Burkholder and her team observed a mass die-off of fish in the Neuse River and wanted to know why it happened. Such observing and questioning is where the process of scientific research begins.

**FORMING HYPOTHESES** Observation and questioning lead a scientist to formulate a *hypothesis.* A **hypothesis** is a *testable* conjecture about how something works. It may be an idea, a proposition, a possible mechanism of interaction, or a statement about an effect. For example, we might hypothesize that when the air temperature rises, certain plant species will be more likely, and others less likely, to persist.

What makes a hypothesis testable? We can test the idea about the relationship between air temperature and plant species by growing plants in a greenhouse at different temperatures. "Fish kills are caused by something

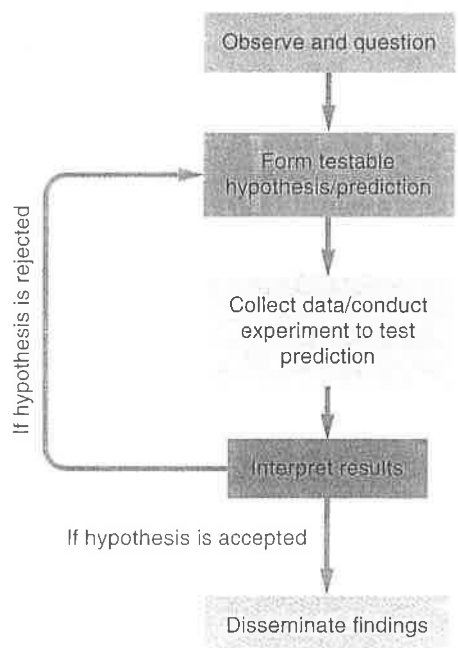



FIGURE 1.16 **The scientific method has a number of steps.** In an actual investigation, a researcher might reject a hypothesis and investigate further with a new hypothesis, several times if necessary, depending on the results of the experiment.

in the water" is a testable hypothesis: it speculates that there is an interaction between something in the water and the observed dead fish.

Sometimes it is easier to prove something wrong than to prove it is true beyond doubt. In this case, scientists use a *null hypothesis*. A **null hypothesis** is a statement or idea that can be falsified, or proved wrong. The statement "Fish deaths have no relationship to something in the water" is an example of a null hypothesis.

**COLLECTING DATA** Scientists typically take several sets of measurements—a procedure called **replication.** The number of times a measurement is replicated is the **sample size** (sometimes referred to as $n$). A sample size that is too small can cause misleading results. For example, if a scientist chose three men out of a crowd at random and found that they all had size 10 shoes, she might conclude that all men have a shoe size of 10. If, however, she chose a larger sample size—100 men—it is very unlikely that all 100 individuals would happen to have the same shoe size.

Proper procedures yield results that are accurate and precise. They also help us determine the possible relationship between our measurements or calculations and the true value. **Accuracy** refers to how close a measured value is to the actual or true value. For example, an environmental scientist might estimate how many songbirds of a particular species there are in an area of 1,000 ha by randomly sampling 10 ha and then projecting or extrapolating the result up to 1,000 ha. If the extrapolation is close to the true value, it is an accurate extrapolation. **Precision** is how close to one another the repeated measurements of the same sample are. In the same example, if the scientist counted birds five times on five different days and obtained five results that were similar to one another, the estimates would be precise. **Uncertainty** is an estimate of how much a measured or calculated value differs from a true value. In some cases, it represents the likelihood that additional repeated measurements will fall within a certain range. Looking at FIGURE 1.17, we see that high accuracy and high precision is the most desirable result.

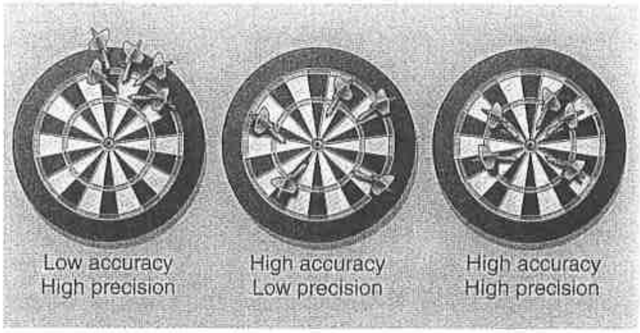



FIGURE 1.17 **Accuracy and precision.** Accuracy refers to how close a measured value is to the actual or true value. Precision is how close repeated measurements of the same sample are to one another.

**INTERPRETING RESULTS** We have followed the steps in the scientific method from making observations and asking questions, to forming a hypothesis, to collecting data. What happens next? Once results have been obtained, analysis of data begins. A scientist may use a variety of techniques to assist with data analysis, including summaries, graphs, charts, and diagrams.

As data analysis proceeds, scientists begin to interpret their results. This process normally involves two types of reasoning: *inductive* and *deductive.* **Inductive reasoning** is the process of making general statements from specific facts or examples. If the scientist who sampled a songbird species in the preceding example made a statement about all birds of that species, she would be using inductive reasoning. It might be reasonable to make such a statement if the songbirds that she sampled were representative of the whole population. **Deductive reasoning** is the process of applying a general statement to specific facts or situations. For example, if we know that, in general, air pollution kills trees, and we see a single, dead tree, we may attribute that death to air pollution. But a conclusion based on a single tree might be incorrect, since the tree could have been killed by something else, such as a parasite or fungus. Without additional observations or measurements, and possibly experimentation, the observer would have no way of knowing the cause of death with any degree of certainty.

The most careful scientists always maintain multiple working hypotheses; that is, they entertain many possible explanations for their results. They accept or reject certain hypotheses based on what the data show and do not show. Eventually, they determine that certain explanations are the most likely, and they begin to generate conclusions based on their results.

**DISSEMINATING FINDINGS** A hypothesis is never confirmed by a single experiment. That is why scientists not only repeat their experiments themselves, but also present papers at conferences and publish the results of their investigations. This dissemination of scientific findings allows other scientists to repeat the original experiment and verify or challenge the results. The process of science involves ongoing discussion among scientists, who frequently disagree about hypotheses, experimental conditions, results, and the interpretation of results. Two investigators may even obtain different results from similar measurements and experiments, as happened in the *Pfiesteria* case. Only when the same results are obtained over and over by different investigators can we begin to trust that those results are valid. In the meantime, the disagreements and discussion about contradictory findings are a valuable part of the scientific process. They help scientists refine their research to arrive at more consistent, reliable conclusions.

Like any scientist, you should always read reports of "exciting new findings" with a critical eye. Question the source of the information, consider the methods or processes that were used to obtain the information, and draw your own conclusions. This process, essential to all scientific endeavor, is known as **critical thinking.**

A hypothesis that has been repeatedly tested and confirmed by multiple groups of researchers and has reached wide acceptance becomes a **theory.** Current theories about how plant species distributions change with air temperature, for example, are derived from decades of research and evidence. Notice that this sense of *theory* is different from the way we might use the term in everyday conversation ("But that's just a theory!"). To be considered a theory, a hypothesis must be consistent with a large body of experimental results. A theory can not be contradicted by any replicable tests.

Scientists work under the assumption that the world operates according to fixed, knowable laws. We accept this assumption because it has been successful in explaining a vast array of natural phenomena and continues to lead to new discoveries. When the scientific process has generated a theory that has been tested multiple times, we can call that theory a *natural law.* A **natural law** is a theory to which there are no known exceptions and which has withstood rigorous testing. Familiar examples include the law of gravity and the laws of thermodynamics, which we will look at in the next chapter. These theories are accepted as fact by the scientific community, but they remain subject to revision if contradictory data are found.

## Case Study: The Chlorpyrifos Investigation

Let's look at what we have learned about the scientific method in the context of an actual scientific investigation. In the 1990s, scientists suspected that organophosphates—a group of chemicals commonly used in insecticides—might have serious effects on the human central nervous system. By the early part of the decade, scientists suspected that organophosphates might be linked to such problems as neurological disorders, birth defects, ADHD, and palsy. One of these chemicals, chlorpyrifos (klor-PEER-i-fos), was of particular concern because it is among the most widely used pesticides in the world, with large amounts applied in homes in the United States and elsewhere.

The researchers investigating the effects of chlorpyrifos on human health formulated a hypothesis: *chlorpyrifos causes neurological disorders and negatively affects human health.* Because this hypothesis would be hard to prove conclusively, the researchers also proposed a null hypothesis: *chlorpyrifos has no observable negative effects on the central nervous system.* We can follow the process of their investigation in FIGURE 1.18.

To test the null hypothesis, the scientists designed experiments using rats. One experiment used two groups of rats, with 10 individuals per group. The first group—the *experimental group*—was fed small doses of chlorpyrifos for each of the first 4 days of life. No chlorpyrifos was fed to the second group. That second group was a **control group:** a group that experiences exactly the same conditions as the experimental group, except for the single variable under study. In this experiment, the only difference between the control group and the

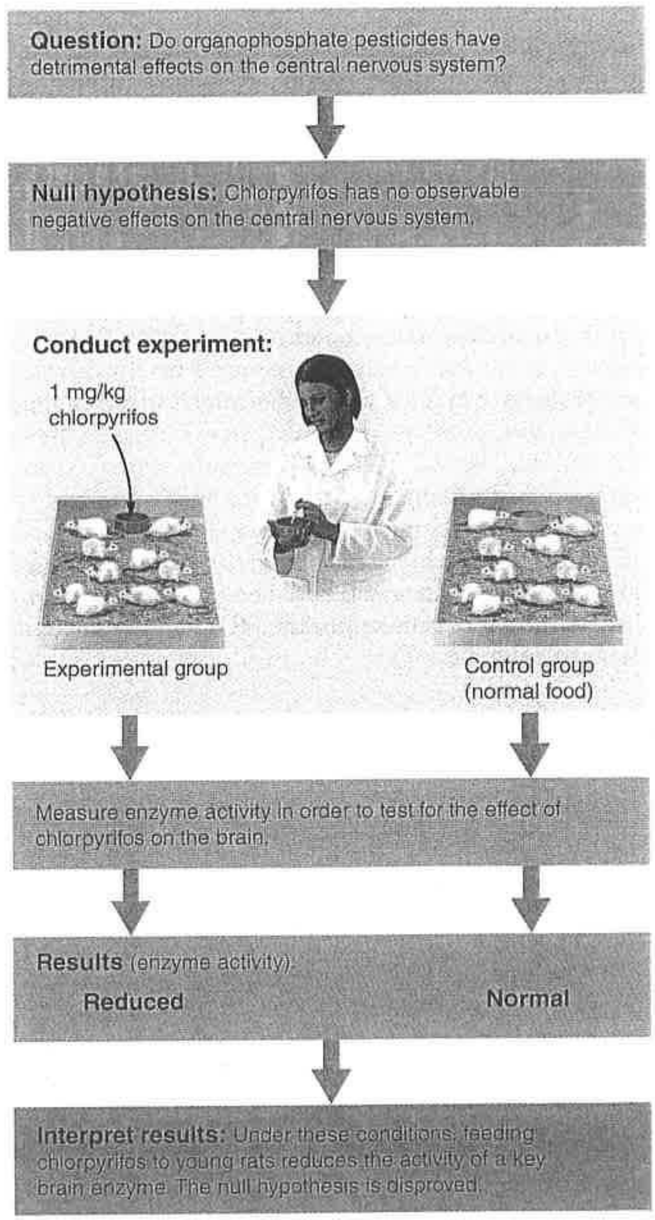



**FIGURE 1.18** **A typical experimental process.** An investigation of the effects of chlorpyrifos on the central nervous system illustrates how the scientific method is used.

experimental group was that the control group was not fed any chlorpyrifos. By designating a control group, scientists can determine whether an observed effect is the result of the experimental treatment or of something else in the environment to which all the subjects are exposed. For example, if the control rats—those that were not fed chlorpyrifos—and the experimental rats—that were exposed to chlorpyrifos—showed no differences in their brain chemistry, researchers could conclude that the chlorpyrifos had no effect. If the control group and experimental group had very different brain chemistry after the experiment, the scientists could conclude that the difference must have been due to the chlorpyrifos. At the end of the experiment, the researchers found that the rats exposed to chlorpyrifos had much lower levels of the enzyme choline acetyltransferase in their brains than the rats in the control group. But without a control group for comparison, the researchers would never have known whether the chlorpyrifos or something else caused the change observed in the experimental group.

The discovery of the relationship between ingesting chlorpyrifos and a single change in brain chemistry might seem relatively small. But that is how most scientific research works: very small steps establish that an effect occurs and, eventually, how it occurs. In this way, we progress toward a more thorough understanding of how the world works. This particular research on chlorpyrifos, combined with numerous other experiments testing specific aspects of the chemical's effect on rat brains, demonstrated that chlorpyrifos was capable of damaging developing rat brains at fairly low doses. The results of this research have been important for our understanding of human health and toxic substances in the environment.

## Controlled Experiments and Natural Experiments

The chlorpyrifos experiment we have just described was conducted in the controlled conditions of a laboratory. However, not all experiments can be done under such controlled conditions. For example, it would be difficult to study the interactions of wolves and caribou in a controlled setting because both species need large amounts of land and because their behavior changes in captivity. Other reasons that a controlled laboratory experiment may not be possible include prohibitive costs and ethical concerns.

Under these circumstances, investigators look for a *natural experiment*. A **natural experiment** occurs when a natural event acts as an experimental treatment in an ecosystem. For example, a volcano that destroys thousands of hectares of forest provides a natural experiment for understanding large-scale forest regrowth (**FIGURE 1.19**). We would never destroy that much forest just to study regrowth, but we can study such natural disasters


(a)

(b)

(c)

**FIGURE 1.19** **A natural experiment.** The Mount St. Helens eruption in 1980 created a natural experiment for understanding large-scale forest regrowth. (a) A pre-eruption forest near Mount St. Helens in 1979; (b) the same location, post-eruption, in 1982; (c) the same location in 2009 begins to show forest regrowth.

when they occur. Still other cases of natural experiments do not involve disasters. For example, we can study the process of ecological succession by looking at areas where forests have been growing for different amounts of time and comparing them. We can study the effects of species invasions by comparing uninvaded ecosystems with invaded ones.

Because a natural experiment is not controlled, many variables can change at once, and results can be difficult to interpret. Ideally, researchers compare multiple examples of similar systems in order to exclude the influences of different variables. For example, after a forest fire, researchers might not only observe how a burned forest responds to the disturbance, but also compare it with a nearby forest that did not burn. In this case, the researchers are comparing similar forests that differ in only one variable: fire. If, however, they tried to compare the burned forest with a different type of forest, perhaps one at a different elevation, it would be difficult to separate the effects of the fire from the effects of elevation. Still, because they may be the only way to obtain vital information, natural experiments are indispensable.

Returning to the study of chlorpyrifos, researchers wanted to know if human brains that were exposed to the chemical would react in the same way as rat brains. For obvious ethical reasons, researchers would never feed pesticides to humans to study their effects. Instead, they conducted a natural experiment. They looked for groups of people in similar circumstances (income, age, level of education) that varied mostly in their exposure to chlorpyrifos. That variation came from their use of pesticides containing chlorpyrifos, the frequency and location of that use, and the brand used. Researchers found that tissue concentrations of chlorpyrifos were highest in groups that worked with the chemical and among poor urban families whose exposure to residential pesticides was high. Among these populations, a number of studies connected exposure to chlorpyrifos with low birth weight and other developmental abnormalities.

### Science and Progress

The chlorpyrifos experiment is a good example of the process of science. Based on observations, the scientists proposed a hypothesis and null hypothesis. The null hypothesis was tested and rejected. Multiple rounds of additional testing gave researchers confidence in their understanding of the problem. Moreover, as the research progressed, the scientists informed the public, as well as the scientific community, about their results. Finally, in 2000, as a result of the step-by-step scientific investigation of chlorpyrifos, the U.S. Environmental Protection Agency (EPA) decided to prohibit its use for most residential applications. It also prohibited agricultural use on fruits that are eaten without peeling, such as apples and pears, or those that are especially popular with children, such as grapes.

**CHECKPOINT**

- ✓ What is the scientific method, and how do scientists use it to address environmental problems?
- ✓ What is a hypothesis? What is a null hypothesis?
- ✓ How are controlled and natural experiments different? Why do we need each type?

## Environmental science presents unique challenges

Environmental science has many things in common with other scientific disciplines. However, it presents a number of challenges and limitations that are not usually found in most other scientific fields. These challenges and limitations are a result of the nature of environmental science and the way research in the field is conducted.

### Lack of Baseline Data

The greatest challenge to environmental science is the fact that there is no undisturbed baseline—no "control planet"—with which to compare the contemporary Earth. Virtually every part of the globe has been altered by humans in some way (FIGURE 1.20). Even though some remote regions appear to be undisturbed, we can still find quantities of lead in the Greenland ice sheet, traces of the anthropogenic compound PCB in the fatty tissue of penguins in Antarctica, and invasive species from many locations carried by ship to remote tropical

**FIGURE 1.20** **Human impacts are global.** The trash washed up onto the beach of this remote Pacific island vividly demonstrates the difficulty of finding any part of Earth unaffected by human activities.

islands. This situation makes it difficult to know the original levels of contaminants or numbers of species that existed before humans began to alter the planet. Consequently, we can only speculate about how the current conditions deviate from those of pre-human activity.

## Subjectivity

A second challenge unique to environmental science lies in the dilemmas raised by subjectivity. For example, when you go to the grocery store, the bagger may ask, "Paper or plastic?" How can we know for certain which type of bag has the least environmental impact? There are techniques for determining what harm may come from using the petrochemical benzene to make a plastic bag and from using chlorine to make a paper bag. However, different substances tend to affect the environment differently: benzene may pose more of a risk to people, whereas chlorine may pose a greater risk to organisms in a stream. It is difficult, if not impossible, to decide which is better or worse for the environment overall. There is no single measure of environmental quality. Ultimately, our assessments and our choices involve value judgments and personal opinions.

## Interactions

A third challenge is the complexity of natural and human-dominated systems. All scientific fields examine interacting systems, but those systems are rarely as complex and as intertwined as they are in environmental science. Because environmental systems have so many interacting parts, the results of a study of one system cannot always be easily applied to similar systems elsewhere.

There are also many examples in which human preferences and behaviors have as much of an effect on environmental systems as the natural laws that describe them. For example, many people assume that if we built more efficient automobiles, the overall consumption of gasoline in the United States would decrease. To decrease gas consumption, however, it is necessary not only to build more efficient automobiles, but also to get people to purchase those vehicles and use them in place of less efficient ones. During the 1990s and early 2000s, even though there were many fuel-efficient cars available, the majority of buyers in the United States continued to purchase larger, heavier, and less fuel-efficient cars, minivans, light trucks, and sport-utility vehicles. Environmental scientists thought they knew how to reduce gasoline consumption, but they neglected to account for consumer behavior. Science is the search for natural laws that govern the world around us, whereas environmental science may involve politics, law, and economics as well as the traditional natural sciences. This complexity often makes environmental science challenging and its findings the subject of vigorous and lively debate.

## Human Well-Being

As we continue our study of environmental science, we will see that many of its topics touch on human well-being. In environmental science, we study how humans impact the biological systems and natural resources of the planet. We also study how changes in natural systems and the supply of natural resources affect humans.

We know that people who are unable to meet their basic needs are less likely to be interested in or able to be concerned about the state of the natural environment. The principle of *environmental equity*—the fair distribution of Earth's resources—adds a moral issue to questions raised by environmental science. Pollution and environmental degradation are inequitably distributed, with the poor receiving much more than an equal share. Is this a situation that we, as fellow humans, can tolerate? The ecological footprint and other environmental indicators show that it would be unsustainable for all people on the planet to live like the typical North American. But as more and more people develop an ability to improve their living conditions, how do we think about apportioning limited resources? Who has the right and the responsibility to make such decisions? **Environmental justice** is a social movement and field of study that works toward equal enforcement of environmental laws and the elimination of disparities, whether intended or unintended, in how pollutants and other environmental harms are distributed among the various ethnic and socioeconomic groups within a society (**FIGURE 1.21**).

Our society faces many environmental challenges. The loss of biodiversity, the growing human demand for

**FIGURE 1.21 A village on the outskirts of New Delhi, India.** The poor are exposed to a disproportionate amount of pollutants and other hazards. The people shown here are recycling circuit boards from discarded electronics products.

resources, and climate change are all complex problems. To solve them, we will need to apply thoughtful analysis, scientific innovation, and strategies that consider human behavior. Around the globe today, we can find people who are changing the way their governments work, changing the way they do business, and changing the way they live their lives, all with a common goal: they are working toward sustainability. Here, and at the end of each chapter of this book, we will tell a few of their stories.

**CHECKPOINT**

- In what ways is environmental science different from other sciences?
- Why (or when) is the lack of baseline data a problem in environmental science?
- What makes environmental systems so complex?



## WORKING TOWARD SUSTAINABILITY

### Using Environmental Indicators to Make a Better City

We have seen that environmental indicators can be used to monitor conditions across a range of scales, from local to global. They are also being used by people looking for ways to apply environmental science to the urban planning process in countries as diverse as China, Brazil, and the United States.

San Francisco, California, is one example. In 1997, the city adopted a sustainability plan to go along with its newly formed Department of the Environment. The San Francisco Sustainability Plan focuses on 10 environmental concerns:

- Air quality
- Biodiversity
- Energy, climate change, and ozone depletion
- Food and agriculture
- Hazardous materials
- Human health
- Parks, open spaces, and streetscapes
- Solid waste
- Transportation
- Water and wastewater

Although some of these topics may not seem like components of urban planning, the drafters of the plan recognized that the everyday choices of city dwellers can have wide-ranging environmental impacts, both in and beyond the city. For example, purchasing local produce or organic food affects the environments and economies of both San Francisco and the agricultural areas that serve it.

For each of the 10 environmental concerns, the sustainability plan sets out a series of 5-year and long-term objectives as well as specific actions required to achieve them. These actions include public education through information sources such as Web sites and newsletters and hands-on activities such as replacing non-native plants with native trees and shrubs.

To monitor the effectiveness of the various actions, San Francisco chose specific environmental indicators for each of the 10 environmental concerns. These indicators had to indicate a clear trend toward or away from environmental sustainability, demonstrate cost-effectiveness, be understandable to the nonscientist, and be easily presented to the media. For example, to evaluate biodiversity, San Francisco uses four indicators:

| Environmental indicator | Desired trend |
|---|---|
| Number of volunteer hours dedicated to managing, monitoring, and conserving San Francisco's biodiversity | INCREASING |
| Number of square feet of the worst non-native species removed from natural areas | INCREASING |
| Number of surviving native plant species planted in developed parks, private landscapes, and natural areas | INCREASING |
| Abundance and species diversity of birds, as indicated by the Golden Gate Audubon Society's Christmas bird counts | INCREASING |

Together, these indicators provide a relatively inexpensive and simple way to summarize the level of biodiversity, the threat to native biodiversity from non-native species, and the amount of effort going into biodiversity protection.

More than 13 years later, what do the indicators show? In general, there has been a surprising amount of improvement. For example, in the category of solid waste, San Francisco has increased the amount of waste

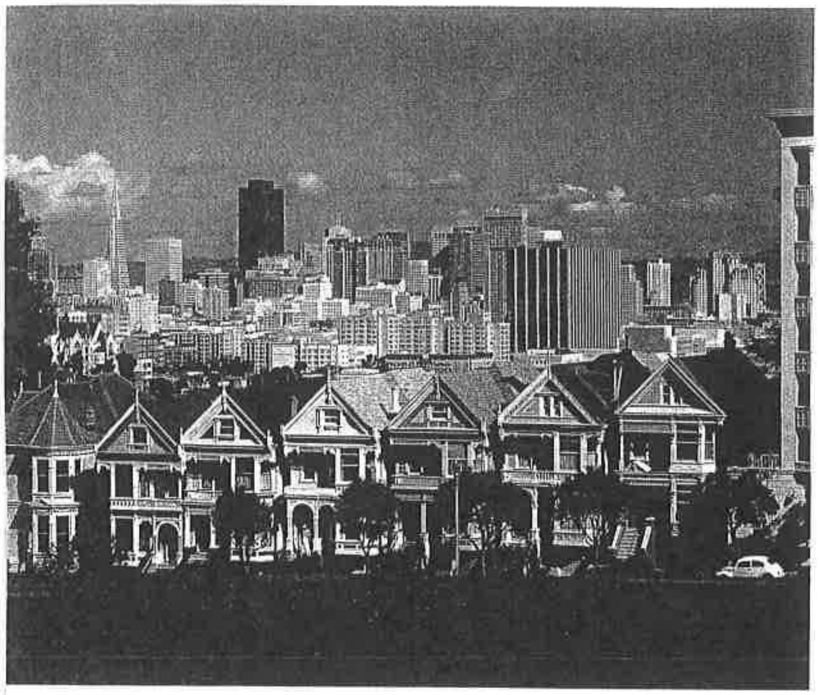


**FIGURE 1.22** **A "green" city.** San Francisco's adoption of environmental indicators has helped it achieve many of its sustainability goals.

recycled from 30 to 70 percent, with a goal of 75 percent by 2020, and it now has the largest urban composting program in the country. San Francisco has also improved its air quality, reducing the number of days in which fine particulate matter exceeded the EPA air quality safe level, from 27 days in 2000 to 10 days in 2006. These and other successes have won the city numerous accolades: it has been selected as one of "America's Top Five Cleanest Cities" by *Reader's Digest* and as one of the "Top 10 Green Cities" by *The Green Guide*. In 2005, San Francisco was named the most sustainable city in the United States by SustainLane (FIGURE 1.22).


**Reference**

www.sustainlane.com.


## KEY IDEAS REVISITED

- **Define the field of environmental science and discuss its importance.**

Environmental science is the study of the interactions among human-dominated systems and natural systems and how those interactions affect environments. Studying environmental science helps us identify, understand, and respond to anthropogenic changes.

- **Identify ways in which humans have altered and continue to alter our environment.**

The impact of humans on natural systems has been significant since early humans hunted some large animal species to extinction. However, technology and population growth have dramatically increased both the rate and the scale of human-induced change.

- **Describe key environmental indicators that help us evaluate the health of the planet.**

Five important global-scale environmental indicators are biological diversity, food production, average global surface temperature and atmospheric $CO_2$ concentrations, human population, and resource depletion.

- **Define sustainability and explain how it can be measured using the ecological footprint.**

Sustainability is the use of Earth's resources to meet our current needs without jeopardizing the ability of future generations to meet their own needs. The ecological footprint is the land area required to support a person's (or a country's) lifestyle. We can use that information to say something about how sustainable that lifestyle would be if it were adopted globally.

- **Explain the scientific method and its application to the study of environmental problems.**

The scientific method is a process of observation, hypothesis generation, data collection, analysis of results, and dissemination of findings. Repetition of measurements or experiments is critical if one is to determine the validity of findings. Hypotheses are tested and often modified before being accepted.

- **Describe some of the unique challenges and limitations of environmental science.**

We lack an undisturbed "control planet" with which to compare conditions on Earth today. Assessments and choices are often subjective because there is no single measure of environmental quality. Environmental systems are so complex that they are poorly understood, and human preferences and policies may have as much of an effect on them as natural laws.

## PREPARING FOR THE AP EXAM

## MULTIPLE-CHOICE QUESTIONS

1. Which of the following events has increased the impact of humans on the environment?
   I Advances in technology
   II Reduced human population growth
   III Use of tools for hunting
   (a) I only
   (b) I and II only
   (c) II and III only
   (d) I and III only
   (e) I, II, and III

2. As described in this chapter, environmental indicators
   (a) always tell us what is causing an environmental change.
   (b) can be used to analyze the health of natural systems.
   (c) are useful only when studying large-scale changes.
   (d) do not provide information regarding sustainability.
   (e) take into account only the living components of ecosystems.

3. Which statement regarding a global environmental indicator is *not* correct?
   (a) Concentrations of atmospheric carbon dioxide have been rising quite steadily since the Industrial Revolution.
   (b) World grain production has increased fairly steadily since 1950, but worldwide production of grain per capita has decreased dramatically over the same period.
   (c) For the past 130 years, average global surface temperatures have shown an overall increase that seems likely to continue.
   (d) World population is expected to be between 8.1 billion and 9.6 billion by 2050.
   (e) Some natural resources are available in finite amounts and are consumed during a one-time use, whereas other finite resources can be used multiple times through recycling.

4. Figure 1.8 (on page 10) shows atmospheric carbon dioxide concentrations over time. The measured concentration of $CO_2$ in the atmosphere is an example of
   (a) a sample of air from over the Antarctic.
   (b) an environmental indicator.
   (c) replicate sampling.
   (d) calculating an ecological footprint.
   (e) how to study seasonal variation in Earth's temperatures.

5. In science, which of the following is the most certain?
   (a) Hypothesis
   (b) Idea
   (c) Natural law
   (d) Observation
   (e) Theory

6. All of the following would be exclusively caused by anthropogenic activities *except*
   (a) combustion of fossil fuels.
   (b) overuse of resources such as uranium.
   (c) forest clearing for crops.
   (d air pollution from burning oil.
   (e) forest fires.

7. Use Figure 1.6 (on page 9) to calculate the approximate percentage change in world grain production per person between 1950 and 2000.
   (a) 10 percent
   (b) 20 percent
   (c) 30 percent
   (d) 40 percent
   (e) 50 percent

8. The populations of some endangered animal species have stabilized or increased in numbers after human intervention. An example of a species that is still endangered and needs further assistance to recover is the
   (a) American bison.
   (b) peregrine falcon.
   (c) bald eagle.
   (d) American alligator.
   (e) snow leopard.

*Questions 9 and 10 refer to the following experimental scenario:*

An experiment was performed to determine the effect of caffeine on the pulse rate of five healthy 18-year-old males. Each was given 250 mL of a beverage with or without caffeine. The men had their pulse rates measured before they had the drink (time 0 minutes) and again after they had been sitting at rest for 30 minutes after consuming the drink. The results are shown in the following table.

| Subject | Beverage | Caffeine content (mg/serving) | Pulse rate at time 0 minutes | Pulse rate at time 30 minutes |
|---|---|---|---|---|
| 1 | Water | 0 | 60 | 59 |
| 2 | Caffeine-free soda | 0 | 55 | 56 |
| 3 | Caffeinated soda | 10 | 58 | 68 |
| 4 | Coffee, decaffeinated | 3 | 62 | 67 |
| 5 | Coffee, regular | 45 | 58 | 81 |

9. Before the researchers began the experiment, they formulated a null hypothesis. The best null hypothesis for the experiment would be that caffeine
   (a) has no observable effect on the pulse rate of an individual.
   (b) will increase the pulse rates of all test subjects.
   (c) will decrease the pulse rates of all test subjects.
   (d) has no observable effects on the pulse rates of 18-year-old males.
   (e) from a soda will have a greater effect on pulse rates than caffeine from coffee.

10. After analyzing the results of the experiment, the most appropriate conclusion would be that caffeine
   (a) increased the pulse rates of the 18-year-old males tested.
   (b) decreased the pulse rates of the 18-year-old males tested.
   (c) will increase the pulse rate of any individual that is tested.
   (d) increases the pulse rate and is safe to consume.
   (e) makes drinks better than decaffeinated beverages.

## FREE-RESPONSE QUESTIONS

1. Your neighbor has fertilized her lawn. Several weeks later, she is alarmed to see that the surface of her ornamental pond, which sits at the bottom of the sloping lawn, is covered with a green layer of algae.
   (a) Suggest a feasible explanation for the algal bloom in the pond. (2 points)
   (b) Design an experiment that would enable you to validate your explanation. (7 points) Include and label in your answer:
      (i) a testable hypothesis. (2 points)
      (ii) the variable that you will be testing. (1 point)
      (iii) the data to be collected. (1 point)
      (iv) a description of the experimental procedure. (2 points)
      (v) a description of the results that would validate your hypothesis. (1 point)
   (c) Based on the data from your experiment and your explanation of the problem, think of, and suggest, one action that your neighbor could take to help the pond recover. (1 point)

2. The study of environmental science sometimes involves examining the overuse of environmental resources.
   (a) Identify one general effect of overuse of an environmental resource. (3 points)
   (b) For the effect you listed above, describe a more sustainable strategy for resource utilization. (3 points)
   (c) Describe how the events from Easter Island can be indicative of environmental issues on Earth today. (4 points)

## MEASURING YOUR IMPACT

**Exploring Your Footprint** Make a list of the activities you did today and attempt to describe their impact on the five global environmental indicators described in this chapter. For each activity, such as eating lunch or traveling to school, make as complete a list as you can of the resources and fuels that went into the activity and try to determine the impacts of using those resources.

After completing your inventory, visit the Web site of the Global Footprint Network (www.footprintnetwork.org) and complete the personal footprint calculator. Compare the impacts you described with the impacts you are asked to identify in the personal footprint calculator.

## EXPLORING THE LITERATURE


Meadows, D. H., J. Randers, and D. L. Meadows. 2004. *Limits to Growth: The 30-Year Update.* Chelsea Green. See also http://www.sustainer.org/.

United Nations Development Programme. 2006. *Human Development Report 2006.* Oxford University Press.

*Vital Signs, 2009.* Worldwatch Institute.

Wackernagel, M., et al. 2004. *Ecological Footprint and Biocapacity Accounts 2004: The Underlying Calculation Method.* Global Footprint Network. www.footprintnetwork.org.

# Environmental Systems

## A Lake of Salt Water, Dust Storms, and Endangered Species

Located between the deserts of the Great Basin and the mountains of the Sierra Nevada, California's Mono Lake is an unusual site. It is characterized by eerie tufa towers of limestone rock, unique animal species, glassy waters, and frequent dust storms. Mono Lake is a *terminal lake*, which means that water flows into it, but does not flow out. As water moves through the mountains and desert soil, it picks up salt and other minerals, which it deposits in the lake. As the water evaporates, these minerals are left behind. Over time, evaporation has caused a buildup of salt concentrations so high that the lake is actually saltier than the ocean, and no fish can survive in its water.

The Mono brine shrimp (*Artemia monica*) and the larvae of the Mono Lake alkali fly (*Ephydra hians*) are two of only a few animal species that can tolerate the conditions of the lake. The brine shrimp and the fly larvae consume microscopic algae, millions of tons of which grow in the lake each year. In turn, large flocks of migrating birds, such as sandpipers, gulls, and flycatchers, use the lake as a stopover, feeding on the brine shrimp and fly larvae to replenish their energy stores. The lake is an oasis on the migration route for these birds. They have come to depend on its food and water resources. The health of Mono Lake is therefore critical for many species.

In 1913, the city of Los Angeles drew up a controversial plan to redirect water away from Mono Lake and its neighbor, the larger and shallower Owens Lake. Owens Lake was diverted first, via a 359 km (223-mile) aqueduct that drew water away from the springs and streams that kept Owens Lake full. Soon, the lake began to dry up, and by the 1930s, only an empty salt flat remained. Today the dry lake bed covers roughly 440 km$^2$ (109,000 acres). It is one of the nation's largest sources of windblown dust, which lowers visibility in the area's national parks. Even worse, because of the local geology, the dust contains high concentrations of arsenic—a major threat to human health.

In 1941, despite the environmental degradation at Owens Lake, Los Angeles extended the aqueduct to draw water from the streams feeding Mono Lake. By 1982, with less fresh water feeding the lake, its depth had decreased by half, to an average of 14 m (45 feet), and the salinity of the water had doubled to more than twice that of the ocean. The salt killed the lake's algae. Without algae to eat, the Mono brine shrimp also died. Most birds stayed away, and newly exposed land bridges allowed coyotes from the desert to prey on those colonies of nesting birds that remained.

**Just when it appeared that Mono Lake would not recover, circumstances changed.**

However, just when it appeared that Mono Lake would not recover, circumstances changed. In 1994, after years of litigation led by the National Audubon Society and tireless work by environmentalists, the Los Angeles Department of Water and Power agreed to reduce the amount of water it diverted and allow the lake to refill to about two-thirds of its historical depth. By summer 2009, lake levels had risen to just short of that goal, and the ecosystem was slowly recovering. Today brine shrimp are thriving, and many birds are returning to Mono Lake. ▶

A California gull feeding on alkali flies.

◀ Tufa towers rise out of the salty water of Mono Lake.

Water is a scarce resource in the Los Angeles area, and demand there is particularly high. To decrease the amount of water diverted from Mono Lake, the city of Los Angeles had to reduce its water consumption. The city converted water-demanding grass lawns to drought-tolerant native shrubs, and it imposed new rules requiring low-flow shower heads and water-saving toilets. Through these seemingly small, but effective, measures, Los Angeles inhabitants were able to cut their water consumption and, in turn, protect nesting birds, Mono brine shrimp, and algae populations, as well as the rest of the Mono Lake ecosystem.

*Sources:* J. Kay, It's rising and healthy, *San Francisco Chronicle*, July 29, 2006; Mono Lake Committee, Mono Lake (2010), http://www.monolake.org/.

## KEY IDEAS

Most problems of interest to environmental scientists involve more than one organism and more than one physical factor. Organisms, nonliving matter, and energy all interact in natural systems. Taking a systems approach to an environmental issue, rather than focusing on only one piece of the puzzle, decreases the chance of overlooking important components of that issue.

After reading this chapter you should be able to

- define *systems* within the context of environmental science.
- explain the components and states of matter.
- distinguish between various forms of energy and discuss the first and second laws of thermodynamics.
- describe the ways in which ecological systems depend on energy inputs.
- explain how scientists keep track of inputs, outputs, and changes to complex systems.
- describe how natural systems change over time and space.

# Earth is a single interconnected system

The story of Mono Lake shows us that the activities of humans, the lives of other organisms, and processes in the environment are interconnected. Humans, water, animals, plants, and the desert environment all interact at Mono Lake to create a complex environmental system. The story also demonstrates a key principle of environmental science: that a change in any one factor can have other, often unexpected, effects.

In Chapter 1, we learned that a system is a set of interacting components connected in such a way that a change in one part of the system affects one or more other parts of the system. The Mono Lake system is relatively small. Other complex systems exist on a much larger scale.

A large system may contain many smaller systems within it. FIGURE 2.1 shows an example of complex, interconnecting systems that operate at multiple space and time scales: the fisheries of the North Atlantic. A physiologist who wants to study how codfish survive in the North Atlantic's freezing waters must consider all the biological adaptations of the cod to be part of one system. In this case, the fish and its internal organs are the system being studied. In the same environment, a marine biologist might study the predator-prey relationship between cod and herring. That relationship constitutes another system, which includes two fish species and the environment they live in. At an even larger scale, an oceanographer might focus on how ocean currents in a particular area affect the dispersal of cod and other fish species. A fisheries management official might study a system that includes all of the systems above as well as people, fishing technology, policy, and law.

The largest system that environmental science considers is Earth. Many of our most important current environmental issues—including human population growth and climate change—exist at the global scale. Throughout this book we will define a given system in terms of the environmental issue we are studying and the scale in which we are interested.

Whether we are investigating ways to reduce pollution, increase food supplies, or find alternatives to fossil fuels, environmental scientists must have a thorough understanding of matter and energy and their interactions within and across systems. We will begin this chapter by exploring the properties of matter. We will then discuss the various types of energy and how they influence and limit systems.

**CHECKPOINT**

- ✓ What is an environmental system? Name some examples.
- ✓ How do systems vary in scale, and how does a large system include a smaller system?
- ✓ What are the largest systems in the Mono Lake ecosystem? What are some examples of smaller systems within that system?

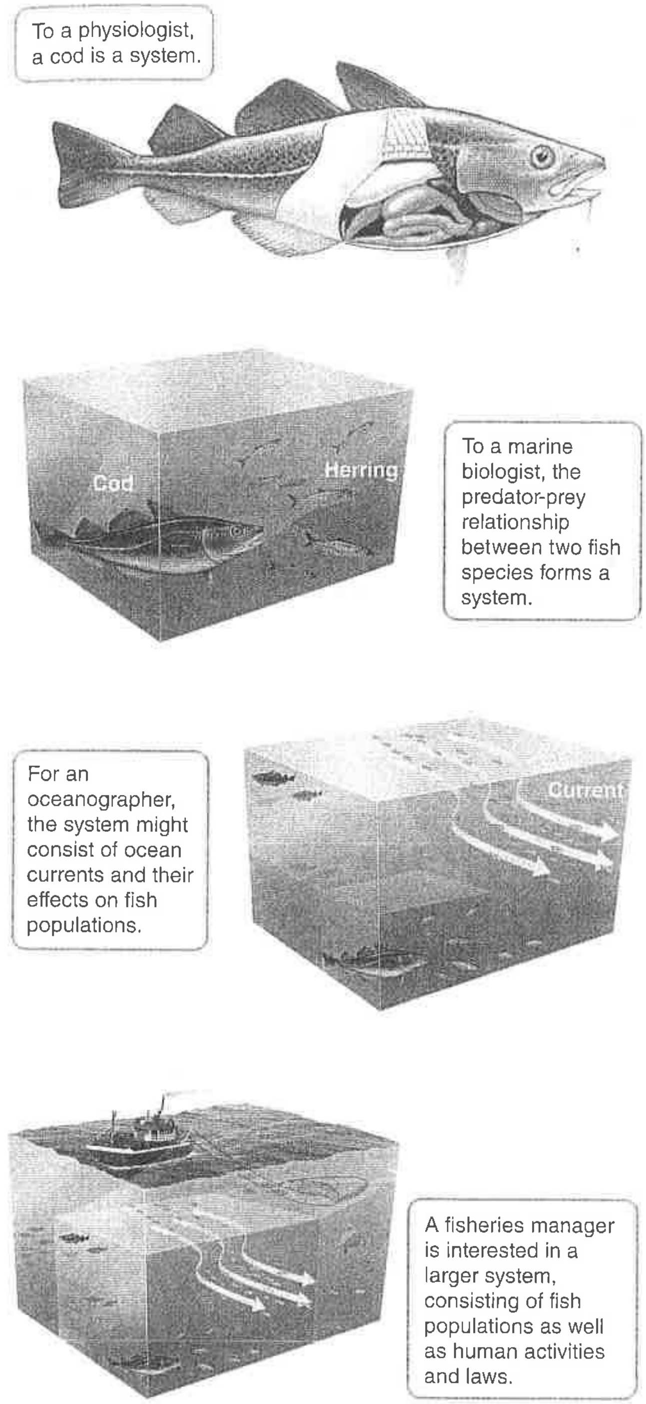



FIGURE 2.1 **Systems within systems.** The boundaries of an environmental system may be defined by the researcher's point of view. Physiologists, marine biologists, oceanographers, and fisheries managers would describe the North Atlantic Ocean fisheries system differently.

# All environmental systems consist of matter

What do rocks, water, air, the book in your hands, and the cells in your body have in common? They are all forms of *matter*. **Matter** is anything that occupies space and has *mass*. The **mass** of an object is defined as a measure of the amount of matter it contains. Note that the words *mass* and *weight* are often used interchangeably, but they are not the same thing. Weight is the force that results from the action of gravity on mass. Your own weight, for example, is determined by the amount of gravity pulling you toward the planet's center. Whatever your weight is on Earth, you would have a lesser weight on the Moon, where the action of gravity is less. In contrast, mass stays the same no matter what gravitational influence is acting on an object. So although your weight would change on the Moon, your mass would remain the same because the amount of matter you are made of would be the same.

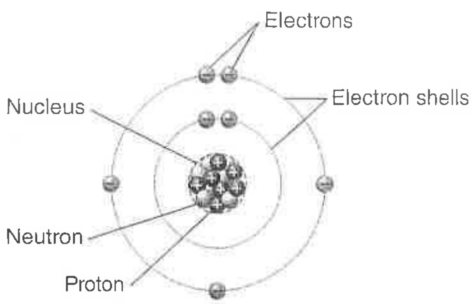
## Atoms and Molecules

All matter is composed of tiny particles that cannot be broken down into smaller pieces. The basic building blocks of matter are known as atoms. An **atom** is the smallest particle that can contain the chemical properties of an element. An **element** is a substance composed of atoms that cannot be broken down into smaller, simpler components. At Earth's surface temperatures, elements can occur as solids (such as gold), liquids (such as bromine), or gases (such as helium). Atoms are so small that a single human hair measures about a few hundred thousand carbon atoms across.

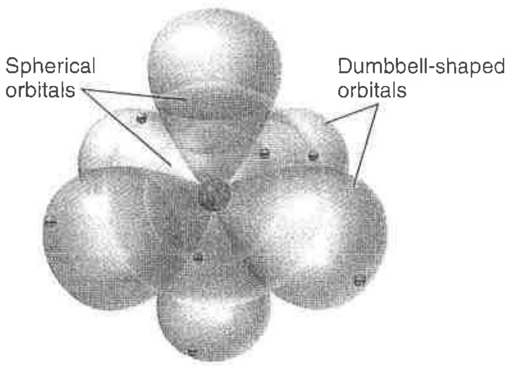
Ninety-four elements occur naturally on Earth, and another 24 have been produced in laboratories. The **periodic table** lists all of the elements currently known. (For a copy of the periodic table, turn to Appendix A.) Each element is identified by a one- or two-letter symbol; for example, the symbol for carbon is C, and the symbol for oxygen is O. These symbols are used to describe the atomic makeup of **molecules,** which are particles containing more than one atom. Molecules that contain more than one element are called **compounds.** For example, a carbon dioxide molecule ($CO_2$) is a compound composed of one carbon atom (C) and two oxygen atoms ($O_2$).

As we can see in FIGURE 2.2a, every atom has a *nucleus,* or core, which contains protons and neutrons. Protons and neutrons have roughly the same mass—both minutely small. Protons have a positive electrical charge, like the "plus" side of a battery. The number of protons in the nucleus of a particular element—called the **atomic number**—is unique to that element. Neutrons have no electrical charge, but they are critical to the stability of nuclei because they keep the positively charged protons together. Without them, the protons would repel one another and separate.

As FIGURE 2.2b shows, the space around the nucleus of the atom is not empty. In this space, electrons exist in *orbitals,* which are electron clouds that extend different distances from the nucleus. Electrons are negatively




(a) Nitrogen atom with electrons shown in shells




(b) Nitrogen atom with electrons in orbitals

**FIGURE 2.2 Structure of the atom.** An atom is composed of protons, neutrons, and electrons. Neutrons and positively charged protons make up the nucleus. Negatively charged electrons surround the nucleus. (a) Moving electrons are commonly represented in shells. (b) In reality, however, they exist in complex orbitals.

charged, like the "minus" side of a battery, and have a much smaller mass than protons or neutrons. In the molecular world, opposites always attract, so negatively charged electrons are attracted to positively charged protons. This attraction binds the electrons to the nucleus. In a neutral atom, the numbers of protons and electrons are equal. The distribution of electrons in an orbital, particularly the outermost part of the orbital, greatly contributes to the atom's chemical characteristics. In any electron orbital, there can be only a certain number of electrons.

The total number of protons and neutrons in an element is known as its **mass number.** Because the mass of an electron is insignificant compared with the mass of a proton or neutron, we do not include electrons in mass number calculations.

Although the number of protons in a chemical element is constant, atoms of the same element may have different numbers of neutrons, and therefore different mass numbers. These various kinds of atoms are called **isotopes.** Isotopes of the element carbon, for example, all have six protons, but can occur with six, seven, or eight neutrons, yielding mass numbers of 12, 13, or 14, respectively. In the natural environment, carbon occurs as a mixture of carbon isotopes. All carbon isotopes behave the same chemically. However, biological processes sometimes favor one isotope over another. Thus certain isotopic "signatures" (that is, different ratios of isotopes) can be left behind by different biological processes. These signatures allow environmental scientists to learn about certain processes by determining the proportions of different isotopes in soil, air, water, or ice.

## Radioactivity

The nuclei of isotopes can be stable or unstable, depending on the mass number of the isotope and the number of neutrons it contains. Unstable isotopes are *radioactive.*

Radioactive isotopes undergo **radioactive decay,** the spontaneous release of material from the nucleus. Radioactive decay changes the radioactive element into a different element. For example, uranium-235 ($^{235}U$) decays to form thorium-231 ($^{231}Th$). The original atom (uranium) is called the *parent* and the resulting decay product (thorium) is called the *daughter.* The radioactive decay of $^{235}U$ and certain other elements emits a great deal of energy that can be captured as heat. Nuclear power plants use this heat to produce steam that turns turbines to generate electricity.

We measure radioactive decay by recording the average rate of decay of a quantity of a radioactive element. This measurement is commonly stated in terms of the element's **half-life:** the time it takes for one-half of the original radioactive parent atoms to decay. An element's half-life is a useful parameter to know because some elements that undergo radioactive decay emit harmful radiation. Knowledge of the half-life allows scientists to determine the length of time that a particular radioactive element may be dangerous. For example, using the half-life allows scientists to calculate the period of time that people and the environment must be protected from depleted nuclear fuel, like that generated by a nuclear power plant. As it turns out, many of the elements produced during the decay of $^{235}U$ have half-lives of tens of thousands of years and more. From this we can see why long-term storage of radioactive nuclear waste is so important.

The measurement of isotopes has many applications in environmental science as well as in other scientific fields. For example, carbon in the atmosphere exists in a known ratio of the isotopes carbon-12 (99 percent), carbon-13 (1 percent), and carbon-14 (which occurs in trace amounts, on the order of one part per trillion). Carbon-14 is radioactive and has a half-life of 5,730 years. Carbon-13 and carbon-12 are stable isotopes. Living organisms incorporate carbon into their tissues at roughly the known atmospheric ratio. But after an organism dies, it stops incorporating new carbon into its tissues. Over time, the radioactive carbon-14 in the organism decays to nitrogen-14. By calculating the proportion of carbon-14 in dead biological material—a technique called *carbon dating*—researchers can determine how many years ago an organism died.

## Chemical Bonds

We have seen that matter is composed of atoms, which form molecules or compounds. In order to form molecules or compounds, atoms must be able to interact or join together. This happens by means of chemical bonds of various types. Chemical bonds fall into three categories: *covalent bonds, ionic bonds,* and *hydrogen bonds.*

**COVALENT BONDS** Elements that do not readily gain or lose electrons form compounds by sharing electrons. These compounds are said to be held together by **covalent bonds.** FIGURE 2.3 illustrates the covalent bonds in a molecule of methane ($CH_4$, also called *natural gas*). A methane molecule is made up of one carbon (C) atom surrounded by four hydrogen (H) atoms. Covalent bonds form between the single carbon atom and each hydrogen atom. Covalent bonds also hold the two hydrogen atoms and the oxygen atom in a water molecule together.

**IONIC BONDS** In a covalent bond, atoms share electrons. Another kind of bond between two atoms involves the transfer of electrons. When such a transfer happens, one atom becomes electron deficient (positively charged), and the other becomes electron rich (negatively charged). This charge imbalance holds the two atoms together. The charged atoms are called *ions,* and the attraction between oppositely charged ions forms a chemical bond called an **ionic bond.** FIGURE 2.4 shows an example of this process. Sodium (Na) donates one electron to chlorine (Cl), which gains one electron, to form sodium chloride (NaCl), or table salt.

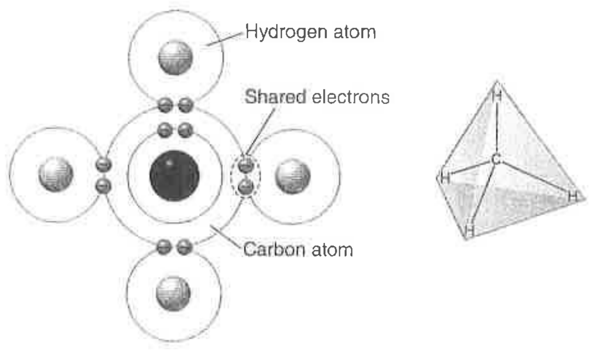



**FIGURE 2.3** **Covalent bonds.** Molecules such as methane ($CH_4$) are associations of atoms held together by covalent bonds, in which electrons are shared between the atoms. As a result of the four hydrogen atoms sharing electrons with a carbon atom, each atom has a complete set of electrons in its outer shell—two for the hydrogen atoms and eight for the carbon atom.

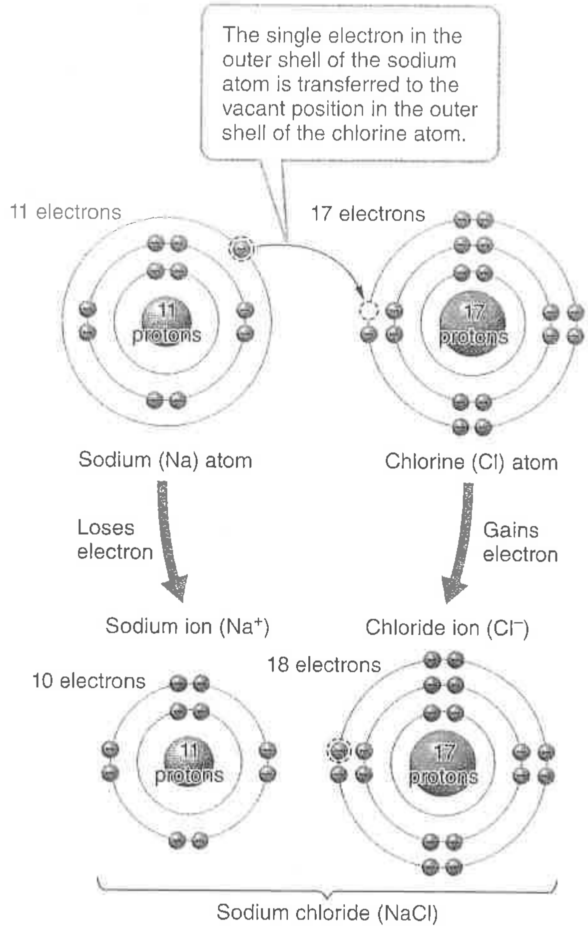



**FIGURE 2.4** **Ions and ionic bonds.** A sodium atom and a chlorine atom can readily form an ionic bond. The sodium atom loses an electron, and the chlorine atom gains one. As a result, the sodium atom becomes a positively charged ion ($Na^+$) and the chlorine atom becomes a negatively charged ion ($Cl^-$, known in ionic form as chloride). The attraction between the oppositely charged ions—an ionic bond—forms sodium chloride (NaCl), or table salt.

An ionic bond is not usually as strong as a covalent bond. This means that the compound can readily dissolve. As long as sodium chloride remains in a salt shaker, it remains in solid form. But if you shake some into water, the salt dissolves into sodium and chloride ions ($Na^+$ and $Cl^-$).

**HYDROGEN BONDS** The third type of chemical bond is weaker than either covalent or ionic bonds. A **hydrogen bond** is a weak chemical bond that forms when hydrogen atoms that are covalently bonded to one atom are attracted to another atom on another molecule. When atoms of different elements form bonds, their electrons may be shared unequally; that is, shared electrons may be pulled closer to one atom than to the other. In some cases, the strong attraction of the hydrogen electron to other atoms creates a charge imbalance within the covalently bonded molecule.

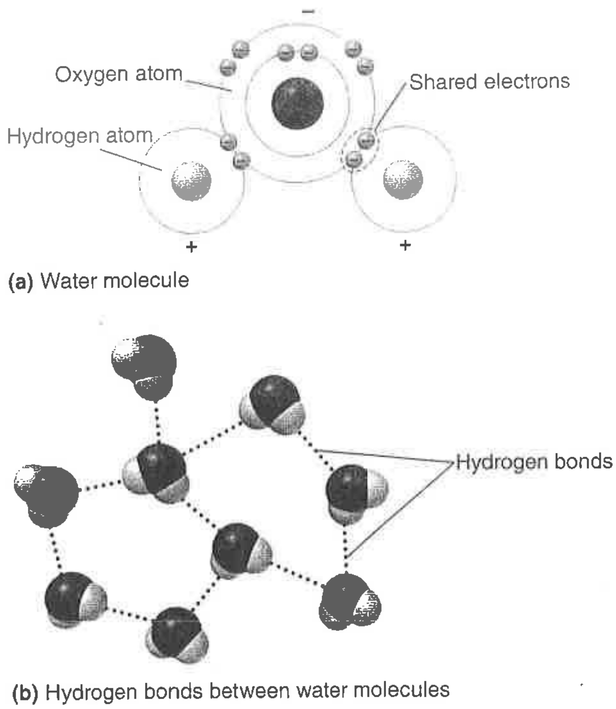



**FIGURE 2.5 The polarity of the water molecule allows it to form hydrogen bonds.** (a) Water ($H_2O$) consists of two hydrogen atoms covalently bonded to one oxygen atom. Water is a polar molecule because its shared electrons spend more time near the oxygen atom than near the hydrogen atoms. The hydrogen atoms thus have a slightly positive charge, and the oxygen atom has a slightly negative charge. (b) The slightly positive hydrogen atoms are attracted to the slightly negative oxygen atom of another water molecule. The result is a hydrogen bond between the two molecules.

Looking at FIGURE 2.5a, we see that water is an excellent example of this type of asymmetric electron distribution. Each water molecule as a whole is neutral; that is, it carries neither a positive nor a negative charge. But water has unequal covalent bonds between its two hydrogen atoms and one oxygen atom. Because of these unequal bonds and the angle formed by the H-O-H bonds, water is known as a *polar* molecule. In a **polar molecule,** one side is more positive and the other side is more negative. We can see the result in FIGURE 2.5b: a hydrogen atom in a water molecule is attracted to the oxygen atom in a nearby water molecule. That attraction forms a hydrogen bond between the two molecules.

By allowing water molecules to link together, hydrogen bonding gives water a number of unusual properties. Hydrogen bonds also occur in nucleic acids such as DNA, the biological molecule that carries the genetic code for all organisms.

## Properties of Water

The molecular structure of water gives it unique properties that support the conditions necessary for life on Earth. Among these properties are surface tension, capillary action, a high boiling point, and the ability to dissolve many different substances—all essential to physiological functioning.

**SURFACE TENSION AND CAPILLARY ACTION** We don't generally think of water as being sticky, but hydrogen bonding makes water molecules stick strongly to one another (*cohesion*) and to certain other substances (*adhesion*). The ability to cohere or adhere underlies two unusual properties of water: *surface tension and capillary action*.

**Surface tension,** which results from the cohesion of water molecules at the surface of a body of water, creates a sort of skin on the water's surface. Have you ever seen an aquatic insect, such as a water strider, walk across the surface of the water? This is possible because of surface tension (FIGURE 2.6). Surface tension also makes water droplets smooth and more or less spherical as they cling to a water faucet before dropping.

**Capillary action** happens when adhesion of water molecules to a surface is stronger than cohesion between the molecules. The absorption of water by a paper towel or a sponge is the result of capillary action. This property is important in thin tubes, such as the water-conducting vessels in tree trunks, and in small pores in soil. It is also important in the transport of underground water, as well as dissolved pollutants, from one location to another.

**BOILING AND FREEZING** At the atmospheric pressures found at Earth's surface, water boils (becomes a gas) at

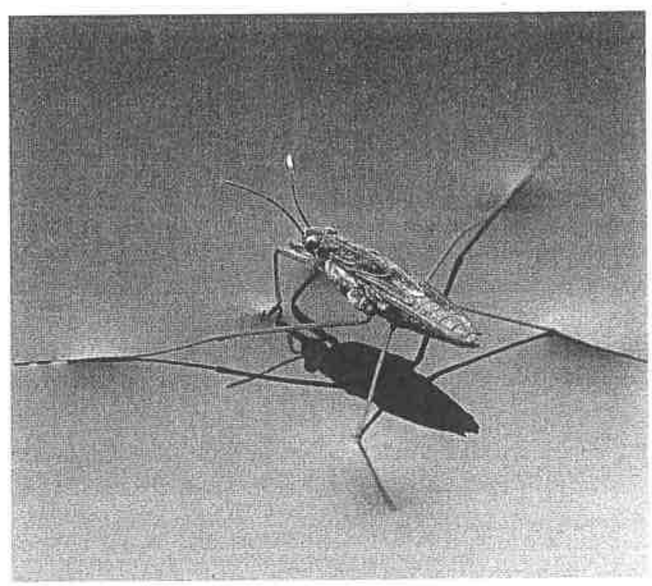


**FIGURE 2.6 Surface tension.** Hydrogen bonding between water molecules creates the surface tension necessary to support this water strider. Where else in nature can you witness surface tension?

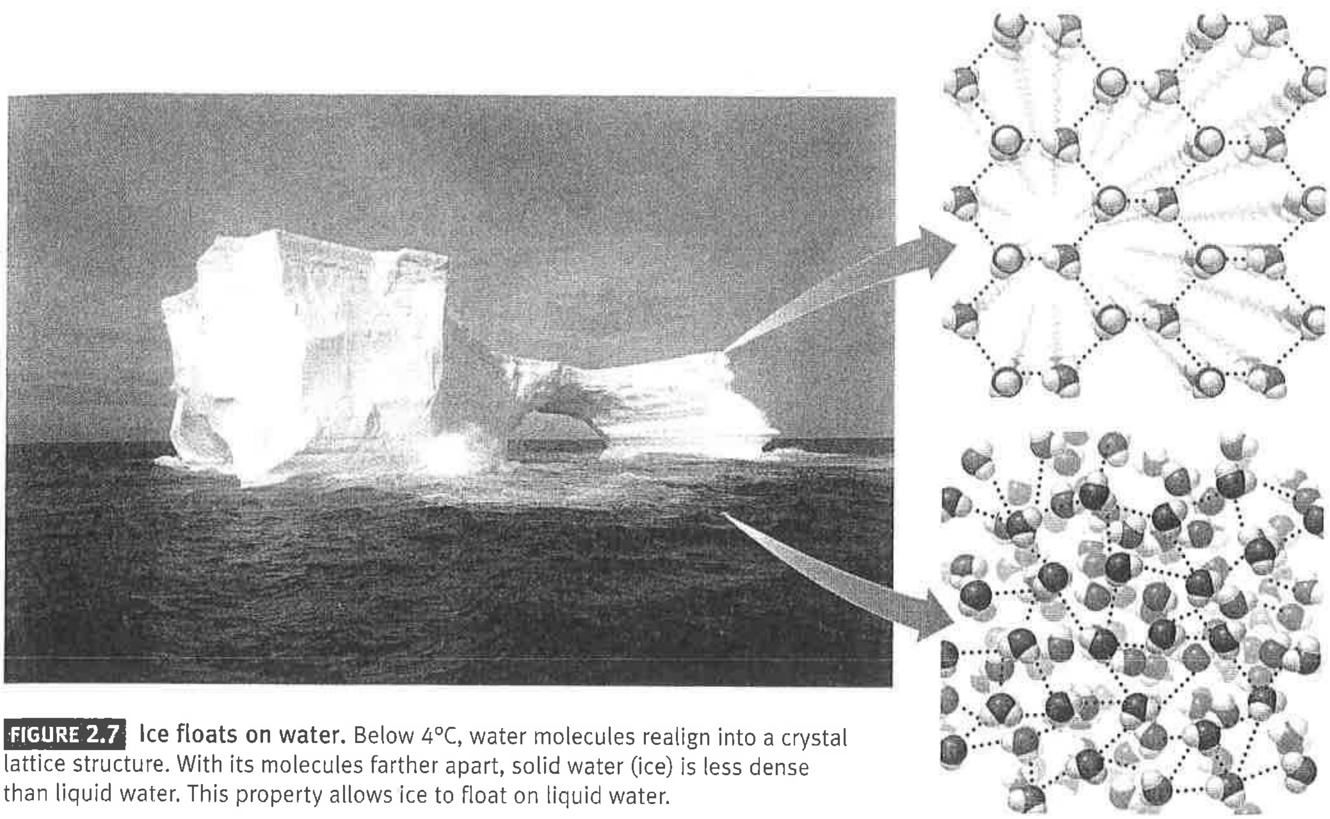


**FIGURE 2.7** **Ice floats on water.** Below 4°C, water molecules realign into a crystal lattice structure. With its molecules farther apart, solid water (ice) is less dense than liquid water. This property allows ice to float on liquid water.

100°C (212°F) and freezes (becomes a solid) at 0°C (32°F). If water behaved like structurally similar compounds such as hydrogen sulfide ($H_2S$), which boils at −60°C (−76°F), it would be a gas at typical Earth temperatures, and life as we know it could not exist. Because of its cohesion, however, water can be a solid, a gas, or—most importantly for living organisms—a liquid at Earth's surface temperatures. In addition, the hydrogen bonding between water molecules means that it takes a great deal of energy to change the temperature of water. Thus the water in organisms protects them from wide temperature swings. Hydrogen bonding also explains why geographic areas near large lakes or oceans have moderate climates. The water body holds summer heat, slowly releasing it as the atmosphere cools in the fall, and warms only slowly in spring, thereby preventing the adjacent land area from heating up quickly.

Water has another unique property: it takes up a larger volume in solid form than it does in liquid form. FIGURE 2.7 illustrates the difference in structure between liquid water and ice. As liquid water cools, it becomes denser, until it reaches 4°C (39°F), the temperature at which it reaches maximum density. As it cools from 4°C down to freezing at 0°C, however, its molecules realign into a crystal lattice structure, and its volume expands. You can see the result any time you add an ice cube to a drink: ice floats on liquid water.

What does this unique property of water mean for life on Earth? Imagine what would happen if water acted like most other liquids. As it cooled, it would continue to become denser. Its solid form (ice) would sink, and lakes and ponds would freeze from the bottom up. As a result, very few aquatic organisms could survive in temperate and cold climates.

**WATER AS A SOLVENT** In our table salt example, we saw that water makes a good solvent. Many substances, such as table salt, dissolve well in water because their polar molecules bond easily with other polar molecules. This explains the high concentrations of dissolved ions in seawater as well as the capacity of living organisms to store many types of molecules in solution in their cells. Unfortunately, many toxic substances also dissolve well in water, which makes them easy to transport through the environment.

## Acids, Bases, and pH

Another important property of water is its ability to dissolve hydrogen- or hydroxide-containing compounds known as *acids* and *bases*. An **acid** is a substance that contributes hydrogen ions to a solution. A **base** is a substance that contributes hydroxide ions to a solution. Both acids and bases typically dissolve in water.

When an acid is dissolved in water, it dissociates into positively charged hydrogen ions ($H^+$) and negatively charged ions. Two important acids we will discuss in this book are nitric acid ($HNO_3$) and sulfuric acid ($H_2SO_4$), the primary constituents of acidic deposition, one form of which is acid rain.

Bases, on the other hand, dissociate into negatively charged hydroxide ions ($OH^-$) and positively charged ions. Some examples of bases are sodium hydroxide ($NaOH$) and calcium hydroxide ($Ca(OH)_2$), which can be used to neutralize acidic emissions from power plants.

The **pH** scale is a way to indicate the strength of acids and bases. In FIGURE 2.8, the pH of many familiar substances is indicated on the pH scale, which ranges from 0 to 14. A pH value of 7 on this scale—the pH of pure water—is neutral, meaning that the number of hydrogen ions is equal to the number of hydroxide ions. Anything above 7 is basic, or alkaline, and anything below 7 is acidic. The lower the number, the stronger the acid, and the higher the number, the more basic the substance is. The pH scale is *logarithmic,* meaning that there is a factor of 10 difference between each number on the scale. For example, a substance with a pH of 5 has 10 times the hydrogen ion concentration of a substance with a pH of 6 (it is 10 times more acidic). Water in equilibrium with Earth's atmosphere typically has a pH of 5.65 because carbon dioxide from the atmosphere dissolves in that water, making it weakly acidic.

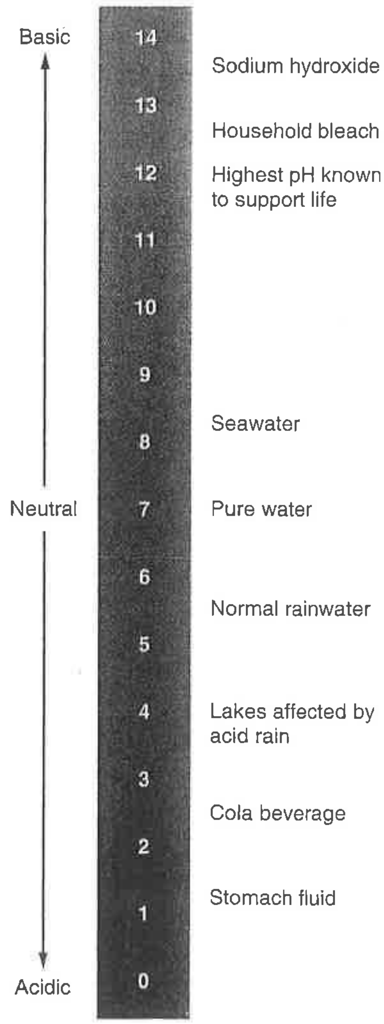



**FIGURE 2.8** **The pH scale.** The pH scale is a way of expressing how acidic or how basic a solution is.

## Chemical Reactions and the Conservation of Matter

A **chemical reaction** occurs when atoms separate from the molecules they are a part of or recombine with other molecules. In a chemical reaction, no atoms are ever destroyed or created. The bonds between particular atoms may change, however. For example, when methane ($CH_4$) is burned in air, it reacts with two molecules of oxygen ($2\ O_2$) to create one molecule of carbon dioxide ($CO_2$) and two molecules of water ($2\ H_2O$):

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

Notice that the number of atoms of each chemical element is the same on each side of the reaction.

Chemical reactions can occur in either direction. For example, during the combustion of fuels, nitrogen gas ($N_2$) combines with oxygen gas ($O_2$) from the atmosphere to form two molecules of nitrogen oxide ($NO$), which is an air pollutant:

$$N_2 + O_2 \rightarrow 2\ NO$$

This reaction can also proceed in the opposite direction:

$$2\ NO \rightarrow N_2 + O_2$$

The observation that no atoms are created or destroyed in a chemical reaction leads us to the **law of conservation of matter,** which states that matter cannot be created or destroyed; it can only change form. For example, when paper burns, it may seem to vanish, but no atoms are lost; the carbon and hydrogen that make up the paper combine with oxygen in the air to produce carbon dioxide, water vapor, and other materials, which either enter the atmosphere or form ash. Combustion converts most of the solid paper into gases, but all of the original atoms remain. The same process occurs in a forest fire, but on a much larger scale (FIGURE 2.9). The only known exception to the law of conservation of matter occurs in nuclear reactions, in which small amounts of matter change into energy.

The law of conservation of matter tells us that we cannot easily dispose of hazardous materials. For example, when we burn material that contains heavy metals, such as an automotive battery, the atoms of the metals in the battery do not disappear. They turn up elsewhere in the environment, where they may cause a hazard to humans and other organisms. For this and other reasons, understanding the law of conservation of matter is crucial to environmental science.

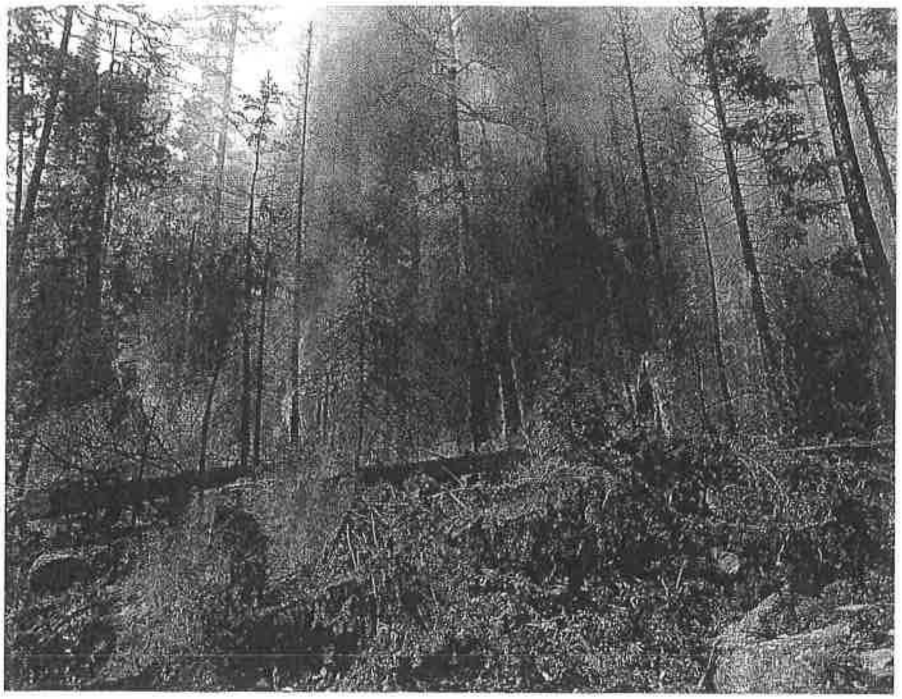


FIGURE 2.9 **The law of conservation of matter.** Even though this forest seems to be disappearing as it burns, all the matter it contains is conserved in the form of water vapor, carbon dioxide, and solid particles.



## Biological Molecules and Cells

We now have a sense of how chemical compounds form and how they respond to various processes such as burning and freezing. To further our understanding of chemical compounds, we will divide them into two basic types: *inorganic* and *organic*. **Inorganic compounds** are compounds that either (a) do not contain the element carbon or (b) do contain carbon, but only carbon bound to elements other than hydrogen. Examples include ammonia ($NH_3$), sodium chloride (NaCl), water ($H_2O$), and carbon dioxide ($CO_2$). **Organic compounds** are compounds that have carbon-carbon and carbon-hydrogen bonds. Examples of organic compounds include glucose ($C_6H_{12}O_6$) and fossil fuels, such as natural gas ($CH_4$).

Organic compounds are the basis of the biological molecules that are important to life: *carbohydrates, proteins, nucleic acids,* and *lipids.* Because these four types of molecules are relatively large, they are also known as *macromolecules.*

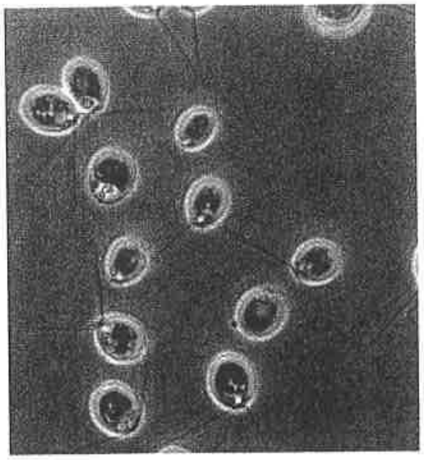
CARBOHYDRATES **Carbohydrates** are compounds composed of carbon, hydrogen, and oxygen atoms. Glucose ($C_6H_{12}O_6$) is a simple sugar (a *monosaccharide,* or single sugar) easily used by plants and animals for quick energy. Sugars can link together in long chains called *complex carbohydrates,* or *polysaccharides* ("many sugars"). For example, plants store energy as starch, which is made up of long chains of covalently bonded glucose molecules. The starch can also be used by animals that eat the plants. Cellulose, a component of plant leaves and stems, is another polysaccharide consisting of long chains of glucose molecules. Cellulose is the raw material for cellulosic ethanol, a type of fuel that has the potential to replace or supplement gasoline.

PROTEINS **Proteins** are made up of long chains of nitrogen-containing organic molecules called *amino acids.* Proteins are critical components of living organisms, playing roles in structural support, energy storage, internal transport, and defense against foreign substances. *Enzymes* are proteins that help control the rates of chemical reactions. The antibodies that protect us from infections are also proteins.

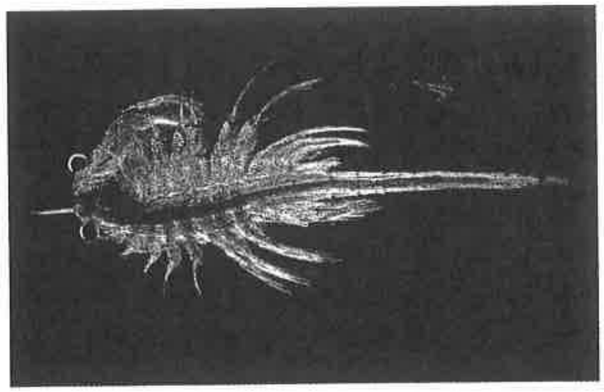
NUCLEIC ACIDS **Nucleic acids** are organic compounds found in all living cells. Long chains of nucleic acids form *DNA* and *RNA.* **DNA (deoxyribonucleic acid)** is the genetic material organisms pass on to their offspring that contains the code for reproducing the components of the next generation. **RNA (ribonucleic acid)** translates the code stored in the DNA and allows for the synthesis of proteins.

LIPIDS **Lipids** are smaller biological molecules that do not mix with water. Fats, waxes, and steroids are all lipids. Lipids form a major part of the membranes that surround cells.

CELLS We have looked at the four types of macromolecules required for life. But how do they work as part of a living organism? The smallest structural and functional component of organisms is known as a *cell.*



(a)



(b)

**FIGURE 2.10** **Organisms are composed of cells.** (a) Some organisms, such as these green algae, consist of a single cell. (b) More complex organisms, such as the Mono brine shrimp, are made up of millions of cells.

A **cell** is a highly organized living entity that consists of the four types of macromolecules and other substances in a watery solution, surrounded by a *membrane.* Some organisms, such as most bacteria and some algae, consist of a single cell. That one cell contains all of the functional structures, or *organelles,* needed to keep the cell alive and allow it to reproduce (FIGURE 2.10a). Larger and more complex organisms, such as Mono Lake's brine shrimp, are multicellular (FIGURE 2.10b).

**CHECKPOINT**

- ✓ What are the three types of chemical bonds?
- ✓ What are the unique properties of water? In what ways do those properties make life possible on Earth?
- ✓ What are the four types of biological molecules, and how do they differ from one another?

## Energy is a fundamental component of environmental systems

Earth's systems cannot function, and organisms cannot survive, without *energy.* **Energy** is the ability to do work, or transfer heat. Water flowing into a lake has energy because it moves and can move other objects in its path. All living systems absorb energy from their surroundings and use it to organize and reorganize molecules within their cells and to power movement. Plants absorb solar energy and use it in photosynthesis to convert carbon dioxide and water into sugars, which they then use to survive, grow, and reproduce. The sugars in plants are also an important energy source for many animals. Humans, like other animals, absorb the energy they need for cellular respiration from food. This provides the energy for our daily activities, from waking to sleeping and everything in between.

Ultimately, most energy on Earth derives from the Sun. The Sun emits **electromagnetic radiation,** a form of energy that includes, but is not limited to, visible light, ultraviolet light, and infrared energy, which we perceive as heat. The scale at the top of FIGURE 2.11 shows these and other types of electromagnetic radiation.

Electromagnetic radiation is carried by **photons,** massless packets of energy that travel at the speed of light and can move even through the vacuum of space. The amount of energy contained in a photon depends on its *wavelength*—the distance between two peaks or troughs in a wave, as shown in the inset in Figure 2.11. Photons with long wavelengths, such as radio waves, have very low energy, while those with short wavelengths, such as X-rays, have high energy. Photons of different wavelengths are used by humans for different purposes.

### Forms of Energy

The basic unit of energy in the metric system is the *joule* (abbreviated J). A **joule** is the amount of energy used when a 1-watt light bulb is turned on for 1 second—a very small amount. Although the joule is the preferred energy unit in scientific study, many other energy units are commonly used. Conversions between these units and joules are given in Table 2.1.

**ENERGY AND POWER** Energy and *power* are not the same thing, even though we often use the words inter-

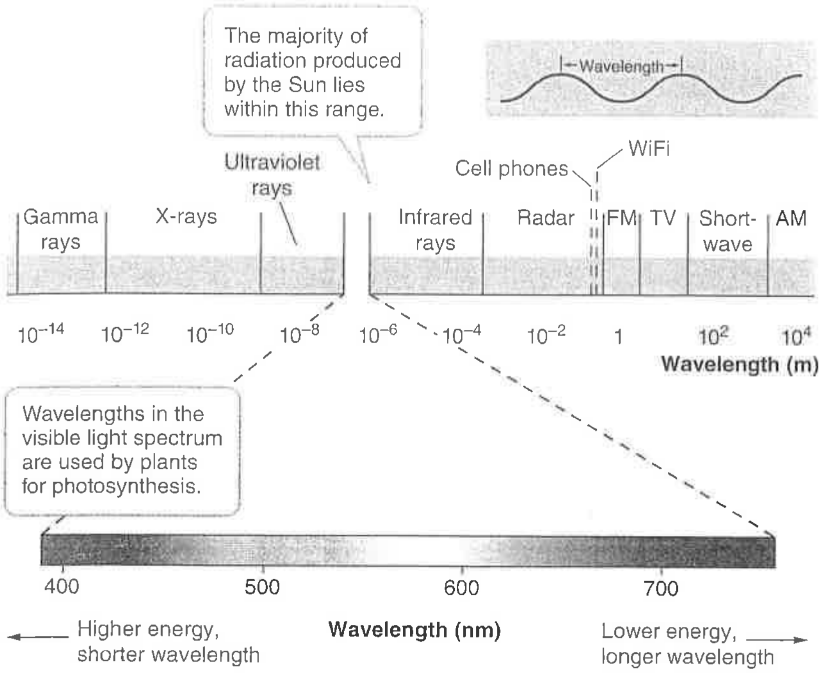



**FIGURE 2.11 The electromagnetic spectrum.** Electromagnetic radiation can take numerous forms, depending on its wavelength. The Sun releases photons of various wavelengths, but primarily between 250 and 2,500 nanometers (nm) ($1 \text{ nm} = 1 \times 10^{-9}$ m).

changeably. Energy is the ability to do work, whereas **power** is the rate at which work is done:

$$\text{energy} = \text{power} \times \text{time}$$
$$\text{power} = \text{energy} \div \text{time}$$

When we talk about generating electricity, we often hear about kilowatts and kilowatt-hours. The kilowatt (kW) is a unit of power. The kilowatt-hour (kWh) is a unit of energy. Therefore, the capacity of a turbine is given in kW because that measurement refers to the turbine's power. Your monthly home electricity bill reports energy use—the amount of energy from electricity that you have used in your home—in kWh. Do the Math "Calculating Energy Use and Converting Units" gives you an opportunity to practice working with these units.

**KINETIC AND POTENTIAL ENERGY** Energy takes a variety of forms. Many stationary objects possess a large amount of **potential energy**—energy that is stored but has not yet been released. Water impounded behind a dam contains a great deal of potential energy. When the water is released and flows downstream, that potential energy becomes **kinetic energy,** the energy of motion (FIGURE 2.12). The kinetic energy of moving water can be captured at a dam and transferred to a turbine and generator, and ultimately to the energy in electricity. Can you think of other common examples of kinetic energy? A car moving down the street, a flying honeybee, and a football travelling through the air all have kinetic energy. Sound also has kinetic energy because it travels in waves through the coordinated motion of atoms. Systems can contain potential energy, kinetic energy, or some of each.

**TABLE 2.1 Common units of energy and their conversion into joules**

| Unit | Definition | Relationship to joules | Common uses |
|---|---|---|---|
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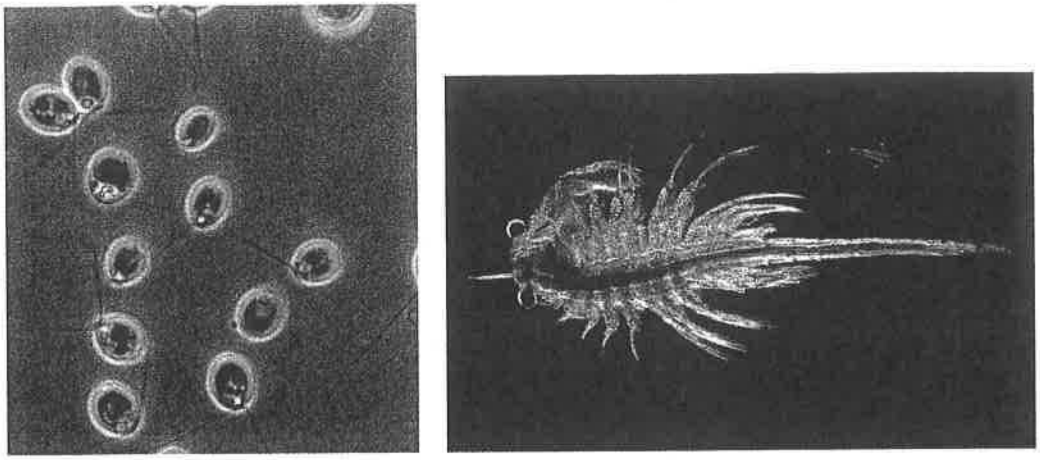

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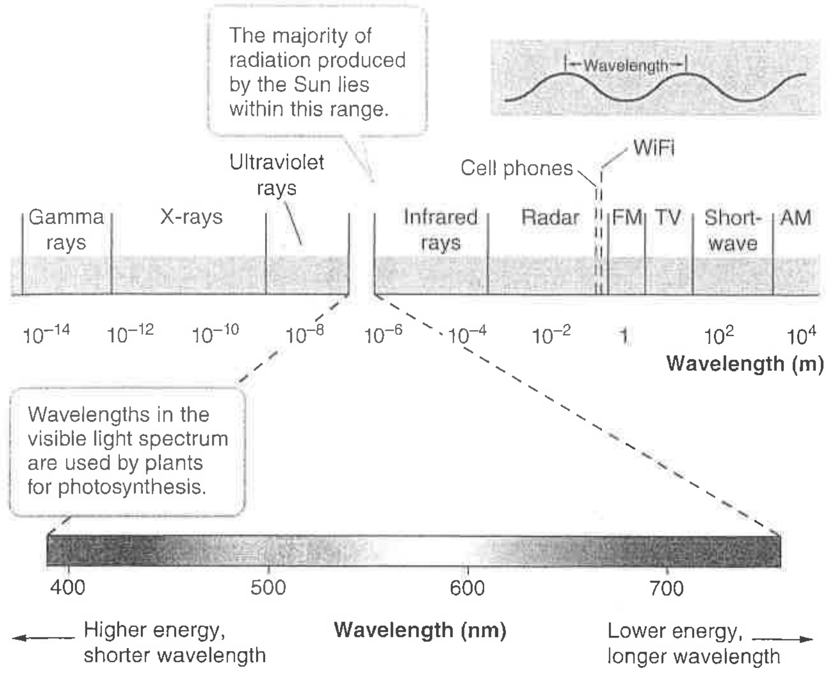


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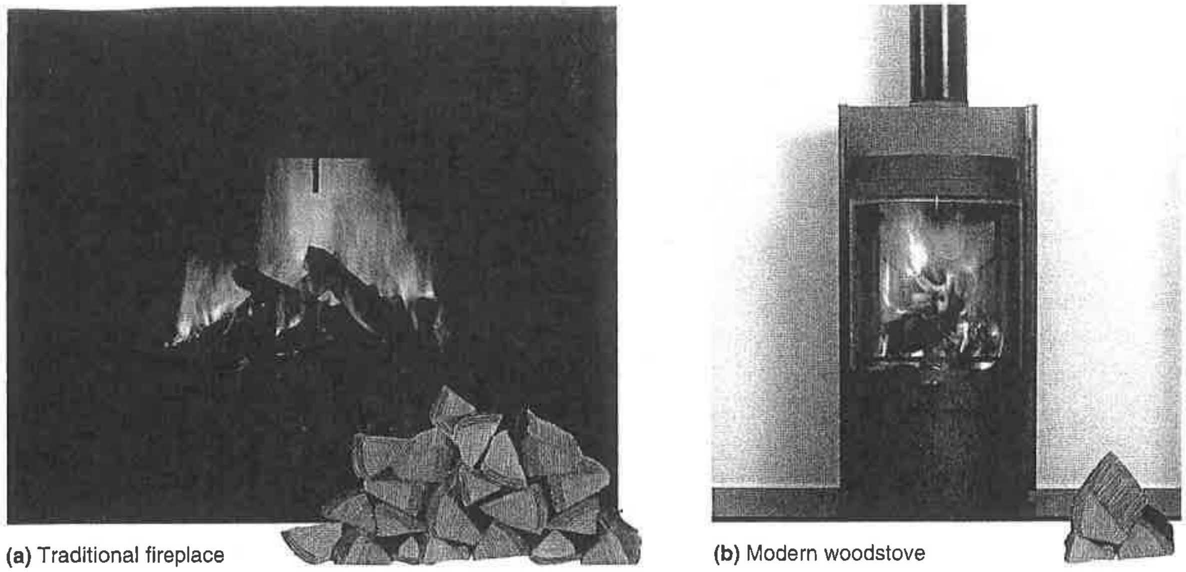


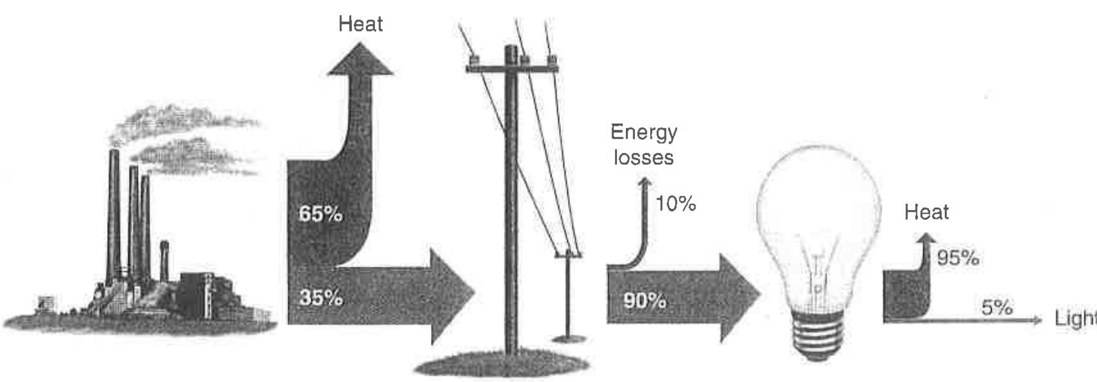

**FIGURE 2.14** **Energy efficiency.** (a) The energy efficiency of a traditional fireplace is low because so much heated air can escape through the chimney. (b) A modern woodstove, which can heat a room using much less wood, is much more energy efficient.

to achieve the same temperature—a sevenfold greater energy input (FIGURE 2.14).

We can also calculate the energy efficiency of transforming one form of energy into other forms of energy. Let's consider what happens when we convert the chemical energy of coal into the electricity that operates a reading lamp and the heat that the lamp releases. FIGURE 2.15 shows the process.

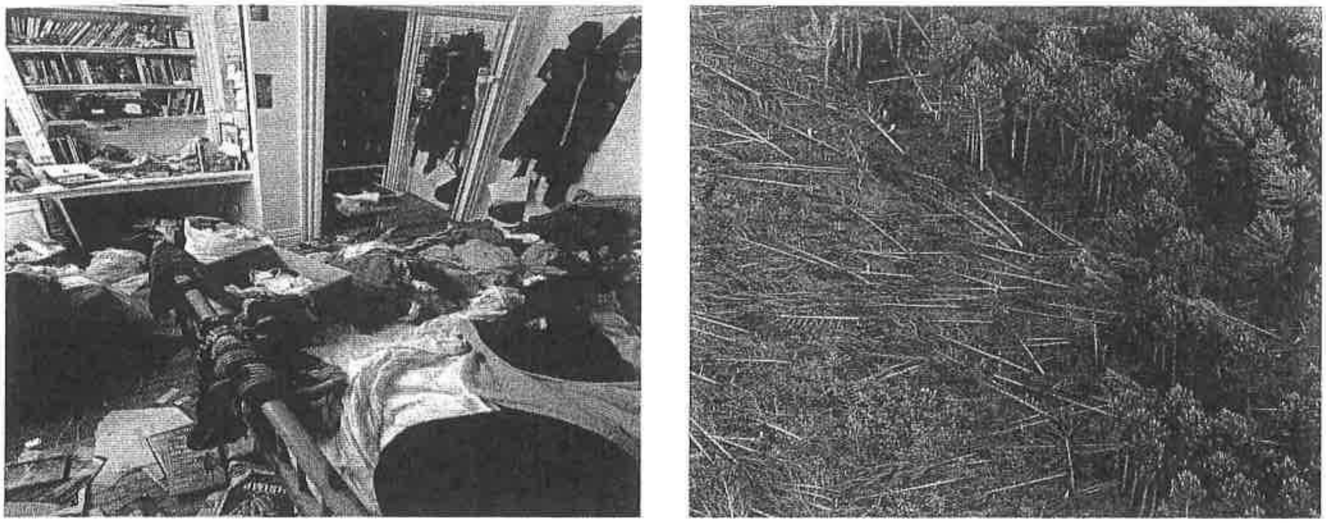
A modern coal-burning power plant can convert 1 metric ton of coal, containing 24,000 megajoules (MJ; 1 MJ = 1 million joules) of chemical energy into about 8,400 MJ of electricity. Since 8,400 is 35 percent of 24,000, this means that the process of turning coal into electricity is about 35 percent efficient. The rest of the energy from the coal—65 percent—is lost as waste heat. In the electrical transmission lines between the power plant and the house, 10 percent of the electrical energy from the plant is lost as heat and sound, so the transport of energy away from the plant is about 90 percent efficient. We know that the conversion of electrical energy into light in an incandescent bulb is 5 percent efficient; again, the rest of the energy is lost as heat. From beginning to end, we can calculate the energy efficiency of converting coal into incandescent lighting by multiplying all the individual efficiencies:

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.35 | × | 0.90 | × | 0.05 | = | 0.016 (1.6% efficiency) |
| coal to electricity | × | transport of electricity | × | light bulb efficiency | = | overall efficiency |




**Calculation: (35%) × (90%) × (5%) = 1.6% efficiency**

**FIGURE 2.15** **The second law of thermodynamics.** Whenever one form of energy is transformed into another, some of that energy is converted into a less usable form of energy, such as heat. In this example, we see that the conversion of coal into the light of an incandescent bulb is only 1.6 percent efficient.



(a) (b)

**FIGURE 2.16** **Energy and entropy.** Entropy increases in a system unless an input of energy from outside the system creates order. (a) In order to reduce the entropy of this messy room, a human must expend energy, which comes from food. (b) A tornado has increased the entropy of this forest system in Wisconsin.

**ENERGY QUALITY** Related to energy efficiency is **energy quality,** the ease with which an energy source can be used for work. A high-quality energy source has a convenient, concentrated form so that it does not take too much energy to move it from one place to another. Gasoline, for example, is a high-quality energy source because its chemical energy is concentrated (about 44 MJ/kg), and because we have technology that can conveniently transport it from one location to another. In addition, it is relatively easy to convert gasoline energy into work and heat. Wood, on the other hand, is a lower-quality energy source. It has less than half the energy concentration of gasoline (about 20 MJ/kg) and is more difficult to use to do work. Imagine using wood to power an automobile. Clearly, gasoline is a higher-quality energy source than wood. Energy quality is one important factor humans must consider when they make energy choices.

**ENTROPY** The second law of thermodynamics also tells us that all systems move toward randomness rather than toward order. This randomness, called **entropy,** is always increasing in a system, unless new energy from outside the system is added to create order.

Think of your bedroom as a system. At the start of the week, your books may be in the bookcase, your clothes may be in the dresser, and your shoes may be lined up in a row in the closet. But what happens if, as the week goes on, you don't expend energy to put your things away (FIGURE 2.16)? Unfortunately, your books will not spontaneously line up in the bookcase, your clothes will not fall folded into the dresser, and your shoes will not pair up and arrange themselves in the closet. Unless you bring energy into the system to put things in order, your room will slowly become more and more disorganized.

The energy you use to pick up your room comes from the energy stored in food. Food is a relatively high-quality energy source because the human body easily converts it into usable energy. The molecules of food are ordered rather than random. In other words, food is a low-entropy energy source. Only a small portion of the energy in your digested food is converted into work, however; the rest becomes body heat, which may or may not be needed. This waste heat has a high degree of entropy because heat is the random movement of molecules. Thus, in using food energy to power your body to organize your room, you are decreasing the entropy of the room, but increasing the entropy in the universe by producing waste body heat.

Another example of the second law can be found in the observation that energy always flows from hot to cold. A pot of water will never boil without an input of energy, but hot water left alone will gradually cool as its energy dissipates into the surrounding air. This application of the second law is important in many of the global circulation patterns that are powered by the energy of the Sun.

**CHECKPOINT**

- ✓ What is the difference between power and energy? Why is it important to know the difference?
- ✓ How do potential energy and kinetic energy differ? What is chemical energy?
- ✓ What are the first and second laws of thermodynamics?

## Energy conversions underlie all ecological processes

Life requires order. If organisms were not made up of molecules organized into structures such as proteins and cells, they could not grow—in fact, they could never develop in the first place. All living things work against entropy by using energy to maintain order.

Individual organisms rely on a continuous input of energy in order to survive, grow, and reproduce. But interactions at levels beyond the organism can also be seen as a process of converting energy into organization. Consider a forest ecosystem. Trees absorb water through their roots and carbon dioxide through their leaves. By combining these compounds in the presence of sunlight, they convert water and carbon dioxide into sugars that will provide them with the energy they need. Trees fight entropy by keeping their atoms and molecules together in tree form, rather than having them dispersed randomly throughout the universe. But then a deer grazes on tree leaves, and later a mountain lion eats the deer. At each step, energy is converted by organisms into work.

The form and amount of energy available in an environment determines what kinds of organisms can live there. Plants thrive in tropical rainforests where there is plenty of sunlight as well as water. Many food crops, not surprisingly, can be planted and grown in temperate climates that have a moderate amount of sunlight. Life is much more sparse at high latitudes, toward the North and South Poles, where less solar energy is available to organisms. The landscape is populated mainly by small plants and shrubs, insects, and migrating animals. Plants cannot live at all on the deep ocean floor, where no solar energy penetrates. The animals that live there, such as eels, anglerfish, and squid, get their energy by feeding on dead organisms that sink from above. Chemical

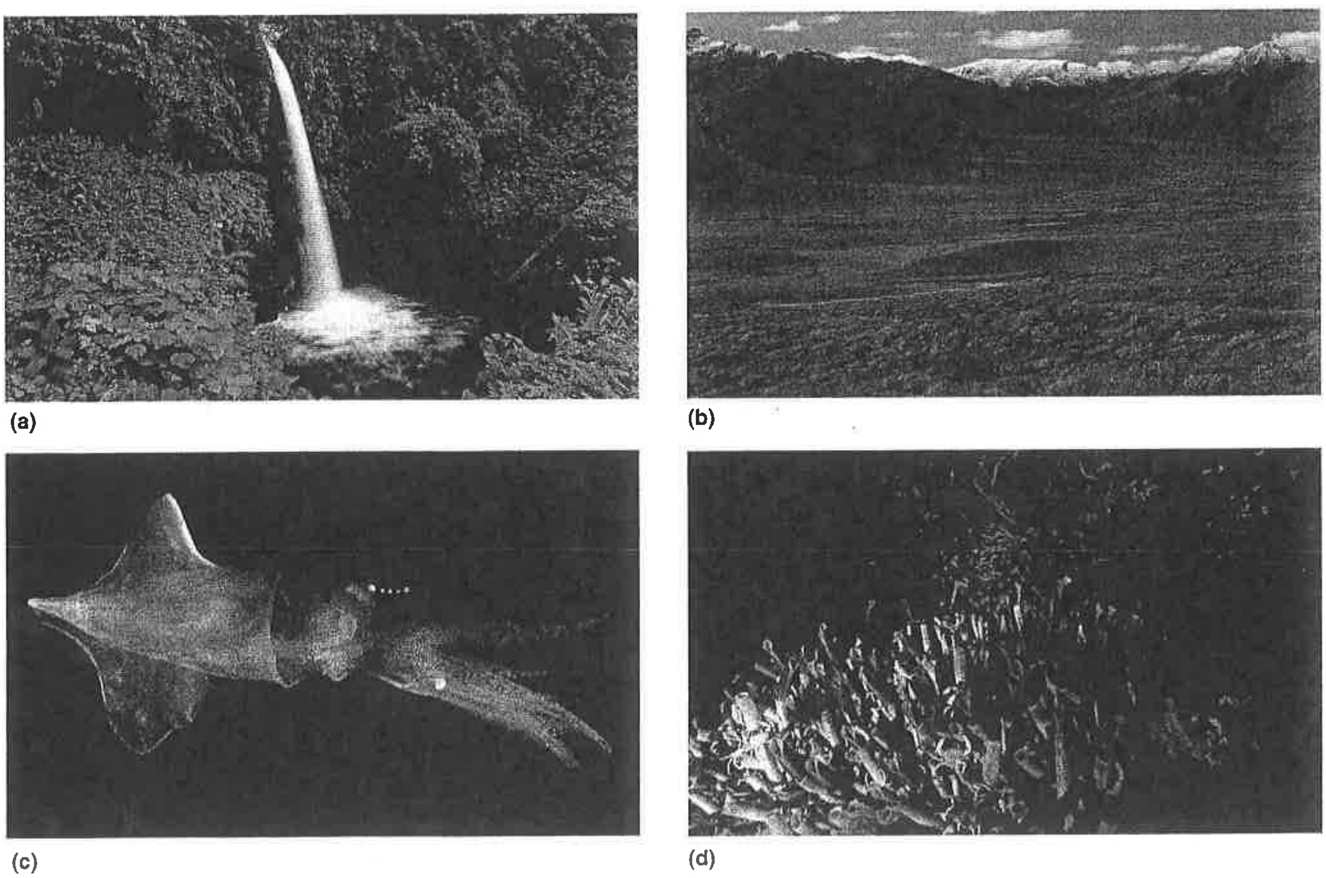


**FIGURE 2.17 The amount of available energy determines which organisms can live in a natural system.** (a) A tropical rainforest has abundant energy available from the Sun and enough moisture for plants to make use of that energy. (b) The Arctic tundra has much less energy available, so plants grow more slowly there and do not reach large sizes. (c) Organisms, such as this squid, living at the bottom of the ocean must rely on dead biological matter falling from above. (d) The energy supporting this deep-ocean vent community comes from chemicals emitted from the vent. Bacteria convert the chemicals into forms of energy that other organisms, such as tube worms, can use.

energy, in the form of sulfides emitted from deep-ocean vents (underwater geysers), supports a plantless ecosystem that includes sea spiders, 2.4 meter (8-foot) tube worms, and bacteria (FIGURE 2.17).

**CHECKPOINT**

- Provide an example of how organisms convert energy from one form into another.
- How does energy determine the suitability of an environment for growing food?

## Systems analysis shows how matter and energy flow in the environment

Why is it important for environmental scientists to study whole systems rather than focusing on the individual plants, animals, or substances within a system? Imagine taking apart your cell phone and trying to understand how it works simply by focusing on the microphone. You wouldn't get very far. Similarly, it is important for environmental scientists to look at the whole picture, not just the individual parts of a system, in order to understand how that system works.

Studying systems allows scientists to think about how matter and energy flow in the environment. In this way, researchers can learn about the complex relationships between organisms and the environment, but more importantly, they can predict how changes to any part of the system—for example, changes in the water level at Mono Lake—will change the entire system.

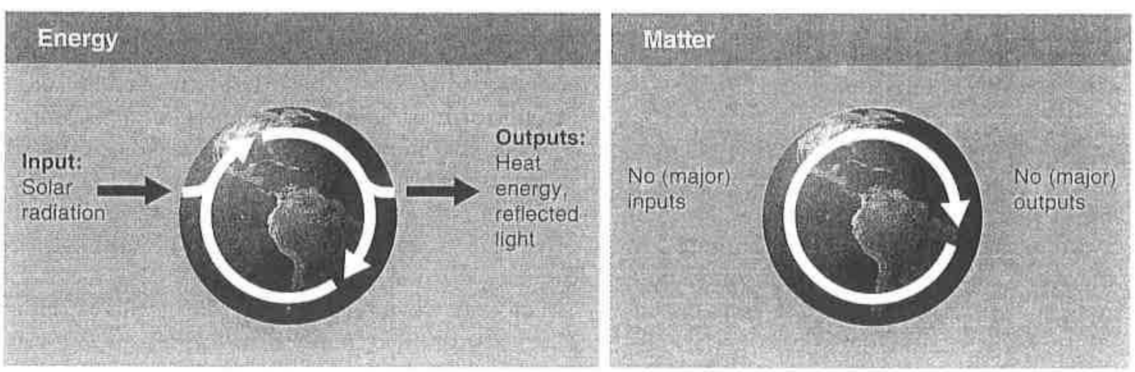
Systems can be either *open* or *closed*. In an **open system,** exchanges of matter or energy occur across system boundaries. Most systems are open. Even at remote Mono Lake, water flows in, and birds fly to and from the lake. The ocean is also an open system. Energy from the Sun enters the ocean, warming the waters and providing energy to plants and algae. Energy and matter are transferred from the ocean to the atmosphere as energy from the Sun evaporates water, giving rise to meteorological events such as tropical storms, in which clouds form and send rain back to the ocean surface. Matter, such as sediment and nutrients, enters the ocean from rivers and streams and leaves it through geologic cycles and other processes.

In a **closed system,** matter and energy exchanges across system boundaries do not occur. Closed systems are less common than open systems. Some underground cave systems are nearly completely closed systems.

As FIGURE 2.18 shows, Earth is an open system with respect to energy. Solar radiation enters Earth's atmosphere, and heat and reflected light leave it. But because of its gravitational field, Earth is essentially a closed system with respect to matter. Only an insignificant amount of material enters or leaves the Earth system. All important material exchanges occur within the system.

### Inputs and Outputs

By now you have seen numerous examples of both **inputs,** or additions to a given system, and **outputs,** or losses from the system. People who study systems often conduct a **systems analysis,** in which they determine inputs, outputs, and changes in the system under various conditions. For instance, researchers studying Mono Lake might quantify the inputs to that system—such as water and salts—and the outputs—such as water that evaporates from the lake and brine shrimp removed by migratory birds. Because no water flows out of the lake, salts are not removed, and even without the aqueduct, Mono Lake, like other terminal lakes, would slowly




(a) Open system (b) Closed system

**FIGURE 2.18** **Open and closed systems.** (a) Earth is an open system with respect to energy. Solar radiation enters the Earth system, and energy leaves it in the form of heat and reflected light. (b) However, Earth is essentially a closed system with respect to matter because very little matter enters or leaves the Earth system. The white arrows indicate the cycling of energy and matter.

DO THE MATH

### The Mystery of the Missing Salt

Before the Los Angeles Aqueduct was built, about 120 billion liters of stream water (31 billion gallons) flowed into Mono Lake in an average year. As a terminal lake, it had no outflow streams. The water level did not rise or fall in an average year. Therefore, the water in the lake had to be going somewhere to balance the water coming in; if the system size was not changing, then inputs must equal outputs. In this case, roughly the same amount of water that entered the lake must have evaporated. The salt content of the stream water flowing into Mono Lake varied, but a typical liter of stream water averaged 50 mg of salt.

1. How much salt entered Mono Lake annually?

To calculate the total amount of salt that entered Mono Lake each year, we can multiply the amount of salt (50 mg) per liter of water by the number of liters of water flowing into the lake (120 billion per year):

$$50 \text{ mg/L} \times 120 \text{ billion L/year} =$$
$$6 \text{ trillion mg/year} = 6 \text{ million kg/year}$$

2. The lake today contains about 285 billion kilograms of dissolved salt. At the rate of salt input we have just calculated, how long would it take to accumulate that much salt, starting with zero salt in the lake?

We have just determined that the salt concentration of Mono Lake increases by 6 million kilograms per year. Mono Lake contains approximately 285 billion kilograms of dissolved salts today, so at the rate of stream flow before the diversion, it would have taken about 47,500 years to accumulate that much salt:

$$285 \text{ billion kg} \div 6 \text{ million kg/year} = 47{,}500 \text{ years}$$

3. No water has flowed out of the Mono Lake basin since it was formed about 120,000 years ago. Assume that Earth's climate hasn't changed much over that time. At today's input rate, how much salt should be in the water of Mono Lake today?

$$6 \text{ million kg/year} \times 120{,}000 \text{ years} = 720 \text{ billion kg}$$

4. The salt loads in questions 2 and 3 do not agree. How can we explain the discrepancy?

The lake's towering tufa formations hold the answer: many of the salts (including calcium and sodium) have precipitated—that is, separated—out of the water to form the tufa rock. In this way, the salts have been removed from the water, but not from the Mono Lake system as a whole. Our analysis is complete when we account for the salts removed from the lake as tufa. **FIGURE 2.19** summarizes these inputs to and outputs from the Mono Lake system.

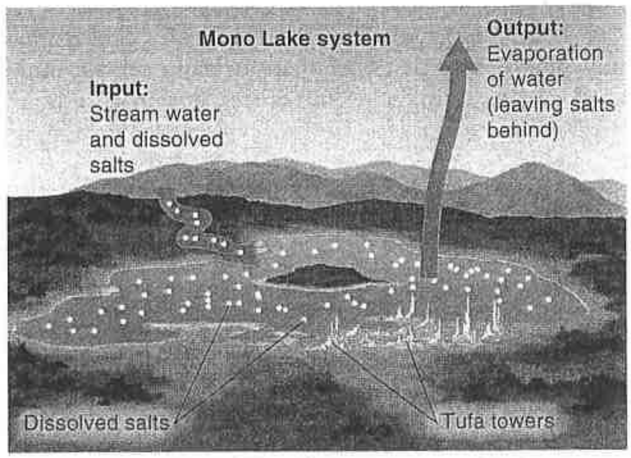



**FIGURE 2.19** **Inputs to and outputs from the Mono Lake ecosystem.**

become saltier. Do the Math "The Mystery of the Missing Salt" provides an example of what calculating inputs and outputs can tell us about a system.

## Steady States

At Mono Lake, in any given period, the same amount of water that enters the lake eventually evaporates. In many cases, the most important aspect of conducting a systems analysis is determining whether your system is in **steady state**—that is, whether inputs equal outputs, so that the system is not changing over time. This information is particularly useful in the study of environmental science. For example, it allows us to know whether the amount of a valuable resource or harmful pollutant is increasing, decreasing, or staying the same.

The first step in determining whether a system is in steady state is to measure the amount of matter and energy within it. If the scale of the system allows, we can perform these measurements directly. Consider the leaky bucket shown in FIGURE 2.20. We can measure the amount of water going into the bucket and the amount of water flowing out through the holes. However, some properties of systems, such as the volume of a lake or the size of an insect population, are difficult to measure directly, so we must calculate or estimate the amount of energy or matter stored in the system. We can then use this information to determine the inputs to and outputs from the system to determine whether it is in steady state.

Many aspects of natural systems, such as the water vapor in the global atmosphere, have been in steady state

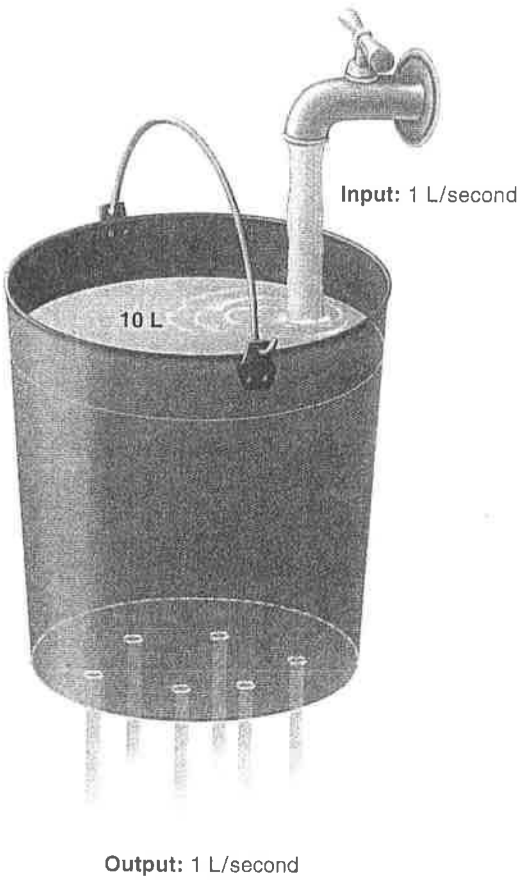



**FIGURE 2.20** **A system in steady state.** In this leaky bucket, inputs equal outputs. As a result, there is no change in the total amount of water in the bucket: the system is in steady state.

for at least as long as we have been studying them. The amount of water that enters the atmosphere by evaporation from oceans, rivers, and lakes is roughly equal to the amount that falls from the atmosphere as precipitation. Until recently, the oceans have also been in steady state: the amount of water that enters from rivers and streams has been roughly equal to the amount that evaporates into the air. One concern about the effects of global climate change is that some global systems, such as the system that includes water balance in the oceans and atmosphere, may no longer be in steady state.

It's interesting to note that one part of a system can be in steady state while another part is not. Before the Los Angeles Aqueduct was built, the Mono Lake system was in steady state with respect to water (the inflow of water equaled the rate of water evaporation), but *not* with respect to salt: salt was slowly accumulating, as it does in all terminal lakes.

## Feedbacks

Most natural systems are in steady state. Why? A natural system can respond to changes in its inputs and outputs. For example, during a period of drought, evaporation from a lake will be greater than precipitation and stream water flowing into the lake. Therefore, the lake will begin to dry up. Soon there will be less surface water available for evaporation, and the evaporation rate will continue to fall until it matches the new, lower precipitation rate. When this happens, the system returns to steady state, and the lake stops shrinking.

Of course, the opposite is also true. In very wet periods, the size of the lake will grow, and evaporation from the expanded surface area will continue to increase until the system returns to a steady state at which inputs and outputs are equal.

Adjustments in input or output rates caused by changes to a system are called *feedbacks*. The term **feedback** means that the results of a process *feed back* into the system to change the rate of that process. Feedbacks, which can be diagrammed as loops or cycles, are found throughout the environment.

There are two kinds of feedback, *negative* and *positive*. In natural systems, scientists most often observe **negative feedback loops,** in which a system responds to a change by returning to its original state, or at least by decreasing the rate at which the change is occurring. FIGURE 2.21a shows a negative feedback loop for Mono Lake: when

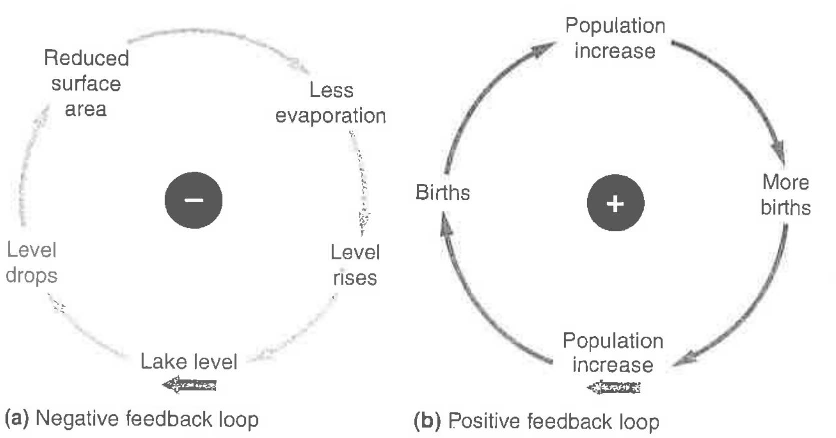



**FIGURE 2.21** **Negative and positive feedback loops.** (a) A negative feedback loop occurs at Mono Lake: when the water level drops, the lake surface area is reduced, and evaporation decreases. As a result of the decrease in evaporation, the lake level rises again. (b) Population growth is an example of positive feedback. As members of a species reproduce, they create more offspring that will be able to reproduce in turn, creating a cycle that increases the population size. The green arrow indicates the starting point of each cycle.

water levels drop, there is less lake surface area, so evaporation decreases as well. With less evaporation, the water in the lake slowly returns to its original volume.

Positive feedbacks also occur in the natural world. FIGURE 2.21b shows an example of how births in a population can give rise to a **positive feedback loop.** The more members of a species that can reproduce, the more births there will be, creating even more of the species to give birth, and so on.

It's important to note that *positive* and *negative* here do not mean *good* and *bad;* instead, positive feedback *amplifies* changes, whereas negative feedback *resists* changes. People often talk about the balance of nature. That balance is the logical result of systems reaching a state at which negative feedbacks predominate—although positive feedback loops play important roles in environmental systems as well.

One of the most important questions in environmental science is to what extent Earth's temperature is regulated by feedback loops, and if so, what types, and at what scale. In general, warmer temperatures at Earth's surface increase the evaporation of water. The additional water vapor that enters the atmosphere by evaporation causes two kinds of clouds to form. Low-altitude clouds reflect sunlight back into space. The result is less heating of Earth's surface, less evaporation, and less warming—a negative feedback loop. High-altitude clouds, on the other hand, absorb terrestrial energy that might have otherwise escaped the atmosphere, leading to higher temperatures near Earth's surface, more evaporation of water, and more warming—a positive feedback loop. In the absence of other factors that compensate for or balance the warming, this positive feedback loop will continue making temperatures warmer, driving the system further away from its starting point. This and other potential positive feedback loops may play critical roles in climate change.

The health of many environmental systems depends on the proper operation of feedback loops. Sometimes, natural or anthropogenic factors lead to a breakdown in a negative feedback loop and drive an environmental system away from its steady state. This is particularly true when a new component is added to a system, as with the introduction of an invasive species, or when humans use too much of a natural resource. As you study the exploitation of natural resources, try to determine what factors may be disrupting the negative feedback loops of the systems that provide those resources.

**CHECKPOINT**

- ✓ What is an open system? What is a closed system?
- ✓ Why is it important to look at a whole system rather than only at its parts?
- ✓ What is steady state? What are feedback loops? Why are they important?

## Natural systems change across space and over time

The decline in the water level of Mono Lake was caused by people: humans diverted water from the lake for their own use. Anthropogenic change in an environmental system is often very visible. We see anthropogenic change in rivers that have been dammed, air that has been polluted by automobile emissions, and cities that have encroached on once wild areas.

Differences in environmental conditions affect what grows or lives in an area, creating geographic variation among natural systems. Variations in temperature, precipitation, or soil composition across a landscape can lead to vastly different numbers and types of organisms. In Texas, for example, sycamore trees grow in river valleys where there is plenty of water available, whereas pine trees dominate mountain slopes because they can tolerate the cold, dry conditions there. Paying close attention to these natural variations may help us predict the effect of any change in an environment. So we know that if the rivers that support the sycamores in Texas dry up, the trees will probably die.

Natural systems are also affected by the passage of time. Thousands of years ago, when the climate of the Sahara was much wetter than it is today, it supported large populations of Nubian farmers and herders. Small changes in Earth's orbit relative to the Sun, along with a series of other factors, led to the disappearance of monsoon rains in northern Africa. As a result, the Sahara—now a desert nearly the size of the continental United States—became one of Earth's driest regions. Other, more dramatic changes have occurred on the planet. In the last few million years, Earth has moved in and out of several ice ages; 70 million years ago, central North America was covered by a sea; 240 million years ago, Antarctica was warm enough for 6-foot-long salamander-like amphibians to roam its swamps. Natural systems respond to such changes in the global environment with migrations and extinctions of species as well as the evolution of new species.

Throughout Earth's history, small natural changes have had large effects on complex systems, but human activities have increased both the pace and the intensity of these natural environmental changes, as they did at Mono Lake. Studying variations in natural systems over space and time can help scientists learn more about what to expect from the alterations humans are making to the world today.

**CHECKPOINT**

- ✓ Give some examples of environmental conditions that might vary among natural systems.
- ✓ Why is it important to study variation in natural systems over space and time?

## Managing Environmental Systems in the Florida Everglades

South Florida's vast Everglades ecosystem extends over 50,000 $km^2$ (12,500,000 acres) (FIGURE 2.22). The region, which includes the Everglades and Biscayne Bay national parks, is home to many threatened and endangered bird, mammal, reptile, and plant species, including the Florida panther (*Puma concolor coryi*) and the Florida manatee (*Trichechus manatus latirostris*). The 4,000 $km^2$ (988,000-acre) subtropical wetland area for which the region is best known has been called a "river of grass" because a thin sheet of water flows constantly through it, allowing tall water-tolerant grasses to grow (FIGURE 2.23).

A hundred years of rapid human population growth, and the resulting need for water and farmland, have had a dramatic impact on the region. Flood control, dams, irrigation, and the need to provide fresh water to Floridians have led to a 30 percent decline in water flow through the Everglades. Much of the water that does flow through the region is polluted by phosphorus-rich fertilizer and waste from farms and other sources upstream. Cattails thrive on the input of phosphorus, choking out other native plants. The reduction in water flow and water quality is, by most accounts, destroying the Everglades. Can we save this natural system while still providing water to the people who need it?

The response of scientists and policy makers has been to treat the Everglades as a set of interacting systems and manage the inputs and outputs of water and pollutants to those systems. The Comprehensive Everglades Restoration Plan of 2000 is a systems-based approach to the region's problems. It covers 16 counties and 46,600 $km^2$ (11,500,000 acres) of South Florida. The plan is based on three key steps: increasing water flow into the Everglades, reducing pollutants coming in, and developing strategies for dealing with future problems.

The first step—increasing water flow—will counteract some of the effects of decades of drainage by local communities. Its goal is to provide enough water to support the Everglades' aquatic and marsh organisms. The plan calls for restoring natural water flow as well as natural hydroperiods (seasonal increases and decreases in water flow). Its strategies include removal of over 390 km (240 miles) of inland levees, canals, and water control structures that have blocked this natural water movement.

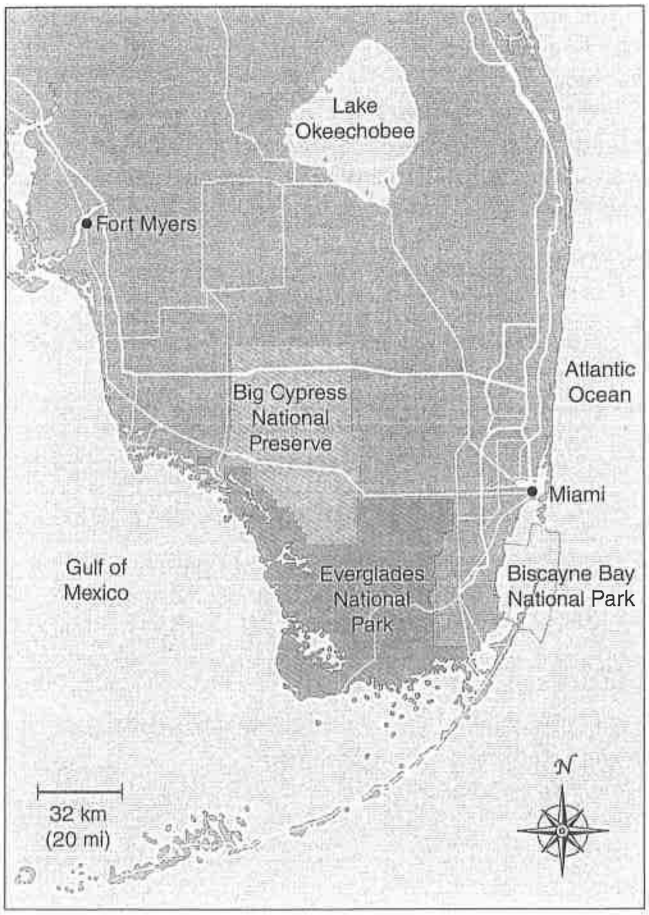



**FIGURE 2.22** **The Florida Everglades Ecosystem.** This map shows the locations of the Florida Everglades, Lake Okeechobee, and the broader Everglades ecosystem, which includes Everglades and Biscayne Bay National Parks and Big Cypress National Preserve.

**FIGURE 2.23** **River of grass.** The subtropical wetland portion of the Florida Everglades has been described as a river of grass because of the tall water-tolerant grasses that cover its surface.

Water conservation will also be a crucial part of reaching this goal. New water storage facilities and restored wetlands will capture and store water during rainy seasons for use during dry seasons, redirecting much of the 6.4 billion liters (1.7 billion gallons) of fresh water that currently flow to the ocean every day. About 80 percent of this fresh water will be redistributed back into the ecosystem via wetlands and aquifers. The remaining water will be used by cities and farms. The federal and state governments also hope to purchase nearby irrigated cropland and return it to a more natural state. In 2009, for example, the state of Florida purchased 29,000 ha (71,700 acres) of land from the United States Sugar Corporation, the first of a number of actions that will allow engineers to restore the natural flow of water from Lake Okeechobee into the Everglades. Florida is currently negotiating to purchase even more land from United States Sugar.

To achieve the second goal—reducing water pollution—local authorities will improve waste treatment facilities and place restrictions on the use of agricultural chemicals. Marshlands are particularly effective at absorbing nutrients and breaking down toxins. Landscape engineers have designed and built more than 21,000 ha (52,000 acres) of artificial marshes upstream of the Everglades to help clean water before it reaches Everglades National Park. Although not all of the region has seen water quality improvements, phosphorus concentrations in runoff from farms south of Lake Okeechobee are lower, meaning that fewer pollutants are reaching the Everglades.

The third goal—to plan for the possibility of future problems—requires an **adaptive management plan:** a strategy that provides flexibility so that managers can modify it as future changes occur. Adaptive management is an answer to scientific uncertainty. In a highly complex system such as the Everglades, any changes, however well intentioned, may have unexpected consequences. Management strategies must adapt to the actual results of the restoration plan as they occur. In addition, an adaptive management plan can be changed to meet new challenges as they come. One such challenge is global warming. As the climate warms, glaciers melt, and sea levels rise, much of the Everglades could be inundated by seawater, which would destroy freshwater habitat. Adaptive management essentially means paying attention to what works and adjusting your methods accordingly. The Everglades restoration plan will be adjusted along the way to take the results of ongoing observations into account, and it has put formal mechanisms in place to ensure that this will occur.

The Everglades plan has its critics. Some people are concerned that control of water flow and pollution will restrict the use of private property and affect economic development, possibly even harming the local economy. Yet other critics fear that the restoration project is underfunded or moving too slowly, and that current farming practices in the region are inconsistent with the goal of restoration.

In spite of its critics, the Everglades restoration plan is, historically speaking, a milestone project, not least because it is based on the concept that the environment is made up of interacting systems.

**Reference**

Kiker, C., W. Milon, and A. Hodges. 2001. South Florida: The reality of change and the prospects for sustainability. Adaptive learning for science-based policy: The Everglades restoration. *Ecological Economics* 37: 403–416.

## KEY IDEAS REVISITED

- **Define *systems* within the context of environmental science.**

Environmental systems are sets of interacting components connected in such a way that changes in one part of the system affect the other parts. Systems exist at multiple scales, and a large system may contain smaller systems within it. Earth itself is a single interconnected system.

- **Explain the components and states of matter.**

Matter is composed of atoms, which are made up of protons, neutrons, and electrons. Atoms and molecules can interact in chemical reactions in which the bonds between particular atoms may change. Matter cannot be created or destroyed, but its form can be changed.

- **Distinguish between various forms of energy and discuss the first and second laws of thermodynamics.**

Energy can take various forms, including energy that is stored (potential energy) and the energy of motion (kinetic energy). According to the first law of thermodynamics, energy cannot be created or destroyed, but it can be converted from one form into another. According to the second law of thermodynamics, in any conversion of energy, some energy is converted into unusable waste energy, and the entropy of the universe is increased.

- **Describe the ways in which ecological systems depend on energy inputs.**

Individual organisms rely on a continuous input of energy in order to survive, grow, and reproduce. More organisms can live where more energy is available.

■ **Explain how scientists keep track of inputs, outputs, and changes to complex systems.**

Systems can be open or closed to exchanges of matter, energy, or both. A systems analysis determines what goes into, what comes out of, and what has changed within a given system. Environmental scientists use systems analysis to calculate inputs to and outputs from a system and its rate of change. If there is no overall change, the system is in steady state. Changes in one input or output can affect the entire system.

■ **Describe how natural systems change over time and space.**

Variation in environmental conditions, such as temperature or precipitation, can affect the types and numbers of organisms present. Short-term and long-term changes in Earth's climate also affect species distributions.

## PREPARING FOR THE AP EXAM

## MULTIPLE-CHOICE QUESTIONS

1. Which of the following statements about atoms and molecules is *correct?*
   (a) The mass number of an element is always less than its atomic number.
   (b) Isotopes are the result of varying numbers of neutrons in atoms of the same element.
   (c) Ionic bonds involve electrons while covalent bonds involve protons.
   (d) Inorganic compounds never contain the element carbon.
   (e) Protons and electrons have roughly the same mass.

2. Which of the following does *not* demonstrate the law of conservation of matter?
   (a) $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$
   (b) $NaOH + HCl \rightarrow NaCl + H_2O$
   (c) $2\ NO_2 + H_2O \rightarrow HNO_3 + HNO_2$
   (d) $PbO + C \rightarrow 2\ Pb + CO_2$
   (e) $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

3. Pure water has a pH of 7 because
   (a) its surface tension equally attracts acids and bases.
   (b) its polarity results in a molecule with a positive and a negative end.
   (c) its ability to dissolve carbon dioxide adjusts its natural pH.
   (d) its capillary action attracts it to the surfaces of solid substances.
   (e) its $H^+$ concentration is equal to its $OH^-$ concentration.

4. Which of the following is *not* a type of organic biological molecule?
   (a) Lipids
   (b) Carbohydrates
   (c) Salts
   (d) Nucleic acids
   (e) Proteins

5. A wooden log that weighs 1.00 kg is placed in a fireplace. Once lit, it is allowed to burn until there are only traces of ash, weighing 0.04 kg, left. Which of the following *best* describes the flow of energy?
   (a) The potential energy of the wooden log was converted into the kinetic energy of heat and light.
   (b) The kinetic energy of the wooden log was converted into 0.04 kg of ash.
   (c) The potential energy of the wooden log was converted into 1.00 J of heat.
   (d) Since the ash weighs less than the wooden log, matter was converted directly into energy.
   (e) The burning of the 1.00 kg wooden log produced 0.96 kg of gases and 0.04 kg of ash.

6. Consider a power plant that uses natural gas as a fuel to generate electricity. If there are 10,000 J of chemical energy contained in a specified amount of natural gas, then the amount of electricity that could be produced would be
   (a) greater than 10,000 J because electricity has a higher energy quality than natural gas.
   (b) something less than 10,000 J, depending on the efficiency of the generator.
   (c) greater than 10,000 J when energy demands are highest; less than 10,000 J when energy demands are lowest.
   (d) greater than 10,000 J because of the positive feedback loop of waste heat.
   (e) equal to 10,000 J because energy cannot be created or destroyed.

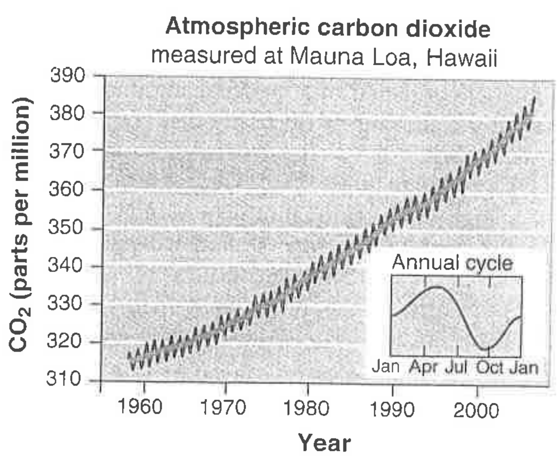
7. A lake that has been affected by acid rain has a pH of 4. How many more times acidic is the lake water than seawater? (See Figure 2.8 on page 34.)
   (a) 4
   (b) 10
   (c) 100
   (d) 1,000
   (e) 10,000

8. An automobile with an internal combustion engine converts the potential energy of gasoline (44 MJ/kg) into the kinetic energy of the moving pistons. If the average internal combustion engine is 10 percent efficient and 1 kg of gasoline is combusted, how much potential energy is converted into energy to run the pistons?
(a) 39.6 MJ
(b) 20.0 MJ
(c) 4.4 MJ
(d) Depends on the capacity of the gas tank
(e) Depends on the size of the engine

9. If the average adult woman consumes approximately 2,000 kcal per day, how long would she need to run in order to utilize 25 percent of her caloric intake, given that the energy requirement for running is 42,000 J per minute?
(a) 200 minutes
(b) 50 minutes
(c) 5 minutes
(d) 0.05 minutes
(e) 0.012 minutes

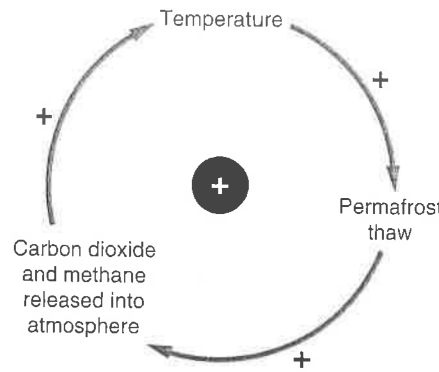
10. The National Hurricane Center studies the origins and intensities of hurricanes over the Atlantic and Pacific oceans and attempts to forecast their tracks, predict where they will make landfall, and assess what damage will result. Its systems analysis involves
(a) changes within a closed system.
(b) inputs and outputs within a closed system.
(c) outputs only within an open system.
(d) inputs from a closed system and outputs in an open system.
(e) inputs, outputs, and changes within an open system.

11. Based on the graph below, which of the following is the *best* interpretation of the data?




(a) The atmospheric carbon dioxide concentration is in steady state.
(b) The output of carbon dioxide from the atmosphere is greater than the input into the atmosphere.
(c) The atmospheric carbon dioxide concentration appears to be decreasing.
(d) The input of carbon dioxide into the atmosphere is greater than the output from the atmosphere.
(e) The atmospheric carbon dioxide concentration will level off due to the annual cycle.

12. The diagram below represents which of the following concepts?




(a) A negative feedback loop, because melting of permafrost has a negative effect on the environment by increasing the amounts of carbon dioxide and methane in the atmosphere.
(b) A closed system, because only the concentrations of carbon dioxide and methane in the atmosphere contribute to the permafrost thaw.
(c) A positive feedback loop, because more carbon dioxide and methane in the atmosphere result in greater permafrost thaw, which releases more carbon dioxide and methane into the atmosphere.
(d) An open system that resists change and regulates global temperatures.
(e) Steady state, because inputs and outputs are equal.

13. Which of the following statements about the Comprehensive Everglades Restoration Plan is *not* correct?
(a) Human and natural systems interact because feedback loops lead to adaptations and changes in both systems.
(b) Water conservation will alter land uses and restore populations of aquatic and marsh organisms.
(c) Improvements in waste treatment facilities and restrictions on agricultural chemicals will reduce the nutrients and toxins in the water that reaches the Everglades.
(d) Adaptive management will allow for the modification of strategies as changes occur in this complex system.
(e) The Florida Everglades is a closed system that includes positive and negative feedback loops and is regulated as such.

14. Which of the following would represent a system in steady state?
I The birth rate of chameleons on the island of Madagascar equals their death rate.
II Evaporation from a lake is greater than precipitation and runoff flowing into the lake.
III The steady flow of the Colorado River results in more erosion than deposition of rock particles.
(a) I only
(b) II only
(c) III only
(d) I and II
(e) I and III

## FREE-RESPONSE QUESTIONS

1. The atomic number of uranium-235 is 92, its half-life is 704 million years, and the radioactive decay of 1 kg of $^{235}U$ releases $6.7 \times 10^{13}$ J. Radioactive material must be stored in a safe container or buried deep underground until its radiation output drops to a safe level. Generally, it is considered "safe" after 10 half-lives.
   (a) Assume that a nuclear power plant can convert energy from $^{235}U$ into electricity with an efficiency of 35 percent, the electrical transmission lines operate at 90 percent efficiency, and fluorescent lights operate at 22 percent efficiency.
      (i) What is the overall efficiency of converting the energy of $^{235}U$ into fluorescent light? (2 points)
      (ii) How much energy from 1 kg of $^{235}U$ is converted into fluorescent light? (2 points)
      (iii) Name one way in which you could improve the overall efficiency of this system. Explain how your suggestion would improve efficiency. (2 points)
   (b) What are the first and second laws of thermodynamics? (2 points)
   (c) How long would it take for the radiation from a sample of $^{235}U$ to reach a safe level? (2 points)
2. U.S. wheat farmers produce, on average, 3,000 kg of wheat per hectare. Farmers who plant wheat year after year on the same fields must add fertilizers to replace the nutrients removed by the harvested wheat. Consider a wheat farm as an open system.
   (a) Identify two inputs and two outputs of this system. (4 points)
   (b) Using one input to and one output from (a), diagram and explain one positive feedback loop. (2 points)
   (c) Identify two adaptive management strategies that could be employed if a drought occurred. (2 points)
   (d) Wheat contains about 2.5 kcal per gram, and the average U.S. male consumes 2,500 kcal per day. How many hectares of wheat are needed to support one average U.S. male for a year, assuming that 30 percent of his caloric intake is from wheat? (2 points)

## MEASURING YOUR IMPACT

**Bottled Water versus Tap Water** A 2007 study traced the energy input required to produce bottled water in the United States. In addition to the energy required to make plastic bottles from PET (polyethylene terephthalate), energy from 58 million barrels of oil was required to clean, fill, seal, and label the water bottles. This is 2,000 times more than the amount of energy required to produce tap water.

In 2007, the population of the United States was 300 million people, and on average, each of those people consumed 114 L (30 gallons) of bottled water. The average 0.6 L (20-ounce) bottle of water cost $1.00. The average charge for municipal tap water was about $0.0004 per liter.

(a) Complete the following table for the year 2007. Show all calculations.

| Liters of bottled water consumed in 2007 | Liters of bottled water produced per barrel of oil |
|---|---|
| | |

(b) How much energy (in barrels of oil) would be required to produce the amount of tap water equivalent to the amount of bottled water consumed in 2007? How many liters of tap water could be produced per barrel of oil?
(c) Compare the cost of bottled water versus tap water per capita per year.
(d) Identify and explain one output of the bottled water production and consumption system that could have a negative effect on the environment.
(e) List two reasons for using tap water rather than bottled water.

## EXPLORING THE LITERATURE

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# Were We Successful in Halting the Growth of the Ozone Hole?

We rely on refrigeration to keep our foods safe and edible, and on air conditioning to keep us comfortable in hot weather. For many years, the same chemicals that made refrigeration and air conditioning possible were also used in a host of other consumer items, including aerosol spray cans and products such as Styrofoam. These chemicals, called chlorofluorocarbons, or CFCs, were considered essential to modern life, and producing them was a multibillion-dollar industry. CFCs were considered "safe" because they are both nontoxic and nonflammable.

## Why do we need an ozone layer?

In the 1970s, scientists learned that CFCs might be responsible for destroying ozone in the upper atmosphere. This discovery led to great concern because a layer of ozone in the upper atmosphere protects us from high-energy ultraviolet (UV) radiation, which causes sunburns, skin cancer, and cataracts as well as environmental damage. In the 1980s, scientists reported an ozone "hole," or depletion of ozone, over Antarctica and documented dangerous thinning of the ozone layer elsewhere.

The nations of the world faced a critical choice: should they continue to produce and use CFCs, and risk further damage to the ozone layer and the resulting effects on people and natural systems, or should they reduce ozone depletion by discontinuing use of this important class of chemicals? In 1987, the majority of nations chose the latter course. As of this writing, most of the world has stopped using CFCs. But the choice at the time was a difficult one. What were the scientific findings that convinced nations to phase out CFCs, the economic consequences of this important decision, and finally, the impact of the CFC ban on the environment? Have we, indeed, protected the ozone layer?

## How do chlorofluorocarbons damage the ozone layer?

As we saw in Chapter 2, the Sun radiates energy at many different wavelengths, including the ultraviolet range. The ultraviolet wavelengths are further classified into three groups: UV-A, or low-energy ultraviolet radiation, and the shorter, higher-energy UV-B and UV-C wavelengths. UV radiation of all types can damage the tissues and DNA of living organisms. Exposure to UV-B radiation increases the risks of skin cancer and cataracts and suppresses the immune system. Exposure to UV-B is also harmful to the cells of plants and reduces their ability to convert sunlight into usable energy. UV-B exposure can therefore lead to crop losses and effects on entire biological communities. For example, losses of phytoplankton—the microscopic algae that form the base of many marine food chains—can harm fisheries.

Next we examine the chemistry of ozone production and how the introduction of chlorine atoms disturbs ozone's steady state in the stratosphere. Oxygen molecules ($O_2$) are common throughout Earth's atmosphere. When solar radiation hits $O_2$ in the stratosphere, 16 to 50 km (10–31 miles) above Earth's surface, a series of chemical reactions begins that produces a new molecule: ozone ($O_3$).

In the first step, UV-C radiation breaks the molecular bond holding an oxygen molecule together:

$$O_2 + \text{UV-C} \rightarrow O + O \qquad (1)$$

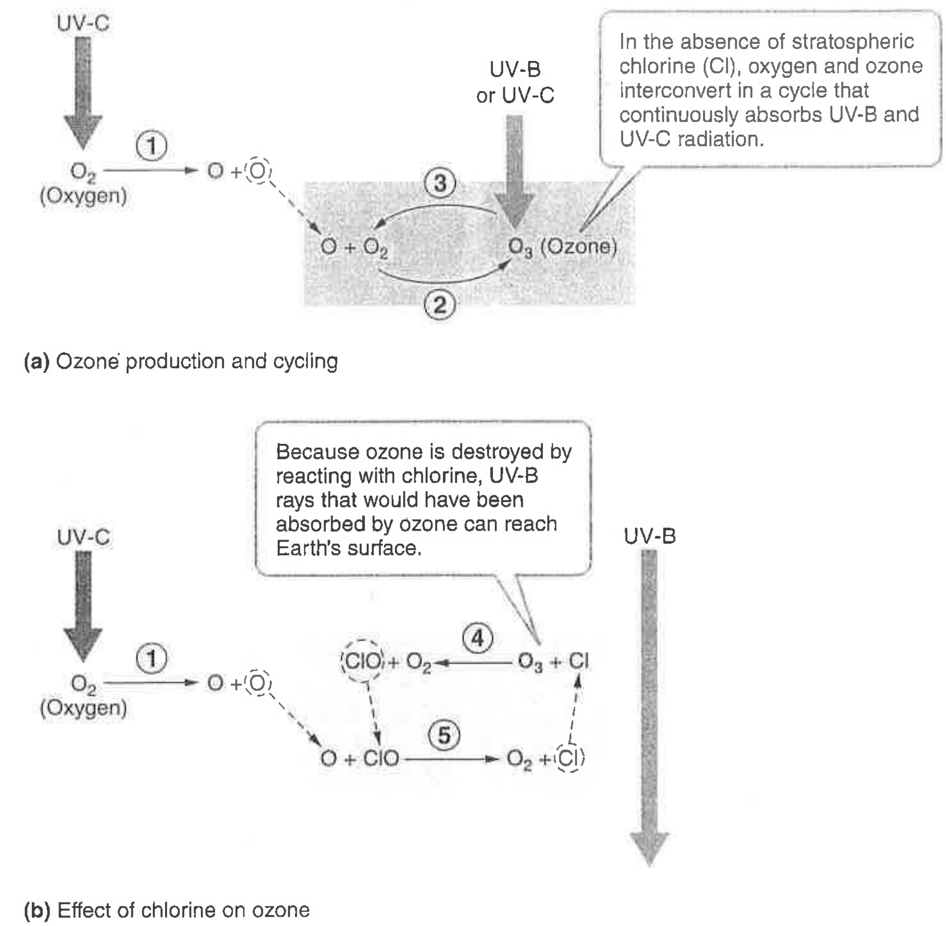


**FIGURE SA1.1** **Oxygen-ozone cycles in the stratosphere.** Circled numbers refer to the numbered chemical reactions in the text.

This happens to only a few oxygen molecules at any given time. The vast majority of the oxygen in the atmosphere remains in the form $O_2$.

In the second step, a free oxygen atom (O) produced in reaction 1 encounters an oxygen molecule, and they form ozone. The simplified form of this reaction is written as follows:

$$O + O_2 \rightarrow O_3 \qquad (2)$$

Both UV-B and UV-C radiation can break a bond in this new ozone molecule, forming molecular oxygen and a free oxygen atom once again:

$$O_3 + \text{UV-B or UV-C} \rightarrow O_2 + O \qquad (3)$$

Thus the formation of ozone in the presence of sunlight and its subsequent breakdown is a cycle (**FIGURE SA1.1**) that can occur indefinitely as long as there is UV energy entering the atmosphere. Under normal conditions, the amount of ozone in the stratosphere remains at steady state.

However, certain chemicals can promote the breakdown of ozone, disrupting this steady state. Free chlorine (Cl) is one such chemical. The concern over CFCs began when atmospheric scientists realized that CFCs were introducing chlorine into the stratosphere. When chlorine is present, it can attach to an oxygen atom in an ozone molecule, thereby breaking the bond between that atom and the molecule and forming chlorine monoxide (ClO) and $O_2$:

$$O_3 + Cl \rightarrow ClO + O_2 \qquad (4)$$

Subsequently, the chlorine monoxide molecule reacts with a free oxygen atom, which pulls the oxygen from the ClO to produce free chlorine again:

$$ClO + O \rightarrow Cl + O_2 \qquad (5)$$

Looking at reactions 4 and 5 together, we see that chlorine starts out and ends up as a free Cl atom. In contrast, an ozone molecule and a free oxygen atom are converted into two oxygen molecules. A substance that

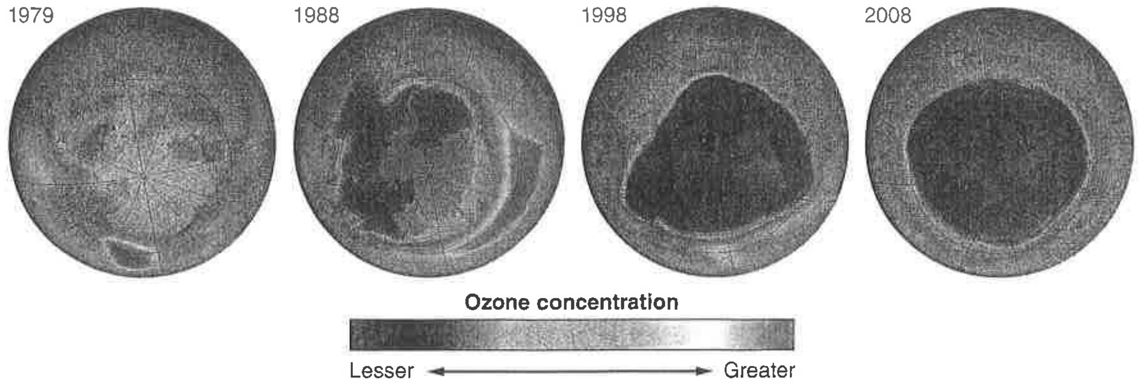


**FIGURE SA1.2 The ozone hole over time.** An area of decreased atmospheric ozone concentration has been forming during the Antarctic spring (September–December) every year since 1979. There has been a decrease in ozone to about one-third of its 1979 concentration.

aids a reaction but does not get used up itself is called a **catalyst.** A single chlorine atom can catalyze the breakdown of as many as 100,000 ozone molecules, until finally one chlorine atom finds another and the process is stopped. The ozone molecules are no longer available to absorb incoming UV-B radiation. As a result, the UV-B radiation can reach Earth's surface and cause biological harm.

## How did nations address the ozone crisis?

In response to the findings described above, the U.S. Environmental Protection Agency banned the use of CFCs in most aerosol sprays in 1978. Policy makers deemed further actions to reduce CFC use too expensive.

By 1986, however, the political climate had changed dramatically. British scientists announced the discovery of a vast ozone "hole" forming seasonally over Antarctica (**FIGURE SA1.2**). This region of unusually low ozone concentrations had not been predicted by scientific models, and the idea of an unexpected hole in the ozone layer captured public attention. Moreover, two important reports appeared in 1985 and 1986, from the World Meteorological Organization and the EPA, that demonstrated an emerging scientific consensus on the magnitude of the ozone depletion problem. Finally, DuPont, the world's leading producer of CFCs, stated that CFC alternatives could be available within 5 years, given the right market conditions.

The issue remained contentious, however. In order to convert to CFC alternatives, many industries would need to be retrofitted with new equipment, and those industries were strongly opposed to the change. In 1987, a trade group called the CFC Alliance estimated that just stopping the *growth* of new CFC production would cost more than $1 billion and affect 700,000 jobs in the United States. In addition, because chlorine remains in the stratosphere for tens to hundreds of years, some argued that a reduction in CFCs would have minimal short-term benefits for the environment and would result in an improvement only after several decades, not justifying expensive changes now.

In spite of these objections, in 1987, 24 nations signed an agreement called the Montreal Protocol on Substances That Deplete the Ozone Layer. Those nations committed to taking concrete steps to cut the production of CFCs in half by the year 2000. As the scientific case against CFCs strengthened and the economic costs turned out to be less than had been projected, more nations joined the Montreal Protocol, and amendments added in 1990 and 1992 strengthened the treaty by calling for a complete phaseout of CFCs in developed countries by 1996.

Small amounts of CFCs continue to be used in developing countries, and certain agricultural chemicals and CFC replacements can also destroy ozone, although to a lesser degree than CFCs. However, because of the Montreal Protocol, CFC production worldwide had fallen to 2 percent of its peak value by 2004, and chlorine concentrations in the stratosphere are slowly decreasing. Scientists believe that stratospheric ozone depletion will decrease in subsequent decades as chlorine concentrations stabilize. New cases of skin cancer should eventually decrease as well, again after a significant time lapse due to the fact that some cancers take many years to appear.

The Montreal Protocol demonstrated that the manufacturers of products and the nations that used them were willing to make changes in manufacturing processes, and incur economic hardship, in order to protect the environment. Even more importantly, the agreement protects both human health and nonhuman organisms. A 1997 study by the Canadian government estimated that the Montreal Protocol would cost the global economy $235 billion (Canadian dollars) between 1987 and 2060, but would result in benefits worth twice that amount, even before considering the benefits to human health. For example, the study's economists estimated a global savings of almost $200 billion in agriculture because without the Montreal Protocol, the increased UV-B radiation would have damaged crop productivity. They also found that protection of the ozone layer avoided $238 billion in losses to global fisheries that depend on UV-B–sensitive phytoplankton as a food source. Because of its success, policy makers and environmental scientists view the Montreal Protocol as a model for future action on other international environmental problems such as climate change.

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