THE ENVIRONMENT AND YOU

THIRD EDITION

Norm Christensen
Lissa Leege
Justin St. Juliana

Brief Contents

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About the Authors

Norm Christensen is professor emeritus and founding dean of Duke University's Nicholas School of the Environment. A central theme in Norm's career has been ecosystem change from both natural and human causes. Norm has worked on numerous national advisory committees on environmental issues and on the boards of several environmental organizations including Environmental Defense Fund and The Wilderness Society. He is a fellow in the American Association for the Advancement of Science and a fellow and past president of the Ecological Society of America. Norm was the 2017 recipient of the Herbert Stoddard Lifetime Achievement Award from the American Association for Fire Ecology.

This book is very much a product of Norm's passion for connecting students with their environment. Norm was honored twice by the Duke University with awards for distinguished undergraduate teaching. He was instrumental in the development of Duke's undergraduate program in environmental science and policy, and he taught the introductory course for this program for over 15 years.

Lissa Leege is a professor of biology and the founding director of the Center for Sustainability at Georgia Southern University. She earned her undergraduate degree in biology from St. Olaf College and received her Ph.D. in plant ecology at Michigan State University. Her ecological research concerns threats to rare plants, including the effects of fire and invasive species on endangered plant populations and communities. She has also conducted 20 years of research on the impacts of invasive pines on the sand dunes of Lake Michigan and the subsequent recovery of this system following invasive species removal. Lissa was instrumental in the development of an Interdisciplinary Concentration in Environmental Sustainability for undergraduates at Georgia Southern. Under her direction, the Center for Sustainability engages the campus and community with annual sustainability celebrations, a sustainability grant program, and a robust speaker series. Lissa is also involved with the environment on a statewide level as a member of the 2013 Class of the Institute for Georgia Environmental Leadership and a founding member of the Georgia Campus Sustainability Network.

Lissa has taught nonmajors environmental biology for 19 years with an emphasis on how students can contribute to environmental solutions. In 2006, she established an Environmental Service Learning project, through which thousands of environmental biology students have engaged in tens of thousands of hours of environmental service in the local community. Lissa has been honored with both college and university service awards and has served as a faculty fellow in Service-Learning. Her contributions to this book have been inspired by her passion for engaging students in positive solutions to environmental problems.

Justin St. Juliana is a lecturer in the Ecology and Evolutionary Biology Department at Cornell University. He received his bachelor's degree in animal ecology at Iowa State University, his master's degree in evolutionary ecology from Ben Gurion University of the Negev (Israel), and his Ph.D. in biology from Indiana State University. Justin's research lies at the interface of predator prey interactions, optimal foraging, and stress hormones. His study organisms include rodents, foxes, fleas, owls, snakes, and feral cats. Before taking his position at Cornell University, Justin was an associate professor at Ivy Tech Community College (Terre Haute Campus) in Indiana. While at Ivy Tech he taught at multiple biological levels from microbiology to environmental science. Justin also developed and still administers a statewide online nonmajors biology course taken by thousands of Ivy Tech students every year.

Justin teaches the large mixed majors/nonmajors Ecology and the Environment course at Cornell University. He is very interested in the latest teaching innovations and heavily incorporates active and community-based learning into his courses. Justin believes that scientific concepts can be taught as stories that relate to a student's life. He also extensively utilizes technology to improve student learning outcomes. In addition to being a coauthor, Justin developed the Process of Science, Global Connects, and Focus on Figures activities associated with this book, in ***Mastering™ Environmental Science***.

Dedication

To Nicholas, Natalie, Noelle, Nicole, Riley, and all other of Earth's children. May we make decisions today that ensure the future beauty, diversity, and health of the environment on which they will depend.

To Micah and Emory, my constant joy and inspiration. I owe you the beautiful world I inherited, and it is my hope that education will motivate all kinds of students to take leadership and action in bringing about a bright and sustainable future.

To my father, Ronald, who, having spent his formative years as a hunting and fishing guide, enabled me to appreciate the natural world and taught me the value of a strong land ethic. I hope that, in this book, I can pass his valuable lessons along to the readers.

Practice making decisions about complex environmental issues

***The Environment and You*, 3rd Edition**, by Norm Christensen, Lissa Leege, and new co-author Justin St. Juliana, gives today's generation of students reason to be hopeful about environmental challenges. The unbiased approach equips students with important analytical and quantitative reasoning skills, including how to ask questions to seek information required to develop informed opinions. The authors strive to inspire students, by connecting the course to choices they can make as citizens and demonstrating the role science can play in influencing personal, community and global environmental issues.

Who or What Matters?

Environmental ethics differs regarding who or what has value.

In any ethical framework, we must identify *who* or *what* is to be valued. In consequence-based ethics, we must specify who or what should receive the greatest benefit. In duty-based ethics, we must define to whom or what we have a duty. For example, does the commandment, "Thou shall not kill," extend to animals?

Systems of environmental ethics also require us to consider whether the value is intrinsic or instrumental. A person, organism, or object valued as an end unto itself is said to have **intrinsic value.** A thing that is valued as a means to some other end has **instrumental value.** Most ethicists agree that every human life has intrinsic value. Some ethicists argue that other living things have value if only as a means to support the well-being of humans. Thus, their value is instrumental.

Anthropocentric ethics assigns intrinsic value only to humans; it defines right actions in terms of outcomes for human beings. Other organisms and objects have instrumental value because they contribute to human well-being. The conservationist view of environmental management is certainly anthropocentric. There are also situations for which the preservationist view could be considered anthropocentric. Things that are not essential to our well-being, such as a place of beauty (Yosemite) or a charismatic animal (panda bear), acquire instrumental value because humans happen to care about them.

Biocentric ethics argues that the value of other living things is equal to the value of humans. Biocentric ethics extends intrinsic value to *individual* organisms beyond human beings; the organisms do not need to benefit humans in order to have value.

There are two distinct schools of biocentric ethics. Some biocentrists argue that for a thing to have intrinsic value, it must be able to experience pleasure or satisfaction. Therefore, it must possess qualities such as self-perception, desires, memory, and a sense of future. In this view, animals such as dogs, chimpanzees, and porpoises have intrinsic value, but plants and animals lacking a complex nervous system do not. This biocentric ethic motivates many in the animal rights movement.

Other biocentric ethicists argue that any individual organism that is the product of natural evolution has intrinsic value. Therefore, an amoeba or a jellyfish has the same value as a porpoise or a chimpanzee (Figure 2.10).

Ecocentric ethics places value on communities of organisms and ecosystems. Ecocentric ethicists believe that *collections* of organisms or critical features in the environment have intrinsic value. Aldo Leopold's assertion that "a thing is right when it tends to preserve the integrity, stability and beauty of the biotic community" is an example of ecocentrism. An ecocentric ethicist might argue that because hunting individual animals improves the health of that species' populations by removing diseased animals, it is a right action. On the other hand, many biocentrists argue that hunting is unethical because it violates the intrinsic value of the individual organism.

The most expansive form of ecocentrism asserts that intrinsic value derives directly from naturalness. Philosopher Andrew Brennan, for example, argues that a natural entity such as a river has intrinsic value and is not a "mere instrument." Nature does not exist in order to meet our particular needs. Instead, it deserves moral respect in its own right. Because we are the air we breathe, the water we drink, and the food we eat, all elements of the environment have equal intrinsic value. Humans have no right to diminish the diversity and richness of Earth's ecosystems except to meet vital needs. This concept is the basis for what is called the **deep ecology movement.**

▲ **Figure 2.10 Photogenic Flora and Fauna**
To which of these organisms do you assign intrinsic value? What is the basis for your decision?

you decide

Should "big game" hunting be banned in African wildlife preserves?

In July 2015, a lion was killed by a recreational big game hunter just outside the Hwange National Park in Zimbabwe. The lion, nicknamed Cecil, was well known to park visitors and was being studied and tracked by researchers from Oxford University. Cecil's death received media attention around the world and set off a vigorous debate about the ethics of big game hunting. Many argue that such hunting is cruel, and it threatens the long-term survival of already endangered species. Hunting proponents counter that big game hunting is an important source of income in many underdeveloped African countries. Furthermore, many game species are too abundant and often come into conflict with rural farmers. Place yourself in the position of the Minister of Environment, Wildlife, and Tourism in Zimbabwe:

- ► What would be your decision on hunting?
- ► Explain the ethical basis for your decision.

NEW! You Decide discussions provide students with complex environmental issues, then prompts them to consider options and take a position. Teaching suggestions and PowerPoint lecture slides accompany each You Decide in the text, providing instructors with a guide and resources for use in class.

You Decide topics include:

- Should big game hunting be banned in African wildlife preserves? (chapter 2)
- Should we attempt to slow global warming by using engineering techniques? (chapter 9)
- Should you have to consider the global consequences of your food buying decisions? (chapter 12)

And more!

Explore a fresh approach to environmental concerns

NEW! Misconceptions address common misunderstandings and push students to examine the evidence that contradict their ideas. Topics include climate change, water and air quality, evolution, and more.

Seeing Solutions highlight how the work of corporations, municipalities, and organizations around the world are using teamwork and new approaches to solve environmental challenges.

that reduce the impact on the environment, such as solar panels and scrubbers that control air pollution, are instead represented as $1/T$, modifying the equation to

$$I = (PA) \times 1/T$$

It is worth noting that wealth is not inherently destructive to the environment: It can be used to develop sustainable technologies and to conserve land area, for example. Only when wealth results in greater resource consumption does its environmental impact increase. *It is important to note that the IPAT equation is a simplified conceptual model; it is not designed to calculate numerical values, but instead to illustrate relative impacts with modifications among parameter values.*

The IPAT equation emphasizes that the size of a population is not the only factor to consider when determining its impact on the environment. Consumption of ecosystem goods and services and use of technology are also key factors. For the sake of demonstration, you can calculate the environmental impact of an imaginary population by plugging simple numbers into the IPAT equation: $P = 2$, $A = 2$, $T = 2$. The equation becomes:

$$I = 2 \times 2 \times 2 = 8$$

If the population size (P) doubles to 4, its impact (I) also doubles:

$$I = 4 \times 2 \times 2 = 16$$

Note that the impact on the environment would be the same if the size of the population (P) remained constant but its use of technology (T) doubled:

$$I = 2 \times 2 \times 4 = 16$$

Of course, the interaction of the factors is not as simple as the IPAT equation may suggest. A change in one factor invariably causes another factor to change. For example, increases in population may lead to increases in technology. Increases in affluence also tend to increase technology.

Much of the impact of affluence and technology is associated with the use of energy to power motor vehicles and generate electricity. Although people living in developed countries make up only about 16% of the world population, they consume approximately 75% of the total energy used each year. Ehrlich and Holdren estimate that the average citizen of a developed country has 7.5 times more impact on Earth's ecosystems than the average inhabitant of a developing country. Based on energy use alone, Ehrlich and Holdren suggest that the environmental impact of an average American is nearly 30 times greater than that of a citizen of Haiti or Niger.

As consumption (A) increases around the globe, it plays an increasingly significant role in the calculation of impact (I) on Earth. The people of developing countries are striving to improve their well-being by acquiring more material goods and better access to technology. As the population and per capita consumption of developing countries increase, their impact on the environment will increase dramatically. For example, between 1980 and 2001, people in developing countries in the Middle East, North Africa, and Asia increased their consumption of electricity by over 370%. During those two decades, the population in the developing countries of Asia grew 1.7%, and the region led the world in pace of economic expansion.

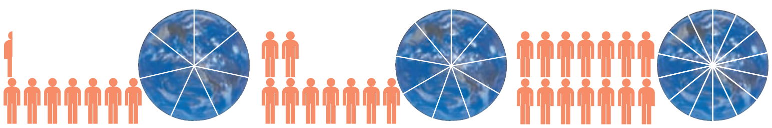
China is the world's most populous country. It is also the second-largest consumer of energy, behind the United States. On average, an American citizen uses over five times more energy than a Chinese citizen. However, between 1990 and 2010, per capita energy use in China grew by over 100% compared to growth of about 12% in the United States.

Because the growth rate of the world's human population is declining, there is hope that we may be able to achieve sustainability. Yet to reach this goal, the rate of consumption will need to change, particularly in the world's richer countries (Figure 5.35). Sustainable development will require increased conservation of ecosystem goods and services. New technologies that help us use those goods and services more efficiently may be the answer. Greater efficiency may provide the means to diminish our collective footprint while sustaining our well-being.

misconception

Aren't countries with rapidly increasing populations primarily responsible for the depletion of resources needed to sustain the human population?

When determining the impact of a country on Earth's resources, you must also take into account its consumption per person, which can be predicted by its income. In fact, countries with the highest GDP consume far more resources per person than those with the highest birth rates. So, no, this is a false assumption.



Present: World population >7.5 billion
With its present population of over 7.5 billion, Earth's natural resources are supporting many millions of people at a high level of expected well-being and many more millions at a low level.

2035: World population 9 billion
If, as expected, the world's human population increases by nearly 1.5 billion by 2035, expectations of what is a sufficient level of well-being will have to decrease.

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▲ **Figure 5.35 Population Growth Scenarios**
The ability of Earth's environment and natural resources to help future generations meet their needs depends not o
demands for resources change. For ease of comparison here, Earth's resources are divided equally, with one slice p
resources are not actually equally divided among the world's population: The wealthy consume far more resources

SEEING SOLUTIONS

Taking the Fire out of Cooking

How can poor countries diminish indoor pollution using the power of the sun?

▲ **Figure 10.25 Kitchen Pollution**
Each day, the wood fire used by families to heat water and food also exposes them to considerable indoor air pollution.

In developing countries worldwide, smoke from indoor wood-fueled stoves causes many health problems and more deaths than are caused from malaria. Wood smoke contains hundreds of different chemicals and aerosols, many of which cause cancer or encourage respiratory infections, tuberculosis, and other pulmonary diseases. Women and young children suffer the greatest exposure to wood smoke and so are at greatest risk (Figure 10.25). In addition to causing indoor pollution, burning wood for fuel increases the rate of deforestation in developing countries. Furthermore, trips to gather wood take time and energy that could be used for other activities (Figure 10.26). In some regions such trips to gather wood can even be dangerous.

Using smokeless cooking fuels would greatly reduce the risks of indoor pollution. Unfortunately, kerosene and natural gas, the most reasonable alternatives, are too expensive for most families in the world's poorest countries. Charcoal is a more affordable option. Burning charcoal produces far less smoke than wood; it also releases more heat per unit weight. Charcoal can be stored indefinitely, whereas wood rots quickly in tropical regions. But charcoal is more costly than wood. And because charcoal is normally produced from wood, its use still encourages deforestation.

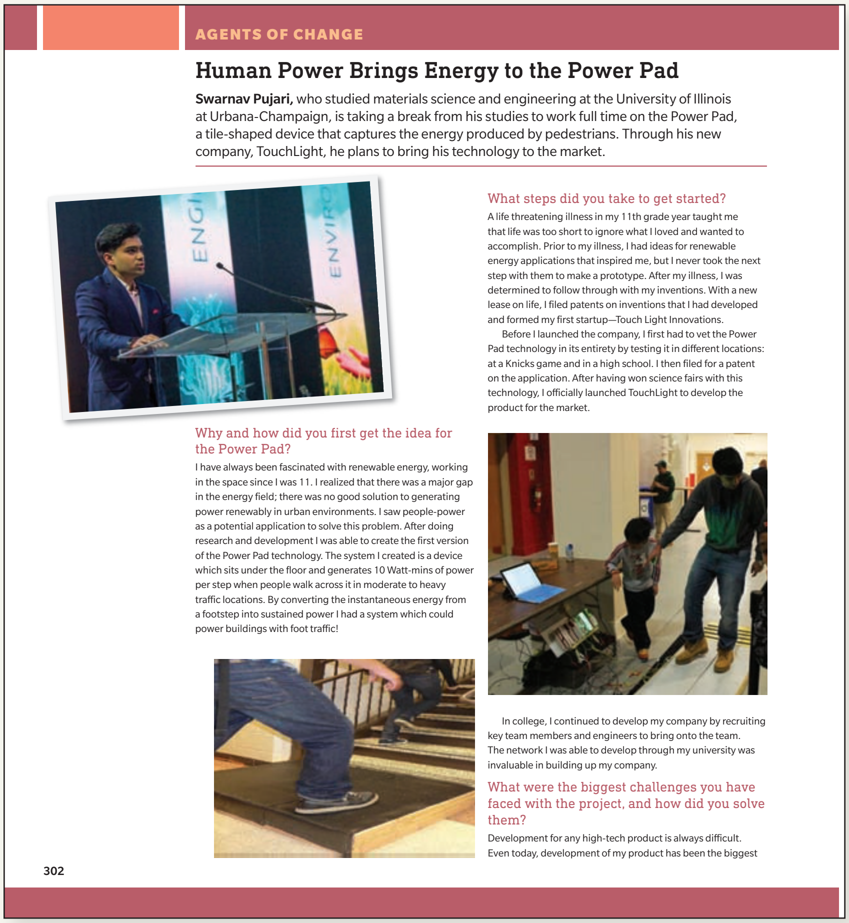
Enter the development of solar cooking. Have you ever stepped barefoot on concrete or blacktop on a sunny day? It was hot, right?! That same energy from the sun can be used to cook food. A basic solar cooker uses low-cost reflective materials to direct sunlight to a pot. That directed sunlight

▲ **Figure 10.26 The Search for Firewood**
Finding firewood is a daily task for women in many countries.

heats up the food. Materials cooked in solar cookers can reach temperatures in excess of 100 °C so they can even be used to sterilize water (Figure 10.27).

Solar cookers are not without their disadvantages. They cannot be used in low light conditions, and cooking durations are often longer than compared to traditional cooking methods. Solar cookers are a developing technology and

See real solutions that support the well-being of humans and the planet



AGENTS OF CHANGE

Human Power Brings Energy to the Power Pad

Swarnav Pujari, who studied materials science and engineering at the University of Illinois at Urbana-Champaign, is taking a break from his studies to work full time on the Power Pad, a tile-shaped device that captures the energy produced by pedestrians. Through his new company, TouchLight, he plans to bring his technology to the market.

Why and how did you first get the idea for the Power Pad?

I have always been fascinated with renewable energy, working in the space since I was 11. I realized that there was a major gap in the energy field; there was no good solution to generating power renewably in urban environments. I saw people-power as a potential application to solve this problem. After doing research and development I was able to create the first version of the Power Pad technology. The system I created is a device which sits under the floor and generates 10 Watt-mins of power per step when people walk across it in moderate to heavy traffic locations. By converting the instantaneous energy from a footstep into sustained power I had a system which could power buildings with foot traffic!

What steps did you take to get started?

A life threatening illness in my 11th grade year taught me that life was too short to ignore what I loved and wanted to accomplish. Prior to my illness, I had ideas for renewable energy applications that inspired me, but I never took the next step with them to make a prototype. After my illness, I was determined to follow through with my inventions. With a new lease on life, I filed patents on inventions that I had developed and formed my first startup—Touch Light Innovations.

Before I launched the company, I first had to vet the Power Pad technology in its entirety by testing it in different locations: at a Knicks game and in a high school. I then filed for a patent on the application. After having won science fairs with this technology, I officially launched TouchLight to develop the product for the market.

In college, I continued to develop my company by recruiting key team members and engineers to bring onto the team. The network I was able to develop through my university was invaluable in building up my company.

What were the biggest challenges you have faced with the project, and how did you solve them?

Development for any high-tech product is always difficult. Even today, development of my product has been the biggest

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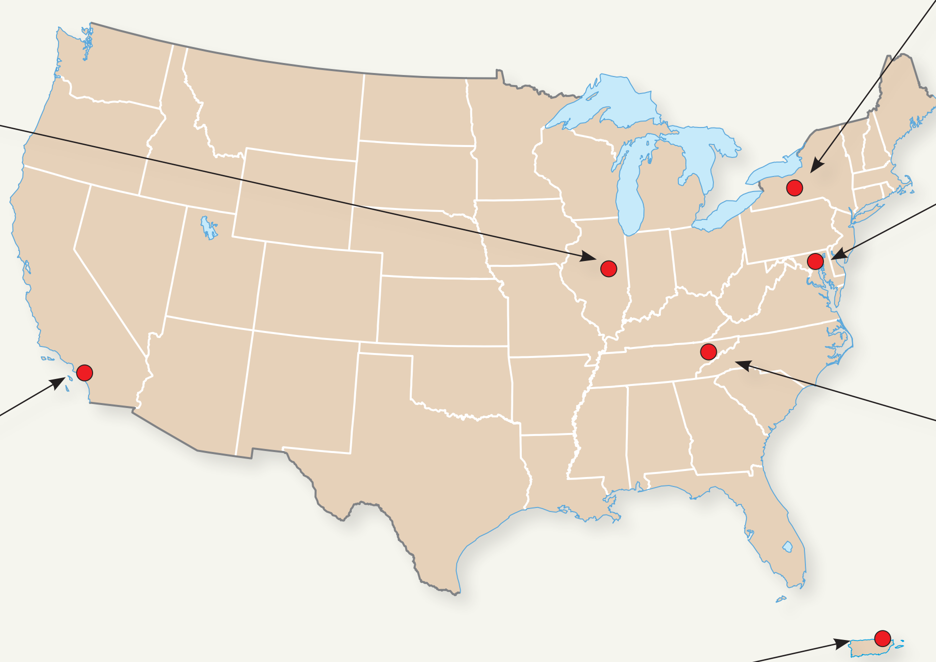
UPDATED! Agents of Change continue to inspire students by showcasing college students and recent graduates who are taking action to develop sustainable environments and improve human well-being. These young leaders represent a variety of locations at different institutions, and they serve as role models for students who are looking for opportunities to take action to influence the future.

Six NEW Agents of Change stories listed below.



Swarnav Pujari, *University of Illinois at Urbana-Chamgpaign*, Power Red

Will Amos, Aldrin Lupisan, *University of California-Irvine*, Plastic Waste Conversion

Dejah Powers, *Cornell University*, Get Them to the Green

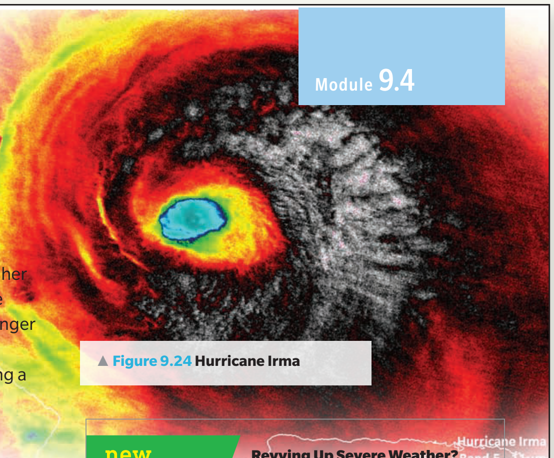
Destiny Watford, *Towson University*, Baltimore Incinerator, Free Your Voice

Erica Davis, *University of Tennessee-Knoxville*, Reform Oil and Natural Gas Severance Taxes

Amira Odeh, *University of Puerto Rico*, Bottle Ban

An accessible, accurate, and current presentation of the science …

Module 9.4



▲ **Figure 9.24** **Hurricane Irma**

9.4 Consequences of Global Warming

BIG IDEA The changes caused by global warming vary from region to region. In some places, increasing temperatures have been accompanied by higher rainfall amounts. In others, they have brought drought. Winters have become milder and shorter in Earth's middle latitudes, and dry seasons have grown longer in some parts of the tropics. Glaciers and ice sheets are melting worldwide. Warming is causing sea levels to rise. Taken together, these changes are having a significant impact on the flora and fauna of many ecosystems.

Drier and Wetter

Global warming is producing wetter conditions in some places and drought in others.

The effects of rising temperatures on precipitation vary geographically. Rainfall has increased significantly in eastern North and South America, as well as in most parts of Europe and Asia. In contrast, sub-Saharan Africa, the Mediterranean region, and western North America have been drier. Since 1970, longer and more intense droughts—as measured by decreased precipitation and higher temperatures—have affected wide areas of the tropics and subtropics. At the same time, there has been a worldwide increase in the frequency of rainstorms that result in flooding, even in areas where total annual rainfall has declined. Warm air holds more moisture (see Module 3.6).

In regions in which rain is highly seasonal, such as sub-Saharan Africa, global warming appears to be changing the length of wet and dry periods. This is a matter of special concern because food production depends on the length of wet seasons. Based on current trends and climate models, growing seasons are expected to become shorter over most of sub-Saharan Africa, with the exception of lands very near the equator.

There is evidence that global warming is influencing drought cycles. For example, the El Niño/La Niña/Southern Oscillation is caused by changes in the temperature of surface waters in the equatorial Pacific Ocean. When waters off the west coast of South and Central America are cold, drought is much more common in the southwestern United States. Some climatologists think that since 1970 the length and intensity of El Niño and La Niña events have been outside the range of natural variability. Although climate models predict that such changes will occur, most scientists feel that it is not clear that they are actually underway.

new frontiers

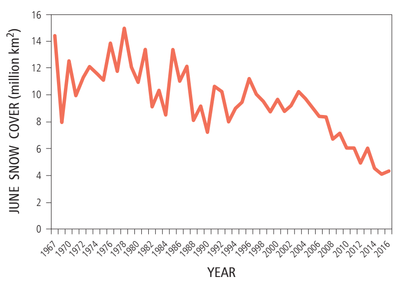
Revving Up Severe Weather? Ocean temperature is an important factor in the development of tropical storms and hurricanes, and ocean temperatures have increased between 0.25 °C and 0.5 °C (0.45–0.9 °F) over the past century. Warmer sea surface temperatures appear to be associated with the observed increase in the number and strength of tropical storms in the Pacific Ocean. But trends in the Atlantic Ocean are far less clear. The very significant damage from Hurricane Sandy in 2012 was largely a consequence of a combination of sea level rise (see the next section) and poorly managed coastal development (see Module 18.2). But the unprecedented rainfall from Hurricane Harvey that devastated much of Houston in 2017 and the record-breaking intensity of Hurricane Irma, also in 2017, appear to have been caused by warmer than normal sea surface temperatures in the Gulf of Mexico and Atlantic Ocean (Figure 9.24).

Debate continues regarding the effects of global warming on past and current storm patterns, but there is consensus among scientists that continued sea surface warming will very likely increase the frequency and severity of tropical storms in the future. How much evidence do you believe we need in order to take strong action to mitigate the effects of future strong storms? How much of the risk associated in living in coastal areas should be the responsibility of property owners versus the government?

Melting Glaciers and Ice Sheets

Over 80% of Earth's glaciers are retreating.

Nearly 75% of Earth's fresh water is contained in various forms of ice. This includes snow cover, which varies seasonally, mountain glaciers, and the massive glaciers or ice sheets that cover most of the landmass of Greenland and Antarctica. It also includes Arctic sea ice and floating ice shelves that surround Antarctica. The total amount of this frozen water depends on the rate of snowfall and ice formation relative to the rate at which it melts. In most places today, the rate of melting exceeds the rate of ice formation. Snowpack in many mountainous regions has been shrinking, and over 80% of Earth's mountain glaciers are retreating. Average snow cover has been steadily decreasing, especially in spring and summer months in the Northern Hemisphere (Figure 9.25).



◀ **Figure 9.25** **Diminishing Snow Cover**
June snow cover is indicative of snow extent in the Northern Hemisphere spring and summer. Although there is year-to-year variation, the downward trend is clear. Average snow extent for 1967–1986 was 11.59 million km^2, but for 1997–2016 it was only 7.57 million km^2.

Data from: The Rutgers University Snow Lab. http://climate.rutgers.edu/snow-cover/table_area.php?ui_set=2.

UPDATED! New Frontiers emphasize the complex inter-actions between new scientific discovery, ethics, and policy. Examples include:

- How will future economic development influence population trends?
- Has global warming increased the frequency and intensity of hurricanes and typhoons?
- Have reduced emissions of CFCs to save the ozone layer also slowed the rate of global warming?

Current and accurate data and research are presented throughout, to emphasize the science behind environmental issues.

... informed by decades of careful research

Updated to reflect new research and current developments, **Focus on Science** essays incorporate critical-thinking questions that encourage students to think about the process of scientific inquiry. These questions can be used to spark class discussion and help students apply and analyze information presented to them.

FOCUS ON SCIENCE

Citizen Science and the Flint Water Crisis

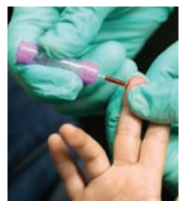
Can regular citizens collect data to help researchers and themselves?

In the traditional model for research, scientists collect and analyze their own data. But scientists are increasingly enlisting the general public to collect scientific data through citizen science programs. *Citizen science* is not entirely new. For example, in 1900, the Audubon Society began working with what is now tens of thousands of bird lovers in North America to collect data on bird populations. State wildlife agencies often acquire valuable data from hunters on game populations.

Recently, citizen science played a key role in identifying and mitigating a public health crisis in Flint, Michigan. In 2014, city managers in Flint decided to switch the municipal water source from Lake Huron to the local Flint River (Figure 18.27). Although the river had suffered decades of industrial pollution, EPA programs had greatly improved its quality. But shortly after the switch, people began complaining that the water had a brown color and foul odor. Then came reports of health problems, including skin rashes and bacterial infections. In early 2015, tap water in one home was found to contain lead at concentrations of 104 parts per billion (ppb); that is 7 times higher than levels deemed safe by the EPA.

▲ **Figure 18.27 The Flint River**
The Flint River had undergone remediation so the water was cleaner, but it still contained some pollutants. The concentration of lead in the river water was not high, but when this water flowed through lead pipes it corroded them. This resulted in high lead levels in the water delivered to homes and businesses.

Because it can have serious effects on brain development in fetuses and children, lead is an especially worrisome toxin (Figure 18.28). The Michigan Department of Environmental Quality (MDEQ) also tested the water in Flint during 2015. Their results did not indicate a significant problem. Therefore, no public warning regarding water use was issued.



▲ **Figure 18.28 The Flint Children**
Children are especially susceptible to the effects of lead. As many as 12,000 Flint children under the age of six were exposed to high levels of lead during the crisis.

Nevertheless, public concerns persisted. One resident asked Dr. Marc Edwards of Virginia Tech, an expert on lead in municipal water systems, to review the MDEQ results. Based on his review,

samples. Their tests revealed that the lead levels in Flint's water were considerably above the government standard at many locations in the city (Figure 18.29).

The lead was not coming directly from the Flint River. Rather, high concentrations of chlorine and other chemicals in the source water were leaching lead from the plumbing of many Flint homes. Municipal managers could have prevented this problem by adding orthophosphate, a chemical that protects lead pipes, to the water.

Armed with these results, Flint citizens demanded action. In December 2015, the city had declared a state of emergency and implemented several actions to remediate the problem. Immediate responses included public information campaigns, distribution of bottled water, increased testing in homes, distribution of water filters, and switching the water source back to Lake Huron. Since the crisis, Flint has dramatically improved its water testing and water safety standards. It has also received money from the EPA and the state of Michigan to improve its water infrastructure. While the situation has improved, those children affected by lead may experience negative lead-related health effects that will influence them for life.

The citizen scientists of Flint, Michigan, played a central role in confirming a serious problem with the quality of their drinking water and in advocating for action to solve it. More important, they have established a model for action for other communities that may face similar challenges.

1. On what topics or issues might you act as a citizen scientist?
2. Do you think data collected by citizen scientists are trustworthy?

▲ **Figure 18.29 Citizen Science Matters**
Dr. Marc Edwards unloads samples from the Flint Water Study to assess in his laboratory at Virginia Tech. With data collected by local citizens, he and his team showed the lead levels in over 5,000 Flint homes exceeded the EPA standard of 15 ppb.

SUSTAINABLE DEVELOPMENT GOALS

▲ **Figure 1.27 An Agenda for 2030**
Seventeen sustainable development goals comprise the 2030 Agenda for Sustainable Development. Visit the UN's Sustainable Development home page and click on the SDGS tab to access an interactive graphic highlighting all Sustainable Development Goals.

1.6 Sustainable Development, The Environment, and You

BIG IDEA On September 25, 2015, the 196 member countries of the United Nations unanimously adopted a resolution entitled "Transforming Our World: The 2030 Agenda for Sustainable Development." A "plan of action for people, planet and prosperity"—the triple bottom line—the Agenda sets 17 sustainable development goals (Figure 1.27). Each of the chapters of *The Environment and You* relates to one or more of these goals. Proposed actions focus on two general themes, protecting our planet and investing in the future we want. The Agenda is ambitious and full implementation by 2030 will require significant commitments not only from UN member nations but also from the people that they represent. Success will depend on our ability to monitor and forecast long-term trends, to better understand connections between social systems and ecosystems, to identify thresholds of change, to formulate incentives for sustainable behavior, and to integrate learning and action.

Sustainable Development Goals

Protecting our planet—investing in the future we want.

Goal 1: No Poverty. End poverty in all its forms everywhere. Since 2002, the number of people living below the extreme poverty line (< $1.90/day/person) dropped by over half, from 26% to 10%. Nevertheless, poverty remains widespread in many regions; over 40% of people in sub-Saharan Africa, for example, endure extreme poverty. Young people are especially vulnerable. Among young adults 15 to 24 years old, 16% live in extreme poverty compared to 9% of people over 25. Poverty clearly has direct impacts on human well-being, but it also impacts our environment.
► *We explore the connection between poverty, well-being, and human population growth in Chapters 5 and 18. The implications of poverty for the conservation of Earth's biological*

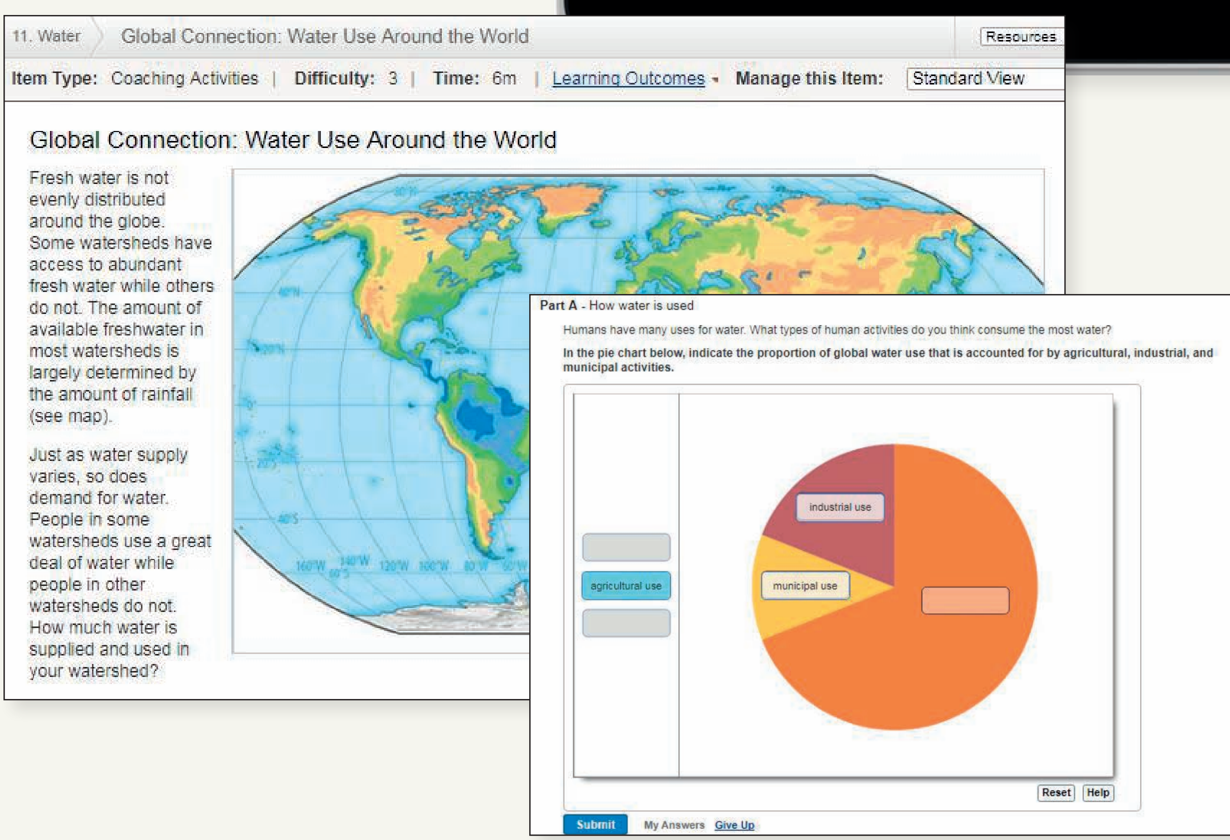
Goal 3: Good Health & Well-Being. Ensure healthy lives and promote well-being for all at all ages. By many measures, the health of Earth's people has improved significantly over the past 15 years. Maternal and infant mortality rates have fallen by nearly half. Nevertheless, nearly 6 million children under age 5 died in 2015, most from communicable diseases. Changes in a variety of environmental factors are influencing the spread of disease worldwide, including urban development, air and water pollution, deforestation, landscape development, and climate change.
► *These topics are covered in Chapters 9, 10, 16, 17, and 18.*

Goal 4: Quality Education. Ensure inclusive

NEW! United Nations Sustainable Development Goals are now included in Chapters 1 and 19, and represent a major international focus and initiative around solving global issues that relate to the environment. This new emphasis enables instructors to demonstrate to students the global scale of environmental issues and the broad impact issues like poverty and human population have on our planet.

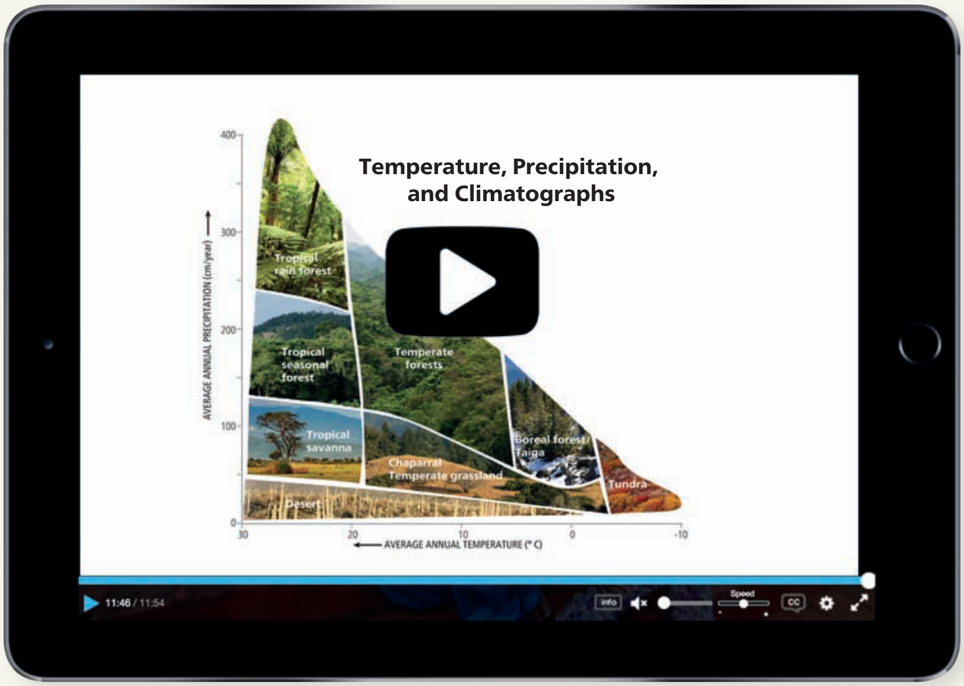
Teach and inspire today's students

NEW! GraphIt Coaching activities invite students to practice their data literacy skills and explore critical issues such as the carbon footprint of food, fresh water availability, ocean acidification and more. Each current and mobile friendly activity equips students with the skills they need to make informed decisions about pressing environmental issues.

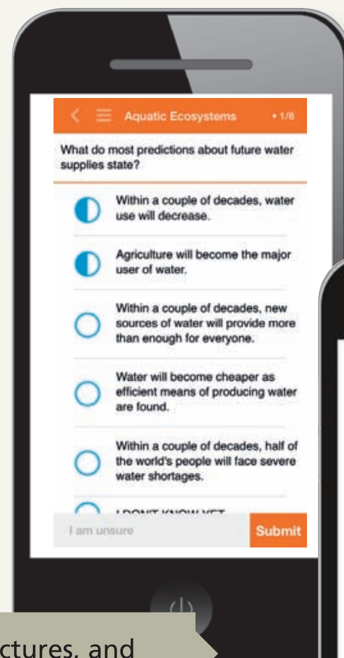


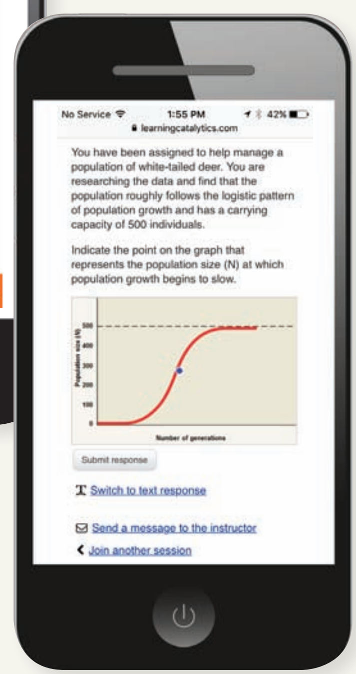
Global Connection activities allow students to explore the relationship between concepts from the text and environmental issues around the world.

with Mastering Environmental Science



NEW! Focus on Figure activities feature 15 select figures from the text and provide brief videos that walk students through the concept to help cement their understanding. Developed with author Justin St. Juliana, the videos are embedded in the eText and assignable in Mastering Environmental Science.





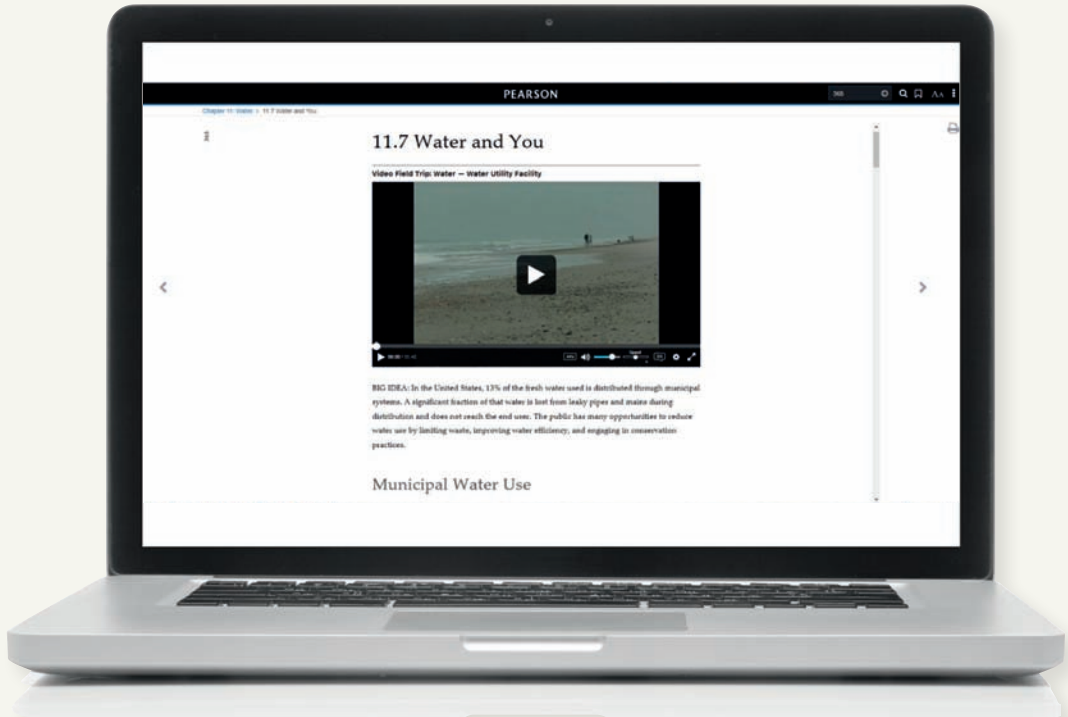
Dynamic Study Modules help students study effectively on their own by continuously assessing their activity and performance in real time. Students complete a set of questions with a unique answer format that also asks them to indicate their confidence level. Questions repeat until the student can answer them all correctly and confidently. Once completed, Dynamic Study Modules explain the concept using materials from the text.

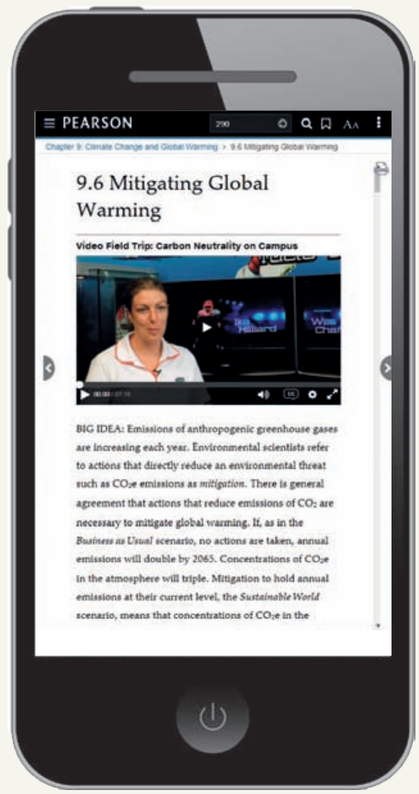
Learning Catalytics™ helps instructors generate class discussion, guide lectures, and promote peer-to-peer learning with real-time analytics. This interactive student response tool uses students' smartphones, tablets, or laptops to engage them in more sophisticated tasks and thinking.

- Pose a variety of open-ended questions that help students develop critical thinking skills
- Monitor responses to find out where students are struggling
- Use real-time data to adjust instructional strategies and try other ways of engaging students during class
- Manage student interactions by automatically grouping students for discussion, teamwork, and peer-to-peer learning

Access the text anytime, anywhere with Pearson eText

NEW! Pearson etext integrates the electronic text with rich media assets, including new Focus on Figures and Video Field Trips in a customizable format that students can use on smartphones, tablets, and computers.





Pearson eText Mobile App can be downloaded for most iOS and Android phones/tablets from the Apple App Store or Google Play.

- Seamlessly integrated videos and other rich media
- Accessible (screen-reader ready)
- Configurable reading settings, including resizable type and night reading mode
- Instructor and student note-taking, highlighting, bookmarking, and search
- Offline access

Preface

It has been said that change is the only constant. For billions of years, Earth's environment and the organisms that inhabit it have been constantly changing. Over tens of millennia we, our species, have constantly changed; each generation's technologies, values, and understanding of its environment have differed from those that preceded it. As a consequence of those technologies and our growing numbers, we have changed Earth's environment more than any other species living now or in the past.

You and the world around you are the current manifestation of this process of inexorable change. The health and well-being of most of Earth's people have markedly improved over the past century but our impacts on Earth's environment have increased significantly. A century ago, our global population was fewer than 2 billion; today there are well over 7.5 billion of us. What's more, each of us today uses several times more resources and generates several times more waste than our century-ago ancestors. The effects on our environment are alarming. Resources such as water and petroleum are dwindling. Air pollution and water pollution have become commonplace. Rates of extinction among Earth's species are more than 100 times higher than in pre-industrial times, and Earth's climate is warming because of human-caused changes in the chemistry of its atmosphere. Sea level rise, dwindling sea ice in the Arctic, and increased severity of droughts and hurricanes are just a few of the consequences of this global warming.

These changes threaten the health of Earth's ecosystems and the well-being of many of its people; they directly affect you. These changes are unsustainable, but they are not inevitable. Sustainability and ecosystems are important themes throughout this book. Sustainable action and change require knowledge and understanding of the ecosystems upon which we depend. Yes, they are complex, but the key elements of ecosystem function and sustainability are beautifully simple. In an increasingly urban and technology-driven world, the connections between Earth's ecosystems and our well-being may seem distant, even irrelevant. But they are at all times immediate and compelling.

We have not downplayed the significant challenges presented by the variety of environmental issues that affect our lives because a balanced view of the challenges is needed. Naïve optimism is not likely to motivate substantial change in our actions and impacts, but neither is pessimism. We can all change the world in directions that are truly sustainable. We are convinced you will be part of that process of change. That confidence and conviction were the motivation for writing this book; hope was the inspiration.

New Innovations and Hallmark Features

A New Author

We welcome Justin St. Juliana to the author team of *The Environment and You.* Justin is a lecturer in the Ecology and Evolutionary Biology Department at Cornell University. Justin believes that scientific concepts can be taught as stories that relate to a student's life. His ability to relate scientific concepts to a student's experiences fits perfectly with our goal of bringing environmental science to life. His ability to use technology to improve student learning and engagement has been brought to bear on the various activities in Mastering™, both in this edition and previous ones. Justin's energy, interests, and teaching philosophy are a welcome addition to the team.

New to this Edition

- ***Misconception*** New to the third edition, this feature addresses common student misunderstandings related to matters of scientific fact and offers a new take on the Q&A feature from prior editions. Is Earth getting warmer because of the ozone hole? Is bottled water safer to drink than tap water? Do vaccines lead to autism in children?
- ***You Decide*** New to the third edition, this feature presents you with a real environmental issue and challenges you to take a stand on that issue, using scientific evidence to support your position. Remember Cecil the lion? Are there some situations where it could be permissible to hunt endangered species? How would you react if fracking were to come to your town?

A Focus on You

A hallmark of each edition, now further reinforced in the third edition, is the importance of humans as agents of environmental change. The effects of those changes on human well-being continue to be a central theme in the third edition. *The Environment and You* emphasizes problem solving and solutions that will enable you to make more informed choices on actions to support the well-being of humans and the health of the planet.

- ***Where You Live*** This feature invites you to use primary data sources to explore environmental principles, issues, and sustainable solutions within the context of your local community. By answering the questions posed, you'll see how concepts and examples from your textbook can be applied to where you live and learn. This will not only satisfy your curiosity but also help you connect local discoveries to central themes of the chapters. Do you know, for example, what biome you live in (Chapter 7) or whether you share your local environment with an endangered species (Chapter 8)? Do you ever think about just how much water you use every day (Chapter 11)? How about the size of your waste footprint (Chapter 17)? These are just a few of the questions you will explore.
- ***Seeing Solutions*** Problems need solutions and this feature highlights how individuals and groups around the world are using new approaches to solve environmental problems. Topics include a city that is investing in green space to solve problems associated with transportation, the local economy, and the health of its citizens (Chapter 16); a business that lessens its impact while improving profit and employee–community relations with a focus on the triple bottom line (Chapter 1); a group that supports increased educational opportunity for young women as a means to improve the health and well-being of their communities (Chapter 5); and efforts designed to support underdeveloped countries in dealing with the economic pressures of a changing world (Chapter 8).
- ***Agents of Change*** This feature showcases the efforts of college students and recent graduates who have taken action to produce sustainable environments and improve human well-being. It is intended to provide guidance and encouragement for any student with a similar drive to make the world a better place. The third edition features six new inspiring Agents of Change: Will Amos and Aldrin Lupisan, inventors of a bike-powered plastic recycling system; Erica Davis, contributor to a reform bill that keeps money from natural resource extraction within local communities; Amira Odeh, leader of a campus-wide plastic bottle ban; Dejah Powell, creator of an environmental summer camp targeted at disadvantaged inner city youth; Swarnav Pujari, inventor and founder of TouchLight, a company that captures kinetic energy from human foot traffic; and Destiny Watford, champion of clean air and environmental justice in Baltimore.

Solid Coverage of Environmental Science

Our current understanding of environmental issues is built on a foundation of decades of careful research by generations of scientists. The third edition not only continues to provide many examples to help you understand the role science and scientific data can play in reducing uncertainty surrounding environmental issues but also engages you in the spirit of inquiry scientists use to ask questions and gather evidence to support predictions.

- ***Currency*** New discoveries are constantly occurring, and our understanding is quickly evolving in all areas of environmental science. Among the many updates to the third edition are recently revised United Nations forecasts for the growth of human populations, the latest information on changes in Earth's climate from the Intergovernmental Panel on Climate Change, and recent innovations in agriculture, energy conservation, and green building practices. This edition provides the most current synthesis of such changes in every environmental field. Graphs and charts use the latest available data, and recent events such as Hurricanes Harvey and Irma; the devastating wildfires in northern California; and the rise and spread of the Zika virus are included.
- ***Motivation*** Each chapter opens with an essay about humans and their interaction with or understanding of the environment. From the historic collapse of the Newfoundland cod fishery (Chapter 1) to the restoration of breeding populations of the California Condor (Chapter 8) or the spread of the Zika virus into the Americas (Chapter 18), environmental science is full of interesting stories. These stories will help you connect to the scientific concepts introduced in each chapter.
- ***Applications and Examples*** *The Environment and You* provides numerous explanations of how scientists have found innovative ways to gather the evidence that supports current conclusions and enables informed predictions.
- ***Focus on Science*** This feature encourages you to think about the process of scientific inquiry and the different methods scientists use to gather evidence by highlighting the work of individual scientists and the contributions they have made. For example, how does a scientist measure the amount of plastic waste in the ocean (Chapter 11)? We emphasize the strategies scientists use to conduct scientific research and include critical thinking questions that will spark class discussion and encourage you to think like a scientist.
- ***New Frontiers*** This feature highlights interesting areas of environmental research as well as unique approaches to problem solving. New Frontier features emphasize the complex interactions between new scientific discovery, ethics, and policy and ask you to consider the implications of the power science has to change the way we live and interact with the environment.

Organized for Learning

The Environment and You is organized to help students understand environmental science.

- Each lesson begins with a big idea so students always have a way to see the forest as well as the trees.
- Manageable amounts of information are organized by key concepts within modules, giving students complete lessons before moving on to the next topic.
- Important concepts are illustrated with clear, purposeful charts and graphs and supported with photographs that capture the essence of the concept being presented.

Supporting All Levels of Students

Students in introductory environmental science classes have vastly different levels of science background. *The Environment and You* is designed and written to serve that diversity.

- ***Self-assessment:*** Questions at the end of every module allow students to assess whether they have truly grasped a topic before they move on. Questions at the end of each chapter are designed to encourage synthesis of concepts and application to real situations.
- ***Mastering™ Environmental Science:*** Used by over a million science students, the Mastering platform is the most effective and widely used online tutorial, homework, and assessment system for the sciences. It motivates students to come to class prepared; provides students with personalized coaching and feedback; quickly monitors and displays student results; easily captures data to demonstrate assessment outcomes; and automatically grades assignments, including concept review activities, 3-D BioFlix® animation activities and quizzes, Graphit! activities, and chapter reading quizzes.

Mastering™ Environmental Science has a suite of activities designed to help your students practice concepts and develop scientific inquiry skills. Assignable activities include:

- *Focus on Figures videos*, new to the third edition, walk students through fifteen of the most critical environmental science figures from *The Environment and You*. Each video, created by Justin St. Juliana, helps students explore and interpret key figures such as the carbon cycle, the Keeling curve, and logistic population growth. The videos are assignable in ***Mastering™ Environmental Science*** as part of an interactive activity that further reinforces student understanding.
- *Process of Science activities* encourage your students to put scientific inquiry skills into action. These interactive activities guide them through current environmental research and help them understand concepts such as developing a hypothesis, making a prediction, understanding variables and independent variables, and more.
- *Global Connection activities* demonstrate the global relevance of local environmental issues and chapter themes. Your students will be able to draw comparisons between environmental issues in the United States and other countries such as water usage, air pollution, or species habitat loss.
- *Interpreting Graphs and Data* activities allow students to practice quantitative skills related to graph interpretation and analysis.
- *Video Field Trips* bring real environmental issues to life. These fourteen videos are embedded in the eText and assignable in ***Mastering™ Environmental Science***. Take a tour of a water desalination plant, explore the sustainability features of a college campus, or visit a coal-fired power plant. These are just a few examples of the issues each video explores.

Acknowledgments

We accept all of the responsibilities of authorship for the third edition of *The Environment and You*, most particularly for any mistakes or flaws. But others deserve much of the credit for its development, organization, presentation, and production. As this project evolved over the course of several years, the Pearson Education publishing team and numerous environmental science colleagues have provided much needed guidance and encouragement.

We are especially grateful to Alison Rodal, our courseware portfolio manager for the second and third editions of *The Environment and You*. She was the catalyst for many of this edition's new features, and her contagious enthusiasm for this project motivated us at every stage.

Our development editor, Mary Hill, expertly and cheerfully guided us on this third edition journey, from start to finish, as she did for the second edition. Mary has an exceptional eye for detail on matters ranging from grammar to module organization and layout to connections among chapters. Even more, we are awed by her nuanced understanding of so many facets of environmental science that informed her suggestions on substance and presentation. Her wonderful sense of humor sustained us throughout this process.

We thank Courseware Portfolio Management, Director Beth Wilbur and Courseware Director, Content Development Ginnie Simione Jutson who encouraged and facilitated this project throughout its second and third editions. In addition, we would not have been able to publish this project without the support from SVP Portfolio Management-Science Adam Jaworski and Managing Director, Higher Education Courseware Paul

Corey. Thank you for taking a risk on this project and for your ongoing collective leadership in science education.

Sophie Mitchell and her wonderful team at Dorling Kindersley Education helped craft and execute the original vision for the first edition of this project.

Producing a book where text and art are created, designed, and arranged in tandem requires a highly collaborative approach to publishing. We are grateful to our production colleagues for overseeing and orchestrating this effort. Mike Early and the content production team oversaw the project's many details and milestones. Mark Ong and Lisa Buckley were responsible for the page and cover design of this third edition, Jason Hammond and Kelly Murphy of SPi-Global oversaw the composition of our text files to actual page layouts, along with Becca Groves who managed to keep all members of the team on point. We thank Kevin Lear of International Mapping for his leadership in the production of illustrations, graphs, and maps and Hilair Chism for her graphic talents utilized in creating this edition's cycle diagrams and other complex figures.

We want to thank Editorial Assistant Alison Candlin for coordinating the Agents of Change contributors and elements so masterfully, and for continuing to follow the vision of this great feature. We also appreciate the support she provided to the entire publishing team.

Special thanks to Rich Media Content Producer Ziki Dekel for overseeing all details on the production of media for the new edition and for ***Mastering™ Environmental Science***, and to Libby Reiser and Sarah Jensen for bringing their creativity and expertise to the development of our new ***Mastering™ Environmental Science*** activities. Todd Brown ensured the smooth release of ***Mastering™ Environmental Science*** for the third edition of the text.

We would also like to thank each contributing supplement author for the edition. Jacquelyn Jordan, Clayton State University, did a wonderful job carefully updating the Instructor's Guide. The Test Bank was written and assembled by David Serrano, Broward State College. David is also the author of the third edition PowerPoint presentations, carefully updating each chapter presentation to help give instructors a headstart in planning each lecture. Reading Questions were crafted by Nilo Marin, Broward State College. We also thank Erica Kipp, Pace University, for her contribution to the updates in ***Mastering™ Environmental Science*** resources for this edition.

After many years spent creating and crafting this book, there comes a time to pass the torch to marketing and sales. We are grateful to Allison Rona Director of Product Marketing, for her support of this text. Christa Pelaez and Mary Salzman brought endless enthusiasm in promoting *The Environment and You*, communicating our vision to instructors all over the country. We are fortunate to have the support of the many sales representatives who work tirelessly to communicate our vision to faculty and ensure instructors' needs are satisfied. We thank them for their dedication and commitment!

Terrence Bensel, Brian Bovard, Robert Kingsolver, and Lester Rowntree made important contributions in the first edition to chapters on climate change, biodiversity, agriculture, energy, and waste management. Their detailed outlines provided road maps through sometimes unfamiliar territory, and many elements from their drafts of several of these chapters are part of the final product.

We owe much to our students at Duke, Georgia Southern, and Cornell Universities. In many ways, they helped shape the spirit and content of this text. They have been guinea pigs for each of its chapters and volunteered many editorial comments. The book is much the better for their input.

Over the years, each of us has had the benefit of working with wonderful mentors and colleagues, all the while being supported by our families. For each of us, individually, we want to thank those people who are so special to us.

Norm: My undergraduate and master's advisor Bert Tribbey passed along much knowledge and wisdom that appears in these pages, and he has long served as my primary role model for teaching excellence. My Duke colleagues William Chameides, Deborah Gallagher, Prasad Kasibhatla, Emily Klein, Randy Kramer, Susan Lozier, Marie Lynn Miranda, Joel Meyer, Lincoln Pratson, William Schlesinger, and Dean Urban were key sources of information and constructive criticism.

I am grateful to my family for their patience with me over the life of this project. My wife Portia has been a sounding board for new ideas, an editor of essays and features, and the best friend ever.

Lissa: My Ph.D. advisor Peter Murphy was an excellent role model who always encouraged my love of teaching and ultimately inspired my desire to reach a wider audience. I am grateful to Georgia Southern University and the Department of Biology for supporting my pursuit of this project, and to my museum colleagues for opening my eyes to the exhilaration of teaching beyond my classroom.

I thank my parents for believing in my passion for sustainability and supporting my path. I owe much to my children Micah and Emory for the time they allowed me to dedicate to this book. Finally, I extend my deepest gratitude to my remarkably patient and supportive husband Frank D'Arcangelo, who encouraged me to follow this dream, even though it meant that he would take on a greater share of parenting responsibilities.

Justin: I would like to thank my undergraduate advisors Fred Janzen and Brent Danielson, my master's advisor Burt Kotler as well as Berry Pinshow, my Ph.D. advisor William Mitchell as well as Steve Lima, and my former department head Janice Webster. Each of these people taught me valuable lessons about science and education.

I am grateful to my family, Paloma, Tanner, Vincent, and Lourdes. When I was a young child I wanted to be an environmental author. Although, I never thought this would take the form of a textbook, or textbook associated activities, my family afforded me the time to pursue this dream.

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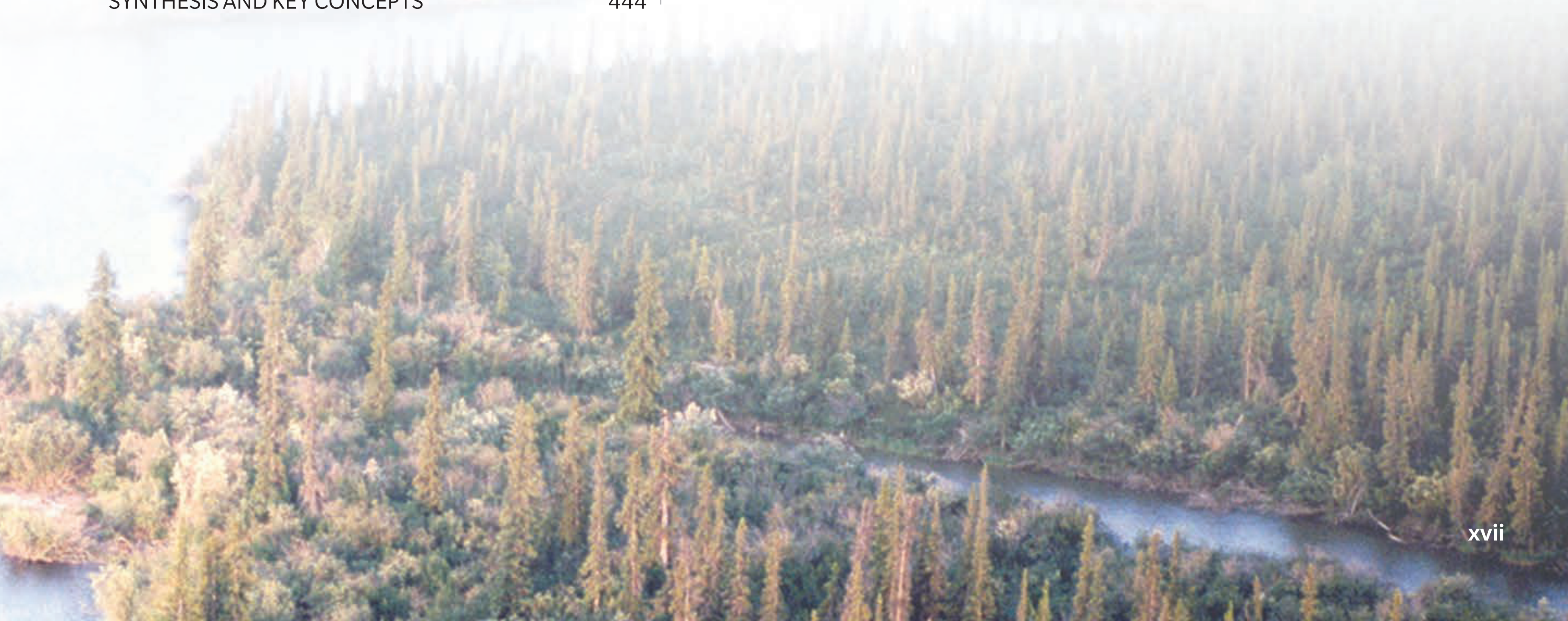
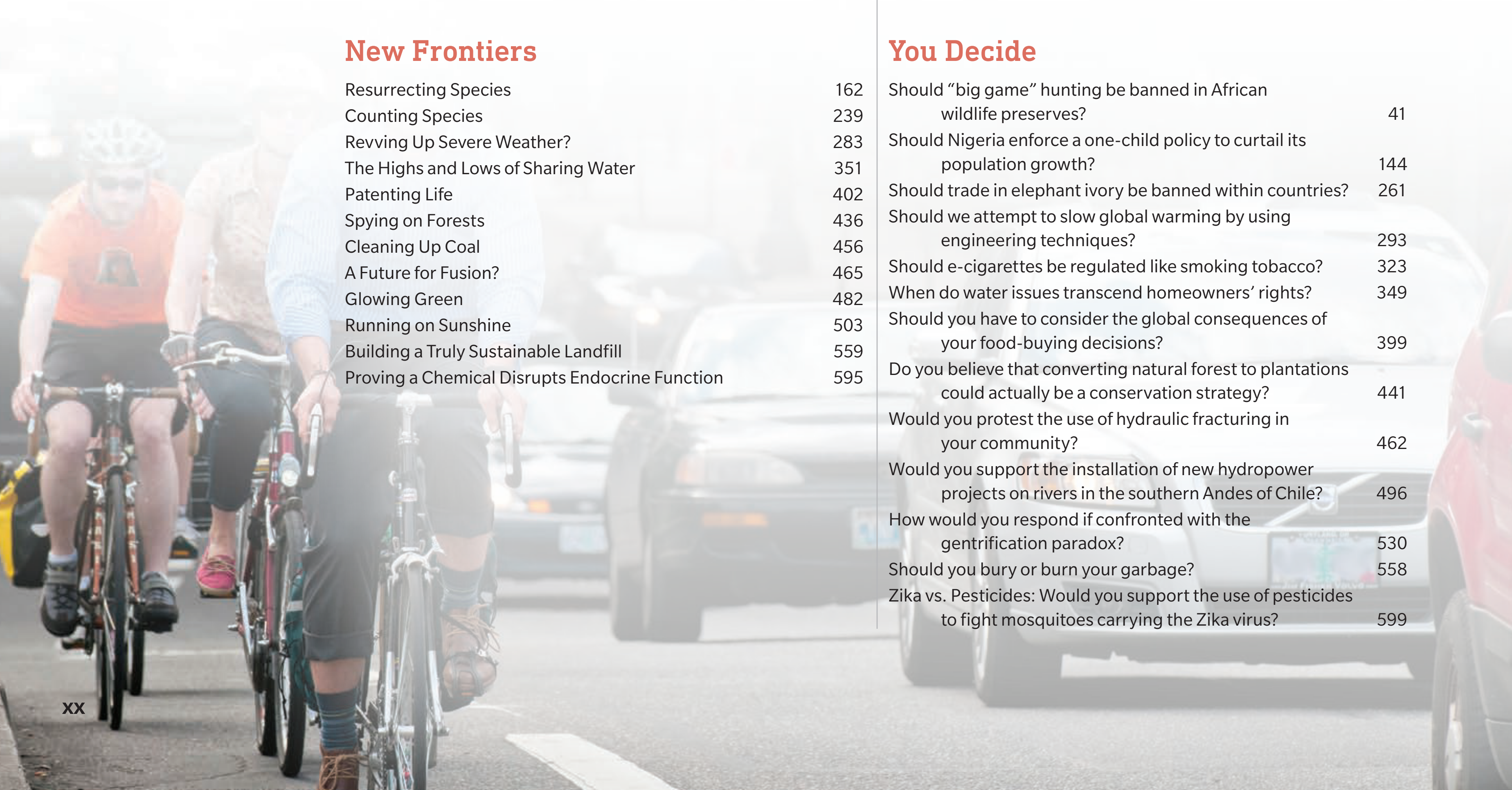
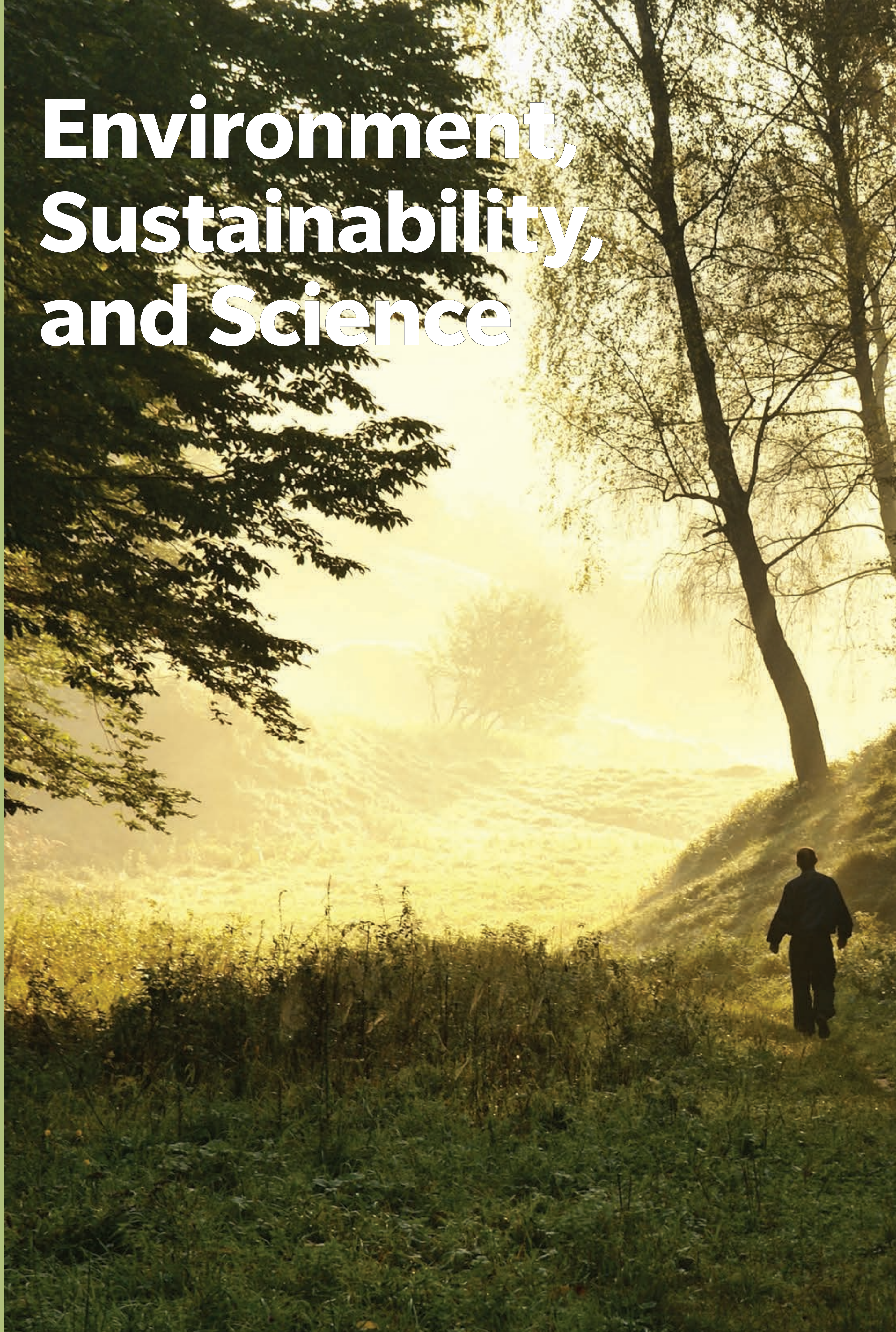




CHAPTER 1

Environment, Sustainability, and Science



Chapter 1

▲ **Figure 1.1 North Atlantic Cod**
For centuries, the social and cultural identity and the well-being of Newfoundland's coastal communities was centered on the cod fishery.

It Takes a Community

Can we collaborate, plan, and act for a sustainable future?

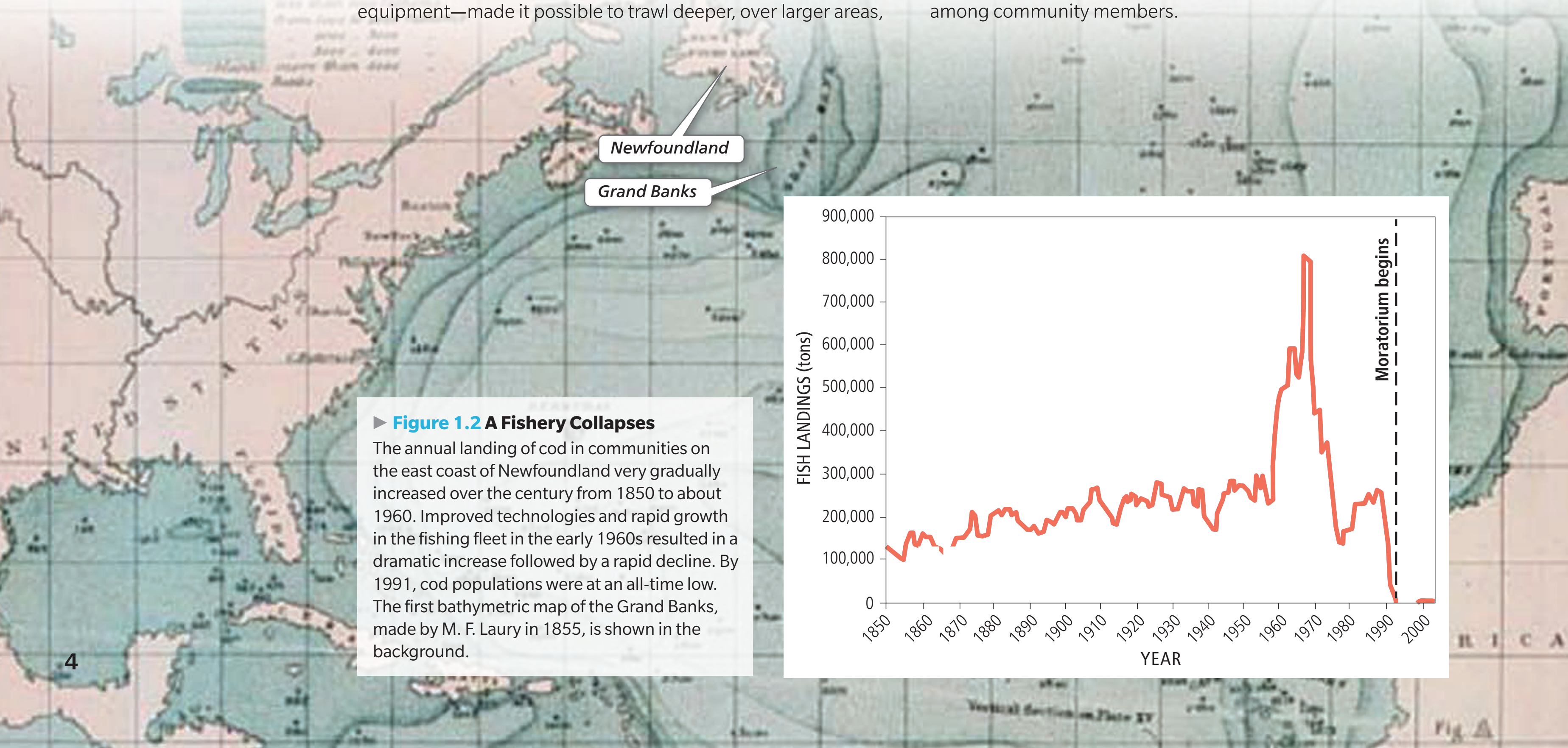
The Grand Banks, which lies off the coast of Newfoundland, Canada, is one of the world's richest fishing grounds. It consists of a group of shallow underwater plateaus that supports shellfish such as scallop and lobster, and a wide variety of fish species including swordfish, haddock, and, most particularly, North Atlantic cod.

For centuries, cod was the economic and social mainstay of the local communities along the coast of Newfoundland (**Figure 1.1**). That changed abruptly in 1992 when the Canadian Minister of Fisheries and Oceans signed a moratorium on the northern cod fishery. Over just a few years prior to 1992, cod landings had plummeted to less than 1% of their historic average (**Figure 1.2**). Landing is the term used to define the amount of fish (usually measured in tons) harvested from the sea and brought to shore. There was no denying that this collapse in cod landings was primarily due to massive overfishing.

For over a decade, fisheries experts had been warning that the harvest levels of the 1970s and 1980s were not sustainable. The size of landed fish had been continuously declining, indicating the loss of the oldest and most productive portion of the cod population. New technologies—more powerful boats equipped with radar, sonar and state-of-the-art navigation equipment—made it possible to trawl deeper, over larger areas, and over longer periods of time. Trawlers were also depleting populations of capelin, an important source of food for cod.

The collapse of the cod fishery in the northern Atlantic is seen by many ecologists as a classic example of the *tragedy of the commons*. The tragedy, first described in 1968 by philosopher Garret Hardin, is the decline and destruction of the natural resources—forests, wildlife, water, and so on—that are shared in common by members of a community. Cooperation, planning, and regulation among community members could avert this tragedy and sustain such resources indefinitely. But, Hardin argued, cooperative behavior diminishes the net benefit that individual members of the community can obtain by uncontrolled exploitation. In essence, it's the idea that when individual interests prevail, common resources are likely to be overexploited. Individuals benefit by using more of a resource, meaning there is little incentive for individuals not to use as much as they can.

We share a great many natural resources in common with Earth's 7.5 billion other human inhabitants. Supplies of many of those resources are diminishing. Each year, for example, 0.2% of Earth's forests are permanently lost and more than 1% are severely degraded. Nearly a third of marine fish stocks are in decline. The species extinction rate is thought to be 1,000 times greater than in pre-human times. We are polluting critical common resources such as the air we breathe and the water we drink. Earth's ecosystems can renew most of these resources, but this would require cooperation, planning, and action among community members.



▶ **Figure 1.2 A Fishery Collapses**
The annual landing of cod in communities on the east coast of Newfoundland very gradually increased over the century from 1850 to about 1960. Improved technologies and rapid growth in the fishing fleet in the early 1960s resulted in a dramatic increase followed by a rapid decline. By 1991, cod populations were at an all-time low. The first bathymetric map of the Grand Banks, made by M. F. Laury in 1855, is shown in the background.

- What is sustainability?
- What are the characteristics of sustainable systems?
- What is an ecosystem?
- What key characteristics do Earth's ecosystems share?
- Why are uncertainty and science important to the sustainable management of systems?
- What important questions remain for a sustainable future?

Are we all doomed to live out the tragedy of the commons? Many environmental scientists believe strongly that we are not. Economist Elinor Ostrom was certainly a vocal champion for this view (**Figure 1.3**). Although she acknowledged that common resources are often overexploited, she also saw numerous cases where they had been and continue to be sustainably managed. The tragedy of the commons, she argued, is an oversimplification, and community members are not necessarily trapped by their greed. Nor are they unwilling to invest time and energy to agree on sustainable resource management strategies.

Ostrom and her colleagues chronicled numerous examples of community success, including sustainable management of fisheries by the Seri people of northwest Mexico and long-term stewardship of forests by communities in Nepal (**Figure 1.4**). She also pointed to successful community collaboration on much larger scales such as the Montreal Protocol, an international program that has successfully limited emissions of chemicals that degrade Earth's protective ozone layer. Such successes have emboldened world governments to try and tackle other large issues like climate change. This was exemplified by the 2015 Paris Agreement where nations around the world compromised and agreed on a plan to combat global warming.

Ostrom compared these situations to ones where the tragedy of the commons prevailed, and she identified key characteristics of resources, governance, and communities that lead to sustainable management of common resources.

The resource: The condition of the resource is very important. When resources become severely exhausted, there are few incentives to manage them sustainably. Therefore, early action is important. Community action is more likely, the more important a resource is to the community.

▲ **Figure 1.3 A Sustainability Optimist**
Elinor Ostrom was convinced that individuals in communities can sustainably manage their resources through collaborative, collective action. Her innovative studies earned her the 2009 Nobel Prize in Economics.

Governance: Choice and voice were important governance characteristics shared by sustainable communities. The more options for management, the better, and community members should have equal say in deciding which options to pursue.

The community: Sustainable communities share three important characteristics. The first is knowledge—the more communities know and understand about essential resources, the more likely it is that they will collaborate to conserve them. The second is leadership—individuals committed to the future of the community and its resources are essential. The third is what Ostrom called social capital—sustainable communities share a vision for the future, and they share values that shape the means of reaching that future.

Although they remain far below their historic levels, stocks of North Atlantic cod are showing signs of recovery. There is general agreement that community-level policies and actions that incorporate these three characteristics have been essential to that recovery.

Ostrom's key community characteristics appear throughout *The Environment and You*. This includes knowledge and understanding of Earth's ecosystems and our impacts on them. It also includes abundant examples of sustainable actions to reduce or eliminate those impacts. Most important, we demonstrate ways that you as individuals can put these actions into practice. We are certain that you will find many reasons to share Ostrom's belief in the potential for sustainable communities at local, regional, and global levels.

◀ **Figure 1.4 Sustainable Communities**
Ⓐ The Seri people have sustainably fished and farmed along the coast of the Sea of Cortez for over 2,000 years. Community members share a commitment to the well-being of their community and the resources that support it. Ⓑ For tens of generations, Nepali farmers have sustainably managed their agricultural fields alongside forest ecosystems. These communities understand that intact diverse forests provide fuelwood, timber, and wildlife, and they also control erosion and support pollinators for their crops.

1.1 Environment and Sustainability

BIG IDEA In Earth's long history, no organism has had a greater effect on the environment than have humans. Our ability to appropriate Earth's resources has been a major factor in the rapid growth in our numbers. Over the past century, we have come to understand that our actions have significant consequences for the well-being of the community of all living things and for ourselves in particular. This understanding is the basis for human actions and behaviors that are mindful of essential environmental processes, economically feasible, and fair to all people now and in the future. These are the key prerequisites for a sustainable future.

The Environment and You

Environmental science and ecology explore the interactions of humans with the natural environment.

You may use the word *environment* to describe where you are and everything around you. Scientists have a more specific definition: the **environment** is all of the physical, chemical, and biological factors and processes that determine the growth and survival of an organism or a community of organisms. The long list of all the factors that make up your environment would include the gases in the air you breathe and the many life forms that nourish and are nourished by you. **Environmental science** studies all aspects of the environment.

Ecology is the branch of environmental science that focuses on the abundance and distribution of organisms in relation to their environment, and to each other. Earth's environments have sustained living organisms for at least 3.8 billion years; they have sustained members of our own species for well over 100,000 years. Throughout this time, Earth's environments and the communities of organisms that depend on them have been constantly changing.

▲ **Figure 1.5 The Frontier**
This painting by Albert Bierstadt of seemingly unending wilderness is typical of many 19th-century depictions of American landscapes.

◀ **Figure 1.6 Too Many Uses?**
Rapid population growth in the United States following World War II placed increasing demands on public lands for timber resources and for other ecosystem services such as grazing, recreation, and the protection of water supplies.

Defining Sustainable Actions

Our understanding of sustainable behavior has changed through time.

The concept of sustainability is central to environmental science. But what does it mean to be sustainable? Over the last 150 years, we have viewed this concept in different ways.

A century and a half ago, the human use of resources, such as wildlife and fisheries, was determined largely by our needs or perceived needs. Earth's forest resources appeared to be inexhaustible, and wildlife was abundant (Figure 1.5). Rivers, lakes, and coastal waters were teeming with fish. We were fully confident of the environment's capacity to produce an abundance of resources and to absorb and process our wastes. And why not? The world's population was only about 1 billion people, and the population of the United States was less than 75 million. (Today, over 7.5 billion people inhabit this planet; more than 300 million live in the United States.)

As human populations and their demand for resources grew, supplies of resources began to dwindle. Between 1920 and 1940, the number of scientific studies of the environment increased greatly. With new knowledge, resource managers began to appreciate the need to align the demand for resources with their supply. In forestry, this included strategies to plant and regrow trees after harvest and to protect them from the threats of pests and fire. In fisheries, this meant establishing catch limits and artificially stocking lakes and streams. These actions helped to sustain the supply of resources.

By 1950, there were 2.5 billion people in the world and 152 million in the United States. As the demand for resources increased, conflicts skyrocketed. In the United States, for example, growth in housing increased the demand for wood from national forests. At the same time, there was increased public interest in using those forests for recreation, for supporting wildlife, and for protecting water supplies. People argued over which use of forest resources should be given priority. To be sustainable, management policies had to recognize the different demands on the environment and its resources. Policies also had to address the conflicts among humans who valued those resources differently. For example, in the management of U.S. national forests there are strongly held values associated with commercial timber management, the provision of clean water, and the conservation of species that have often been in conflict (Figure 1.6).

whereyoulive

What resources does your national forest provide?

Find the nearest national forest to your home by searching the Web for "U.S. national forest" and the name of your state. What important natural resources and public benefits does your forest provide? What potential conflicts might there be among these uses?

▲ **Figure 1.7 Sustainability as a Commitment to the Future**
The 1987 UN Commission on Sustainability was chaired by Norwegian prime minister Gro Brundtland.

In its 1987 report, *Our Common Future*, the United Nations Commission on Sustainability declared, "At its most basic level, sustainability means meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Figure 1.7). This declaration added a critical element of time to our concept of sustainability—sustainable management has its eye on the needs of the future.

The UN Commission on Sustainability was concerned with maintaining **human well-being,** a multifaceted concept that includes life's basic necessities, such as food and shelter, as well as good health, social stability, and personal freedom. Their report noted that the factors necessary to ensure human well-being may change from one generation to the next. Thus, sustainability is not a process of maintaining the status quo. Instead, the commission argued that sustainability is maintaining the ability to accommodate three important sources of change.

1. **The world is changing.** Earth's environments undergo constant change, sometimes in regular daily and seasonal cycles and sometimes in more complicated patterns. Environmental change is both inevitable and essential.
2. **We are changing.** Successive generations of humans have developed and used ever-changing technologies to extract and use resources. Humans also pass their knowledge about their environment and its resources from one generation to the next. As a consequence, our needs for ecosystem goods and services are constantly changing. The value we place on these goods and services changes, too.
3. **We are changing the world.** No other single species has ever shaped its environment to the extent that we have. Our use of technologies, such as fire and agriculture, has allowed our numbers to increase and has changed the world. Our increasing numbers have extended our influence (Figure 1.8). Our increasing use of technology and natural resources has had even greater consequences.

Today we are at a unique moment in history. At no previous time has Earth supported so many humans. At no previous time has overall human well-being been better. We can point with gratitude to actions by previous generations that have helped us meet our current needs, such as the development of agricultural technologies and the establishment of national forests and parks. But we can also identify actions by our ancestors that have impoverished our world. In many regions, poor agricultural practices have permanently diminished soil fertility. Overexploitation has left us with mere snippets of the once vast ancient forests.

Although average well-being among humans is high, variation in well-being is high as well. In developed countries such as the United States, clean water is taken for granted and obesity is all too common. Yet more than one-fifth of Earth's people lack access to clean water and suffer from malnutrition. This disparity has led the United Nations and other world leaders to broaden the definition of sustainability to include the concept of equity. In this context, **sustainability** means meeting the needs of the present *in an equitable and fair fashion* without compromising the ability of future generations to meet their own needs. This is the definition that we will use throughout this text. (It should be noted, however, that scholars and decision makers are not in agreement on what constitutes "equitable and fair.")

► **Figure 1.8 A World of Change**
A crew member of the International Space Station took this photo of the Atlantic Coast, stretching from southern Virginia on the left to New York on the right. The lights shining in six of the great cities of the United States, captured in the image, represent the energy used by nearly 25 million people. It also represents changes in Earth's ecosystems, in human values and technologies, and in our impact on the environment.

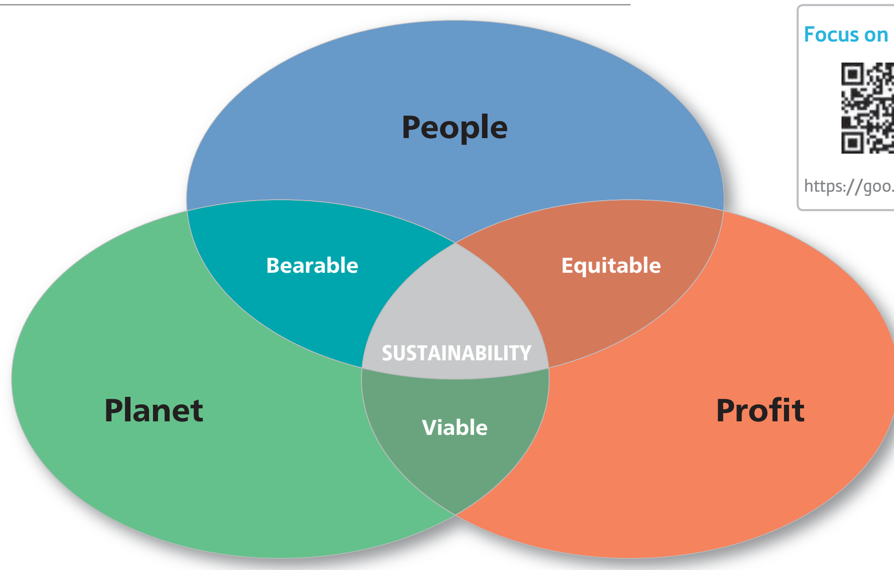
Does this definition of sustainability seem too focused on humans? If so, remember that Earth's environments were self-sustaining for billions of years before our time. If we were to disappear tomorrow, they would eventually recover from our impacts. Our present and future well-being depends heavily on how we treat all of Earth's life and environments. But it also depends on actions that are economically feasible and fair to all people, now and in the future (see Module 1.6).

Planet, People, and Profit: The Triple Bottom Line

Sustainability lies at the intersection of environmental, social, and economic success.

For years, the environmentally minded have insisted on the importance of including the environment in the measurement of profit in business but struggled to develop an accounting system to include these external costs. In 1994, John Elkington, the founder of the British consultancy SustainAbility, developed the concept of the **triple bottom line (TBL).** TBL is an accounting framework by which corporations, nonprofit organizations, and even governments can measure three dimensions of performance: environmental, social, and economic. According to TBL thinking, the intersection of these three dimensions is the only sustainable path for the future (Figure 1.9). Also referred to as the "3 P's"—planet, people, and profit—TBL incorporates the dimension of "planet" or environment, as measured by output of pollutants, conservation of endangered species, waste production, energy use, and so on. The social dimension, or "people," includes such measures as human health and well-being, equity (including the difference in salary between top executives and the lowest-paid workers), access to social resources, and benefit to the community. The economic dimension, or "profit," is the only measure that has been traditionally evaluated.

Reporting the TBL presents a challenge for any organization, in that each dimension is measured in different units. How can the value of pollution that was never emitted be measured in dollars? What is the value of a healthy and happy workforce and a community supported by the businesses therein? Despite the challenges of measurement, TBL is gaining popularity among corporations, nonprofits, and governments, so much so that many have shifted their business models to evaluate and improve all three areas. What is motivating this shift? According to recent MIT/Sloan Management Review reports, consumer preferences, legislative pressure, and resource scarcity are the most important drivers of this change toward a new business model. Executives reported that conserving environmental capital for the future and placing value in their communities and workforce has actually increased their profits. For example, Campbell Soup Company invested significantly in water efficiency measures, resulting in a savings of 1 billion gallons of water during 2008–2013 with a 15–20% return on investment (money saved due to the improvements).



▲ **Figure 1.9 The Triple Bottom Line**
The intersection of these three dimensions is the path to sustainability. Profit without people or planet is short sighted, with no future human or environmental capital to draw from. Environment without people or profit does not support human well-being or allow for economic growth. A focus on the social dimension without accounting for the dimensions of planet or profit does not allow for the preservation of long-term environmental capital or sustaining incomes.

Focus on Figures
https://goo.gl/hiAzZ1

Furthermore, 75% of executives surveyed indicate that the resulting improved revenue performance and operational efficiency make sustainable companies attractive investment targets. Nearly half of the investors surveyed in the MIT/Sloan reports say they would not invest in companies with poor sustainability performance. The bottom line is that corporations that incorporate the TBL into their business model also stand to increase their economic profit.

There is much we can learn from the past to help us ensure a sustainable world for the next generation. Yet in many important respects, that generation will be quite different from all earlier generations. By all indications, it will include over 9 billion people. Those people will use technologies and have expectations that we can hardly imagine. If the management of our resources today is to be truly sustainable, we must be very generous in our projection of future needs. The ecosystem concept described next provides a foundation for defining sustainable behavior and actions.

Questions 1.1

1. Describe how human understanding of sustainable actions has changed over the past century.
2. What kinds of change must be included in our understanding of sustainability?
3. Describe the three dimensions of the TBL. How is each important to sustainability?

For additional review, go to **Mastering Environmental Science™**

DIRTT

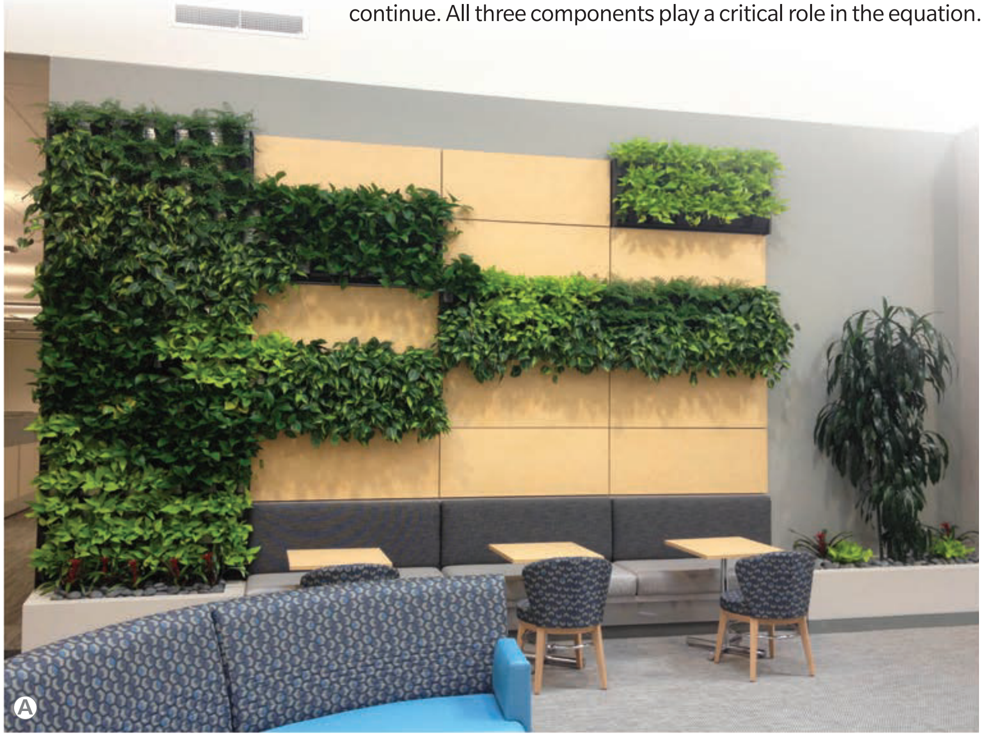
Can a company make a profit based on the triple bottom line?

▼ **Figure 1.10 A DIRTT-y Interior**

Ⓐ Components of DIRTT's office interiors are designed to be completely movable and interchangeable to accommodate the changing needs of a business. Ⓑ Insulation made from used denim lines the prefabricated walls and Ⓒ the plastic "cookies" that separate fragile wall components for shipping are sent back to the factory in a "cookie box" for reuse.

One company that stopped to reconsider its impact and to develop a sustainable approach to business made its intentions clear with its name: DIRTT—Doing It Right This Time. DIRTT creates prefabricated interiors for office buildings, health care, and education facilities, and has developed computer design software that drives the entire manufacturing process, creating efficiencies and reducing waste.

DIRTT measures its success by the TBL: planet (environmental), people (social), and profit (economic). For them, the intersection of these three spheres defines a sustainable business model. If the planet is not considered, resources are depleted and the profit will only continue in the short term. If people are not treated equitably, they are not as productive as they might be and the business will fail. If profit is ignored, people will not have jobs and the business cannot continue. All three components play a critical role in the equation.



Planet. DIRTT considers the environment in every part of its business. The product is built on the concept of reuse. Every piece of the interior is interchangeable, reusable, and movable to accommodate the rapidly changing uses for building interiors (Figure 1.10A). Like Legos™, new pieces fit with the old, and nothing is ever "orphaned" out. Unlike the modern-day electronics industry, DIRTT does not base its profit on "planned obsolescence" but designs its products to be reused indefinitely.

Construction materials are also selected for their environmental sustainability. For example, the prefab walls are insulated with used denim, deferred from the landfill (Figure 1.10B). Shipping materials are reused as well. DIRTT has designed the "cookie"—a small plastic component that effectively separates and protects the prefab materials that are shipped together in stacks to the building site (Figure 1.10C). The cookies significantly reduce shipping weight and the amount of wood used in the shipping process. Every shipment includes a "cookie box" into which all the cookies are deposited and sent back to the factory. DIRTT goes so far as to say that they have failed if they must recycle.

Sustainability at DIRTT goes far beyond the materials they use. By relying on technology and precise manufacturing, there is a radical reduction of material waste compared to what is typically produced on a jobsite. And with reusable components, renovations and reconfigurations don't result in the waste associated with demolition. This reduction in material waste saves money while lessening the load on landfills.

People. In the construction industry, seasonal layoffs are common. DIRTT does not hire seasonally and has kept employees on through tough economic times. Because DIRTT guarantees its clients a two-week turnaround from order to shipment, the company always has trained workers ready to build the product at a moment's notice. When business has been slow, workers have been paid to do community service, thus building goodwill in the communities where the factories are located.

In addition, all DIRTT factories have onsite kitchens that offer inexpensive, local food for all employees. This strategy creates more productive workers by providing healthy food options, thereby reducing illness and absenteeism and building a strong sense of community among the workers who get to know each other over their meals. All of these benefits contribute to a stronger team and a more productive workforce.

Profit. Finally, DIRTT is also motivated by profit. DIRTT leaders recognize that the company cannot be viable if it is not profitable. Between 2013, when it began selling shares of its stock to the public, and 2016, DIRTT's annual revenue grew by 91%. Although they always consider the needs of shareholders, the company does not resort to short-term gains as a trade-off against long-term environmental benefits or loss of employees. This long-term view, combined with TBL measurements of profit, provides a more realistic evaluation of the company's real success.

1.2 Ecosystems

BIG IDEA We use the ecosystem concept as a way to organize all of the factors and processes that make up our environment. An ecosystem includes all of the organisms and their physical and chemical environment within a specific area. The flow of energy and matter through ecosystems influences the distribution and abundance of organisms within them. Ecosystems provide resources and services that are essential to our well-being. Today, human activities influence nearly all of Earth's ecosystems, often in ways that diminish the benefits they provide and threaten our well-being.

Ecosystem Function and Integrity

The ecosystem concept combines living organisms and their environment.

An **ecosystem** is the combination of a community of organisms and its physical and chemical environment, functioning as an integrated ecological unit. A forest and a lake are familiar examples of ecosystems.

Ecosystems include **biota,** or living organisms, and their **abiotic,** or nonliving, environment. The abiotic characteristics of an ecosystem, such as its climate, determine the distribution and abundance of the organisms that live there. At the same time, the actions of the organisms living in an ecosystem change and shape their environment. For example, trees need deep soil to grow, and as they grow, their decaying leaves increase soil fertility and their root systems penetrate rock fractures and accelerate soil formation.

Ecosystems are connected by the flow of energy and matter. Energy and matter are transformed as they move between living organisms and the abiotic environment. Ecologists refer to the flow of matter and energy and the processes influencing the distribution and abundance of organisms as **ecosystem functions.**

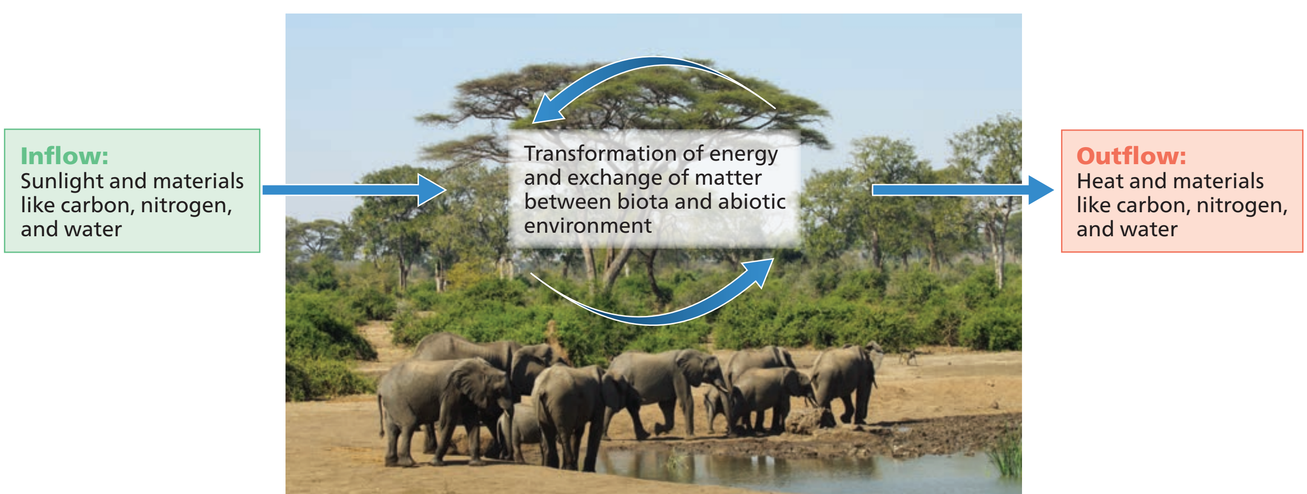
Ecosystem integration. An ecosystem is an *integrated system* made up of living and nonliving parts and the processes that connect them (Figure 1.11). **Ecosystem integrity** refers to the web of interactions that regulate ecosystem functions. Ecologists often compare the functional integrity of an ecosystem to that of an individual organism. For example, the tissues and organs of your body work together to carry out the functions necessary for life, such as breathing and digesting food. Similarly, the microbes, plants, and animals in an ecosystem interact with each other and their environment in ways that determine the overall movement of matter and energy through an ecosystem.

Like individual organisms, ecosystems have the capacity to adjust to disturbances and changes in their environment. This capacity depends upon their integrated nature. Severe disturbances, such as hurricanes and fires, may greatly alter the species living in an ecosystem and the way the ecosystem functions. The ecosystem can then undergo a process of change and recovery that ecologists liken to the process of growth and development of an individual organism.

In one very important way, however, the ecosystem-as-organism metaphor is not accurate. The boundaries of a single organism are quite distinct. For example, your skin forms a well-defined boundary between you and your environment. The boundaries of ecosystems are not so clearly delineated. Instead, they are defined by those who study or manage them; often they are quite artificial.

Ecosystem scale. Ecologists study ecosystems of many sizes. The unit of study may be as large as a forest or river basin, an entire continent, or even the entire globe. However, the ecosystem concept is equally applicable at much smaller scales, such as a cup of sour milk or a rotting log. Figure 1.12 shows the different biological levels of organization at which life and its interactions with the environment can be studied.

▼ **Figure 1.11 An Integrated System**
Ecosystems comprise organisms and their nonliving environment, and they are dependent on inflows and outflows of matter and energy.



▲ **Figure 1.12 Levels of Organization**
"Ecosystem" is just one scale at which life in an environment can be studied.

Questions 1.2

1. Differentiate between ecosystem functions and ecosystem services.
2. Describe four types of ecosystem services.

For additional review, go to **Mastering Environmental Science™**

Ecosystems are often studied and described in the absence of human influences. Ecologists interested in the fundamental workings of ecosystems may choose to study regions of wilderness where human influences are minimal. Today, however, human influences are nearly everywhere. Over the past century, our population has grown from just over 1 billion to over 7.5 billion people. Changes in culture and technology, such as forms of transportation, energy use, and urban development, have greatly magnified our demand for resources. As a consequence, our impacts on Earth's ecosystems have grown by far more than the sevenfold increase in our numbers.

Ecosystem Services

Ecosystems provide the resources and processes upon which humans depend.

Human well-being depends on **ecosystem services,** the multitude of resources and processes that ecosystems supply to humans. Ecosystem services can be classified into four categories: provisioning, regulating, cultural, and supporting services.

Provisioning services supply us with resources, such as food, water, and the air we breathe. We humans are notable for our ability to modify—often simplify—ecosystems in order to increase their provisioning services. For example, an agricultural field of corn provides a large amount of food to humans but supports far fewer species than the grassland that once grew there.

Regulating services are the ways that ecosystems control important conditions and processes, such as climate, the flow of water, and the absorption of pollutants. These services are a consequence of the integrated, self-regulating nature of ecosystems.

Cultural services are the spiritual and recreational benefits that ecosystems provide. If you have visited the Grand Canyon, Yosemite Valley, or simply taken a quiet walk in the woods near your home, you have benefited from cultural services.

Supporting services are the basic ecosystem processes, such as nutrient cycles and soil formation, that are needed to maintain other services. For example, bees and other pollinating insects provide a supporting service by ensuring that flowers are fertilized and fruits form.

Like all living things, we humans rely on ecosystems for survival as well as shape ecosystems through our actions. But unlike other organisms, human interactions with the environment are mediated by beliefs, knowledge, technologies, and institutions that are passed from one generation to the next. For example, rather than relying on the slow process of biological evolution to adapt to new environments, we dress appropriately for changing weather and invent new technologies to heat our homes. We then pass this knowledge on to our children. Our success as a species, as reflected by our growing numbers, is largely attributable to these unique features (Figure 1.13).

In 2006, the United Nations Environment Programme published its *Millennium Ecosystem Assessment*. The work of hundreds of scientists and decision makers, this document evaluated the global impacts of humans on ecosystems and the effects of ecosystem change on human well-being. Three important themes emerged from this assessment. First, many of Earth's ecosystem services are being degraded. Second, there is growing evidence that many ecosystems are becoming more fragile and prone to disturbance. Third, these changes threaten the well-being of all humans, but especially the poor. The report also notes that the effective management of ecosystem services can be a dominant factor in the reduction of poverty and international conflict. The interconnections between ecosystems and human well-being are a major theme of this book.

▼ **Figure 1.13 Humans and Ecosystems**
Human well-being is dependent on the services provided by ecosystems. Human activities produce significant changes in the ecosystem functions that deliver those services.

1.3 Principles of Ecosystem Function

BIG IDEA Ecosystems are integrated systems that can be understood in terms of fundamental scientific principles. Although awesomely complex, ecosystems are not haphazard. Even though living things are continuously consuming and replenishing oxygen, the amount of oxygen in our air remains remarkably constant. The mix of life-forms that surrounds us changes from place to place and season to season in complicated but dependable ways. The organization and function of ecosystems depends on four fundamental principles.

1. Matter and energy are neither created nor destroyed.
2. Ecosystems are always open to gains and losses of matter and energy.
3. Ecosystem processes are self-regulated by interactions among their living and nonliving components.
4. Ecosystem change is inevitable and essential.

Conservation of Matter and Energy

Something cannot be created from nothing, and everything goes somewhere.

Energy and matter can be neither created nor destroyed, although in the cores of stars and nuclear reactors matter can be converted into energy. This is known in physics as the law of energy and mass conservation. If you burn 1 g of coal in the presence of oxygen, the ash, smoke, and gases that are released would exactly equal the weight of the coal plus the oxygen. You would also find that the light and heat energy emitted by the fire, plus the energy left in the ash and smoke, precisely equal the chemical energy that was stored in the oxygen and unburned lump of coal. Something—coal—has been used to generate something else—ash, smoke, gases, heat, and light: But no matter or energy has been lost.

The conservation of energy and mass applies to ecosystems, too. By measuring the amounts of matter in the different parts of an ecosystem and the rates at which this matter flows through it, we can characterize ecosystem functions and make predictions about their future behavior. This accounting of amounts and rates is a fundamental tool in ecosystem science and management.

In environmental science, the law of energy and mass conservation is a powerful reminder of two fundamental truths. First, *something cannot be created from nothing*. Energy and matter can be converted from one form to another, but the total amount of any resource is finite. A resource can be exhausted if it is used faster than it is replenished. Second, *everything goes somewhere*. Energy and matter that we put into ecosystems have fates that may influence ecosystem functions (Figure 1.14).

▼ **Figure 1.14 Shrinking Lake and Stinking Lake**
Something cannot be created from nothing—Lake Mead near Las Vegas, Nevada, is gradually shrinking as water use exceeds water supply in the Colorado River Ⓐ. Everything goes someplace—China struggles to cope with the numerous chemicals that now pollute Lake Tai, one of its largest lakes. Toxic algae and cyanobacteria are now abundant and create a foul odor that can be detected as far as a mile away Ⓑ.

Ecosystems Are Open

Because flows of matter and energy influence ecosystem functions, context matters.

Ecologists often assign arbitrary boundaries to ecosystems based on factors such as type of soil or kind of vegetation. Regardless of the boundaries we choose for them, ecosystems do not have distinct boundaries. Ecosystems are open. Matter and energy can flow into them from their surroundings, and they can also move out. For example, sunlight and rain can enter an ecosystem, and heat and streams can flow out. These gains and losses of matter and energy influence ecosystem functions. An important consequence of this openness is that *context matters*: Functions in an ecosystem are inevitably influenced by the nature of the ecosystems that surround it.

Scientists set the size and boundaries of the ecosystems they study in such a way as to measure inputs and outputs of matter or energy most easily or to monitor key processes within them. For example, ecologists often study the drainage basins of rivers. The boundaries of drainage basins are set by the mountains, hills, and valleys that determine where the water flows. Ecologists can determine the amount of water coming into a drainage basin by measuring rainfall. They can measure the amount leaving by monitoring the flow at the mouth of the river that drains the basin.

To manage ecosystem processes effectively, it would seem logical to do so according to the scale and boundaries by which we can most easily monitor and sustain them. Unfortunately, our political systems often make this difficult to achieve. For example, rivers frequently define the boundaries between counties, states, and countries. These political entities are responsible for managing the water flowing through them. But rivers also divide drainage basins. As a consequence, multiple counties, states, and countries influence and manage water quality and flow (Figure 1.15). This often leads to mismanagement and conflicts among jurisdictions.

Similarly, consider how often straight lines form the boundaries between counties, states, and countries, such as much of the border between the United States and Canada. Such lines have little to do with the movement of the organisms, matter, and energy that shape our environment.

◀ **Figure 1.15 A Problematic Boundary**
The Rio Grande separates Mexico from the United States along nearly 70% of the border between the two countries. In this satellite photo, the river flows between El Paso, Texas, on the right and Ciudad Juarez on the left. Both cities depend on its resources, contribute pollution to its waters, and argue over its management.

Ecosystem Stability

Ecosystem processes are regulated by interactions among biotic and abiotic components.

Ecosystems are constantly changing. Yet key features, such as the total number of species and the processes involving the transformations of matter and energy, remain stable. The stability of ecosystem features and functions derives from the complex interactions among their diverse array of biotic and abiotic components.

Dynamic homeostasis is the process by which systems adjust to changes in ways that minimize how much features or processes vary from their normal values. Your ability to maintain your body temperature around 98.6 °F (37 °C) is an example of dynamic homeostasis. If your temperature cools, even slightly, you put on a sweater or coat to warm yourself. If your temperature rises above this value, you are prone to start shedding layers of clothing.

Examples of dynamic homeostasis abound in ecosystems. Over time, the sizes of plant and animal populations tend to fluctuate above and below average values. The amounts of the chemical elements nitrogen and phosphorus found in lakes or soils vary from time to time, but they maintain long-term average values.

Dynamic homeostasis occurs because of feedback, the ability of a system to adjust based on changes in the system itself. Homeostatic systems "talk and listen to themselves." Again, consider the regulation of your body temperature. A part of your brain called the *hypothalamus* is very sensitive to changes in your body temperature. If your blood temperature drops below 98.6 °F, your hypothalamus sends an "I feel cold" signal to your consciousness. It also sends signals that stimulate involuntary responses, such as shivering or increased metabolism. If your blood temperature rises above 98.6 °F, your conscious brain receives the "I feel warm" signal from the hypothalamus. It also stimulates involuntary responses that cool your body, such as sweating.

The regulation of temperature in your body is an example of a negative feedback system. **Negative feedback** occurs when directional change in a process alters the system in a manner that reverses the direction of that change. A change in your body temperature causes your body to respond in ways that help your body return to its normal temperature. Note that "negative" refers to the *direction* of the change (in the opposite direction), not to the value of the consequences of the change.

Many ecosystem processes are regulated by negative feedback in the interactions between their living and nonliving components. In a pond ecosystem, for example, the rapid growth of algae may deplete the supply of an element in the water that is essential for growth. Consequently, the growth of the algae slows and the supply of that element is again stabilized (Figure 1.16). Negative feedback systems tend to stabilize ecosystems.

Positive feedback occurs when the directional change in a process alters the ecosystem so as to reinforce that change. For example, because tree roots hold soil and limit erosion, the loss of forests on steep mountain slopes accelerates soil erosion. This erosion leads to the loss of even more forest (Figure 1.17). Another example concerns global climate change. As temperatures rise, glaciers melt, decreasing the reflective white cover of Earth. The reduced reflectivity results in greater absorption of sun energy and even more melting ice. If not counteracted, positive feedback can destabilize ecosystems. Note that "positive" does not refer to the value of the outcome of the change: Indeed, the consequences of increased erosion and the loss of glaciers are inevitably negative for the environment. Positive feedback instead refers to feedback *in the same direction* that the process is progressing.

Ecosystem diversity and complexity matter. The dynamic homeostasis of ecosystem functions derives in part from the diversity of species and the complexity of their interactions. Such diversity and complexity provide multiple alternative paths for the movement of matter and energy within an ecosystem. Human actions that diminish diversity often diminish ecosystem stability. This is explored in more detail later in this chapter.

misconception

Why refer to feedback as negative if its consequences could potentially be good?

Negative and positive in this context refer to the *direction* of change and not whether change has good or bad consequences. Negative feedbacks *reverse* the direction of change, positive feedbacks *accelerate* the direction of change.

◀ **Figure 1.16 Negative Feedback**
The growth of algae and the availability of nutrients that control their growth provide an example of negative feedback in which each change is reversed by the other. Increased nutrients increase algal growth; this then diminishes nutrients and subsequently diminishes algal growth. One change is diminished by the other.

◀ **Figure 1.17 Positive Feedback**
Deforestation and erosion can generate positive feedback. On this hillside in Albania, loss of forest stimulates erosion, which then results in loss of more forest and further erosion. One change is reinforced by the other.

Questions 1.3

1. What important environmental principles derive from the law of conservation of mass and energy?
2. What is meant by the phrase "ecosystems are always open"?
3. What is the difference between negative and positive feedback?

For additional review, go to **Mastering Environmental Science™**

Ecosystem Change

Change is both inevitable and essential.

Dynamic homeostasis implies change. Ecosystems are constantly changing in response to actions from outside as well as to the processes operating within them. Processes of change in ecosystems have played a significant role in the evolution of the organisms that live in them. As a consequence, species have a variety of characteristics that permit them to adjust to change.

Some changes, such as seasonal changes in temperature, are so regular and predictable that we do not consider them to be disturbances. It is the departures from these regular changes, such as abnormally cold summers or extended winter weather, that we call disturbances. Other disturbances include storms, floods, and fire. Though less predictable, such disturbances are inevitable, and ecosystems must adjust to them.

Ecosystem change in response to disturbance is often homeostatic, controlled by feedbacks that produce regular and predictable patterns. For example, a hurricane may fell many of the trees in a forest (Figure 1.18). This creates an opportunity for new trees to grow. Fires recur at regular intervals in many terrestrial ecosystems as a consequence of the accumulation of flammable organic matter. Such fires play an essential role in the reproduction of many forest plants.

Sometimes processes in ecosystems change because of long-term changes in other processes. For example, a gradual change in the climate of a region can produce new patterns of ecosystem change. Between 5,000 and 10,000 years ago, moist tropical forest grew across the Sahel of Africa, the region south of the modern Sahara Desert. When these tropical forests were disturbed by storms or other events, similar forests soon grew in their place. About 4,000 years ago, the climate of this region became hotter and drier. When tropical forests were disturbed, they were replaced by grasslands and savannas, not forests. The hotter climate had caused a new pattern of changes in the ecosystem.

Over the past 10,000 years, humans have become increasingly important agents of change in most of Earth's ecosystems. Whether or not our actions are sustainable depends on the degree to which we recognize and apply the principles of ecosystem function.

▼ **Figure 1.18 Disturbance Dependence**
The lodgepole pine seedlings on this hillside in Yellowstone National Park were established following a wildfire. Lodgepole pine and many other plant species in this ecosystem depend on such fires for regeneration.

1.4 Acting Sustainably

BIG IDEA Ensuring the well-being of present and future generations is a worthy, motivating vision, but how can we know which of our actions are truly sustainable? For this, we must refer to our understanding of ecosystems. An action is sustainable if it does not impair the functions of ecosystems or their ability to deliver the services upon which we depend. The four fundamental principles of ecosystems are guideposts for assessing whether an action is sustainable.

Managing Resources

To be sustainable, actions must conform to the law of mass and energy conservation.

For at least three centuries, scientists have agreed about the unfailing truth of the law of conservation of mass and energy. However, given our overexploitation of natural resources and our dumping of toxic waste into ecosystems, one might conclude that great numbers of us do not share in that agreement.

The resources that we take from ecosystems often can be replenished by natural processes or from outside sources. For example, the water taken from the Great Lakes is replenished by rivers that flow into them. Those rivers, in turn, are fed by rain falling in their headwaters. The fish harvested from the Great Lakes are replenished by a complex array of biotic and abiotic interactions that support fish reproduction and population growth. Resources such as water and fish are said to be renewable, but they can be renewed only if we do not use them more quickly than they can be replenished.

Similarly, ecosystems can transform many waste materials and pollutants into less obnoxious or toxic forms. But ecosystems can carry out this function only if the rate of waste flowing in does not exceed the rate at which the ecosystem can transform it. In other words, the law of mass and energy conservation must be followed.

A resource is **nonrenewable** if its amount in an ecosystem declines with virtually any level of use. In the scale of human history, oil is a nonrenewable resource. The world's oil reserves were produced by geologic processes operating over millions of years. Today, we are using these reserves about 1 million times faster than they can be replenished (Figure 1.19). Exploitation of nonrenewable resources defies the law of mass and energy conservation.

Sustainable use of resources requires two things: an understanding of their rate of renewal and the ability to manage the rate of their use. For example, many of the factors affecting the flow of water into the Great Lakes are understood, but the causes of decade-to-decade changes in rainfall in the Great Lakes basin are not. The ability to manage the use of water in the basin is complicated by the rapid increase in the number of people living in the region and disputes among states and between the United States and Canada.

▼ **Figure 1.19**
A Nonrenewable Resource
It took Earth's ecosystems tens of thousands of years to produce the volume of petroleum consumed by the world's billion-plus automobiles and trucks in a single day.

Understanding Boundaries

To be sustainable, actions must acknowledge the importance of boundaries.

Sustainable environmental management requires an understanding of the spatial scales and landscape features that influence ecosystem functions and services. Whether it is a backyard, a national park, or an entire country, arbitrary scales and boundaries limit our ability to monitor and manage ecosystem processes. We cannot manage the quality of water in the lower reaches of a river, for example, if arbitrary boundaries exclude management options upstream.

The scale and boundaries appropriate for managing one process may not align with those appropriate for managing another process or service. For example, river basins are useful units for managing the flow of water, chemicals in the water, and the organisms that live in the water. However, river basins are usually irrelevant to the management of air pollution or populations of large migratory animals.

Sustainable management also requires communication and collaboration across the boundaries that define differences in ownership, management purpose, and nationality. Unfortunately, these human boundaries often represent some of the most significant challenges to sustainable management.

Maintaining Balance and Integration

To be sustainable, actions must maintain the homeostatic capacity of ecosystems.

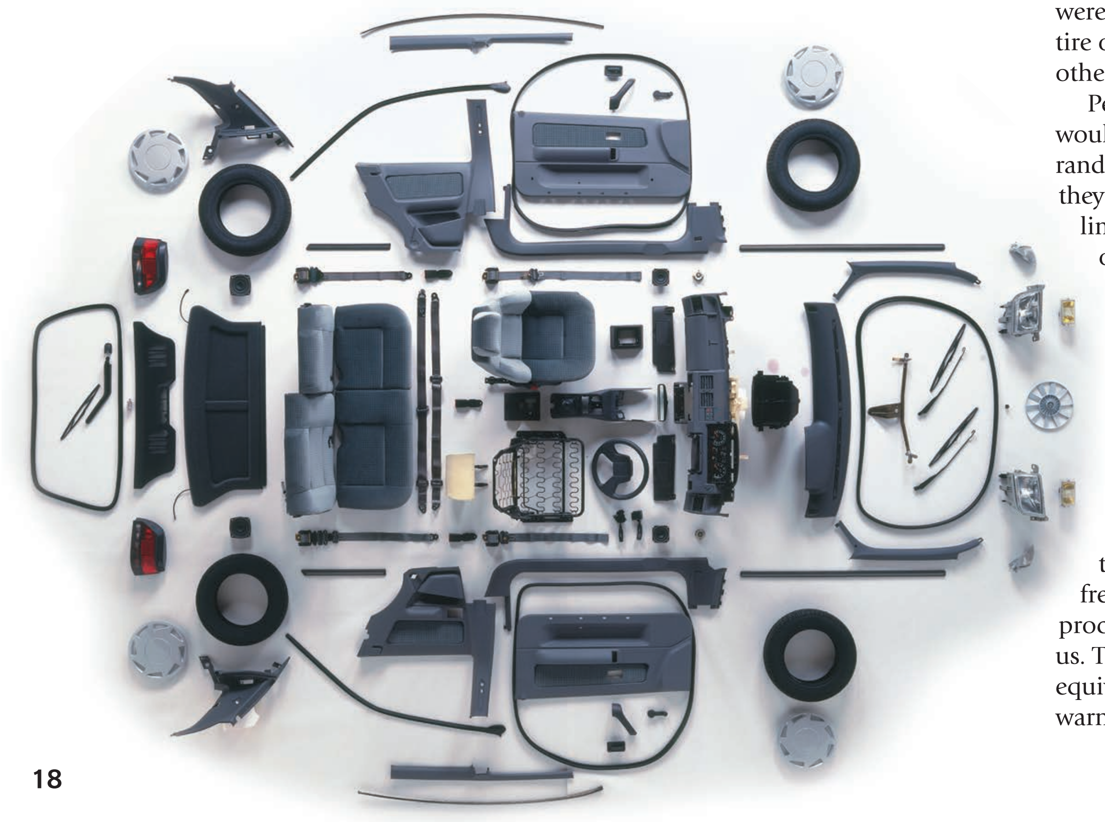
Although our knowledge of ecosystems is far from complete, we must acknowledge that their complexity is key to their integrated character. The many living and nonliving components of an ecosystem play important roles in its functions and the services it provides.

The connection between ecosystem complexity and ecosystem services is similar to the complexity of an automobile. An automobile is made up of thousands of individual parts. To a greater or lesser extent, each part contributes to the automobile's overall function and to the services it provides. The key service you expect from an automobile is to move you from one place to another. Less important services—but ones that might influence which car you purchase—include comfort, climate control, appearance, entertainment, and even navigation. As you drive along, some parts of the car are in use and others are not. If it is summer, you are unlikely to be using the heater. You don't use the brakes until you decide to slow down or stop. Some parts, such as the spare tire and emergency brake, are used only when another part fails.

Now, imagine that you are asked to remove parts from your car sequentially while trying to maintain its most important functions (Figure 1.20). If you have complete knowledge of the relationship between your car's parts and its workings, you can make wise decisions about which services to lose first. For example, you would remove cosmetic features, such as hubcaps and hood ornaments, before giving up a piston or fuel pump. If you were willing to tolerate risk, you might give up the spare tire or emergency brake, since they are only important if other parts fail.

People with a limited understanding of automobiles would approach this disassembly process in a much more random fashion. Unable to associate parts to functions, they would soon disable their cars. They would have a limited ability to set priorities for particular functions or services. They would not understand the risks they might incur by the removal of parts that do not immediately impair a car's function, such as the spare tire or warning lights.

With regard to the manipulation, simplification, and management of ecosystems, we are like children aspiring to be auto mechanics. We can name only a few of the "pieces" in most ecosystems, and we have an even more limited understanding of their importance to particular ecosystem functions and services. We frequently focus on only the most obvious parts and processes or those of most immediate importance to us. Too often, we give little thought to the ecosystem equivalents of spare tires, emergency brakes, and warning lights.



▼ **Figure 1.20 What's Essential?**
Are all these parts necessary for the functioning of your car?

Embracing Change

To be sustainable, actions must not ignore the inevitability of change or interfere with ecosystems' capacity to change.

Sustainable environmental management demands that we do more than accept that change is inevitable. It requires that we understand change and explicitly manage it. Past experience and scientific study have taught us much about how to do this successfully. Three lessons are particularly important.

Beware of attempts to halt or alter the tempo of natural change in ecosystems. Over and over, human attempts to slow or stop normal environmental change have produced surprising and unsustainable consequences. For example, natural factors such as currents and waves are continuously changing the ocean shoreline. Human developers have tried various tactics to halt these changes. Instead of preventing change, these tactics have often damaged coastal ecosystems (Figure 1.21).

Many of our most significant environmental challenges are associated with our limited ability to accommodate inevitable change. In arid regions, plans for managing and allocating water often fail to include contingencies for periods of drought, resulting in much human conflict and hardship. Because agricultural and urban ecosystems lack the homeostatic features of their natural counterparts, they are highly vulnerable to the effects of natural disturbances such as earthquakes and hurricanes.

Copy nature. For many centuries, humans have been among the most powerful agents of change on Earth. We have altered landscapes, modified the flow of rivers, created and drained lakes, and even changed the chemical composition of air. Indeed, it appears that our activities are now warming Earth's climate. But if change is normal in ecosystems, why should we worry about human-caused change? We must be concerned because the character and tempo of much of human-caused change has no precedent in the evolution of Earth's ecosystems.

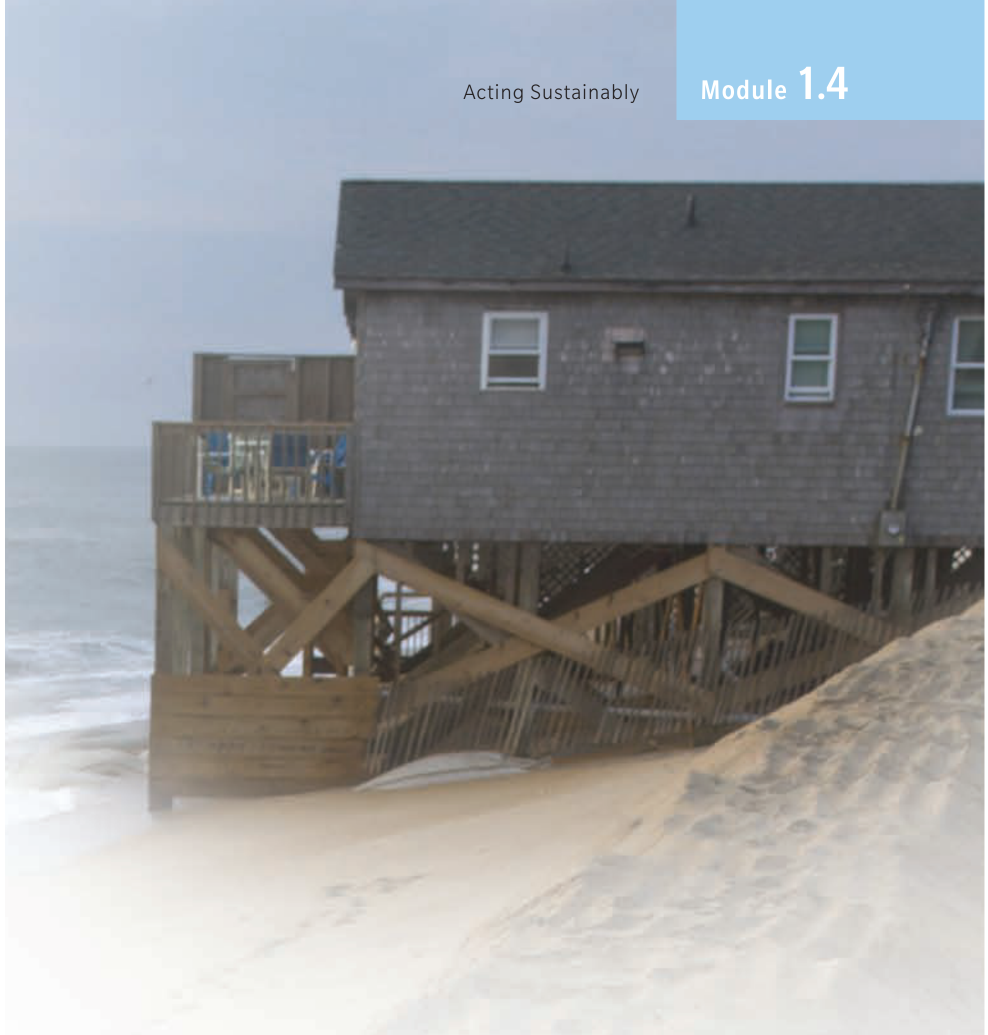
Over the past century, we have added hundreds of novel chemicals to the ecosystems. These chemicals, which are not easily broken down by natural processes, are toxic to many organisms. For example, the manufacture of paper and some herbicides and the incineration of commercial and municipal wastes have released large quantities of toxic chemicals called *dioxins* into our environment. In recent years, environmental regulations in the United States have reduced the release of dioxins by 90%. However, because dioxins decompose very slowly, high levels of them remain in many ecosystems.

In other cases, humans have altered the patterns of natural change in ecosystems. For instance, dams that have been installed on rivers to generate electricity also modify the rate of water flow. This causes significant changes in downstream ecosystems, which are adapted to the rates of flow and patterns of flooding that occurred before the dams were built.

Be alert for thresholds of change, or tipping points. Some human actions can push ecosystems beyond the limits of their normal range of change. This may alter the ecosystems so much that they cannot easily return to their previous state. The point at which an ecosystem changes from one state of homeostasis to another is called a threshold of change, or *tipping point*.

Much of the woodlands in the Sahel region of Africa are at a tipping point. The trees in these woodlands are frequently cut down for fuelwood or to make way for agricultural development. When cut on a small scale, the trees grow back and the woodlands are restored. But when large numbers of trees are repeatedly cut down, the climate becomes drier and soils rapidly erode. When these lands are abandoned, they become deserts rather than woodlands. A threshold of change has been crossed. Human abuse of the land has changed the environment so much that the ecosystem can no longer return to its previous state.

Today, most scientists agree that human activities are contributing to changes in the global climate. With this consensus comes concern that climate change may cause many of Earth's ecosystems to change in ways that cannot be reversed.



▲ **Figure 1.21 Defying Inevitable Change**
Attempts to alter the natural movement of sand along coastal beaches have often produced accelerated erosion such as that along the coast of North Carolina where houses are being washed into the sea.

Questions 1.4

1. How does ecosystem openness affect the sustainability of human actions?
2. How does maintaining the complexity of ecosystems contribute to their sustainability?
3. Describe three strategies for sustainable human actions in the context of change.

For additional review, go to **Mastering Environmental Science™**

1.5 Uncertainty, Science, and Systems Thinking

BIG IDEA Uncertainty abounds. Part of this uncertainty is the consequence of ignorance—our understanding of Earth's ecosystems is very far from complete. Uncertainty is also a consequence of the complexity of ecosystems, which can produce unpredictable changes.

It's all right to be uncertain; in fact, it is inevitable. **Science** is a process that poses and answers questions objectively in order to increase knowledge and lessen uncertainty. Science depends on careful observation and experimentation to produce results that can be duplicated by others. The results and conclusions of scientific research are open to review and revision by other scientists. New knowledge gained by scientific study is most likely to produce sustainable actions and behaviors when it is applied in ways that recognize the integrated nature of ecosystems.

Uncertainty

There is much we do not understand. Why?

It is an understatement to say that there is much that we do not know about ecosystems. Two factors—ignorance and complexity—are especially important sources of uncertainty in our understanding of the environment.

Ignorance. We would be able to meet many environmental challenges more effectively if we simply knew more. Reducing ignorance is the basic justification for most environmental research.

Ignorance presents two different challenges. Sometimes the extent of our ignorance is so overwhelming that it is difficult to know where to start or how to set research priorities. At other times, we don't know what we don't know. Our ignorance leads us to think that we know more than we do, so we fail to ask the right research questions. As Mark Twain wryly quipped, "It's not what you don't know that will kill you, it's what you know for sure that ain't true."

Complexity. Although their parts may interact in a predictable manner, complex systems often behave in ways that are practically impossible to predict. It is not that such behavior is random; rather, it is because miniscule changes that are too small to measure in the individual parts of a complex system can lead to very large differences in that system later on. Because ecosystems are so complex, it is virtually impossible for scientists and resource managers to measure and understand all of their interacting components.

The unpredictable behavior produced by the complexity of ecosystems limits our ability to forecast changes. This is similar to the way that the complexity of weather systems limits our ability to predict the weather. Meteorologists can make reasonably accurate predictions about the weather for tomorrow or the next day. The accuracy of weather forecasts diminishes rapidly the further we look into the future. This is because very small variations in the components of weather systems on one day produce significant differences in the future (Figure 1.22).

Uncertainty regarding environmental challenges is often the basis for inaction and conflict. Most famously, this has been the case in the way that various organizations and governments have responded to the challenge of global warming. In recent years, scientific research has shown conclusively that Earth's lower atmosphere is warming, but questions about the magnitude of this change persist. Uncertainties also remain as to whether human activities are responsible for global warming and what actions would be most effective in mitigating this process. These uncertainties even cause some people to argue that we should not take any action at all.

▼ **Figure 1.22 Complexity Yields Uncertainty**
Data from several sources allow meteorologists to predict the weather a few days in advance. However, weather predictions for the next month or year are much less certain because of the complexity of Earth's atmospheric systems.

Reducing Uncertainty with Science

Science asks questions in a fair and unbiased fashion.

The scientific revolution of the past several centuries has greatly expanded human knowledge and resolved much uncertainty about our world. We are often awed by the technical detail and complicated instrumentation of science. Yet at its core, science is simply the process of asking questions in a way that is as objective, or unbiased, as possible (Figure 1.23).

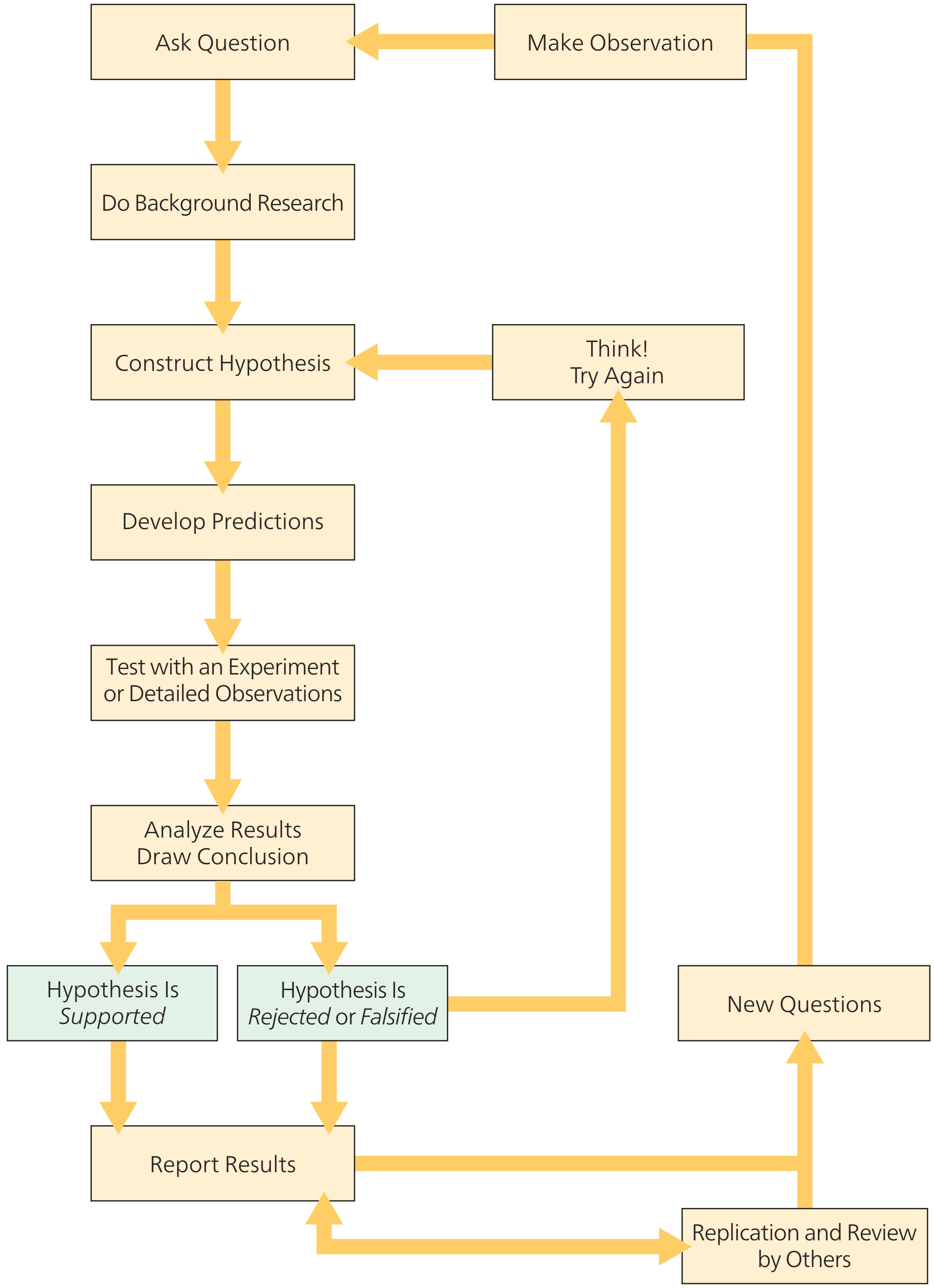
To find an answer to a question, scientists propose **hypotheses,** or alternative answers that can be tested by careful observation or experimentation. For example, scientists might ask why the population of a particular animal is declining. Hypotheses might be that the animals are suffering from a disease, that too many are being killed by hunters, or that their food supply is diminishing. Scientists then develop **predictions,** "if, then" statements that forecast the outcome of a test of the hypothesis. For example, "if animals are given more food, then their population will increase."

This prediction leads to a test of the hypothesis that food supply is important to population growth. Scientists might perform an experiment in which they provide extra food to half of the population, the **treatment group,** while keeping food levels unchanged for the other half, the **control group.** They would then compare the rates of population growth of the two groups.

The scientific process follows very careful rules regarding hypotheses and the strategies to test them. Most important, a scientific hypothesis must be *falsifiable* by observation or experimentation. This means that it is possible to devise an experiment or observation that could prove the hypothesis wrong. Hypotheses based on an immeasurable "force" or on divine intervention are simply not open to scientific inquiry.

Scientists are particularly concerned about precision and bias in their observations and measurements. In the case of our animal study, **precision** refers to the likelihood that measurements or estimates derived by sampling a subset of the population are representative of the actual values for the entire population. In general, the larger the sample size, the greater the precision. **Bias** refers to the possibility that estimates might be skewed in some particular direction. For example, large individuals in a population are more easily seen and sampled than small individuals. This could lead to bias in estimates of body size. To avoid biased observations, scientists pay special attention to sampling technique.

Experiments generally include one or several treatments relevant to the hypotheses, the results of which are then compared to an untreated control. Furthermore, experiments and observations are run multiple times to ensure that the results can be replicated and conclusions can be confirmed. Finally, scientists subject their results and interpretations to review by other experts before they communicate them in scientific journals.



▲ **Figure 1.23 The Scientific Method**
Science is a systematic method for asking questions in an unbiased way. Because results are subject to review and replication by others, science ensures that mistakes are corrected. Inevitably, the process also generates new and interesting questions.

Although scientists may come to consensus regarding the answer to a particular question, no idea, theory, or hypothesis is immune from further question or revision. No uncertainty ever becomes an absolute certainty.

A set of experiments and observations may lead scientists to agree that a particular hypothesis answers a question or that a specific model explains a phenomenon. However, further study may determine that the model is naïve or misguided and replace it with another, very different model.

Questions 1.5

1. Describe two important sources of uncertainty in our understanding of ecosystems.
2. Scientific hypotheses must be falsifiable. What is meant by this statement?
3. How does systems thinking differ from piece thinking?

For additional review, go to **Mastering Environmental Science™**

As much as they aspire to objectivity, scientists are human. As humans, they may become overly protective of their ideas. Occasionally, they are guilty of advocating for particular answers to questions because they align with closely held personal beliefs or values. However, science thrives by falsifying hypotheses. In so doing, it is self-correcting.

Although scientists often have strong opinions, it is not the role of science to make decisions regarding environmental policies or the management of resources. Rather, science provides a context for assessing and resolving uncertainties regarding specific policy or management alternatives.

Systems Thinking

Just because we know things doesn't mean we understand how they fit together.

Sustainable management does not require us to understand every piece and process in an ecosystem (although the more we know the better). It does, however, require systems thinking. *Systems thinking* recognizes the connections among the pieces of a larger, integrated system. In contrast, *piece thinking* focuses on the individual parts of a system, giving little attention to their association with other parts.

Returning to our car metaphor, a piece thinker interested in improving the efficiency of the braking process of a car might focus on the materials that make up the brake pads. Systems thinkers would recognize that the ability to stop is influenced by many interacting features, including brake rotors, tires, and car weight. Thinking across boundaries, systems thinkers would recognize the importance of driver reaction time and road conditions. They would also realize that changes that improve braking efficiency might affect the behavior of other parts of the car.

Many unsustainable actions arise as a consequence of piece thinking. For example, overexploitation of resources such as fish or forest trees is often a consequence of neglecting the complex ecosystems of which fish and trees are part. The air pollution we call smog is a result of piece thinking. City planners focused on transportation and industrial development but ignored the ecosystems of their cities, including chemical transformations in the atmosphere and their effects on human health.

Systems thinkers recognize that the parts of systems are actually systems, too, with behavior that depends on complex linkages among their parts (Figure 1.24). And finally, they recognize that all systems (except, perhaps, the universe) are parts of even larger wholes.

◀ **Figure 1.24 Systems within Systems**
The longest running predator–prey study involves the interactions of wolf and moose populations on the remote island Isle Royale in Lake Superior. Researchers who study the dynamic of these two species note that the wolf population is as small as it has ever been, while the moose population is on the rise. Their concern is that inbreeding among the wolves has adversely affected their ability to hunt moose, reducing their kill rates. These scientists propose a "genetic rescue" for the wolves, bringing new wolves onto the island, adding to the gene pool. Park officials are concerned about how such a move will affect this isolated ecosystem and so plan to study the environmental impacts of such a decision.

Source: Ecological Studies of Wolves on Isle Royale, Annual Report 2013–14, John A. Vucetich and Rolf O. Peterson, School of Forest Resources and Environmental Science, Michigan Technological University.

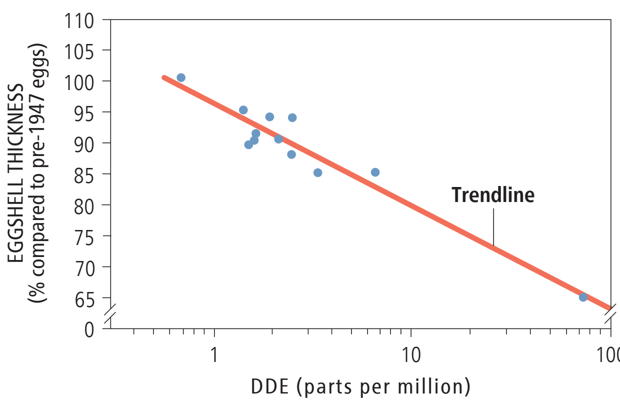
Ways of Knowing

What methods did scientists employ to determine the impacts of the insecticide DDT on bird populations?

Skim the pages of a journal like *Science* or *Nature* and you will quickly discover that scientists employ a wide variety of methodologies. These can be classified into four general categories: observation, experimentation, synthesis, and theory.

Observation—Questions about the properties of individuals, populations, or ecosystems, or the changes in those properties through time or from place to place are best answered with careful observations. The properties being measured are called **variables.** For example, ecologists might wish to know how egg production and hatchling survival for a particular bird species varies at different locations. To do this, they could monitor the nests of multiple individuals of this species at a range of sites. They would ensure precision by sampling as many nests as possible in each place, and they would avoid bias by trying to select sample nests at random from the entire population of nests.

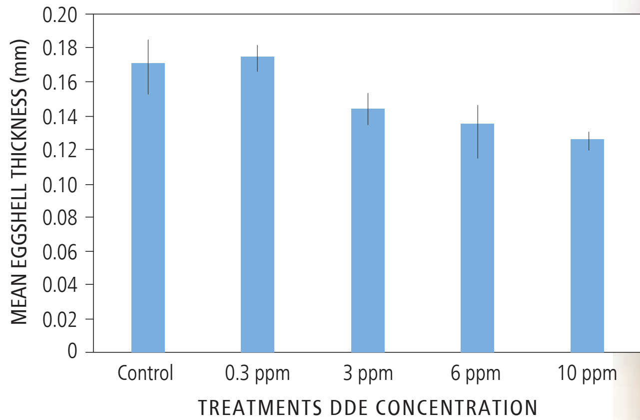
Observations can be used to establish whether there are **correlations** or quantitative relationships between different variables. Positively correlated variables tend to increase and decrease together. Negatively correlated variables tend to change in opposite directions; as one increases, the other decreases. For example, observations of several bird species by ecologists indicated that individual birds that had higher concentrations of DDT-derived chemicals in their tissues produced eggs with thinner shells that were more vulnerable to breakage (Figure 1.25). This negative correlation between these variables led to the hypothesis, but it did not prove, that increasing DDT concentrations were the cause of diminished reproductive success in these species.



▲ **Figure 1.25 Negative Correlation**

In 1969, researchers measured eggshell thickness and concentrations of the DDT residue DDE in parent birds in 10 brown pelican colonies from California, Florida, and South Carolina. Eggshell thickness is expressed as percent of that found in eggs laid prior to 1947, before the widespread use of DDT.

Data from: Blus, L.J., et al. 1971. Eggshell thinning in the brown pelican: implication of DDE. *BioScience* 21: 1213–1215.



▲ **Figure 1.26 Experimental Confirmation**

Controlled laboratory experiments exposed American kestrels, a very common small falcon, to different concentrations of DDE and confirmed that exposure to the chemical resulted in significantly reduced egg shell thickness. The vertical black lines are a measure of variation within each treatment.

Data from: Lincer, J.L. 1975. DDE-induced eggshell-thinning in the American Kestrel: A comparison of the field situation and laboratory results. *Journal of Applied Ecology* 12: 781–793.

Experimentation—To firmly establish a causal relationship between variables, an **experiment** is required. For example, a toxicologist might provide birds with food containing different amounts of DDT and examine the effects on their growth or egg production. This sort of experiment would likely be carried out using domesticated species such as chickens rather than birds from the wild. The experiment must have a control in which food without DDT is provided in exactly the same way as each of the treatment doses (Figure 1.26). Control and treatment groups must include several individual birds to ensure precision and avoid bias. This experiment would be run several times to verify that it is repeatable.

Synthesis—Big ideas and grand theories are built on a foundation of facts and information from hundreds, sometimes thousands, of smaller and less grand observations and experiments. Thus, synthesis is a very important scientific methodology. Nowadays, information technologies, including the Internet, greatly facilitate such synthesis. It was just such a synthesis of information from hundreds of studies that led to a general theory to explain why the reproductive success of many bird species was diminished by DDT in their environment.

Theory—Theories are principles devised to explain a group of facts or phenomena. Theories may be formulated as verbal statements about causes and effects. For example, ecologists theorized that concentrations of DDT were especially high in predatory birds like eagles based on many studies establishing that DDT is not broken down or excreted but rather accumulates in the fatty tissues of animals; predators are, therefore, likely to have higher tissue concentrations than the prey that they eat. Scientists are careful to state clearly the facts and assumptions upon which their theories are based.

In this textbook, *Focus on Science* will highlight important research relevant to the study of environmental science. It will generally include questions related to scientific methods and process. You will see how each of these methodologies is applied, individually and in various combinations, to enable you to better understand what is happening around us.

SUSTAINABLE DEVELOPMENT GOALS

▲ **Figure 1.27 An Agenda for 2030**
Seventeen sustainable development goals comprise the 2030 Agenda for Sustainable Development. Visit the UN's Sustainable Development home page and click on the SDGS tab to access an interactive graphic highlighting all Sustainable Development Goals.

1.6 Sustainable Development, The Environment, and You

BIG IDEA On September 25, 2015, the 196 member countries of the United Nations unanimously adopted a resolution entitled "Transforming Our World: The 2030 Agenda for Sustainable Development." A "plan of action for people, planet and prosperity"—the triple bottom line—the Agenda sets 17 sustainable development goals (Figure 1.27). Each of the chapters of *The Environment and You* relates to one or more of these goals. Proposed actions focus on two general themes, protecting our planet and investing in the future we want. The Agenda is ambitious and full implementation by 2030 will require significant commitments not only from UN member nations but also from the people that they represent. Success will depend on our ability to monitor and forecast long-term trends, to better understand connections between social systems and ecosystems, to identify thresholds of change, to formulate incentives for sustainable behavior, and to integrate learning and action.

Sustainable Development Goals

Protecting our planet—investing in the future we want.

Goal 1: No Poverty. End poverty in all its forms everywhere. Since 2002, the number of people living below the extreme poverty line (< $1.90/day/person) dropped by over half, from 26% to 10%. Nevertheless, poverty remains widespread in many regions; over 40% of people in sub-Saharan Africa, for example, endure extreme poverty. Young people are especially vulnerable. Among young adults 15 to 24 years old, 16% live in extreme poverty compared to 9% of people over 25. Poverty clearly has direct impacts on human well-being, but it also impacts our environment.

▶ *We explore the connection between poverty, well-being, and human population growth in Chapters 5 and 18. The implications of poverty for the conservation of Earth's biological diversity, its forests, and its aquatic and marine habitats are considered in Chapters 8, 11, and 13.*

Goal 2: Zero Hunger. Improve nutrition and promote sustainable agriculture. Although the proportion of the population suffering from hunger has declined from 15% to 11% since 2002, the number of malnourished people remains above 800 million. Agricultural production appears to be sufficient to meet the nutritional needs of all of Earth's people, but access to food is often limited by inadequate distribution systems, corruption, and international conflicts. Agricultural practice is also the source of a variety of environmental challenges in many places (Figure 1.28).

▶ *These issues and strategies to make agriculture more sustainable are prominent themes in Chapter 12.*

▼ **Figure 1.28 Agricultural Production and Sustainability**
This Kenyan farmer is plowing his field in much the same way as his great grandfather did a century ago. The UN Agenda aims to provide assistance to increase farm production in developing countries in a sustainable fashion.

Goal 3: Good Health & Well-Being. Ensure healthy lives and promote well-being for all at all ages. By many measures, the health of Earth's people has improved significantly over the past 15 years. Maternal and infant mortality rates have fallen by nearly half. Nevertheless, nearly 6 million children under age 5 died in 2015, most from communicable diseases. Changes in a variety of environmental factors are influencing the spread of disease worldwide, including urban development, air and water pollution, deforestation, landscape development, and climate change.

▶ *These topics are covered in Chapters 9, 10, 16, 17, and 18.*

Goal 4: Quality Education. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. In 2013, almost 60 million primary school-age children did not have access to school. Worldwide, about 10% of adults cannot read or write; two-thirds of these people are women. Education or the lack of it presents significant opportunities or challenges for moving societies on a more sustainable path.

▶ *This is discussed in detail in Chapters 5 and 19.*

Goal 5: Gender Equality. Achieve gender equality and empower all women and girls. The proportion of women who marry before their 18th birthday has dropped by about 20% in the past 25 years. This has been an important factor in the worldwide decline in birth rates during that time. Increased access to education and employment has contributed to that change. However, women still experience a variety of forms of discrimination, and access to sexual and reproductive health services is limited in many places. This goal aims to eliminate all forms of discrimination and violence against women.

▶ *This is covered in Chapter 5.*

◀ **Figure 1.29 Sustainable Energy Transition**
As for this Indian woman, wood is the primary source of energy for many people in developing countries. However, wood fires pollute the air, and the harvesting of wood contributes to deforestation in some places.

Goal 6: Clean Water & Sanitation. Ensure availability and sustainable management of water and sanitation for all. In 2015, over 90% of Earth's people had access to clean drinking water compared to 82% in 2002. Still, nearly 700 million people must use unsanitary sources of water. Water shortages affect more than 2 billion people, and that number is expected to rise as climates warm and groundwater resources are depleted. Achieving this goal will require much more international cooperation and the support of local communities in improving water and sanitation management.

▶ *These topics are the focus of discussions in Chapters 11, 17, and 19.*

Goal 7: Affordable & Clean Energy. Ensure access to affordable, reliable, sustainable, and modern energy for all. Even though over 85% of people now have access to electricity, over 40% of the world's people must use polluting fuels such as wood and charcoal for cooking (Figure 1.29). Broader energy access and increased use of renewable energy are central to this goal. This will require expanded infrastructure and continued development of clean energy technologies.

▶ *The importance of energy access for human well-being and the impacts of energy consumption on our environment and climate are explored in Chapters 14 and 15.*

Goal 8: Decent Work & Economic Growth. Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. Economic growth has contributed directly and indirectly to many environmental problems, but economic development is nonetheless essential to the development of sustainable technologies and the implementation of environmental regulations. Economic uncertainties and the growing inequality in the distribution of wealth among countries and among people within countries are major barriers to sustainable development.

▶ *These challenges are discussed in Chapter 2.*

Goal 9: Industry, Innovation & Infrastructure. Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. Since 2000, energy efficiency and cleaner fuels have reduced emissions of carbon dioxide and other heat trapping gases per unit of economic output by almost 15%. Research, innovations, and infrastructure development needed to accelerate sustainable development are the targets of this goal.

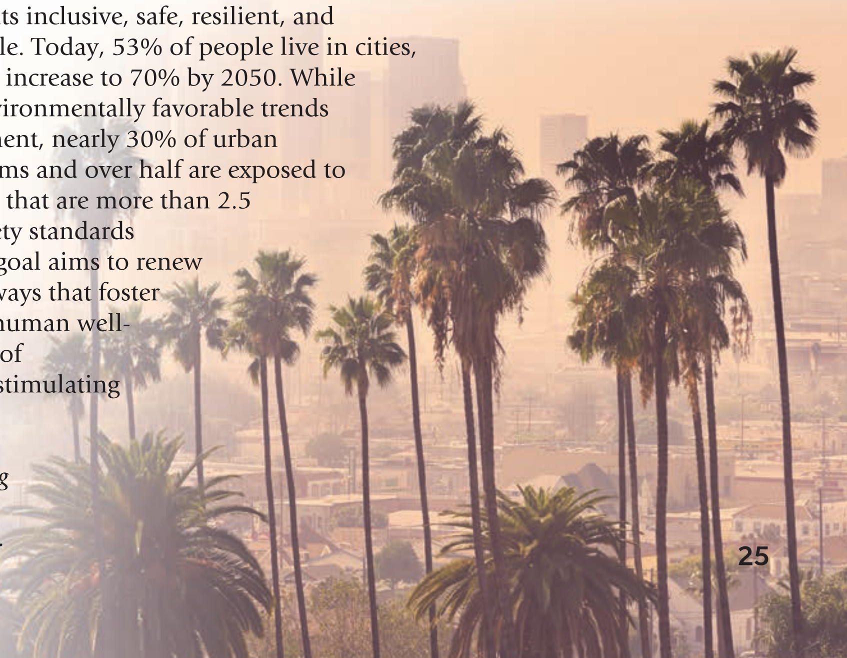
▶ *These are important themes in the Focus on Science and Seeing Solutions features that appear throughout* The Environment and You.

Goal 10: Reduced Inequalities. Reduce inequality within and among countries. There are large inequalities in opportunity, income, and well-being among people based on sex, age, race, class, ethnicity, and religion.

▶ *This goal is not the theme of a specific chapter in this book, but is central to discussions of sustainable development throughout.*

Goal 11: Sustainable Cities & Communities. Make cities and human settlements inclusive, safe, resilient, and sustainable. Today, 53% of people live in cities, and that will likely increase to 70% by 2050. While there are many environmentally favorable trends in urban development, nearly 30% of urban dwellers live in slums and over half are exposed to air pollution levels that are more than 2.5 times accepted safety standards (Figure 1.30). This goal aims to renew and plan cities in ways that foster personal security, human well-being, and a sense of community while stimulating innovation and employment.

▶ *Strategies for doing this are discussed in detail in Chapter 16.*



▼ **Figure 1.30 A Major Urban Challenge**
The polluted air on an afternoon in Los Angeles demonstrates that, even in developed countries, air pollution can affect the health of urban people. As we discuss in Chapter 16, urbanization can be a strategy for sustainable development, but this will require management of the processes that produce urban pollution.

Goal 12: Responsible Consumption & Production. Ensure sustainable consumption and production patterns. Sustainable development depends not only on stemming the growth in our numbers, but also on reducing the amount of resources that each of us consumes. The stark differences between economically developed and developing countries present significant challenges in this regard. Sustainable development will depend on improving the lives of the world's poor while working to reduce global levels of resource use. This will necessarily require that Earth's wealthiest citizens become much more energy and resource efficient.

▶ *These challenges are discussed in Chapters 5, 17, and 19.*

Goal 13: Climate Action. Take urgent action to combat climate change and its impacts. The Agenda asserts that "climate change presents the single biggest threat to development, and its widespread, unprecedented effects disproportionately burden the poorest and most vulnerable." The Paris Climate Agreement signed by 195 UN member states in 2016 provides a framework for climate action to limit global warming and encourage adaptation to likely climate change.

▶ *Climate, the causes and consequences of global warming, and technical and political strategies to limit and adapt to warming are central themes in Chapters 3, 9, and 10.*

Goal 14: Life below Water. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development. Marine resources are increasingly stressed, yet they are essential to the lives of 37% of the world's population who live in coastal communities (Figure 1.31). Forty years ago 90% of global marine fish stocks were considered biologically sustainable; today, only 68% meet that standard. The good news is that there has been a 30% increase in the area of preserves designed to protect the most diverse and fragile marine ecosystems.

▶ *Ecology and conservation of marine ecosystems are discussed in detail in Chapters 4, 6, 7, 8, and 11.*

Goal 15: Life on Land. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. The current rate of extinction among Earth's plants and animals is currently 100–1,000 times the rate in preindustrial times, and at least 23,000 species are critically endangered. The rate of deforestation, one of the most important causes of extinction, results in a net loss of 3.3 million hectares (8 million acres) of forest each year.

▶ *Ecology and conservation of terrestrial ecosystems are discussed in Chapters 4, 6, 7, 8, and 13.*

Goal 16: Peace, Justice & Strong Institutions. Promote peaceful and inclusive societies for sustainable development; provide access to justice for all; and build effective, accountable, and inclusive institutions at all levels. Violence, armed conflict, and limited rule of law are widespread and they are major barriers to sustainable development. This goal aims to promote transparent and effective governance, basic human rights, and accountable institutions.

▶ *Ethics, governance, and policy are major themes in Chapter 2, and their implications for sustainable development in relation to environmental issues are discussed throughout this book.*

Goal 17: Partnerships for the Goals. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development. In 2000, the United Nations established the Global Partnership for Sustainable Development, a multinational consortium whose goal is to promote trading and financial systems that support sustainable development. In 2015, this partnership had generated over $131 billion of assistance to meet the development needs of the world's least developed countries. This is "investment in the future we want."

▶ *Chapter 2 provides an overview of economics of the environment and sustainable development, and this topic is discussed throughout the book in association with specific environmental issues.*

▶ **Figure 1.31 We Depend on a Stressed Resource**
Street vendors in Ho Chi Minh City, Vietnam, sell fresh fish to a community that obtains over half its dietary protein from the ocean.