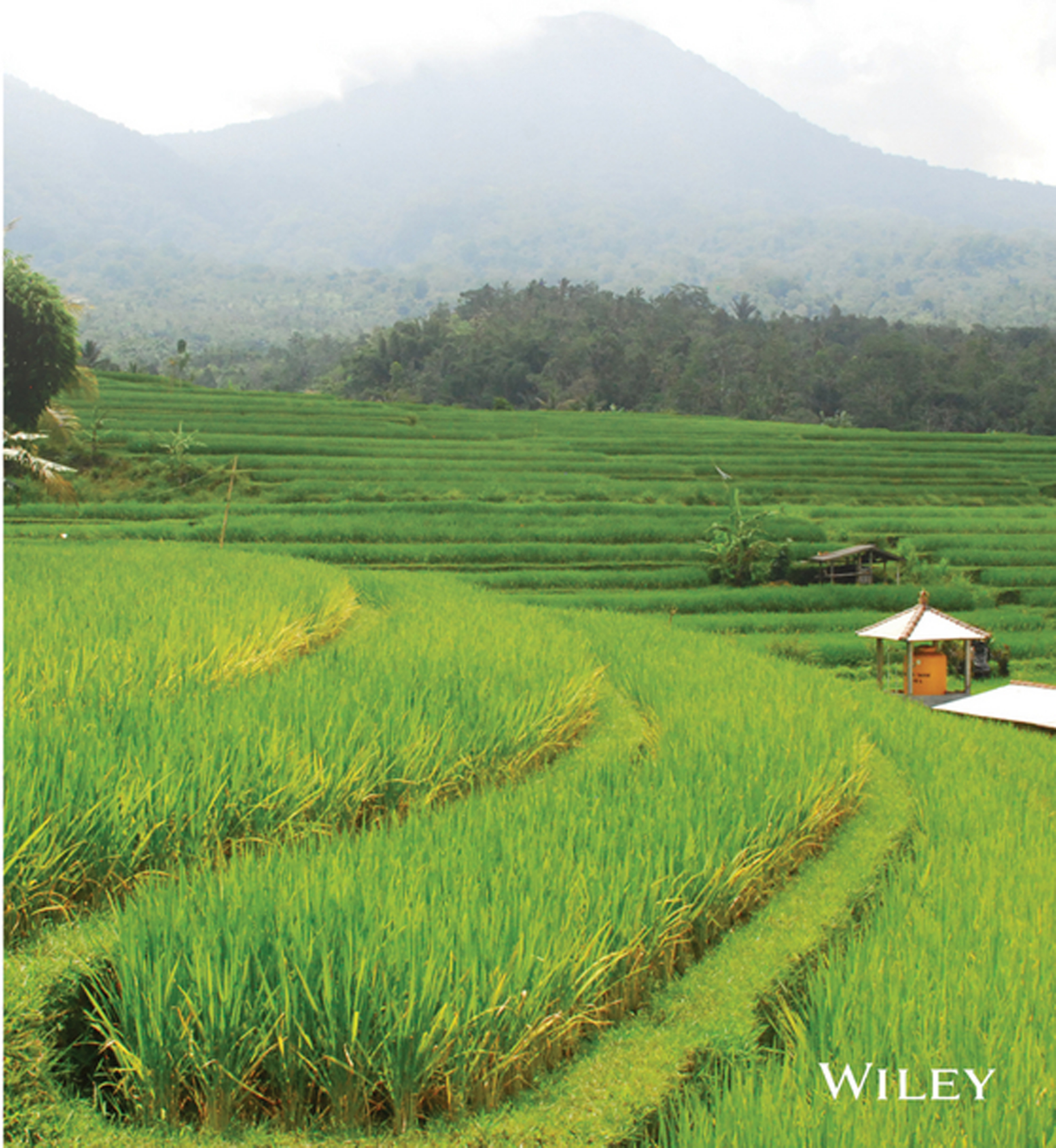
ENVIRONMENT

Raven | Hassenzahl | Hager | Gift | Berg | 9e



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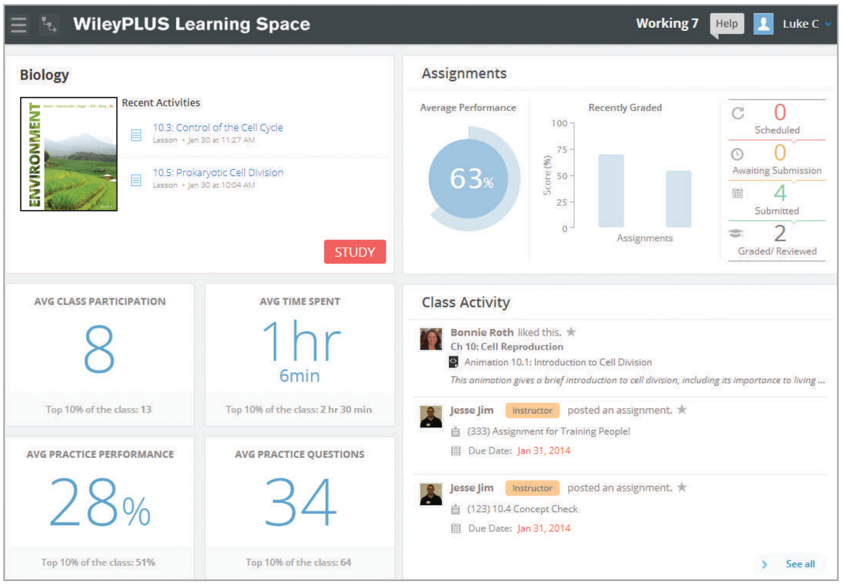
WileyPLUS Learning Space

An easy way to help your students **learn**, **collaborate**, and **grow**.



Personalized Experience

Students create their own study guide while they interact with course content and work on learning activities.

Flexible Course Design

Educators can quickly organize learning activities, manage student collaboration, and customize their course—giving them full control over content as well as the amount of interactivity between students.

Clear Path to Action

With visual reports, it's easy for both students and educators to gauge problem areas and act on what's most important.

Instructor Benefits

- Assign activities and add your own materials
- Guide students through what's important in the interactive e-textbook by easily assigning specific content
- Set up and monitor collaborative learning groups
- Assess learner engagement
- Gain immediate insights to help inform teaching

Student Benefits

- Instantly know what you need to work on
- Create a personal study plan
- Assess progress along the way
- Participate in class discussions
- Remember what you have learned because you have made deeper connections to the content

We are dedicated to supporting you from idea to outcome.

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9th Edition

Environment

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Preface

The environmental challenges that today's students will face throughout their lives are characterized by a seeming paradox: They are both increasingly global and increasingly local. Threats to local food production include global climate change. An energy resource can endanger a rare species when it is extracted and global public health after it is used, as when mercury from coal burning reaches the ocean. Improving the conditions of our environment requires that we understand how the choices we make impact air, water, soil, and organisms, as well as their interrelationships. Science is the most appropriate and effective approach to gaining that understanding. It is therefore critical that students learn about the science behind energy, climate change, and other environmental issues that affect them, not only because they will make decisions about energy and climate change but also because they will experience the repercussions if these problems are not dealt with effectively.

The overarching concept of environmental sustainability has never been more important to the field of environmental science than it is today. Sustainability, a central theme of *Environment,* is integrated throughout the text. Yet the more we learn about the environment, the more we realize that interactions among different components of the environment are many and complex. Therefore, a second important theme of *Environment* is environmental systems. Understanding how change to one component affects other processes, places, and organisms is essential to managing existing problems, avoiding future problems, and improving the world in which we live.

From the opening pages, we acquaint students with current environmental issues—issues that have many dimensions and that defy easy solutions. We begin by examining the scientific, historical, ethical, governmental, and economic underpinnings of environmental science. This provides a conceptual foundation for students that they can then bring to bear on the rest of the material in the book. We next explore the basic ecological principles that govern the natural world and consider the many ways in which humans affect the environment. Later chapters examine in detail the effects of human activities, including overpopulation, energy production and consumption, depletion of natural resources, and pollution. Throughout *Environment,* 9th Edition, we relate the topics of a given chapter to food, energy, and climate change, which further reinforces the interactions of environmental systems.

While we avoid unwarranted optimism when presenting these problems, we do not see value in the gloomy predictions of disaster so commonly presented by the media. Instead, we encourage students to take active, positive roles to understand and address the environmental challenges of today and tomorrow.

Raven, Hassenzahl, Hager, Gift, and Berg's *Environment,* 9th Edition, is intended as an introductory text for undergraduate students, both science and nonscience majors. Although relevant to all students, *Environment,* 9th Edition, is particularly appropriate for those majoring in education, journalism, government and politics, and business, as well as the traditional sciences. We assume that our students have little prior knowledge of environmental science. Important ecological concepts and processes are presented in a straightforward, unambiguous manner.

All of the chapters have been painstakingly researched, and extraordinary efforts have been made to obtain the most recent data available. Both instructors and students will benefit from the book's currency because environmental issues and trends are continually changing.

Environment, 9th Edition, integrates important information from many different fields, such as biology, geography, chemistry, geology, physics, economics, sociology, natural resources management, law, and politics. Because environmental science is an interdisciplinary field, this book is appropriate for use in environmental science courses offered by a variety of departments, including (but not limited to) biology, geology, geography, and agriculture.

New to the 9th Edition is an emphasis on food and the environment. This includes a substantially updated chapter on food by new team member Nancy Y. Gift, increased attention to food systems woven throughout the text, and a challenge in each chapter for students to think about food and environment in contexts that affect them. Co-author Mary Catherine Hager likewise brings expertise in ecosystems, population biology, and water ecology. Together, their contributions deepen our ability to present the complex systems that make up our environment in a clear and compelling fashion.

Effective Learning Tools in *Environment*, 9th Edition

A well-developed pedagogical plan that facilitates student mastery of the material has always been a hallmark of *Environment*. The 9th Edition has continued to refine the **learning tools** to help students engage with the key material and apply it to their daily lives. Pedagogical features in this 9th edition include:

Chapter Introductions illustrate certain concepts in the chapter with stories about some of today's most pressing environmental issues.

NEW Food for Thought features in each chapter challenge students to consider how issues in the chapter relate to some aspect of food systems.

In Your Own Backyard feature provides a critical thinking question at the beginning of each chapter and connects the broad themes of the text to local issues and resources students can investigate.

Learning Objectives at the beginning of each section head indicate in behavioral terms what the student must be able to do to demonstrate mastery of the material in the chapter.

Review Questions at the end of each section give students the opportunity to test their comprehension of the learning objectives.

EnviroNews features provide additional topical material about relevant environmental issues.

EnviroNews on Campus features report on recent campus and student efforts to improve the environment.

Meeting the Challenge boxes profile environmental success stories.

You Can Make a Difference boxes suggest specific courses of action or lifestyle changes students can make to improve the environment.

Tables and Graphs, with complete data sources cited in the text, summarize and organize important information.

Marginal Glossaries, located in every chapter, provide handy definitions of the most important terms.

Case in Point features offer a wide variety of in-depth case studies that address important issues in the field of environmental science.

Energy and Climate Change features relate energy and/or climate change to the topics in each chapter. This feature is easy to locate by its it icon—a compact fluorescent lightbulb superimposed over the sun. This icon is also paired with key graphs and illustrations in each chapter wherever energy and climate change are discussed, and accompanied by a critical thinking question.

Review of Learning Objectives with Selected Key Terms restates the chapter learning objectives and provide a review of the material presented. Boldfaced selected key terms, including marginal glossary terms, are integrated within each summary, enabling students to study vocabulary words in the context of related concepts.

Critical Thinking and Review Questions, many new to this edition, encourage critical thinking and highlight important concepts and applications. At least one question in each chapter provides a systems perspective; another question relates climate and energy to the chapter. Visual questions have been added to each chapter.

Suggested Reading lists for each chapter are available online to provide current references for further learning.

Major Changes in the Ninth Edition

A complete list of all changes and updates to the 9th Edition is too long to fit in the Preface, but several of the more important changes to each chapter follow:

Chapter 1, Introducing Environmental Science and Sustainability, has a new chapter introduction on food systems and sustainability, and a new section on renewable and nonrenewable resources.

In Chapter 2, Environmental Laws, Economics, and Ethics, environmental policies were updated through 2014 and a feature on food and zoning policy was added.

Chapter 3, Ecosystems and Energy, includes an updated discussion of how humans have affected the Antarctic food web.

Chapter 4, Ecosystems and the Physical Environment, features recent examples of deadly and destructive tornadoes and tropical cyclones, and new evidence of how mangroves protect areas against typhoons.

Chapter 5, Ecosystems and Living Organisms, features an expanded section on logistic population growth with added emphasis on implications for sustainable yield and pest control.

Chapter 6, Major Ecosystems of the World, has an added connection between ecosystem productivity across biomes and how that relates to human food available in those biomes.

Chapter 7, Human Health and Environmental Toxicology, features expanded coverage of endemic diseases including ebola, HIV/AIDS, and polio.

Chapter 8, The Human Population, features all-new population data through 2013, and updated discussions of global AIDS, human migration, aging populations, and other pertinent demographic issues.

Chapter 9, The Urban Environment, includes increased emphasis on urban land use and relationship with food production, decreased emphasis on differences between developed/less developed urban centers.

Chapter 10, Energy Consumption, features additional materials on food and energy consumption, and new images of fuel cell vehicles and plug in electric hybrid vehicles.

Chapter 11, Fossil Fuels, now reflects the shifts in domestic energy production in the United States as natural gas imports have declined substantially as hydraulic fracturing has grown, and domestic oil production has increased significantly.

Chapter 12, Renewable Energy and Nuclear Power, includes details on the Fukushima Daiichi nuclear power plant meltdown, and an updated chapter introduction on biofuels.

Chapter 13, Water: A Limited Resource, includes a section on Mississippi River flooding with an extensive evaluation of flood control efforts, offers a new EnviroNews on climate change and crops in Southern Africa, and features current trends in U.S. drought and aquifer depletion, as well as recent data on worldwide availability of clean water and new examples of global water conflicts.

Chapter 14, Soil Resources, now addresses biodynamic farming, and has increased information about micorrhizae

Chapter 15, Mineral Resources, offers a new EnviroNews on conflict minerals and a revised look at the link between industrialization and mineral consumption.

Chapter 16, Biological Resources, includes the most recent numbers of known and endangered species, a substantive update on the status of Earth's biodiversity hotspots, new approaches to combating invasive species, and a new EnviroNews on Campus featuring habitat restoration.

Chapter 17, Land Resources, includes updated National Park information, and discussion of harvesting rainforest fruit in the Food for Thought feature.

Chapter 18, Food Resources, as noted above, is the most substantial update in this edition, with particular focus on urban agriculture practices, green roofs, a discussion of food insecurity and the relationship of policy to hunger, and a new section on Grow Appalachia.

Chapter 19, Air Pollution, features an update of the chapter introduction on southeast Asian air pollution to 2014, and reorganized learning objectives for ozone, acid deposition, and indoor air pollution sections.

Chapter 20, Global Climate Change, features data and figures updated to be consistent with the most recent Intergovernmental Panel on Climate Change reports.

Chapter 21, Water Pollution, includes updated data throughout and features new examples of energy-related water pollution in a revised chapter introduction, as well as a revamped discussion of pharmaceuticals in wastewater.

Chapter 22, Pest Management, includes expanded discussion of Roundup, GM crops, Bt, and pest control in kitchen gardens.

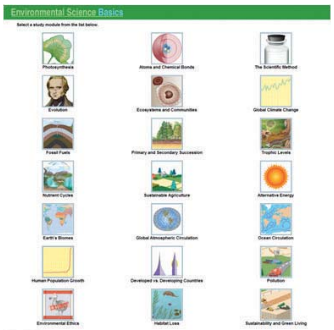
Chapter 23, Solid and Hazardous Wastes, features updated data throughout the chapter, including current statistics on e-waste generation and legislation, and trends in U.S. recycling programs.

Chapter 24, Tomorrow's World, has increased focus on solutions and hopefulness, with additional material on **Wangari Maathai**.

For Students

Different learning styles, different levels of proficiency, different levels of preparation—each of your students is unique. *WileyPLUS Learning Space* empowers them to take advantage of their individual strengths. With *WileyPLUS Learning Space*, students receive timely access to resources that address their demonstrated needs, and get immediate feedback and remediation when needed.

Integrated multimedia resources include:



- **Environmental Science Basics** provides a suite of animated concepts and tutorials to give students a solid grounding in key basic environmental concepts. Concepts ranging from global climate change to sustainable agriculture are presented across 21 modules in easy-to-understand language.

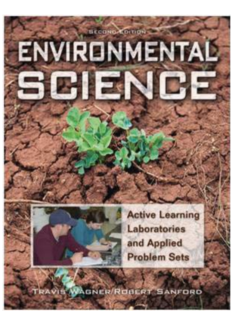
For Instructors

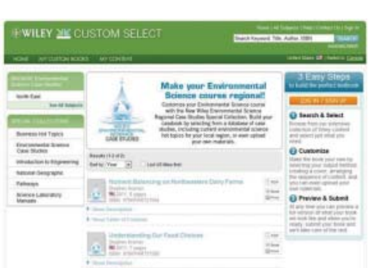
WileyPLUS Learning Space empowers you with the tools and resources you need to make your teaching even more effective:

- You can customize your classroom presentation with a wealth of resources and functionality from PowerPoint slides to a database of rich visuals. You can even add your own materials to your *WileyPLUS Learning Space* course.
- With *WileyPLUS Learning Space* you can identify those students who are falling behind and intervene accordingly, without having to wait for them to come to office hours.
- *WileyPLUS Learning Space* simplifies and automates such tasks as student performance assessment, making assignments, scoring student work, keeping grades, and more.
- **Project Activities** relating to the Virtual Field Trips and In Your Own Backyard questions allow instructors to bring learning outside of the classroom and assign critical thinking questions and projects. Students will have the ability to submit completed Project Activities through their *WileyPLUS Learning Space* course.
- **Test Bank** is available on both the instructor companion site and in WileyPLUS *Learning Space*. Containing approximately 60 multiple-choice and essay test items per chapter, this Test Bank offers assessment of both basic understanding and conceptual applications. The Environment, 9th Edition, Test Bank is offered in two formats: MS Word files and a Computerized Test Bank through Respondus. The easy-to-use test-generation program fully supports graphics, print tests, student answer sheets, and answer keys. The software's advanced features allow you to create an exam to your exact specifications.
- **Instructor's Manual,** originally by our co-author David Hassenzahl, is available on both the instructor companion site and in *WileyPLUS Learning Space*. The Instructor's Manual now provides over 90 creative ideas for in-class activities. Also included are answers to all end-of-chapter and review questions prepared by.
- **All Line Illustrations and Photos** from *Environment*, 9th Edition, in jpeg files and PowerPoint format, are available both on the instructor companion site and in *WileyPLUS Learning Space*.
- **PowerPoint Presentations,** are tailored to the topical coverage and learning objectives of *Environment*, 9th Edition. These presentations are designed to convey key text concepts, illustrated by embedded text art. An effort has been made to reduce the number of words on each slide and increase the use of visuals to illustrate concepts. All are available on the instructor companion site and in *WileyPLUS Learning Space*.
- **Animations.** Select text concepts are illustrated using flash animation for student self-study or classroom presentation.

Also Available

Environmental Science: Active Learning Laboratories and Applied Problem Sets, 2rd Edition, by Travis Wagner and Robert Sanford, both of the University of Southern Maine, is designed to introduce environmental science students to the broad, interdisciplinary field of environmental science. It presents specific labs that use natural and social science concepts and encourages a hands-on approach to evaluating the impacts from the environmental/human interface. The laboratory and homework activities are designed to be low cost and to reflect a sustainable approach in both practice and theory. *Environmental Science: Active Learning Laboratories and Applied Problem Sets*, 2rd Edition, is available as a stand-alone or in a package with *Environment*, 9th Edition. Contact your Wiley representative for more information.





For more Environmental Science Case Studies, visit **customselect.wiley.com** to view the **Environmental Science Regional Case Study Collection** and customize your course materials with a rich collection of local and global examples (http://customselect.wiley.com/collection/escasestudies).

Book Companion Site (www.wiley.com/college/raven)

For Students

- Flashcards and Animations
- Quantitative and Essay Questions, as well as useful website links

For Instructors

- Visual Library; all images in jpg and PowerPoint formats
- Instructor's Manual; Test Bank; Lecture PowerPoint Presentations

Instructor Resources are password protected.

Wiley may provide complementary instructional aids and supplements or supplement packages to those adopters qualified under our adoption policy. Please contact your sales representative for more information. If as an adopter or potential user you receive supplements you do not need, please return them to your sales representative or send them to: Attn: Wiley Returns Department, Heller Park Center, 360 Mill Road, Edison, NJ 08817.

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THE EDITORIAL ENVIRONMENT

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THE PROFESSIONAL ENVIRONMENT

The success of *Environment*, 9th Edition, is due largely to the quality of the many professors and specialists who have read the manuscript during various stages of its preparation and provided us with valuable suggestions for improving it. In addition, the reviewers of the first eight editions made important contributions that are still part of this book.

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Richard Pemble, *Moorhead State University*;
Barry Perlmutter, *College of Southern Nevada*;
Scott Peterson, *Nuclear Energy Institute*;
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Ervin Poduska, *Kirkwood Community College*;
Sandra Postel, *Global Water Policy Project*;
Lowell Pritchard, *Emory University*;
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Elizabeth Reeder, *Loyola College*;
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Maralyn Renner, *College of the Redwoods*;
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Sandy Rock, *Bellevue Community College*;
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Dr. Raven is a trustee of the National Geographic Society and is a past president of the American Association for the Advancement of Science. He is the recipient of numerous prizes and awards, including the prestigious National Medal of Science in 2001, the highest award for scientific accomplishments in this country; Japan's International Prize for Biology; the Environmental Prize of the Institut de la Vie; the Volvo Environment Prize; the Tyler Prize for Environmental Achievement; and the Sasakawa Environment Prize. He also has held Guggenheim and MacArthur fellowships.

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Photo by Jason A. Halley. Courtesy of California State University, Chico

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Previously, Dr. Hassenzahl served as founding dean of the Falk School of Sustainability at Chatham University, and Chair of the Department of Environmental Studies at the University of Nevada, Las Vegas. Dr. Hassenzahl holds a B.A. in environmental science and paleontology from the University of California at Berkeley and a Ph.D. in science, technology, and environmental policy from Princeton University.

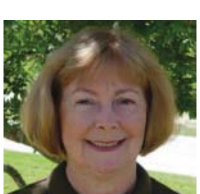
A Senior Fellow of the National Council for Science and the Environment, Dr. Hassenzahl's work has been supported by the National Science Foundation and the National Aeronautics and Space Administration. He has received the Society for Risk Analysis Outstanding Educator Award and the UNLV Foundation Distinguished Teaching Award.

Mary Catherine Hager is a professional science writer and editor specializing in life and earth sciences. She received a double-major B.A. in environmental science and biology from the University of Virginia and an M.S. in zoology from the University of Georgia. Ms. Hager worked as an editor for an environmental consulting firm and as a senior editor for a scientific reference publisher. For more than 20 years, she has written and edited for environmental science, biology, and ecology textbooks primarily targeting college audiences. Additionally, she has published articles in environmental trade magazines and edited federal and state assessments of wetlands conservation issues. Her writing and editing pursuits are a natural outcome of her scientific training and curiosity, coupled with her love of reading and effective communication.

Nancy Y. Gift

Nancy Y. Gift, Compton Chair of Sustainability at Berea College, in Berea, Kentucky, enjoys teaching in a wide range of sustainability-related courses. She has taught women's nature writers, first-year writing, grant writing, ecology, weed science, sustainable agriculture, history of African-American farmers, and mathematics for the environment; she continually teaches introductory sustainability and environmental science. She has written two books for the public on the role of weeds in healthy lawns, and she is an associate editor for *Agronomy Journal*. She holds a B.A. in biology from Harvard University, an M.S. in crop and soil science from the University of Kentucky, and a Ph.D. in crop science from Cornell University.

Dr. Gift currently works with faculty across a variety of disciplines to encourage the infusion of sustainability in a wide range of fields. She won the Buhl Professor of Humanities award at Chatham University for her work there in teaching interdisciplinary courses. She taught environmental biology courses at the University of Chicago. Before committing to life as an academic, she worked at Cornell as a summer forest laborer for Arnot Forest, as an apple post-harvest storage lab technician, as a statistical analyst in veterinary epidemiology, and as an extension educator in sustainable weed management.



Linda R. Berg is an award-winning teacher and textbook author. She received her Ph.D. from the University of Maryland, College Park, after completing her B.S. and M.S. at the same institution. Her recent interests involve the Florida Everglades and conservation biology.

Dr. Berg formerly taught at the University of Maryland, College Park, for almost two decades, followed by St. Petersburg College in Florida for one decade. She taught introductory courses in environmental science, biology, and botany to thousands of students and received numerous teaching and service awards. Dr. Berg is also the recipient of many national and regional awards, including the National Science Teachers Association Award for Innovations in College Science Teaching, the Nation's Capital Area Disabled student Services Award, and the Washington Academy of Sciences Award in University Science Teaching.

During her career as a professional science writer, Dr. Berg has authored or co-authored several leading college science textbooks. Her writing reflects her teaching style and love of science.

Contents

1

Introducing Environmental Science and Sustainability

HECTOR GUERRERO / AFP / GettyImages

Industrial production of chicken requires many inputs, including feed, heating and cooling, and often antibiotics and hormones to accelerate growth. It also generates waste streams that can lead to air and water pollution if not treated or managed.

One of the best ways to understand our complex relationship with the global environment is to use food as a lens. Culture, price, personal tastes, and availability often determine our food choices. However, we rarely think about how a particular meal comes to our plate, and how its production impacts the environment.

Consider a simple chicken sandwich. To make bread, commercial bakeries rely on wheat from farms that require large amounts of inputs (land, irrigation water, fertilizers, and pesticides) and mechanization (usually diesel-fueled trucks and tractors). Using land for agriculture displaces native plants and animals, excess fertilizers and pesticides enter waterways and flow to the ocean, and burning diesel releases pollutants into the atmosphere. Once wheat is harvested, it is sent to a plant that grinds it into flour. This requires additional energy and produces a stream of organic waste material. The wheat is then shipped to a bakery, which adds water, sugar, yeast, corn syrup, vitamins and minerals, preservatives, oil, and other ingredients—each of which has also been processed and transported. The bread is then packed into plastic bags and delivered to stores and restaurants, hundreds or thousands of miles from where the wheat was grown. Each step uses energy, adds packaging, and generates solid and liquid wastes. Packaging, as well as uneaten or damaged bread, is usually thrown into the garbage and sent to a landfill.

Commercially grown chicken produces even more impact on the environment, since chicken feed grain has to be grown, processed, and delivered to a poultry farm (**photo**). Raising, processing, cooking, packaging, and delivering the chicken all require energy and material inputs and result in pollution and waste. In addition, chickens and other animals are often given antibiotics to make them grow faster. This can lead to antibiotic-resistant diseases, and the antibiotics can disrupt natural ecosystems.

There are more sustainable alternatives to the chicken sandwich. Wheat, grain, and chicken can be grown using methods that greatly reduce impacts on the environment. Foods that are grown near where they are consumed require less energy for transportation. Alternative pest management can reduce demand for pesticides and antibiotics. Bulk packaging and composted food waste can reduce or even eliminate the need for landfills. But even when these practices are adopted, growing and processing food requires land, water, energy, and other inputs.

Humans have developed agriculture over several thousand years. In so doing, we have altered ecosystems, cut down forests, shifted waterways, and driven plants and animals to extinction. At the same time, we have helped some plants and animals—including wheat and chicken, but rats and cockroaches as well—to become dominant species. Our agricultural practices have even contributed to climate change, which in turn forces us to adapt our food production practices. Knowing how something as simple as a choice between two sandwiches can have wide-ranging impacts on the environment is a great point from which to begin to understand the relationship between humans and the environment.

In Your Own Backyard…

Where and by whom is food grown near where you live? Look in your cupboards and refrigerator: Where and by whom are most of the foods you eat grown? How might switching to locally grown foods affect your diet and your food budget?

Human Impacts on the Environment

LEARNING OBJECTIVES

- Explain how human activities affect global systems.
- Describe the factors that characterize human development and how they impact environment and sustainability.

Earth is remarkably suited for life. Water, important both in the internal composition of organisms and as an external environmental factor affecting life, covers three-fourths of the planet. Earth's temperature is habitable—neither too hot, as on Mercury and Venus, nor too cold, as on Mars and the outer planets. We receive a moderate amount of sunlight—enough to power photosynthesis, which supports almost all the life-forms that inhabit Earth. Our atmosphere bathes the planet in gases and provides essential oxygen and carbon dioxide that organisms require. On land, soil develops from rock and provides support and minerals for plants. Mountains that arise from geologic processes and then erode over vast spans of time affect weather patterns, provide minerals, and store reservoirs of fresh water as ice and snow that melt and flow to lowlands during the warmer months. Lakes and ponds, rivers and streams, wetlands, and groundwater reservoirs provide terrestrial organisms with fresh water.

Earth's abundant natural resources have provided the backdrop for a parade of living things to evolve. Life has existed on Earth for about 3.8 billion years. Although early Earth was inhospitable by modern standards, it provided the raw materials and energy needed for early life-forms to arise and adapt. Some of these early cells evolved over time into simple multicellular organisms—early plants, animals, and fungi. Today, several million species inhabit the planet. A representative sample of Earth's biological diversity includes intestinal bacteria, paramecia, poisonous mushrooms, leafhoppers, prickly pear cacti, seahorses, dogwoods, angelfish, daisies, mosquitoes, pitch pines, polar bears, spider monkeys, and roadrunners (**Figure 1.1**).

About 100,000 years ago—a mere blip in Earth's 4.5-billion-year history—an evolutionary milestone began with the appearance of modern humans in Africa. Large brains and the ability to communicate made our species successful. Over time, our population grew; we expanded our range throughout the planet and increasingly impacted the environment with our presence and our technologies. These technologies have allowed many people in the world lives with access to well-lit and air-conditioned buildings, effective medical treatment, high-speed transportation, and uninterrupted food supplies. This has been particularly true in North America, Western Europe, and Japan; increasingly, many urban residents in China, India, South America, and parts of Africa have similar access to wealth and material goods.

Figure 1.1 A male greater roadrunner carries a desert spiny lizard it has captured. Life abounds on Earth, and every organism is linked to many others, including humans. Photographed in New Mexico.

Today, the human species is the most significant agent of environmental change on our planet. Our burgeoning population and increasing use of energy, materials, and land transform natural systems to meet our needs and desires. Our activities consume ever-increasing amounts of Earth's abundant but finite resources—rich topsoil, clean water, and breathable air. This alteration of natual systems eradicates many types of ecosystems and thousands upon thousands of unique species that inhabit them. Evidence continues to accumulate that human-induced climate change alters the natural environment in disruptive ways. Human activities are disrupting global **systems**.

system A set of components that interact and function as a whole.

This book introduces the major impacts that humans have on the environment. It considers ways to better manage those impacts, while emphasizing that each possible choice has the potential to cause additional impacts. Most important, it explains the value of minimizing human impact on our planet. Our lives and well-being, as well as those of future generations, depend on our ability to manage Earth's environmental resources effectively.

INCREASING HUMAN NUMBERS

Figure 1.2, a nighttime satellite photograph of North America, including the United States, Mexico, and Canada, depicts the home of about 470 million people. The tiny specks of light represent cities, with the great metropolitan areas, such as New York along the northeastern seacoast, ablaze with light.

The driver of all other environmental problems, the one that links all others, is the many people who live in the area shown in this picture. According to the United Nations, in 1950 only eight cities in the world had populations larger than 5 million, the largest being New York, with 12.3 million. By 2011 Tokyo, Japan had 17.8 million inhabitants, with 37.2 million inhabitants in the greater Tokyo metropolitan area. The combined population of the world's 10 largest urban agglomerations was over 200 million (see Table 9.1).

In 2011, the human population as a whole passed a significant milestone: 7 billion individuals. Not only is this figure incomprehensibly large, but also our population grew this large in a brief span of time. In 1960, the human population was only 3 billion (**Figure 1.3**). By 1975, there were 4 billion people, and by 1999, there were 6 billion. The 7.2 billion people who currently inhabit our planet consume great quantities of food and water, use a great deal of energy and raw materials, and produce much waste.

Despite family planning efforts in many countries, population growth rates do not change quickly. Several billion people will be

Figure 1.2 Satellite view of North America at night. This image shows most major cities and metropolitan areas in the United States, Mexico, and Canada.

added to the world in the twenty-first century, so even if we remain concerned about the impacts of a growing population and even if our solutions are effective, the coming decades may be clouded with tragedies. The conditions of life for many people may worsen considerably.

On a global level, nearly one of every two people live in extreme **poverty** (**Figure 1.4**). One measure of poverty is having a per capita income of less than $2 per day, expressed in U.S. dollars adjusted for purchasing power. More than 2.5 billion people—about 40% of the total world population—currently live at this level of poverty. Poverty is associated with low life expectancy, high infant mortality, illiteracy, and inadequate access to health services, safe water, and balanced nutrition. According to the UN Food and Agricultural Organization, at least 1 billion people (many of them children) lack access to the food needed for healthy, productive lives.

poverty A condition in which people cannot meet their basic needs for adequate food, clothing, shelter, education, or health.

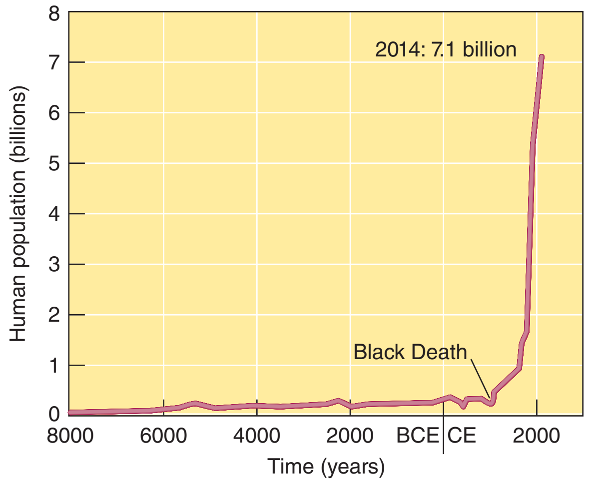


Figure 1.3 Human population growth. It took thousands of years for the human population to reach 1 billion (in 1800) but only 130 years to reach 2 billion (1930). It took only 30 years to reach 3 billion (1960), 15 years to reach 4 billion (1975), 12 years to reach 5 billion (1987), 12 years to reach 6 billion (1999), and 13 years to reach 7 billion (2012). (Population Reference Bureau)

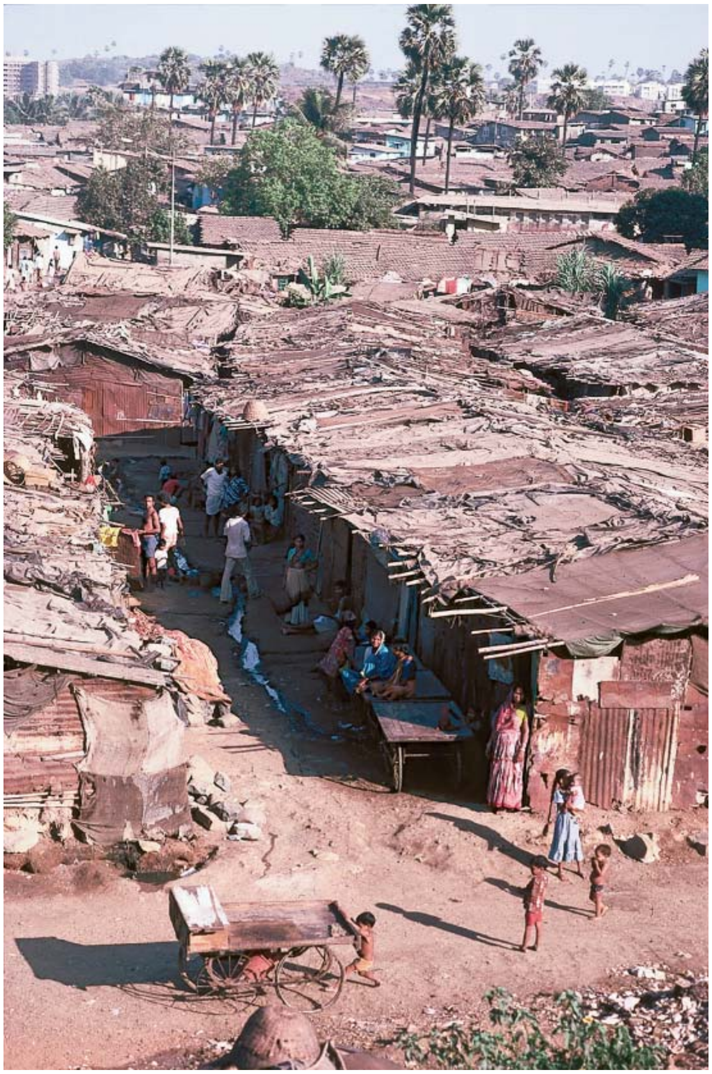


Figure 1.4 Slum in Mumbai (Bombay), India. Many of the world's people live in extreme poverty. One trend associated with poverty is the increasing movement of poor people from rural to urban areas. As a result, the number of poor people living in or around the fringes of cities is mushrooming.

Most demographers (people who study human populations) expect the world population to stabilize before the end of the current century. Worldwide, fertility rates have decereased to a current average of about three children per family, and this average is projected to continue to decline in coming decades. Expert projections for world population at the end of the twenty-first century range from about 8.3 billion to 10.9 billion, depending largely on how fast the fertility rate decreases (see Figure 8.3).

No one knows whether Earth can support so many people indefinitely. Among the tasks we must accomplish is feeding a world population considerably larger than the present one without undermining the natural resources that support us. Our ability to achieve this goal will determine the quality of life for our children and grandchildren.

DEVELOPMENT, ENVIRONMENT, AND SUSTAINABILITY

Until recently, demographers differentiated countries as highly developed, moderately developed, and less developed. The United States, Canada, Japan, and most of Europe, which represent 19% of the world's population but more than 50% of global economic activity, are **highly developed countries.** Development in this context is based mainly on total wealth of the country. The world's poorest countries, including Bangladesh, Kenya, and Nicaragua, are considered **less developed countries (LDCs).** Cheap, unskilled labor is abundant in LDCs, but capital for investment is scarce. Most LDC economies are agriculturally based, often for only one or a few crops. As a result, crop failure or a lower world market value for that crop is catastrophic to the economy. Hunger, disease, and illiteracy are common in LDCs.

highly developed countries Countries with complex industrial bases, low rates of population growth, and high per capita incomes.

less developed countries (LDCs) Developing countries with a low level of industrialization, a high fertility rate, a high infant mortality rate, and a low per capita income (relative to highly developed countries).

However, recent decades have seen substantial increases in wealth for many urban residents in previously less developed countries, including China, India, Brazil, and Mexico. These countries have substantial *income disparities,* meaning that other urban residents and most of the rural inhabitants of those remain poor, and lack access to cars, electricity, fresh water, and modern medical technology. Consequently, using the total wealth or income of a country may not usefully describe the well-being of people in that country. More appropriate measures can include the percentage of residents who make more than $2 per day, have access to fresh water and electricity, or have access to education.

REVIEW

1. What is one example of a global system?
2. How do the total wealth of a country and income disparity relate to sustainability?

Population, Resources, and the Environment

LEARNING OBJECTIVES

- Differentiate between renewable and nonrenewable resources.
- Explain the impact of population and affluence on consumption.
- Define *ecological footprint.*
- Describe the three most important factors that determine human impact on the environment.

The relationships among population growth, use of natural resources, and environmental degradation are complex. We address the details of resource management and environmental problems in this and later chapters, but for now, let us consider two useful generalizations: (1) The resources essential to an individual's survival are small, but a rapidly increasing population tends to overwhelm and deplete local soils, forests, and other natural resources (**Figure 1.5a**). (2) In highly developed countries, individual resource demands are large, far above what is needed for survival. Consumption by people in affluent nations can exhaust resources and degrade the environment on a global scale (**Figure 1.5b**).

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(a) A trend towards larger homes leads to greater consumption in a number of ways: more energy to heat and cool, more distance to travel between homes, and more furnishings inside the home.

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(b) The "tiny house" movement seeks to simplify individual living, and as a consequence reduces consumption. Tiny house occupants have no place to accumulate material goods, and so must be more selective in their purchasing.

Figure 1.5 **Consumption of natural resources.**

TYPES OF RESOURCES

When examining the effects of humans on the environment, it is important to distinguish between two types of natural resources: nonrenewable and renewable (**Figure 1.6**). **Nonrenewable resources**, which include minerals (such as aluminum, copper, and uranium) and fossil fuels (coal, oil, and natural gas), are present in limited supplies and are depleted by use. Natural processes do not replenish nonrenewable resources within a reasonable period on the human time scale. Fossil fuels, for example, take millions of years to form.

In addition to a nation's population, several other factors affect how nonrenewable resources are used, including how efficiently the resource is extracted and processed as well as how much of it

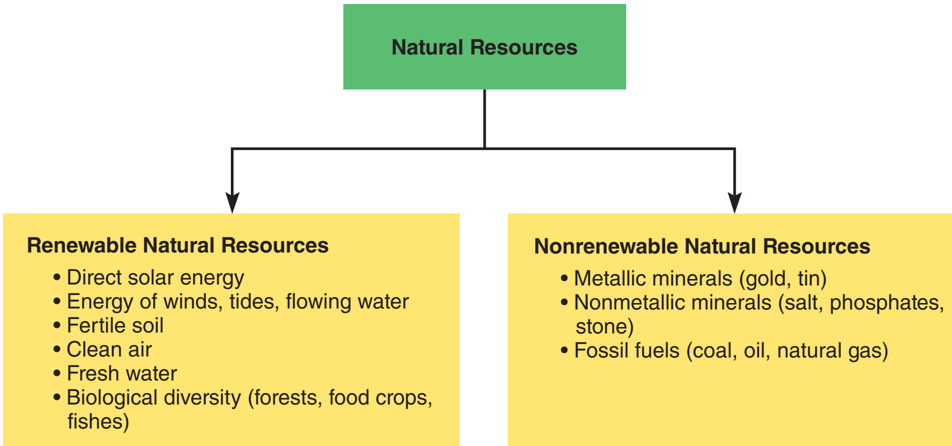


Figure 1.6 Natural resources. Nonrenewable resources are replaced on a geologic time scale, and their supply diminishes with use. Renewable resources can be (but are not always) replaced on a fairly short time scale; as will be explained in later chapters, most renewable resources are derived from the sun's energy.

is required or consumed by different groups. People in the United States, Canada, and other highly developed nations tend to consume most of the world's nonrenewable resources. Nonetheless, Earth has a finite supply of nonrenewable resources that sooner or later will be exhausted. In time, technological advances may provide substitutes for some nonrenewable resources. Slowing the rate of population growth and consumption will buy time to develop such alternatives.

Some examples of **renewable resources** are trees, fishes, fertile agricultural soil, and fresh water. Nature replaces these resources fairly rapidly (on a scale of days to centuries), and they can be used forever as long as they are not overexploited in the short term. In developing countries, forests, fisheries, and agricultural land are particularly important renewable resources because they provide food. Indeed, many people in developing countries are subsistence farmers who harvest just enough food so that they and their families can survive.

Rapid population growth can cause the overexploitation of renewable resources. For example, large numbers of poor people must grow crops on land inappropriate for farming, such as on mountain slopes or in tropical rain forests. Although this practice may provide a short-term solution to the need for food, it does not work in the long term: When these lands are cleared for farming, their agricultural productivity declines rapidly, and severe environmental deterioration occurs. Renewable resources are usually only *potentially* renewable. They must be used in a *sustainable* way—in a manner that gives them time to replace or replenish themselves.

The effects of population growth on natural resources are particularly critical in developing countries. The economic growth of developing countries is often tied to the exploitation of their natural resources, usually for export to highly developed countries. Developing countries are faced with the difficult choice of exploiting natural resources to provide for their expanding populations in the short term (to pay for food or to cover debts) or conserving those resources for future generations.

It is instructive to note that the economic growth and development of the United States, Canada, and other highly developed nations came about through the exploitation and, in some cases, the destruction of resources. Continued economic growth in highly developed countries now relies significantly on the importation of these resources from less developed countries. One of the reasons economic growth in highly developed countries has been possible is the uneven distribution of both renewable and nonrenewable resources around the world. Many very poor countries—Ethiopia, for example—have only limited fossil-fuel resources.

RESOURCE CONSUMPTION

Consumption is the human use of materials and energy. Consumption, which is both an economic and a social act, provides the consumer with a sense of identity as well as status among peers. Advertisers promote consumption as a way to achieve happiness. Western culture encourages spending and consumption well beyond that which is necessary for survival.

In general, people in highly developed countries are extravagant consumers; their use of resources is greatly out of proportion to their numbers. A single child born in a highly developed country may have a greater impact on the environment and on resource depletion than 12 or more children born in a developing country. Many natural resources are used to provide the automobiles, air conditioners, disposable diapers, cell phones, DVD players, computers, clothes, newspapers, athletic shoes, furniture, boats, and other comforts of life in highly developed countries. Yet such consumer goods represent a small fraction of the total materials and energy required to produce and distribute them. According to the Worldwatch Institute, a private research institution in Washington, D.C., Americans collectively consume almost 10 billion tons of materials every year. The disproportionately large consumption of resources by highly developed countries affects natural resources and the environment as much as or more than the population explosion in the developing world.

Unsustainable Consumption Consumption in a country is unsustainable if the level of demand on its resource base damages the environment or depletes resources to such an extent that future generations will have lower qualities of life. In comparing human impact on the environment in developing and highly developed countries, we see that unsustainable consumption can occur in two ways. First, environmental quality and resource depletion can result from too many people, even if those people consume few resources per person. This is the current situation in many developing nations.

In highly developed countries, unsustainable consumption results when individuals consume substantially more resources than necessary for survival. Both types of unsustainable consumption have the same effect—pollution, environmental degradation, and resource depletion. Many affluent, highly developed countries, including the United States, Canada, Japan, and most of Europe, consume unsustainably: *Highly developed countries represent less than 20% of the world's population, yet they consume significantly more than half of its resources*.

According to the Worldwatch Institute, highly developed countries account for the lion's share of total resources consumed:

- 86% of aluminum used
- 76% of timber harvested
- 68% of energy produced
- 61% of meat eaten
- 42% of the fresh water consumed

These nations also generate 75% of the world's pollution and waste.

ECOLOGICAL FOOTPRINT

Environmental scientists **Mathis Wackernagel** and **William Rees** developed the concept of ecological footprint to help people visualize what they use from the environment. Each person has an **ecological footprint**, an amount of productive land, fresh water, and ocean required on a continuous basis to supply that person with food, wood, energy, water, housing, clothing, transportation, and waste disposal. The *Living Planet Report 2010*, produced by scientists at the Global Footprint Network, World Wildlife Fund, and Zoological Society of London, estimates that since about 1975, the human population has been consuming more of the productive land, water, and other resources than Earth can support (**Figure 1.7**). In 2010, annual consumption was about 50% more than Earth produces. This is an unsustainable consumption rate.

The *Living Planet Report* estimates that Earth has about 11.4 billion hectares (28.2 billion acres) of productive land and water. If we divide this area by the global human population, we see that each person is allotted about 1.6 hectares (4.0 acres). However, the average global ecological footprint is currently about 2.7 hectares (6.7 acres) per person, which means we humans have an *ecological overshoot*. We can see the short-term results around us—forest destruction, degradation of croplands, loss of biological diversity, declining ocean fisheries, local water shortages, and increasing pollution. The long-term outlook, if we do not seriously address our consumption of natural resources, is potentially disastrous. Either per-person consumption will drop, population will decrease, or both.

In the developing nation of India, the per capita ecological footprint is 0.9 hectare (2.2 acres); India is the world's second-largest country in terms of population, so even though its per capita footprint is low, the country's footprint is high: 986.3 million hectares (**Figure 1.8**). In France, the per capita ecological footprint is 4.9 hectares (12.1 acres); although its per capita footprint is high, France's footprint as a country is 298.1 million hectares, which is lower than India's, because its population is much smaller. In the United States, the world's third-largest country, the per capita ecological footprint is 7.9 hectares (19.5 acres); the U.S. footprint as a country is 2,457 million hectares! If all people in the world had the same lifestyle and level of consumption as the average North American, and assuming no changes in technology, we would need about four additional planets the size of Earth.

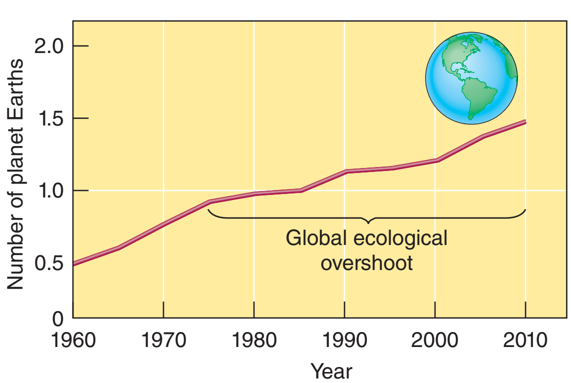
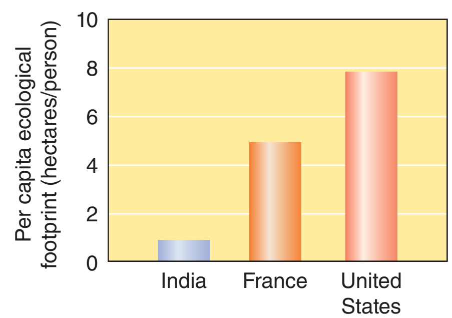
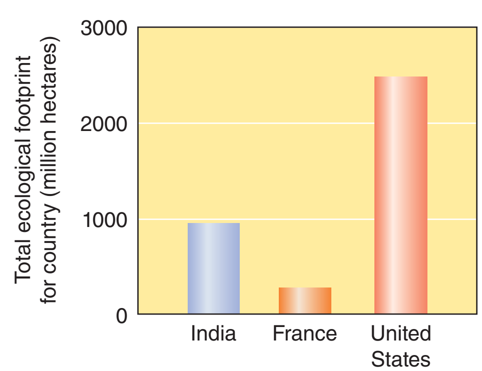


Figure 1.7 Global ecological overshoot. Earth's ecological footprint has been increasing over time. By 2010, humans were using the equivalent of 1.5 Earths, a situation that is not sustainable. (Data from World Wildlife Fund, *Living Planet Report 2010*)



(a) The average ecological footprint of a person living in India, France, or the United States. For example, each Indian requires 0.9 hectare (2.2 acres) of productive land and ocean to meet his or her resource requirements.



(b) The total ecological footprint for the countries of India, France, and the United States. Note that India, although having a low per capita ecological footprint, has a significantly higher ecological footprint as a country because of its large population. If everyone in the world had the same level of consumption as the average American, it would take the resources and area of five Earths.

Figure 1.8 Ecological footprints. (Data from World Wildlife Fund, *Living Planet Report 2012*)

As developing countries increase their economic growth and improve their standard of living, more and more people in those nations purchase consumer goods. More new cars are now sold annually in Asia than in North America and Western Europe combined. These new consumers may not consume at the high level of the average consumer in a highly developed country, but their consumption has increasingly adverse effects on the environment. For example, air pollution caused by automotive traffic in urban centers in developing countries is terrible and getting worse every year. Millions of dollars are lost because of air pollution–related health problems in these cities. One of society's challenges is to provide new consumers in developing countries (as well as ourselves) with less polluting, less consuming forms of transportation.

THE *IPAT* MODEL

Generally, when people turn on the tap to brush their teeth in the morning they do not think about where the water comes from or about the environmental consequences of removing it from a river or the ground. Similarly, most North Americans do not think about where the energy comes from when they flip on a light switch or start a car. We do not realize that all the materials in the products we use every day come from Earth, nor do we grasp that these materials eventually are returned to Earth, much of them in sanitary landfills.

Such human impacts on the environment are difficult to assess. They are estimated using the three factors most important in determining environmental impact *(I)*:

1. The number of people *(P)*
2. Affluence, which is a measure of the consumption or amount of resources used per person *(A)*
3. The environmental effects (resources needed and wastes produced) of the technologies used to obtain and consume the resources *(T)*

These factors are related in this way:

$$I = P \times A \times T$$

model A representation of a system; describes the system as it exists and predicts how changes in one part of the system will affect the rest of the system.

In science, a **model** is a formal statement that describes the behavior of a system. The *IPAT* model, which biologist **Paul Ehrlich** and physicist **John Holdren** first proposed in the 1970s, shows the mathematical relationship between environmental impacts and the forces driving them.

For example, to determine the environmental impact of emissions of the greenhouse gas CO_2 from motor vehicles, multiply the population times the number of cars per person (affluence/consumption per person) times the average car's annual CO_2 emissions per year (technological impact). This model demonstrates that although increasing motor vehicle efficiency and developing cleaner technologies will reduce pollution and environmental degradation, a larger reduction will result if population and per capita consumption are also controlled.

The *IPAT* equation, though useful, must be interpreted with care, in part because we often do not understand all the environmental impacts of a particular technology on complex environmental systems. Motor vehicles are linked not only to global warming from CO_2 emissions but also to local air pollution (tailpipe exhaust), water pollution (improper disposal of motor oil and antifreeze), and solid waste (disposal of nonrecyclable automobile parts in sanitary landfills). There are currently more than 600 million motor vehicles on the planet, and the number is rising rapidly.

The three factors in the *IPAT* equation are always changing in relation to one another. Consumption of a particular resource may increase, but technological advances may decrease the environmental impact of the increased consumption. For example, there are more television and computer screens in the average household than there were 20 years ago (increased affluence) and more households (increased population). However, many of the new units are flat screens, which require less materials to produce and less energy to operate (more efficient technology). Thus, consumer trends and choices may affect environmental impact.

Similarly, the average fuel economy of new cars and light trucks (sport-utility vehicles, vans, and pickup trucks) in the United States declined from 22.1 miles per gallon in 1988 to 20.4 miles per gallon in the early 2000s, in part because of the popularity of sport-utility vehicles (SUVs). In addition to being less fuel efficient than cars, SUVs emit more emissions per vehicle mile. More recently, hybrids have helped to increase the average fuel economy (**Figure 1.9**). Such trends and uncertainties make the *IPAT* equation of limited usefulness for long-term predictions.

The *IPAT* equation is valuable because it helps identify what we do not know or understand about consumption and its environmental impact. The National Research Council of the U.S. National Academy of Sciences[1] has identified research areas we must address, including the following: Which kinds of consumption have the greatest destructive impact on the environment? Which groups in society are responsible for the greatest environmental disruption? How can we alter the activities of these environmentally disruptive groups? It will take years to address such

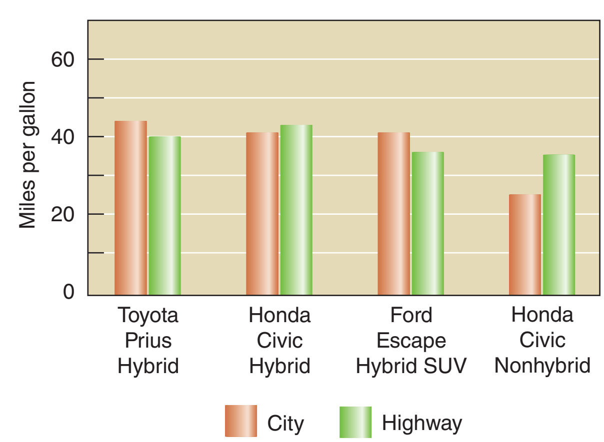


Figure 1.9 **Fuel-efficient hybrids.** Shown are city and highway miles per gallon for three hybrid models available in 2014. (U.S. Department of Energy)

[1] The National Research Council is a private, nonprofit society of distinguished scholars. It was organized by the National Academy of Sciences to advise the U.S. government on complex issues in science and technology.

questions, but the answers should help decision makers in government and business formulate policies to alter consumption patterns in an environmentally responsible way. Our ultimate goal should be to reduce consumption so that our current practices do not compromise the ability of future generations to use and enjoy the riches of our planet.

REVIEW

1. How do renewable resources differ from nonrenewable resources?
2. How are human population growth and affluence related to natural resource depletion?
3. What is an ecological footprint?
4. What does the *IPAT* model demonstrate?

Sustainability

LEARNING OBJECTIVES

- Define *sustainability.*
- Relate Garrett Hardin's description of the tragedy of the commons in medieval Europe to common-pool resources today.
- Briefly describe sustainable development.

One of the most important concepts in this text is **sustainability**. A sustainable world is one in which humans can have economic development and fair allocation of resources without the environment going into a decline from the stresses imposed by human society on the natural systems (such as fertile soil, water, and air) that maintain life. When the environment is used sustainably, humanity's present needs are met without endangering the welfare of future generations (**Figure 1.10**). Environmental sustainability applies at many levels, including individual, community, regional, national, and global levels.

sustainability The ability to meet current human economic and social needs without compromising the ability of the environment to support future generations.

- Our actions can affect the health and well-being of natural *ecosystems*, including all living things.
- Earth's resources are not present in infinite supply; our access is constrained by ecological limits on how rapidly renewable resources such as fresh water regenerate for future needs.
- The products we consume can impose costs to the environment and to society beyond those captured in the price we pay for those products.
- Sustainability requires a concerted and coordinated effort of people on a global scale.

Many experts in environmental problems think human society is not operating sustainably because of the following human behaviors:

- We extract nonrenewable resources such as fossil fuels as if they were present in unlimited supplies.

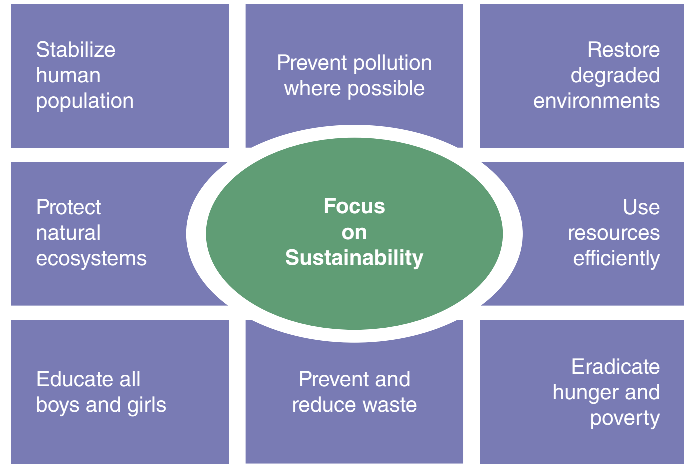


Figure 1.10 **Sustainability.** Sustainability requires a long-term perspective to protect human welfare and natural resource assets, such as the efforts shown here.

- We consume renewable resources such as fresh water and forests faster than natural systems can replenish them (**Figure 1.11**).
- We pollute the environment with toxins as if the capacity of the environment to absorb them is limitless.
- A small fraction of the human population dominates a large percentage of Earth's resources.
- Our numbers continue to grow despite Earth's finite ability to feed us, sustain us, and absorb our wastes.

If left unchecked, these activities could threaten Earth's life-support systems to such a degree that recovery is impossible. If major resources like agricultural land, fisheries, and fresh water are exhausted to the point that they cannot recover quickly, substantial human suffering would result. Thus managing these resources sustainably means more than protecting the environment: sustainability promotes human well-being.

Topham/The Image Works

Figure 1.11 **A logger cuts down the last standing tree on a clear-cut forest slope.** Logging destroys the habitat for forest organisms and increases the rate of soil erosion on steep slopes. Photographed in Canada.

At first glance, the issues may seem simple. Why do we not just reduce consumption, improve technology, and limit population growth? The answer is that various interacting ecological, societal, and economic factors complicate the solutions. Our inadequate understanding of how the environment works and how human choices affect the environment is a major reason that problems of sustainability are difficult to resolve. The effects of many interactions between the environment and humans are unknown or difficult to predict, and we generally do not know if we should take corrective actions before our understanding is more complete.

SUSTAINABILITY AND THE TRAGEDY OF THE COMMONS

Garrett Hardin (1915–2003) was a professor of human ecology at the University of California–Santa Barbara who wrote about human environmental dilemmas. In 1968, he published his classic essay, "The Tragedy of the Commons," in the journal *Science.* He contended that our inability to solve many environmental problems is the result of a struggle between short-term individual welfare and long-term environmental sustainability and societal welfare.

Hardin used the commons to illustrate this struggle. In medieval Europe, the inhabitants of a village shared pastureland, called the commons, and each herder could bring animals onto the commons to graze. If the villagers did not cooperatively manage the commons, each might want to bring more animals onto it. If every herder in the village brought as many animals onto the commons as possible, the plants would be killed from overgrazing, and the entire village would suffer. Thus, an unmanaged commons would inevitably be destroyed by the people who depended on it.

Hardin argued that one of the outcomes of the eventual destruction of the commons would be private ownership of land, because when each individual owned a parcel of land, it was in that individual's best interest to protect the land from overgrazing. A second outcome Hardin considered was government ownership and management of such resources, because the government had the authority to impose rules on users of the resource and thereby protect it.

Hardin's essay has stimulated a great deal of research in the decades since it was published. In general, scholars agree that degradation of the self-governing commons—now called **common-pool resources**—typically is not a problem in closely knit communities. Indeed, sociologist **Bill Freudenberg** has pointed out that medieval commons were successfully managed but became degraded after they were privatized. Economist **Elinor Ostrum** demonstrated that common pool resources can be sustainably managed by communities with shared interests, strong local governance, and community-enforced accountability.

common-pool resources Those parts of our environment available to everyone but for which no single individual has responsibility—the atmosphere and climate, fresh water, forests, wildlife, and ocean fisheries.

As one goes from local to regional to global common-pool resources, the challenges of sustainably managing resources become more complex. In today's world, Hardin's parable has particular relevance at the global level. These modern-day commons are experiencing increasing environmental stress (see, for example, the discussion of climate change in Chapter 20). No individual, jurisdiction, or country owns common-pool resources, and they are susceptible to overuse. Although exploitation may benefit only a few, everyone on Earth must pay for the environmental cost of exploitation.

The world needs effective legal and economic policies to prevent the short-term degradation of common-pool resources and ensure their long-term well-being. We have no quick fixes because solutions to global environmental problems are not as simple or short term as are solutions to some local problems. Most environmental ills are inextricably linked to other persistent problems such as poverty, overpopulation, and social injustice—problems beyond the capacity of a single nation to resolve. The large number of participants who must organize, agree on limits, and enforce rules complicates the creation of global treaties to manage common-pool resources. Cultural and economic differences among participants make finding solutions even more challenging.

Clearly, all people, businesses, and governments must foster a strong sense of **stewardship**—shared responsibility for the sustainable care of our planet. Cooperation and commitment at the international level are essential if we are to alleviate poverty, stabilize the human population, and preserve our environment and its resources for future generations.

stewardship Shared responsibility for the sustainable care of our planet.

GLOBAL PLANS FOR SUSTAINABLE DEVELOPMENT

In 1987, the World Commission on Environment and Development released a groundbreaking report, *Our Common Future* (see Chapter 24). A few years later, in 1992, representatives from most of the world's countries met in Rio de Janeiro, Brazil, for the *UN Conference on Environment and Development*. Countries attending the conference examined environmental problems that are international in scope: pollution and deterioration of the planet's atmosphere and oceans, a decline in the number and kinds of organisms, and destruction of forests.

In addition, the Rio participants adopted *Agenda 21*, an action plan of **sustainable development** in which future economic development, particularly in developing countries, will be reconciled with environmental protection. The goals of sustainable development are achieving improved living conditions for all people while maintaining a healthy environment in which natural resources are not overused and excessive pollution is not generated. Three factors—environmentally sound decisions, economically viable decisions, and socially equitable decisions—are necessary for truly sustainable development. To use sustainability as a guiding principle for environmental management requires that we think about how these three factors interact as parts of a complex and interlinked system (**Figure 1.12**).

sustainable development As defined by the Brundtland report, economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

A serious application of the principles of environmental sustainability to economic development will require many changes in such fields as population policy, agriculture, industry, economics,