Environmental Science

Systems & Solutions

SIXTH EDITION

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To my children, Jeannie, Michael, Holli, and Maddi

–MLM

To my sons, Nicholas Schoch and Edward Schoch

–RMS

To my parents, Liane Salgado and Don Yonavjak

–LY

To my parents, Christine Kolich Tillman and Lloyd Thomas Mincy

–GAM

Satellite Image of North America

Map of North America

Political Map of the World

Physical Map of the World

Brief Contents


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Contents

SECTION 2 The Environment and History of Life on Planet Earth 57

SECTION 3 Resource Use and Management 157

Preface

The future which we hold in trust for our own children will be shaped by our fairness to other people's children.

—Marian Wright Edelman

Nothing is more honorable to any large mass of people assembled for the purpose of a fair discussion, than that kind and respectful attention that is yielded not only to your political friends, but to those who are opposed to you in politics.

—Stephen Douglas, from the Lincoln–Douglas debates

THE CRITICAL IMPORTANCE of environmental science and environmental studies cannot be disputed as virtually everyone is aware of the issues—be they climate change, the depletion of the ozone layer, the controversy over nuclear power, or the continuing problems of water pollution and solid waste disposal. Issues regarding the environment are in the news every day, and as the world becomes increasingly industrialized we will surely hear more about environmental concerns and advances. *Environmental Science: Systems and Solutions, Sixth Edition*, offers the basic principles necessary to understand and address these multifaceted and often very complex environmental concerns.

We wrote this book to serve as a comprehensive overview and synthesis of environmental science. *Environmental Science: Systems and Solutions* provides the reader with the basic factual data necessary to understand current environmental issues. But to know the raw facts is not enough. A well-informed person must understand how various aspects of the natural environment interconnect with each other and with human society. We thus use a systems approach as a means of organizing complex information in a way that highlights connections for the reader. The systems approach allows the reader to take in the information without feeling overwhelmed, as often happens when large amounts of information are presented in a disorganized fashion. With a subject as diverse as environmental science, it is easy to get lost in the details. We have always kept the "big picture" in mind.

All too often environmental discussions become bogged down in partisan rhetoric or "gloom and doom" tactics. Our intention is not to preach but to inform. Accordingly, in approaching what is often an extremely controversial subject, we have adopted an objective and practical perspective that tries to highlight what is going right in dealing with modern environmental problems. Furthermore, we have consciously aimed at being both fair and balanced (presenting differing opinions and information) in our approach to many controversial issues. In this text, you will read critical analyses of public and private policy with an honest discussion of what has worked and what has failed.

A key concept among modern environmentalists is sustainability. In this book, we have adopted the sustainability paradigm: we focus on sustainable technologies and economic systems and the ways that sustainable development can be implemented around the world. Our emphasis is on specific examples that can give concrete meaning to the concept: Sustainable technological and social solutions to environmental problems are discussed throughout the book. Environmental science is global in scope so it is important for all of us to know that there are regional and local solutions to complex global problems and that individual actions can be a big part of the solution. We hope to inspire the reader to move beyond simple awareness of current environmental problems to become an active promoter of sustainable solutions to these problems.

Organization and What's New in This Edition

Building on the framework of the five previous editions, we have rewritten the text to improve the discourse. Furthermore, recent disasters and noteworthy updates are reflected in this edition. We have updated case studies that cover topics relevant to the current environmental situation, including captive breeding, Hurricane Katrina, the Colorado River, sustainable agriculture practices, overpopulation concerns, the Keystone XL pipeline, pollution, the Flint water crisis, global earthquakes, and measuring ecological footprints. Additional changes include updated statistics throughout the text, revised and updated figures and tables, and more coverage of sustainability, climate change, fossil fuels, national parks, and water resources. We believe that all of these changes will make the book both more timely and more accessible to the reader. The five sections of the book are:

Section 1, The Environment and People (Chapters 1 and 2), introduces the systems approach and gives an overview of environmental science in Chapter 1, while Chapter 2 focuses on the increasing impact that the growing human population has had on all natural systems.

Section 2, The Environment of Life on Planet Earth (Chapters 3 through 5), describes how natural systems work, including both biological systems and physical systems. Here we introduce such concepts as populations, communities, ecosystems, the distribution of life on Earth, biogeochemical cycles, weather patterns and climatic zones, the rock cycle and plate tectonics, deep time, and natural hazards.

Section 3, Resource Use and Management (Chapters 6 through 13), deals with issues surrounding the use of natural resources by human society. Chapter 6 introduces the broad principles of resource management, both in urban and wild environments. The following chapters address energy use, water use, mineral use, ecosystem services, and the use of biological resources (including agriculture and soil resources). A major theme is that humans have been rapidly depleting many of these resources and that we must begin using them in a sustainable manner if we are to survive and flourish in the future.

Section 4, Dealing with Environmental Degradation (Chapters 14 through 18), concentrates on various forms of pollution and waste—the results of dumping large amounts of the by-products of human society into the environment. Chapter 14 introduces the principles of pollution control, toxicology, and risk, while subsequent chapters deal with such subjects as water pollution, air pollution, the destruction of the ozone layer, global climate change, municipal solid waste, and hazardous waste. Every chapter includes discussions of how we can limit or mitigate the effects of excessive pollution, especially by limiting the production of pollutants in the first place, as well as by increased efficiency, reuse, recycling, and substitutions.

Section 5, Social Solutions to Environmental Concerns (Chapters 19 and 20), includes discussions of economic, social, historical, and legal aspects of environmental issues. A major emphasis of the book is on solutions to current environmental concerns. Woven throughout the text are discussions and examples of environmentally friendly technological, legal, and economic solutions. We firmly believe that sustainable and realistic solutions must be implemented and that the root causes of the environmental problems we now face must be addressed. Such problems cannot be solved using science and technology alone; the human aspect must also be taken into account. This section is available online and in eBook formats.

Using This Book for a Course in Environmental Science or Environmental Studies

We designed this book to be accessible to introductory nonmajor students, but it has enough depth and breadth to be used in a majors' course. It can be adapted to either an environmental science course or an environmental studies course, and it can be used for either one or two semesters. Also, we designed the book so that the chapters need not necessarily be used in the order in which they appear. In particular, depending on the nature and emphasis of a specific course, an instructor may choose to use the chapters of Section 5 (Social Solutions to Environmental Concerns) at either the beginning or end of the course, or these or other chapters may be omitted entirely.

Assuming a standard 15 full weeks for a semester (usually about a week is lost due to holidays, exams, and the like), the chapters of this text might be assigned according to one of the following schedules:

For a comprehensive environmental science and environmental studies course:
Week 1: Chapters 1 & 2, An Overview of Environmental Science and Human Population Growth
Week 2: Chapter 3, The Ever-Changing Earth: The Biosphere and Biogeochemical Cycles
Week 3: Chapters 4 & 5, The Distribution of Life on Earth and Dynamic Earth and Natural Hazards
Week 4: Chapter 6, People and Natural Resources
Week 5: Chapter 7, Fundamentals of Energy, Fossil Fuels, and Nuclear Energy
Week 6: Chapter 8, Renewable (including Hydropower) and Alternative Energy Sources
Week 7: Chapters 9 & 10, Water and Mineral Resources
Week 8: Chapter 11, Conserving Biological Resources
Week 9: Chapter 12, Land Resources and Management
Week 10: Chapter 13, Food and Soil Resources
Week 11: Chapters 14 & 15, Principles of Pollution Control and Water Pollution
Week 12: Chapter 16, Local and Regional Air Pollution
Week 13: Chapter 17, Destruction of the Ozone Layer and Global Climate Change
Week 14: Chapter 18, Municipal Solid Waste and Hazardous Waste
Week 15: Chapters 19 & 20, Economic, Historical, Social, and Legal Aspects of Current Environmental Concerns

For a basic environmental science course:
Week 1: Chapters 1 & 2, An Overview of Environmental Science and Human Population Growth
Week 2: Chapter 3, The Ever-Changing Earth: The Biosphere and Biogeochemical Cycles
Week 3: Chapter 4, The Distribution of Life on Earth
Week 4: Chapter 5, The Dynamic Earth and Natural Hazards
Week 5: Chapter 6, People and Natural Resources
Week 6: Chapter 7, Fossil Fuels and Nuclear Energy
Week 7: Chapter 8, Renewable (including Hydropower) and Alternative Energy Sources
Week 8: Chapters 9 & 10, Water and Mineral Resources
Week 9: Chapter 11, Conserving Biological Resources
Week 10: Chapter 12, Land Resources and Management
Week 11: Chapter 13, Food and Soil Resources
Week 12: Chapters 14 & 15, Principles of Pollution Control and Water Pollution
Week 13: Chapter 16, Local and Regional Air Pollution
Week 14: Chapter 17, Destruction of the Ozone Layer and Global Climate Change
Week 15: Chapter 18, Municipal Solid Waste and Hazardous Waste

For a general environmental studies course (emphasizing social and historical aspects):

Week 1: Chapter 1, An Overview of Environmental Science

Week 2: Chapter 17, Destruction of the Ozone Layer and Global Climate Change—Examples of the impacts humans are having on the environment

Week 3: Chapter 20, Historical, Cultural, and Legal Aspects of Current Environmental Concerns

Week 4: Chapter 2, Human Population Growth

Week 5: Chapter 6, People and Natural Resources

Week 6: Chapter 7, Fossil Fuels and Nuclear Energy

Week 7: Chapter 8, Renewable (including Hydropower) and Alternative Energy Sources

Week 8: Chapters 9 & 10, Water and Mineral Resources

Week 9: Chapter 11, Conserving Biological Resources

Week 10: Chapter 12, Land Resources and Management

Week 11: Chapter 13, Food and Soil Resources

Week 12: Chapters 14 & 15, Principles of Pollution Control and Water Pollution

Week 13: Chapter 16, Local and Regional Air Pollution

Week 14: Chapter 18, Municipal Solid Waste and Hazardous Waste

Week 15: Chapter 19, Environmental Economics

If this book is used for a two-semester course, some of the chapters should be used over a period longer than 1 week. In particular, we recommend that the following chapters be split as indicated and extended over 2 weeks:

Chapter 3, The Ever-Changing Earth: The Biosphere and Biogeochemical Cycles

Chapter 4, The Distribution of Life on Earth

Chapter 5, The Dynamic Earth and Natural Hazards

Chapter 7, Fundamentals of Energy & Fossil Fuels/Nuclear Energy

Chapter 8, Renewable and Alternative Energy Sources

Chapter 13, Food/Soil Resources

Chapter 14, Pollution Control/Toxicology

Chapter 17, Destruction of the Ozone Layer/Global Climate Change

Chapter 18, Municipal Solid Waste/Hazardous Waste

Chapter 20, Historical and Social Perspectives/Environmental Law and Decision Making

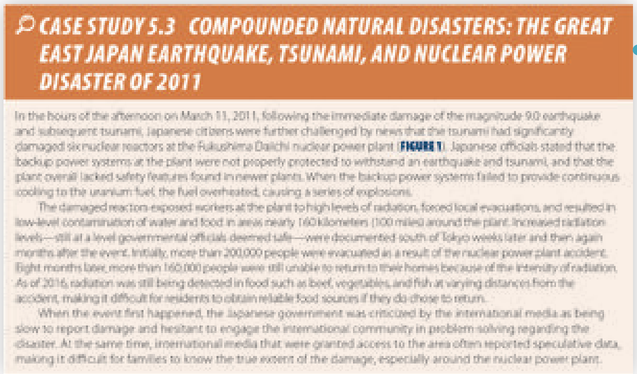
If these chapters are used as suggested, then chapter or subchapter readings from the text will easily fit into a two-semester schedule (approximately 30 full weeks).

The Student Experience

Each chapter uses the same basic organizational format. Following an opening photograph and learning objectives, the chapter begins with an introduction that offers an overview of the subject matter of the chapter and places it in context.

We have written the text to be interesting and accessible to the average reader, and we have illustrated it with numerous diagrams, charts, tables, and photographs demonstrating basic concepts and key ideas. Throughout the text key terms denoting important concepts are in **boldface** type.

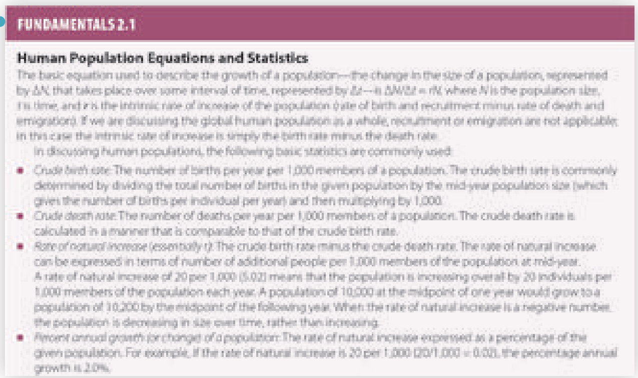
Case Studies: Thought-provoking case studies provide detailed examples of interesting environmental applications, experimental work, and controversies. All of the Case Studies provide follow-up questions that ask the reader to examine the facts, the arguments, and the conclusions.


CASE STUDY 5.3 COMPOUNDED NATURAL DISASTERS: THE GREAT EAST JAPAN EARTHQUAKE, TSUNAMI, AND NUCLEAR POWER DISASTER OF 2011

In the hours of the afternoon on March 11, 2011, following the immediate damage of the magnitude 9.0 earthquake and subsequent tsunami, Japanese citizens were further challenged by news that the tsunami had significantly damaged six nuclear reactors at the Fukushima Daiichi nuclear power plant (FIGURE 1). Japanese officials stated that the backup power systems at the plant were not properly protected to withstand an earthquake and tsunami, and that the plant overall lacked safety features found in newer plants. When the backup power systems failed to provide continuous cooling to the uranium fuel, the fuel overheated, causing a series of explosions.

The damaged reactors exposed workers at the plant to high levels of radiation, forced local evacuations, and resulted in low-level contamination of water and food in areas nearly 160 kilometers (100 miles) around the plant. Increased radiation levels—still at a level governmental officials deemed safe—were documented south of Tokyo weeks later and then again months after the event. Initially, more than 200,000 people were evacuated as a result of the nuclear power plant accident. Eight months later, more than 160,000 people were still unable to return to their homes because of the intensity of radiation. As of 2016, radiation was still being detected in food such as beef, vegetables, and fish at varying distances from the accident, making it difficult for residents to obtain reliable food sources if they do chose to return.

When the event first happened, the Japanese government was criticized by the international media as being slow to report damage and hesitant to engage the international community in problem-solving regarding the disaster. At the same time, international media that were granted access to the area often reported speculative data, making it difficult for families to know the true extent of the damage, especially around the nuclear power plant.


FUNDAMENTALS 2.1

Human Population Equations and Statistics

The basic equation used to describe the growth of a population—the change in the size of a population, represented by ΔN, that takes place over some interval of time, represented by Δt—is $\Delta N/\Delta t = rN$, where N is the population size, t is time, and r is the intrinsic rate of increase of the population (rate of birth and recruitment minus rate of death and emigration). If we are discussing the global human population as a whole, recruitment or emigration are not applicable; in this case the intrinsic rate of increase is simply the birth rate minus the death rate.

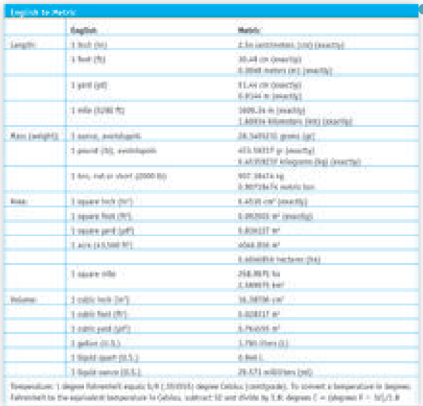
In discussing human populations, the following basic statistics are commonly used:

- *Crude birth rate*: The number of births per year per 1,000 members of a population. The crude birth rate is commonly determined by dividing the total number of births in the given population by the mid-year population size (which gives the number of births per individual per year) and then multiplying by 1,000.
- *Crude death rate*: The number of deaths per year per 1,000 members of a population. The crude death rate is calculated in a manner that is comparable to that of the crude birth rate.
- *Rate of natural increase (essentially r)*: The crude birth rate minus the crude death rate. The rate of natural increase can be expressed in terms of number of additional people per 1,000 members of the population at mid-year. A rate of natural increase of 20 per 1,000 (0.02) means that the population is increasing overall by 20 individuals per 1,000 members of the population each year. A population of 10,000 at the midpoint of one year would grow to a population of 10,200 by the midpoint of the following year. When the rate of natural increase is a negative number, the population is decreasing in size over time, rather than increasing.
- *Percent annual growth (or change) of a population*: The rate of natural increase expressed as a percentage of the given population. For example, if the rate of natural increase is 20 per 1,000 (20/1,000 = 0.02), the percentage annual growth is 2.0%.

Fundamentals boxes: This set of boxes reviews quantitative information covering human population equations and statistics, energy and thermodynamics, and common measures of energy and power.

A **Study Guide** at the end of each chapter includes a bulleted summary, a list of the chapter's key terms, and several kinds of questions. Answers to the odd-numbered questions are available online.

- **Study Questions**: These review questions generally test objective knowledge and require fairly short answers. Some require more analytical and critical-thinking skills.
- **What's the Evidence?** Unique to this book, these innovative questions ask the reader to review the authors' arguments and decide whether the authors have successfully supported their conclusions. The questions then challenge the reader to support their own position if they disagree.
- **Calculations**: Calculation questions, written at a precalculus level or lower, are provided for courses that have a quantitative component.
- **Illustration and Table Review**: These questions are designed to help readers strengthen their data interpretation skills.



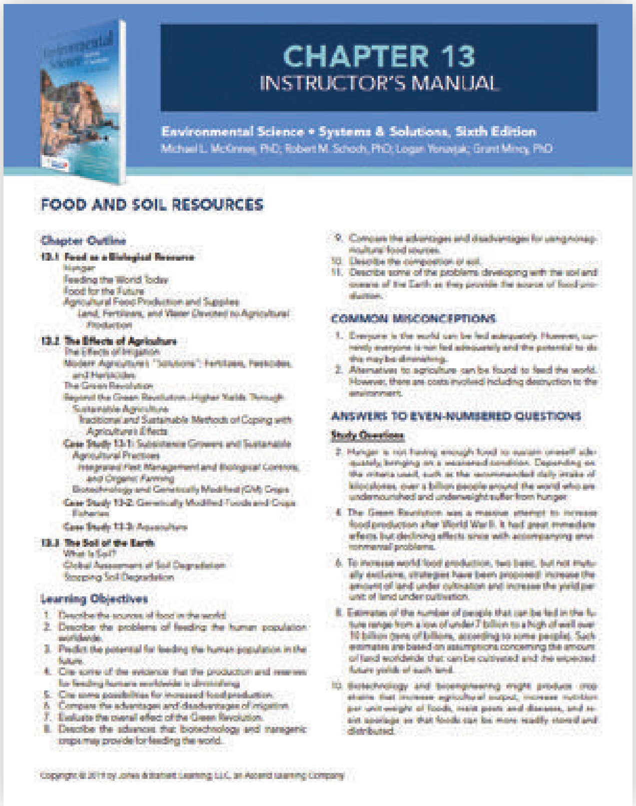
This book includes several special features. On pages iv and v are maps of North America showing the physical geography and political boundaries of all the states and provinces of the United States, Mexico, and Canada. On pages vi and vii are physical and political maps of the world. These maps will serve as handy reference guides for the reader when various states, provinces, and countries are mentioned in the text. It is increasingly important that everyone be familiar with basic global political geography.

Appendix: The book concludes with English/Metric Conversion Tables, a glossary of key terms, and a detailed index.

Teaching Tools

To assist you in teaching this course and supplying your students with the best in teaching aids, Jones & Bartlett Learning, in conjunction with Stacy K. Zell, PhD of Carroll Community College in Westminster, Maryland, has prepared a complete ancillary package available to all adopters of the text. Additional information and review copies of any of the following items are available through your Jones & Bartlett Learning Sales Representative.

The Instructor's Manual includes complete chapter lecture outlines, learning objectives, discussions of common student misconceptions, and answers to the even-numbered study questions in the text.



CHAPTER 13
INSTRUCTOR'S MANUAL

Environmental Science • Systems & Solutions, Sixth Edition

FOOD AND SOIL RESOURCES

Chapter Outline

13.1 Food as a Biological Resource
Hunger
Feeding the World Today
Food for the Future
Agricultural Food Production and Supplies

13.2 The Effects of Agriculture
The Effects of Irrigation
The Green Revolution

13.3 The Soil of the Earth
What Is Soil?
Global Assessment of Soil Degradation
Stopping Soil Degradation

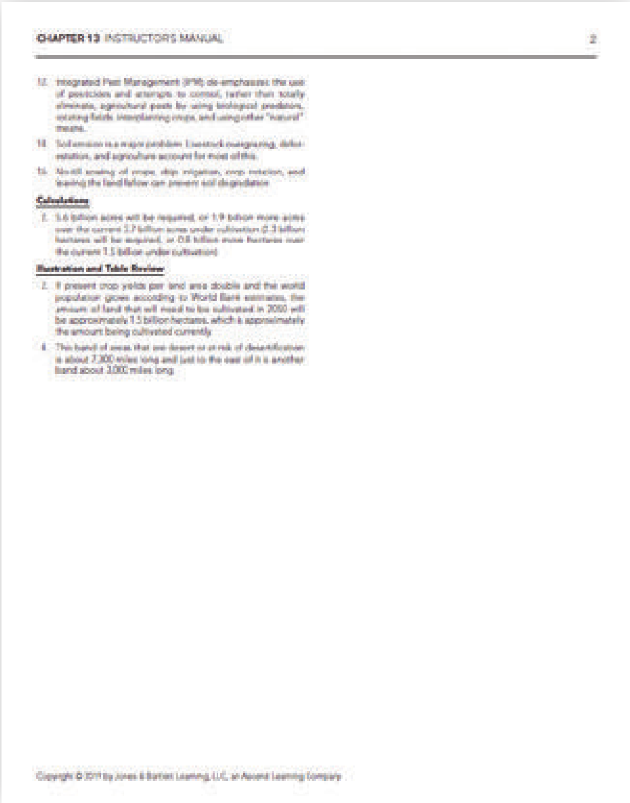
Learning Objectives

1. Describe the sources of food in the world.
2. Describe the problems of feeding the human population worldwide.
3. Predict the potential for feeding the human population in the future.
7. Evaluate the overall effect of the Green Revolution.
10. Describe the composition of soil.

COMMON MISCONCEPTIONS

ANSWERS TO EVEN-NUMBERED QUESTIONS

Study Questions

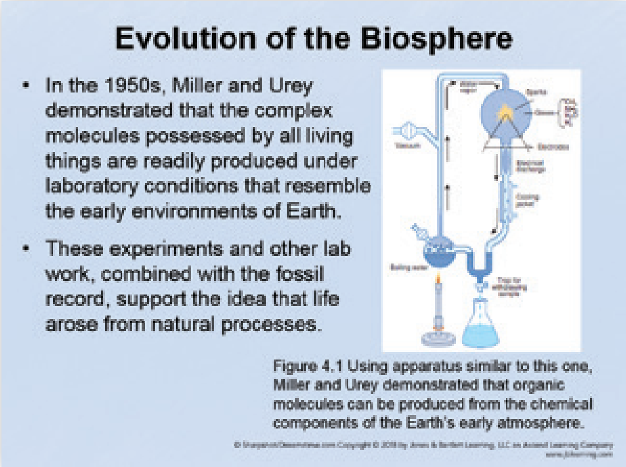


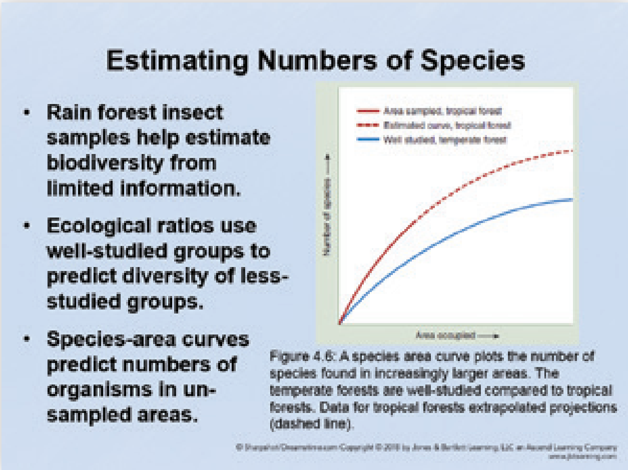
CHAPTER 13 INSTRUCTOR'S MANUAL

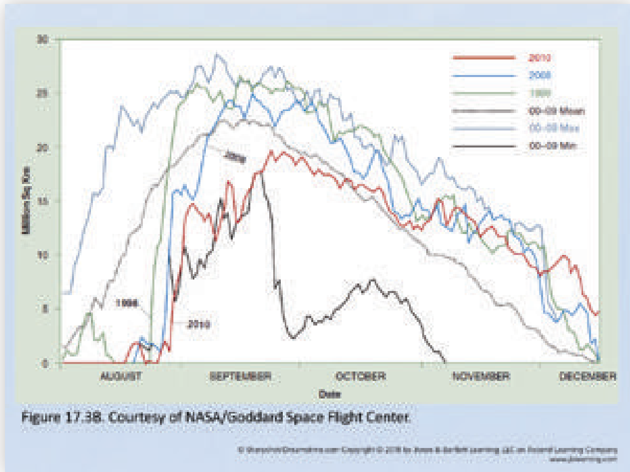
Calculations

Illustration and Table Review

The PowerPoint Lecture Outline presentation package provides lecture notes, graphs, and images for each chapter of *Environmental Science*. Instructors with the Microsoft PowerPoint software can customize the outlines, art, and order of presentation.







The PowerPoint Image Bank provides a library of all of the art, tables, and photographs in the text to which Jones & Bartlett Learning holds the copyright or has permission to reproduce.

The test bank is available as electronic text files. The test bank contains approximately 2,000 multiple-choice, true/false, fill-in-the-blank, matching, short-answer, analogy, and quantitative questions.

Michael L. McKinney
Robert M. Schoch
Logan Yonavjak
Grant A. Mincy

Acknowledgments

As authors, we are ultimately responsible for the content of this book, but dozens of people have provided help, encouragement, and advice. In particular, we are grateful for the advice of many teachers and practitioners of environmental science. Due to its depth and breadth, environmental science contains far more information than only four people can master, and we drew heavily on the expertise of people who have specialized in its many subfields. We therefore wish to express our deep appreciation to the reviewers of various editions of this book. Reviewers whose input was used for this edition are in bold.

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About the Authors

Michael L. McKinney is Director of the Environmental Studies Program at the University of Tennessee, Knoxville. He is also a Professor in the Geological Science Department and the Ecology & Evolutionary Biology Department. Since 1985, he has taught a variety of courses, focusing on environmental science and biodiversity issues at the undergraduate level.

Dr. McKinney has two master's degrees, one from the University of Colorado at Boulder and one from the University of Florida. He received his Ph.D. from Yale University in 1985. Since that time, he has published several books and dozens of technical articles. Most of his recent research has focused on conservation biology. Dr. McKinney has received several teaching awards and a prestigious University award for creative research. He is currently working on a book documenting the harmful impact of urban sprawl on native species.

In addition to his scholarly work, Dr. McKinney is very active in promoting environmental solutions where he lives, the Southern Appalachian bioregion. He is on the Board of Directors of the Foothills Land Conservancy, which is the major private land trust that creates wilderness preserves around the Smoky Mountain National Park. In 2001, Dr. McKinney received the Environmental Achievement award from the city's main newspaper, the *Knoxville News-Sentinel,* given to the individual who has done the most to promote a better environment. Dr. McKinney is also an active member of the Tennessee Citizens for Wilderness Planning, the East Tennessee Sierra Club (Harvey Broome Chapter), the Southern Alliance for Clean Energy, the Tennessee Clean Water Network, and Ijams Nature Center. He writes a bimonthly column called the "Suburban Ecologist" in the *Hellbender,* the environmental newspaper of East Tennessee.

Dr. McKinney lives in Knoxville, Tennessee, where he greatly enjoys hiking and promoting sustainable living.

Robert M. Schoch, a full-time faculty member of the College of General Studies at Boston University, received his Ph.D. in geology and geophysics from Yale University in 1983. Since 1984, he has specialized in teaching undergraduate science, including environmental science, biology, physical science, geology, geography, and courses in science and public policy—with a strong environmental component in all courses he teaches. He is a recipient of his college's Peyton Richter Award for interdisciplinary teaching, and serves as director of its Institute for the Study of the Origins of Civilization.

Dr. Schoch is the author or coauthor of books both technical and popular, including *Phylogeny Reconstruction in Paleontology; Stratigraphy: Principles and Methods; Horns, Tusks, and Flippers: The Evolution of Hoofed Mammals; Voices of the Rocks; Voyages of the Pyramid Builders; Forgotten Civilization: The Role of Solar Outbursts in Our Past and Future;* and *Origins of the Sphinx.* Keenly interested in how environmental factors have helped shape ancient and modern civilizations, and passionate in his assertion that understanding past environmental changes is important as we face future challenges, Dr. Schoch has undertaken fieldwork in numerous countries, including England, Wales, Scotland, Norway, Malta, Egypt, Turkey, South Africa, Mexico, Peru, Bolivia, Chile (Easter Island), Romania, Bulgaria, Bosnia, India, Japan, and Indonesia.

Besides his academic and scholarly studies, Dr. Schoch is an active environmental advocate who stresses a pragmatic, hands-on approach. In this connection, he helped found a local community land trust devoted to protecting land from harmful development, for many years serving on its Board of Directors. Furthermore, he takes an active part in "green" politics and for over a decade served as an elected member of the city council of Attleboro, Massachusetts.

Logan Yonavjak is an investment professional who has worked with a variety of organizations on a suite of projects ranging from ESG product development, the development of social and environmental impact metrics methodologies, and a variety of renewable energy and conservation finance deals. She is currently the Manager of Research and Analysis at CREO Syndicate, a network of family offices focused on driving more private capital to solve global environmental challenges. More recently she worked at Morgan Stanley's Institute for Sustainable Investing, Align Impact, and the Yale Investments Office. Logan received her B.A. with Distinction from the University of North Carolina at Chapel Hill. Logan is a Startingbloc Fellow, a Property and Environment Research (PERC) Fellow, and a Kinship Fellow. She has also been a freelance writer for Ashoka Changemakers, *Forbes*, ImpactAlpha, and NextBillion, and is also the author of several books. Logan received her master's in Forestry and MBA (with a concentration in Asset Management) from Yale in 2016. Logan currently sits on the Board of Slow Money NYC, which connects investors with local food entrepreneurs in New York City. She is also an Advisor to the Yale Initiative on Sustainable Investing (YISF).

Grant A. Mincy is an Instructor of Biology at Pellissippi State Community College in Knoxville, Tennessee, where he leads the Concepts of Biology curriculum and teaches courses in general biology and conservation science. He has also taught physical geology, historical geology, and environmental geology. In the classroom, Grant includes information regarding issues of concern in his town of Knoxville and the Southern Appalachian bioregion. He also likes to discuss local environmental policy and new sustainable initiatives having great success in the area as well.

Grant earned his graduate degree from the University of Tennessee, Knoxville where he studied earth and planetary science with a concentration in conservation biology and environmental science. During his time at the University of Tennessee, Grant was Dr. McKinney's student and worked on many local and regional environmental research projects with his mentor. Grant is still very active in environmental issues. He serves as the Elinor Ostrom Chair of Environmental Studies and Commons Governance at the Molinari Institute and is also an Energy and Environment Advisory Council Member for the Our America Initiative. He has numerous publications on sites such as The Ecologist, Counter Punch, and Resiliency and has published columns regarding environmental issues in numerous newspapers around the world, including the local *Knoxville News Sentinel* and the *Knoxville Mercury*. In addition, Grant regularly volunteers his time to Ijams Nature Center and encourages service learning in all of his courses.

Grant's most important role is that of a husband and a father. In his free time he likes to pass the time hiking away the day with his wife and 3-year-old son in the Great Smoky Mountains National Park.

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SECTION 1

The Environment and People

INTRODUCTION: A GUIDE TO THE ENVIRONMENT

CHAPTER 1. Environmental Science: An Overview

CHAPTER 2. Human Population Growth

We stand now where two roads diverge. But . . . they are not equally fair. The road we have long been traveling is deceptively easy, a smooth superhighway on which we progress with great speed, but at its end lies disaster. The other fork of the road—the one less traveled by—offers our last, our only chance to reach a destination that assures the preservation of the earth.

—**Rachel Carson** (1907–1964), environmentalist and author, *Silent Spring*[1]*

Introduction: A Guide to the Environment

This text provides an overview of the natural environment and the ways people are increasingly affecting it. Through an understanding of environmental science, you will be in a position to make sound decisions that will affect the future of the planet. An important aspect of genuine understanding is the ability to relate seemingly diverse and disparate facts and phenomena to one another within a larger picture. A truism in environmental science is that everything is related to everything else. The environment is a finely tuned, grand, and extremely complex system; if one component is modified or tampered with, there will be ramifications in other, often unexpected, portions of the system. Therefore, it is particularly beneficial to use a *systems approach* in analyzing global environmental issues. Note that a *system* can be defined as a "set of components functioning together as a whole." A systems view allows us to isolate a part of the world and focus on those aspects that

* Excerpt from "The Other Road" from *Silent Spring* by Rachel Carson. Copyright © 1962 by Rachel L. Carson, renewed 1990 by Roger Christie. Reprinted by permission with Houghton Mifflin Harcourt Publishing Company, Frances Collin, Trustee. All rights reserved.

interact more closely than others. For example, a cell, in the system we call a human body, generally interacts much more closely with other cells in the body than with the outside world. By focusing only on the cells that function in digestion, we confine our view further to the digestive system. The key point here is that most systems are hierarchical: they are composed of smaller sets of systems made of smaller interacting parts.

The chapters in this text are subdivided into five major sections. These sections reflect the input–output, or *throughput*, processes that can be used to describe the global environment; how the environmental system is modified; and solutions to environmental problems (such as the depletion of resources or pollution of nature) brought on by anthropogenic activities.

- *Section 1: The Environment and People.* The natural environment and the people living on planet Earth form a complex, integrated system, as introduced here. The overview of environmental science and discussion of human population growth describe the explosive growth of the human population, the development of modern technological and industrial society, and some of the ramifications that these have had for the natural environment. Many environmental scientists consider human population growth, or more precisely, the impact of increased consumption of natural resources, to be the single most important issue that the world currently faces. With this text, you will learn that the raw elements of the natural environment pass through human society to produce the global environment in which we currently live. For all practical purposes, no pristine wilderness remains anywhere on Earth.

Even parts of remote Arctic, shown here, have become dumping grounds for human waste.

- *Section 2: The Environment of Life on Planet Earth.* Earth and life form an interconnected system based on energy flow and matter cycles. Study of these natural systems includes the disciplines of biology, chemistry, geology, climatology, and many other natural sciences. Learning the basic principles of these fields permits a better understanding of natural systems and how they can be used, protected, or disturbed. People use, modify, and are dependent on these natural systems.
- *Section 3: Resource Use and Management.* Simply by using resources we run the risk of overusing and depleting them. Depletion of environmental resources is one of the two basic types of environmental disturbances. It includes depletion of water, minerals (including fossil fuels), soils, wildlife and wildlife habitat, and many other resources. To avoid depletion problems, we must learn to manage our resources in a more sustainable manner.
- *Section 4: Dealing with Environmental Degradation.* Discharging waste into the environment is the other basic type of environmental disturbance. It includes pollution of air, water, land, and biological communities, but there are ways to use resources productively without the levels of pollution and concomitant environmental damage that have been so widespread in the past.
- *Section 5: Social Solutions to Environmental Concerns.* Technological solutions are insufficient unless society is willing to use them. Social solutions are interwoven throughout this text, but these final chapters allow us to focus on specific social institutions and their legal and economic aspects. Ultimately, through a combination of scientific analysis, technological advances, and the continuing development of social institutions, humanity must lessen its detrimental impact on the environment if we are to avoid living on an impoverished planet in a very bleak postindustrial age.

The global environment of the future (represented in Section 5) will not be the preindustrial environment of the past (represented in Section 2) because we (Section 1) have a tremendous impact on the environment (Sections 1, 3, and 4). Our actions today will have a profound effect on the environment of the future. By our deeds we will determine whether the environment of future generations will be more or less hospitable to us and numerous other species.

CHAPTER 1

Environmental Science: An Overview

CHAPTER OBJECTIVES

After reading this chapter, you should be able to do the following:

- Describe what is meant by *environmental science*.
- Understand how the environment works as a system.
- Describe the key traits of the environmental system.
- Discuss the concepts and consequences of consumption and exponential growth.
- Relate the concept of sustainability to individual actions.
- Understand and defend the concept of a commons.
- Outline a brief history of environmental movements.
- Analyze throughput.
- Discuss true costs and explain why people avoid them.

Chapter Opener Image: Much of the world's land area has been disturbed by humans. Historically, profit-driven environmental decisions, enclosure movements, and unintentional consequences, such as industrial waste seepage into waterways, have left a negative impact on local biodiversity and the sustainability of related ecosystem services. In recent years, the increase in protected areas and community involvement aided by social media, as well as the current trend toward more sustainable business practices, have begun to reverse damage to the environment in some areas. Still, the loss of agricultural land to increased desertification, the mismanagement of critical resources such as water, resource extraction, and the persistent political unrest in many of the world's most critical areas present an ongoing call to action for global citizens committed to the process of preserving and protecting the array of ecosystem services that support life on Earth.

The critical importance of environmental science and environmental studies cannot be disputed. Virtually everyone is aware of environmental issues—climate change, the depletion of the ozone layer, the controversy over nuclear power, the global extinction crisis, the loss of endemic species and biodiversity, water shortages and increased drought, the introduction of hormone-altering pollutants into the natural environment, the use of and controversy surrounding genetically engineered crops, or the continuing problem of solid-waste disposal. No citizen of the Earth can afford to be ignorant of environmental issues.

Our planet has existed for 4.6 billion years, yet never before has one species dominated the Earth and other species so completely. Humanity now stands at a unique crossroads: because of human technological capabilities and impacts, the next few decades will witness drastic changes to the Earth and its inhabitants. It is our individual responsibility to try to influence the outcome of such changes, to leave the world better than we found it, so that the welfare of our posterity and the environment is best served.

Although this text presents many important facts, it also has three larger goals. The first is to help you sort through the huge amount of environmental information available and to focus on important "core" issues. Today, especially with the widespread availability of the Internet and the World Wide Web, little bits of information on almost any environmental issue are readily available; nevertheless, even as we become overwhelmed with factoids, the bigger picture, a larger perspective, often is lost. It can be difficult to distinguish the truly important from the merely interesting, or even the downright trivial. As the old saying indicates, it can be hard to see the forest because all of the trees block the view.

Seeing the big picture will help you to understand the differing points of view of individuals or groups who have economic, political, or even personal stakes in the possible solutions. Environmental issues are complex. With every solution comes a different set of potential advantages and disadvantages. The second goal of this text then is to help you understand the problems; evaluate the solutions, keeping all the stakeholders in mind; and then to make up your own mind.

The third goal of this text is to get you, the reader, seriously thinking about how you can put an understanding of environmental issues to work to effectively help your household, community, or nation make the fundamental changes needed to build a world that can sustain many generations of people with a decent standard of living while minimizing the human impact on the natural environment. We encourage you to become actively involved in environmental concerns.

1.1 Environmental Science Defined

Environmental science is the study of the relationships in the natural world that occur between organisms and their environment. It involves all fields of natural science as they bear on the physical and biological environment. Aspects of biology, geology, chemistry, physics, meteorology, and many other disciplines must be considered when studying environmental science. A major component of modern environmental science involves addressing current environmental problems brought about directly by human activity. Therefore, in addition to presenting the scientific concepts underlying environmental issues, environmental science also examines social aspects of environmental problems. This includes technology and scientific understanding as well as laws, ethics, economics, and other aspects of human behavior that will play a key role in solving our current environmental dilemmas.

The Scientific Method

Environmental science is a natural science and thus operates under the rules of the **scientific method**. We hear an awful lot about *the* scientific method. Truth be told, however, scientists use an array of methods to collect data and explore the processes of the natural world. These methods have developed via trial and error over centuries of inquiry. The framework of such methods do follow a certain rubric, though, that has been polished over time, as shown in **FIGURE 1.1**. In general, the scientific method requires observations and the collection of evidence that is visible and can be tested:

Step 1: Observe and gather data. Scientists first investigate a question in order to better understand a concept or phenomenon. To do this, natural scientists pursue their interests and collect dependable data, usually in the form of **quantitative research**, by making observations and measurements.

Step 2: Formulate a hypothesis. Scientists attempt to explain their observations and understand their data by developing a **hypothesis**, a plausible but yet to be proved explanation for how something occurs. This facilitates the development of new ideas and models that have the potential to help us understand how the planet really operates.

Step 3: Test the hypothesis. The developed hypothesis, or hypotheses if there are more than one, is used to make predictions and develop tests. Tests vary in form or function; some take the

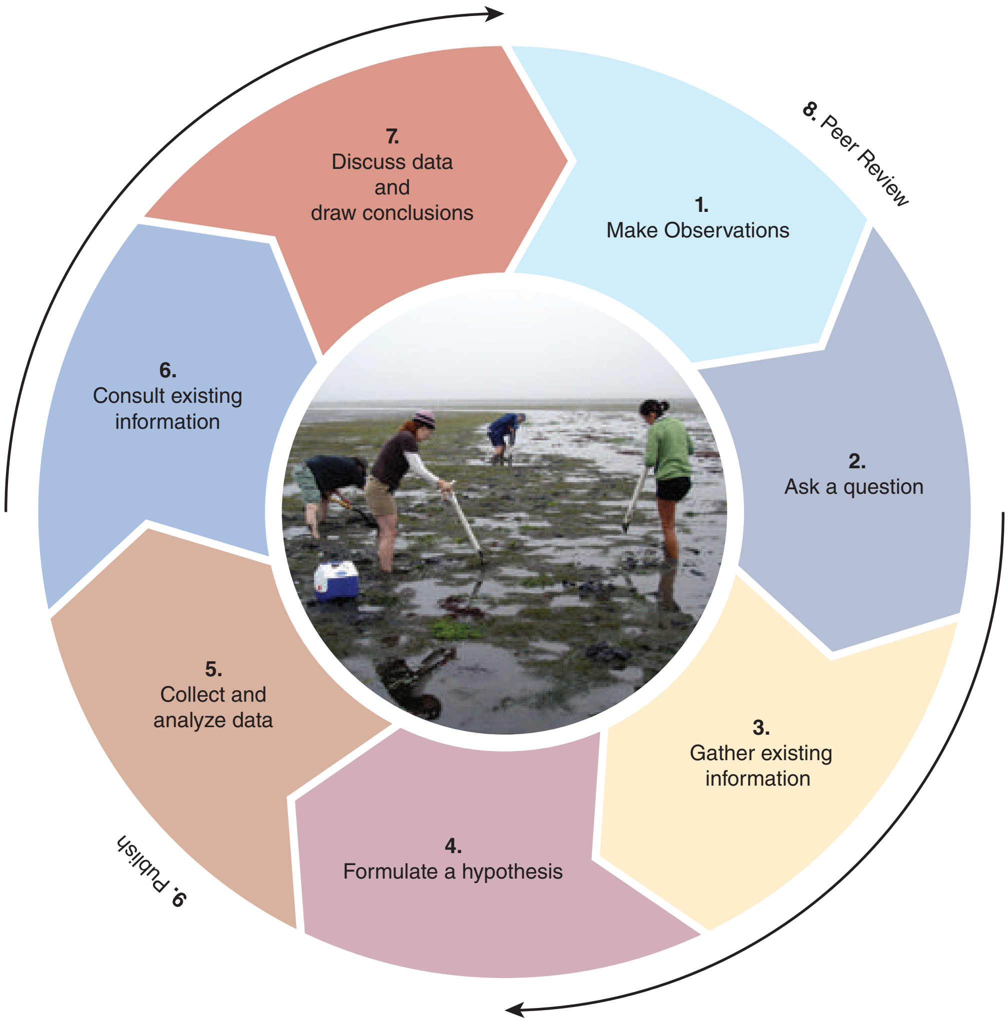


FIGURE 1.1 The scientific method includes making observations, formulating a hypothesis, gathering and interpreting data, and nullifying or upholding the hypothesis.

Photo: Courtesy of Tim Carruthers / IAN Image Library (ian.umces.edu/imagelibrary/).

form of controlled experiments in the confines of a laboratory, others involve data collection and experimental procedures performed at a field locality. Sometimes, mathematical models are developed depending on the nature of the questions being asked. The goal is not to prove the hypothesis, but rather to disprove, or *nullify*, the hypothesis.

Step 4: Develop a theory. If, after numerous tests, scientists fail to nullify a hypothesis, the scientific community becomes more confident in its validity. When this happens, the hypothesis can earn the status of a *theory*. A theory is taken very seriously in the scientific world. In our everyday lives, when we say "I have a theory," what we really mean is "I have a (very often untested) hypothesis." This is not to say that theories cannot be overturned or are excluded from further testing, but theories are supported by substantial evidence. Some theories, such as the one explaining gravity, never display deviations and can earn the title of a scientific **law**, **principle**, or **paradigm**.

Avoiding "Information Overload"

One of the challenges we face today is how to cope with information overload. Newspapers, radio, television, and the Internet along with social media bombard us daily with data and statistics. Feeling overwhelmed, most people react by "tuning out."

Rather than quit trying to assimilate all this information, we might recall Henry David Thoreau's advice to "Simplify! Simplify!" Thoreau has become a hero to many nature lovers because he long ago predicted many of the problems that we now face. His advice to simplify was a response to what he saw as a tendency for civilization to become increasingly more complex and removed from the natural world. This, he said, led to anxieties and spiritual impoverishment despite material wealth. On a pragmatic level, it also has led to a weakened and damaged natural environment.

We can heed Thoreau's advice by mentally stepping back and keeping our priorities set on what we think is important. The **systems approach** to environmental science greatly heeds the process. In this way, we can focus on the information that we can use, instead of trying to learn it all (which no one can do). Ideally, we can strive to achieve what might be called **environmental wisdom**. Wisdom is the ability to sort through facts and information to make reasonable decisions and plan sensible long-term strategies. Wisdom is gained through education and practical experience, so environmental wisdom takes time to develop. Wisdom also means that we take a broad view in solving problems and weigh all kinds of information, social and economic, as well as scientific and technical. Environmental science is often referred to as being **holistic**, meaning that it seeks connections among all aspects of a problem.

A lack of environmental wisdom is costly in many ways. It is costly to other species, to our quality of life, to future generations, and often to human happiness itself; however, currently the most easily measured costs are economic. A good example is illustrated in **FIGURE 1.2**, which shows that money spent on environmental problems does not always correlate directly to the actual magnitude of the problem. For instance, problems related to land preservation and restoration receive more money than those associated with global change (such as fixing the hole in the

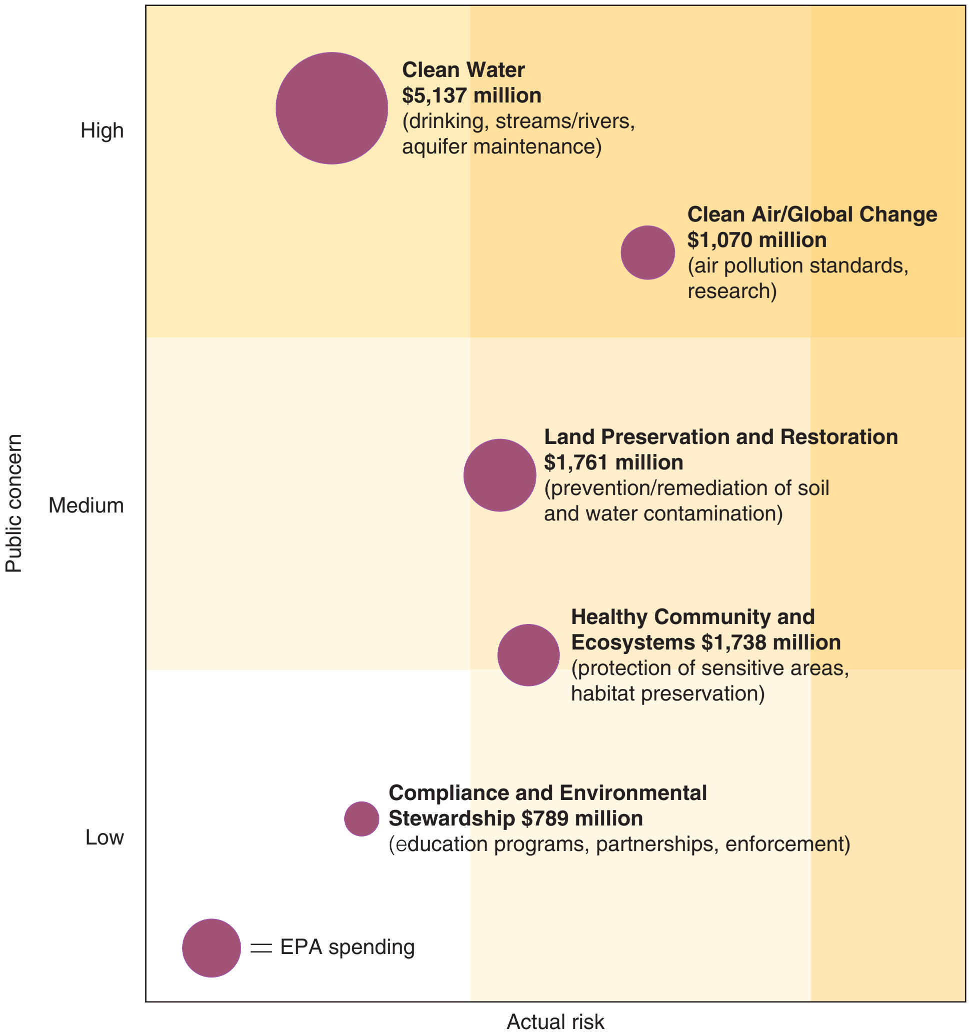


FIGURE 1.2 The actual risk of a hazard compared to the amount of public concern about the risk. A direct correlation does not always exist between the actual magnitude of a problem or its associated risks and the amount of money spent to mitigate the problem. As a result, large amounts of money (size of dot) are spent on issues with less direct risks, such as soil remediation projects, while at the same time problems such as air pollution and global climate change with more immediate consequences receive less money.

Data from U.S. Environmental Protection Agency and Worldwater.org.

ozone layer or addressing clean air issues related to the increased incidence of asthma in children living in urban areas). Such spending inefficiencies occur because people often lack adequate information about the true risk of environmental problems.

Building a Sustainable World

Many concerned conservationists point out that past efforts have tended to focus on short-term emergency actions rather than long-term solutions. Examples of this approach include cleanup of wastes and pollution after they are produced (**FIGURE 1.3**) and trying to save species only when they are nearly extinct. Besides being less effective, such piecemeal, late-acting remedial solutions are almost always the most expensive way to solve environmental problems.

FIGURE 1.3 Cleaning up toxic waste is an expensive after-the-fact approach. It is much cheaper to design methods that produce less waste.

Courtesy of Enivronmental Protection Agency.

In the last decade, the rising costs and inefficiencies of cleaning up pollution after it is produced have led to a search for better approaches to solving environmental problems. Generally, holistic approaches have been able to solve problems more cheaply and efficiently. By examining society and the environment as an interconnected system, we often can solve many problems at once. The **input** of materials and energy through society is commonly called **throughput**. Environmental resources (or inputs) are referred to as **sources** of throughput. Environmental reservoirs that receive throughput are called **sinks** and are the ultimate repository of societal **output**, which could become input and throughput again, as in recycled materials. As illustrated in **FIGURE 1.4**, environmental problems arise from (1) resource depletion and (2) pollution. Past efforts at pollution control were largely "end-of-pipe" solutions, cleaning up waste after it was produced. Reducing the flow of material through society can also control pollution. Such **input reduction**, which conserves resources and reduces pollution at the same time, is now widely accepted by environmental economists and others as a better solution to most environmental problems. Input reduction illustrates the kind of fundamental change needed to build a society that can be maintained for many years without degrading the environment. The works of chemist Michael Braungart and architect and designer William McDonough illustrate this last point. Together, they have put to use nature's practice that nothing goes to waste and that, in the end, waste equals food. Through their Cradle to Cradle certification process, factories and other businesses worldwide are proving that industrial design that promotes sustainability through reduced negative impact on the environment can occur through creative problem-solving and ingenuity, and that these solutions

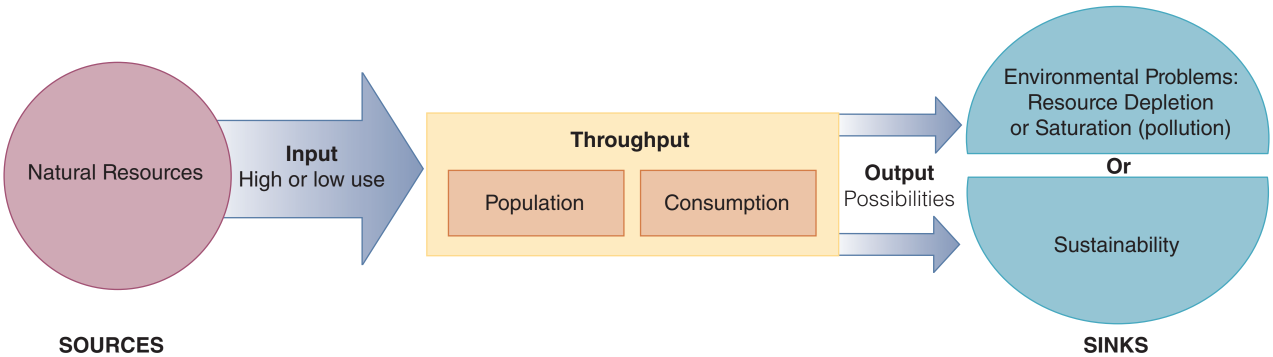


FIGURE 1.4 People use resources from the natural environment and deposit wastes back into it. Materials and energy that people draw from are known as *sources*; environmental reservoirs that receive the products of human society are known as *sinks*. Environmental problems can arise from resource depletion and pollution of sinks. Controlling consumption and reducing the flow of material through society can alleviate many environmental problems.

are profitable for the companies and societies that commit to them.

Figure 1.4 also identifies the two basic causes of most current environmental problems: human population pressures and consumption of material goods. Increases in population and consumption have led to increased resource depletion and pollution. Both need to be addressed if long-term solutions are to be achieved.

1.2 The Environment as a System: An Overview

The entire environment of planet Earth can be divided into four spheres: the **biosphere** (living organisms of Earth), the **atmosphere** (the gaseous envelope surrounding the planet), the **hydrosphere** (the liquid water on the surface of Earth), and the **lithosphere** (the stony or rocky matter composing the bulk of the surface of Earth). Matter cycles and energy flows through these spheres (**FIGURE 1.5**). A systems approach provides a convenient overview and manner of understanding how our environment works.

What Is a System?

A **system** can be defined as "a set of components functioning together as a whole." A systems view allows us to isolate a part of the world and focus on those aspects that interact more closely than others. A system is a concept that allows us to control the limits of our experiments. The systems we choose to explore can be as simple as a single prokaryotic cell or as complex as an entire marine ecosystem. For example, consider a forest in autumn. Fall detritus is a system, which comes from a tree (a larger system), which is part of a forest (and even larger system), and so on. The key point here is that most systems are composed of smaller sets of systems made of smaller interacting parts.

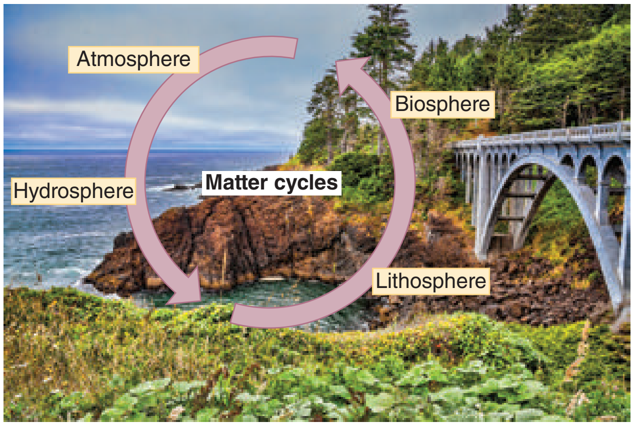


FIGURE 1.5 The Earth is open to energy, which flows into and out of it. However, the Earth is essentially closed to matter, which cycles over and over through the four spheres.

Photo courtesy of David Charles Morgan photography.

Three Key Traits of the Environmental System

We can analyze the global environment in terms of three system traits: openness, integration, and complexity. **Openness** refers to whether a system is isolated from other systems. An **open system** is not isolated in that it exchanges matter and/or energy with other systems. A **closed system** is isolated and exchanges nothing with other systems.

The law of **entropy** means that energy cannot be fully recycled; rather, "high-quality" energy is degraded to "lower-quality" energy (such as waste heat). Therefore, any system that does not have a renewing supply of energy from outside will eventually cease to exist. Not surprisingly, the Earth is an open system in terms of energy. Figure 1.5 shows how energy flows from the sun and is often radiated back into space. In contrast, the Earth, for all practical purposes, is a closed system in terms of matter. If we discount the relatively small amount of matter added from meteorites and other space debris, the Earth contains all of the matter it will ever have. Driven by energy from the sun, this matter cycles over and over among the various parts of the Earth system, often moving back and forth among the gaseous, liquid, and solid states and participating in the metabolism of living things.

As stated earlier, the Earth system can be divided into four spheres: the lithosphere, the biosphere, the atmosphere, and the hydrosphere. The systems are hierarchical in their own right and can be further subdivided. For example, the lithosphere can be divided into continental or oceanic crust, then the **pedosphere** (the outermost layer of Earth's crust consisting of soil), the **asthenosphere** (the layer of the Earth that lies directly underneath the lithosphere), and so on. These spheres are all interconnected and are constantly exchanging materials.

Integration refers to the strength of the interactions among the parts of the system. For instance, the human body is a highly integrated system whose cells are interdependent and in close communication. The loss of certain cells, such as those composing the heart or brain, can result in the death of all of the other cells in the system (the whole organism) because the cells are so interdependent. At the other extreme are systems with very weak integration, such as the cells in a colony of single-celled organisms (such as the green algae *Volvox*). Removal of many cells (to a point) will have little effect on the remaining cells because they are less dependent on one another.

Complexity is often defined as how many *kinds* of parts a system has. This definition conforms to our intuition: a tiny insect seems more complex to us than a large rock because it has many more types of "parts." The insect has more complex molecules as well as more different types of molecules, and these are used to construct cells and organs. This example also illustrates that complexity is often hierarchical, with smaller components being used to construct larger ones.

As you would expect, the environment is enormously complex. The four spheres, with their matter cycles and energy flows, have trillions and trillions of different components operating at many spatial and temporal scales. Organisms, soils, rainwater, air, and many other components interact in complicated ways. The individual spheres themselves are equally complex. Even with advanced computers, no one has been able to predict accurately and precisely the weather, or even climate, very far into the future because the atmosphere is so complex. Indeed, the many interactions make unpredictability a basic characteristic of complex systems (**CASE STUDY 1.1**). This inability to predict how the environment will respond to changing conditions (which is why it is so dangerous to tamper) is perhaps the major reason for so much of the controversy about and inaction with regard to environmental problems.

Major Obstacles: Delayed and Unpredictable Impacts

Social responses to environmental problems are greatly hindered by two of the key traits of the environmental system: its moderate integration and high complexity. Any system that is integrated, such as the environment, can transmit disturbances from one

CASE STUDY 1.1 SYSTEMS AND CHAOS THEORIES: WAYS TO STUDY COMPLEXITY

Studying complex systems can be difficult because they have many parts that often interact in different ways. Over the past few decades, researchers have developed several methods of studying complexity. For example, systems theory and chaos theory try to produce general "laws" of complexity. Such laws would not only make complex systems more understandable, but they also would allow us to predict more accurately how these systems will behave. Think of how important such predictions could be for a complex system such as the stock market or for weather and climate forecasting!

None of these theories have been entirely successful in providing a complete understanding of complexity or producing accurate predictions of how any particular complex system will behave. Nevertheless, they have provided a better idea of how complex systems will generally behave under a given set of conditions. Consequently, we have a general understanding of how a lake ecosystem will respond to excess nutrients even though we cannot specify every event.

Systems theory (or *general systems theory*) was one of the first widely used attempts to find "laws" of complex systems. It traditionally has focused on how systems are regulated and become unregulated. Systems theory treats a complex system as a "black box" with inputs and outputs. Such a system is kept at equilibrium by negative feedback processes, which are processes that counteract perturbations. An example is a thermostat that turns a furnace on to produce heat when a house is cold and turns on air conditioning when it is hot. In contrast, positive feedback processes amplify perturbations. For example, a cooling global climate can cause more snow to remain on the ground, which leads to more global cooling because the snow reflects sunlight back into space. This, in turn, causes yet more snow, and so on (a snowball effect).

Systems theory often has been criticized as too general or vague, because by treating a system as a black box the theory omits many of the details of how the system operates. More recent efforts to study complex systems have focused on more mathematical, rigorous descriptions of them. One theory that has received much attention is *chaos theory*. A chaotic system is one in which the workings are sensitive to even the slightest change: a slight perturbation can become greatly amplified through positive feedback. The classic example is the weather, as E. Lorenz, who helped establish chaos theory in the early 1960s, first described. Lorenz created a set of equations that precisely described atmospheric conditions and showed how even tiny changes in one of the parameters could cause a massive alteration of the weather in a few days. This is often called the *butterfly effect*, with the idea

(continues)

CASE STUDY 1.1 (continued)

that the flapping of a butterfly's wings in South America could eventually affect the weather in North America (**FIGURE 1**). By creating tiny changes in atmospheric turbulence, which, in turn, create cascading effects on larger airflows, the butterfly's wing flapping could have a major impact. (Of course, the chances that it actually will produce such a major impact are extremely low.)

Chaos theory's most important finding so far is that even simple systems, such as several atoms, often have chaotic properties. How can we make predictions when a minute unseen change, as in the butterfly effect, can have cascading effects? Many theorists think it will always be impossible to predict accurately precise future behaviors in complex systems, which have even more potential for chaos than do simple systems. Nevertheless, by applying chaos theory, patterns of regularity can be discerned and studied.

FIGURE 1 Can a butterfly in the rain forest affect the weather in North America?

Critical Thinking

1. If you were to survey your household trash, what do you think would comprise the most waste—food, plastic, Styrofoam, paper, or another substance? What is the environmental footprint of such waste?
2. Thinking of this environmental footprint, how many Earth systems are resourced to provide for your lifestyle? Thinking of global society, is it feasible to say that our individual actions can have cascading effects across the Earth system?

part of the system to another. Integration results from connectedness so that resource depletion or pollution of one part of the environment can have cascading, or domino, effects into other parts. For example, burning sulfur-rich coal affects the atmosphere as air pollution, but it also affects the hydrosphere when it falls as acid rain to acidify lakes. The biosphere is also affected because aquatic organisms in the lake can die due to the increased acidity of the lake water. The burning coal can even affect the lithosphere when the acid rain dissolves limestone and other alkaline rocks to form caves and sinkholes. This example shows how just one activity, burning coal, can affect all four spheres of the environment. Such wide-ranging cascading effects are anything but rare. This connectedness of the environment means that virtually any action has a number of consequences, many of which are unforeseen and unintended. Such cascades are so important that the biologist Garrett Hardin formulated the **first law of ecology**: "We can never do merely one thing." This is often called the *law of unintended consequences*.

That the environment is only moderately integrated ("loosely connected") greatly hinders our ability to observe, predict, and ultimately correct the unintended consequences of our actions. The indirect connections and interactions in the environment create delays, or long lag times, before cascading effects become visible (**FIGURE 1.6**). Returning to the acid rain example, it may take many years of burning coal

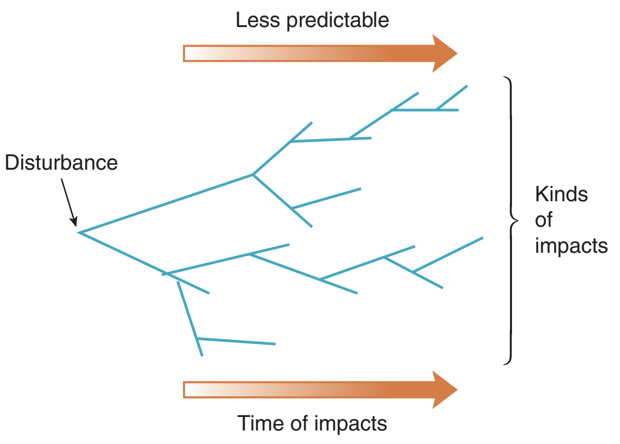


FIGURE 1.6 "We can never do merely one thing." Whenever we do something, we cause a cascade of impacts. These impacts become less predictable with time.

before the trees on mountaintops or fish populations in lakes are affected. In other cases, the impacts can be delayed for centuries, millennia, or even longer. Environmental impacts on a global scale usually take an especially long time to occur.

As we have seen, the complexity of the environment leads to unpredictability, which hinders social responses to environmental problems. As Figure 1.6 illustrates, the unintended cascades we cause not only take a long time, but also occur as unexpected, complicated chains of events. Take the example of climate change and disease. Strong evidence has shown for many years that certain communicable diseases are spreading because of changing climate. In 2006, an article in the peer-reviewed journal *Transactions of the Royal Society of Tropical Medicine and Hygiene* noted that Ebola (a violent hemorrhagic fever that leads to internal and external bleeding) will become more frequent as climate change progresses. Less than a decade after this report, West Africa saw a devastating Ebola outbreak in 2014, followed by successive outbreaks in 2016, and an ongoing Ebola crisis in the Congo in 2017. Human activities that exacerbate global change, such as deforestation, and declines in biodiversity, such as those resulting from increased hunting of bush meat (i.e., meat from nondomesticated animals residing in forests), will bring wildlife and human populations closer together. The virus is found in the wild, and as habitat is destroyed and animal populations are increasingly hunted, humans will be at an increased chance of contamination. The scientists argued that global warming creates a ripe environment for Ebola and other infectious diseases (**FIGURE 1.7**). Many other studies also have linked climate change with the spread of diseases.

FIGURE 1.7 A medical worker is decontaminated in West Africa. The Ebola outbreak started in 2014 and spread to several countries, including the United States.
Courtesy of Daniel "Dan" Martin/CDC.

In a 2016 article, the *New York Times* reported that the World Health Organization (WHO) stated that the spread of Zika and dengue fever across South America and Latin America was affecting more than a 100 million people a year. Zika has been linked to severe birth defects; dengue fever causes severe flu-like symptoms and can result in death. Both viruses are transmitted by mosquitos. As climate change continues, higher average temperatures and increased rainfall may expand the territory of the mosquitos that carry these diseases. In 2015 and 2016, cases of Zika and dengue fever were reported in the southern United States, which has been historically out of range for the mosquitoes that carry these viruses.

Along with food safety, water scarcity, and the impact of extreme weather on communication and transportation systems, U.S. intelligence officials list the spread of disease as one of their top four climate change–related security concerns.

In addition to the large number of interactions involved, complex systems also are unpredictable because some of the interactions exhibit positive feedback. As noted earlier, **positive feedback** occurs when part of a system responds to change in a way that magnifies the initial change. For example, evidence indicates that a slight increase in average global temperature can cause a further increase in the melting of glaciers and snow that reflect sunlight back into space. Instead of reflecting light, more of the Earth's surface becomes available to absorb heat. Another example is poverty in developing countries that results from overpopulation; poverty leads to high reproductive rates, and thus still more overpopulation. In nontechnical terms, positive feedback is often referred to as a "snowball effect" or "vicious circle."

Society in the Environmental System

FIGURE 1.8 illustrates how modern society is embedded within the environment, being dependent on it for the materials and energy needed to maintain civilization. It also shows how industrialized society accelerates the cycling of matter and the flow of energy through itself and the four spheres.

The equation $I = f(P, A, T)$, where I represents human impact as a function of P, population; A, affluence; and T, technology, further demonstrates how society accelerates matter cycling. As we continue our advance into the 21st century, the human population, especially in developing countries, continues to grow at a fast rate. This spike in population, coupled with affluence, consumption, and technological advancement in the developed world, fuels our impacts on the environment. These variables are just a function of our

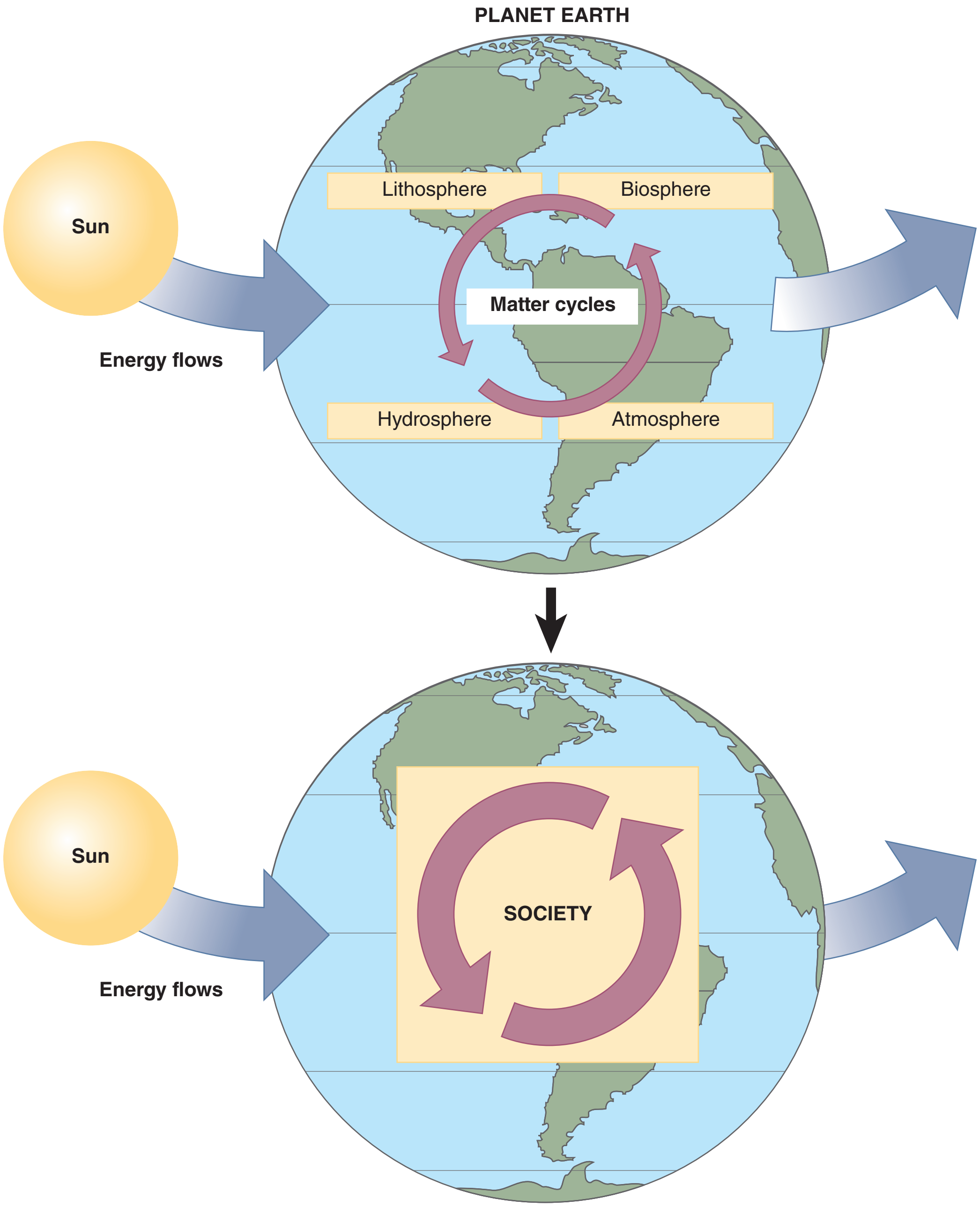


FIGURE 1.8 Society accelerates the cycling of matter through the four spheres, which depletes resources (matter inputs to society) and causes pollution (matter outputs by society). This acceleration is increasing because of increasing population (*P*) and consumption (*C*). Slowing population growth and reducing personal consumption will reduce this acceleration.

impact on the environment, however, and each can help alleviate detrimental effects to the Earth system. Technological improvements in the developed world, for example, have reduced the number of large industrial disasters in the United States.

Fundamentally, all environmental problems involve either depletion of sources (*consumption*) or pollution of sinks (*production of waste*). Because our planet is a closed system, there is no other place for this waste to go—there is no "away" for us to throw it to. Therefore, these two processes can help us measure the net environmental impact of society. Depletion occurs when the accelerated cycling and flow remove matter and energy faster than natural processes are renewing them (such as the burning of fossil fuels or overuse of groundwater). Conversely, pollution occurs when the accelerated cycling and flow are discharged into the environment, overwhelming the local natural purification processes (**FIGURE 1.9**).

Problems of environmental depletion and pollution both exhibit the delayed and unpredictable impacts we have discussed.

FIGURE 1.9 Pollution occurs when natural purification processes are overwhelmed, such as by large amounts of nutrients or poisons. Shown here is the impact of nutrient loading to Lake Erie. In the summer of 2014, nitrogen and phosphorous loading caused an algal bloom, restricting access to freshwater to nearly 400,000 people in the Toledo, Ohio, area.

NASA image by Jeff Schmaltz, LANCE/EOSDIS MODIS Rapid Response.

1.3 What Is Environmental Impact?

Environmental impact refers to the alteration of the natural environment by human activity. We have already identified two basic types of environmental impact: resource depletion and pollution (Figure 1.4). In other words, there is either too much input (resources) and/or too much output (pollution). Input reduction seeks to slow both depletion and pollution, whereas output reduction slows only pollution.

Population growth and increased consumption are the two main forces accelerating resource depletion and pollution. The following equation is a simple way to remember this:

$$\text{Impact} = \text{Population} \times \text{Consumption}$$

$$\text{or } I = P \times C$$

It is easy to see why the number of people affects impact (**FIGURE 1.10**). Consumption is a product of affluency and technology. The more affluent a society, the more technological a society, the more its market depends on consumption. Consumption historically has tended to increase the effect of each person. For example, a baby born in the United States has many times the impact of a baby born in a developing country because over a lifetime the U.S. resident consumes

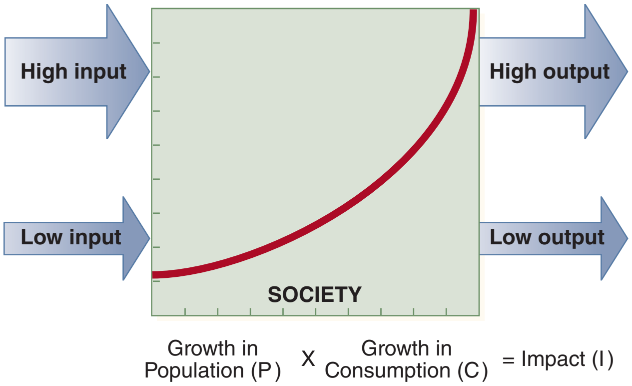


FIGURE 1.10 Personal consumption (*C*) has increased the throughput per person. This is multiplied by the number of people (population, or *P*) to obtain the total resource depletion and pollution produced by society.

many more resources, close to 20 times more, such as fossil fuels, and produces much more pollution. Although it accounts for only about 5% of the world's population, researchers have pointed out that the United States consumes nearly a quarter of all the energy used worldwide.

Current research indicates that population growth rates remain high but have begun to decrease slightly for most industrialized countries, while continuing to rise extremely rapidly in many developing nations. According to the United Nations Population Fund, population growth occurs in areas most challenged by poverty, civil unrest, malnutrition, and the lack of resources needed to disrupt the cycle. In many of these countries, population is predicted to double, in some cases triple, by 2050. Despite differences in growth rate, consumption of nonrenewable resources continues to increase at alarming rates. This worldwide trend has led to a rapid increase in environmental impact. This section briefly examines both of these factors.

Exponential Growth

Multiplicative processes cause **exponential growth**. It occurs in population growth because biological reproduction is inherently multiplicative: most organisms have the ability to produce more offspring than are necessary to simply replace the parental generation. If conditions allow, the population of each successive generation will be larger than the previous generation. Consider, for example, a pond where the algae cover starts from a single algal cell and doubles in size each day. For a long time, you would see nothing happening. However, after larger areas are covered, the algae would spread quickly: one day, the pond would be only half covered; the next day, it would be completely covered.

Exponential Growth of the Human Population

In 2011 the United Nations reported that the current world population had reached 7 billion people. As of late 2017 that number was approximately 7.6 billion people. For tens of thousands of years, relatively few people were on Earth at any given time. The total human population on Earth remained quite low until the development of agriculture. Even then, population growth did not become explosive until the 1900s, when it was aided by the global spread of industry, increased urbanization, and modern medicine. Currently, each year the world population experiences a net gain of approximately 77 million people, the equivalent of nearly one-third of the population of the United States. Since 1960, the world population has more than doubled. At the current world population growth rate (estimated to be approximately 1.2%), the world population will double again in less than 60 years. The last 50 years has seen more population growth than in the entire history of human existence. Even if population growth rates stabilize around the year 2050, as many scientists predict they might, the world population would still be about 9 billion people, an increase of approximately 30% over the 2011 population. The stabilization of population growth rates is speculative, based on several factors, including increasing access to education and birth control for women in developing nations, increasing financial assistance and programs promoting more sustainable ways of life, and natural causes such as diseases assisting in the stabilization of the population. Because population growth is most dramatic in the most politically unstable regions of the world, experts disagree about the accuracy of stability models. One fact remains, however: Earth's resources are being consumed at rates never before seen with consequences that are hard to predict.

How long will human population growth continue before it encounters environmental limitations? The answer depends on how many people the Earth can support, a question that is much debated, in part because the answer depends on how high a standard of living one assumes. However, many estimates predict that the Earth can adequately and sustainably support between 6 and 8 billion people at a reasonable standard of living. If this is true, population growth clearly must decline very soon if **overshoot** is to be avoided. Almost all population projections put forth by the United Nations, the World Bank, and other organizations indicate that the world population probably will not stabilize until it reaches 9 billion, sometime in the middle to late 21st century.

Exponential Growth of Consumption

The second basic factor in our impact equation, $I = P \times C$, is consumption. Here, we use the term **consumption** in the economic sense to refer to the purchase and use of material goods, energy, and services in our daily lives. Consumption includes all of the things we do and buy to meet our wants and needs. Consumption has increased the overall environmental impact by increasing the impact per person:

$$\begin{aligned}\text{Overall impact} &= \text{population} \times \text{consumption} \\ &= \text{number of individuals} \\ &\quad \times (\text{impact/individual})\end{aligned}$$

This impact per person occurs through an increase in both resource depletion and pollution. Because natural resources are used to make the increasing amount of things we buy, consumption has tended to increase per capita resource use and pollution. **FIGURE 1.11** illustrates that solid-waste output has grown dramatically in the United States in the past few decades.

However, personal consumption in wealthy nations could be reduced easily with no reduction in quality of life. For example, many new sustainable, or "green," technologies are being developed that can greatly reduce individual impact. More efficient technologies, such as fuel-efficient cars, use fewer resources and produce less pollution when an individual uses them. Alternative technologies can eliminate many impacts altogether. For example, replacing coal-burning machines with solar-powered machines conserves nonrenewable fossil fuels and eliminates many air pollutants that are released by the burning of coal.

Exponential Growth of Environmental Impact

The exponential increases of population and traditional industrial technology (which correlate with increasing consumption) have caused an exponential increase in environmental impact. The increase in total solid waste shown in Figure 1.11 is typical of the pattern seen in many other kinds of pollution. A society that produces such waste is likely to be consuming many resources that ultimately generate the waste. For example, global consumption of fossil fuel has risen exponentially because of the growing world population and the spread of technologies that use fossil fuels (increasing per capita use of fuels). As consumptive technology and population grow, more materials and energy move through society. This accelerates the depletion of environmental resources. In addition, the

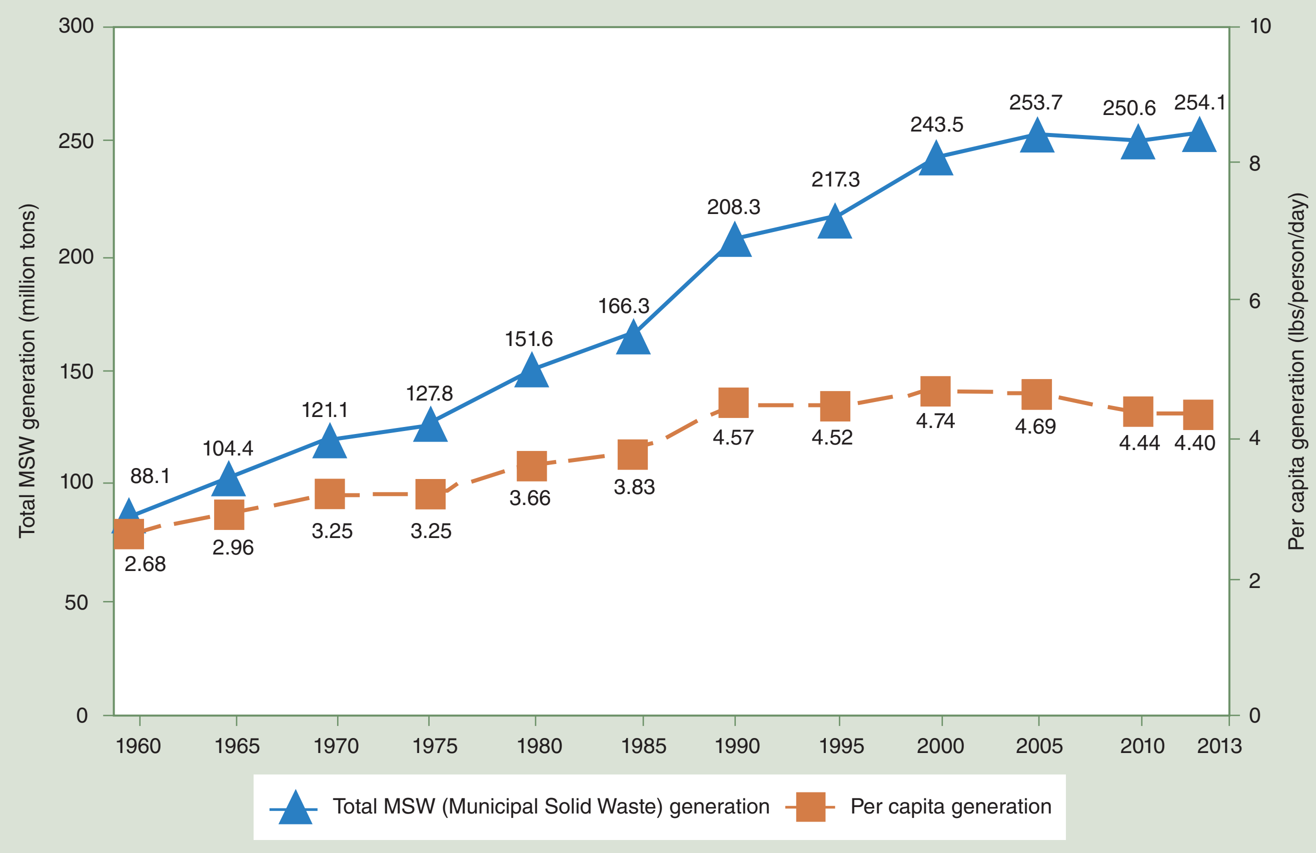


FIGURE 1.11 Trends in U.S. total solid waste production, output per person, and population.

Reproduced from U.S. Environmental Protection Agency. (2016). Municipal solid waste. Retrieved from https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/

materials and energy that move through society must have somewhere to go when society is finished with them. Solid waste, air and water pollution, and other outputs ultimately end up in the environment.

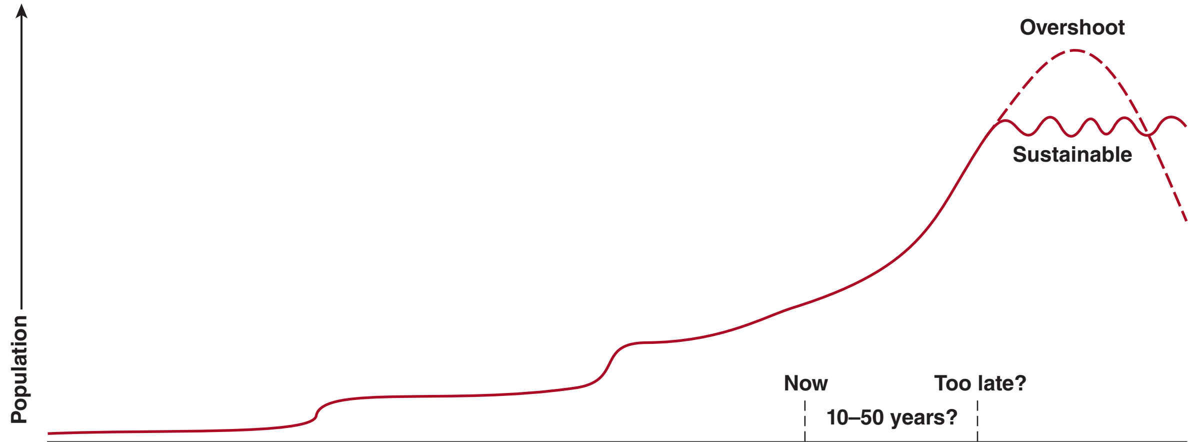
In summary, the two basic kinds of environmental impacts are depletion and pollution. Both have increased because growing consumption of resources increases pollution as throughput is accelerated. The main causes of increased throughput have been the growth of (1) population and (2) consumption.

1.4 A Brief History of Environmental Impact

Considering that our human species (*Homo sapiens*) has inhabited Earth for 100,000 or more years, the current massive global environmental impact of people is a very recent development. Indeed, our relationship with the environment has changed dramatically as we and our technology have evolved.

Conceptually, we can distinguish five basic developmental stages in the relationship between people and their environment (**FIGURE 1.12**). The economic activity people engage in using the technologies available to them at the time largely determines these stages. In turn, this activity affects how people have an impact on the environment. At any one time on Earth, different human populations may be in different stages simultaneously, yet the general global trend has been to progress through these stages.

1. *Gathering and hunting.* Early humans were largely at the mercy of their environment, so they might have viewed it in adversarial terms. Weather, predators, food shortages, and disease were constant threats. However, during this stage, humans also had a familiarity with the environment that in general has been lost. Population levels typically remained low, and any human-induced effects on the environment (such as purposefully setting forest fires) were relatively localized.
2. *Agriculture and conservationism.* The shift from hunting and gathering to cultivating food is one of the most profound milestones in human evolution. It allowed a great



Economic activity	Gathering and hunting	Agriculture	Industry	Transition	Postindustrial
Perception of environment	Adversary	Resource	Dumping ground	Awareness of limits	Spaceship or wasteland
Environmental impact	Minimal	Vanishing wilderness	Pollution	Widespread degradation	Minimal or massive
Environmentalist response	—	Conservation movement	Environmental movement	Sustainability movement	—
Examples	—	Game preserves, parks	Clean Air, Water, Waste Acts of 1970s	Market-based incentives	—

Time →

FIGURE 1.12 Population and personal consumption have increased the human impact on the environment in an exponential fashion. Those concerned have responded with the preservation movement, the conservation movement, the environmental movement, and the sustainability movement. Many people believe that we are in a transition stage and that people have no more than 50 years to prevent overshoot and attain sustainability.

increase in population size and permitted people to settle in large towns and cities; however, agriculture also had a major impact on the environment. People began to view land as a resource to be exploited as needed. As land was cleared and cultivated, the wilderness vanished. Conservationism developed to balance our biological and social need for resources with sustainable management, so that systems have time to replenish themselves and the human population can depend on their bounty for longer periods of time, if not forever.

3. *Industry and environmentalism.* As nations industrialized, populations grew faster, and the environment was increasingly perceived as both a source of raw materials and a place to dispose of the concentrated waste by-products of industry. The result was a rapid increase in air and water pollution, as well as problems with solid and hazardous waste disposal. Toward the end of this stage, pollution became so widespread that antipollution social movements emerged. In the United States, these social movements began in the early 1960s and peaked in the 1970s. When people talk about classic "environmentalism," this antipollution movement may be what they mean.

4. *Transition and sustainability.* Today, we live in a time of rapid change and technological advancement. The decisions that we, as a global community, make over the next few decades almost certainly will determine the long-term fate of the environment for many future generations. For this reason, we can refer to the current stage of many developed countries as a "transition" stage. Although some forms of pollution have been reduced, many other environmental problems have increased. For example, in the United States, species of wildlife are imperiled as habitat is destroyed unnecessarily. Recently released reports indicate that the catastrophic events surrounding the April 2010 Deepwater Horizon rig explosion and oil well blowout

in the Gulf of Mexico that killed 11 people were preventable and caused primarily by lack of communication, poor management, and profit-driven greed. Such reports underscore the urgency for sustainable industry practices grounded in policies, decisions, and practices that hold stewardship for the environment in higher regard.

Keeping with the Deepwater Horizon example, new research published in the *Proceedings of the National Academy of Sciences* (2014) reveals that a large fallout plume of oil from the disaster has been deposited on the seafloor. Originally, scientists thought that the 2-million-barrels' worth of oil was trapped in the deep sea. Instead, a 1,250-square-mile patch of rare habitat is now contaminated by the rupture. Research suggests that this may represent 4 to 31% of the oil lost from the Macondo well that was being drilled by the oil rig. The rest of the oil is likely deposited elsewhere, avoiding detection because of its patchy nature. This means that the actual size of the blowout is still unknown, and thus its long-term ecological impacts are still not fully understood.

The actions we undertake in the first part of the 21st century will affect subsequent generations' sustainability in ways seen at no other time in history. Among other challenges we face are groundwater contamination, including endocrine-altering by-products from pharmaceutical waste that interrupt normal adolescent development and the presence of many thousands of hazardous and radioactive waste sites that likely will not be cleaned up for centuries. Despite efforts in recycling and precycling (i.e., the reduction of packaging material by manufacturers), the amount of solid waste produced per person remains high. Globally, the Environmental Protection Agency (EPA) has cited global warming, ozone depletion, and increasing species extinction as the greatest environmental threats to future generations.

As developing nations grow, it is important for them to look beyond the often-inadequate example of developed nations' use of the environment. Current models for sustainable development include technological advances that are sustainable by design. Both the rapidly increasing populations in developing countries and the increasing demands for goods and services by the populations of developed countries cause these problems. Only recently, with the sustainability movement, has there been widespread interest in addressing the systematic causes that underlie these problems.

Sustainability means meeting the needs of today without reducing the quality of life for future generations. This includes not reducing the quality of the future environment. Sustainability can be achieved in many ways, such as through the use of sustainable technologies that use renewable resources (e.g., solar power) and recycling or upcycling (i.e., converting waste materials or useless products into usable materials or better products) of material components. These technologies allow a **sustainable economy** that produces wealth and provides jobs for many human generations without degrading the environment. An example of the practical application of sustainable design is looking at materials as natural components of an ecosystem. Nature recycles and does not waste. Waste in nature ends up as the basic components of food, achieved by natural decomposition of biological by-products. Industry that commits to material reuse, renewable energy use, water stewardship, and social responsibility can qualify for the Cradle to Cradle recognition, which means that the manufacturer commits to safe materials that can be reused or composted and accepts the responsibility of business-as-stewards in the use of environmental materials. Not only does this model make sense for future generations, but it also is profitable for business owners.

5. *Postindustrial stage: sustainability or overshoot?* The next (future) stage of society has been called the *postindustrial stage*. Just what form postindustrial society will take is open to speculation and debate, but two possible alternatives have been proposed. One is a sustainable future, where the human population stabilizes and technology becomes less environmentally harmful. The second alternative is overshoot, where the human population climbs so high and technology is so harmful that the environment is degraded to the point that relatively few people can be supported, at least with a decent standard of living. Which alternative

comes into being could depend on the collective actions of humanity during this first half of the 21st century.

1.5 The Environment as a Commons

In 1968, the biologist Garrett Hardin wrote the famous essay "The Tragedy of the Commons." He argued that property that many people hold in common will be destroyed or at least overused until it deteriorates. He gave the example of a pasture where each herdsman in the village can keep his cattle. The herdsman who overgrazes the most will also benefit the most. Each cow that a herdsman adds will benefit the owner, but the community as a whole will bear the cost of overgrazing. Because the benefit of adding another cow goes to the individual and the cost of overgrazing goes to the community, the "rational" choice of each individual is to add cows. Thus, the commons rewards behaviors that lead to deterioration, such as overgrazing, and punishes individuals who show restraint. Those who add fewer cows will simply obtain fewer benefits while the commons itself deteriorates because of the individuals who continue to add cows.

Many local, regional, and global environmental problems illustrate this view of the commons as a source or a sink:

Source or Sink	Problem
Atmosphere as global common sink	Global warming, ozone loss
Atmosphere as a regional common sink	Acid rain
Atmosphere as a local common sink	Urban smog
Ocean as a global common sink	Ocean pollution
Ocean as global common resource	Overfishing
Rain forest as common resource	Global warming promoted by deforestation, biodiversity reduced by deforestation

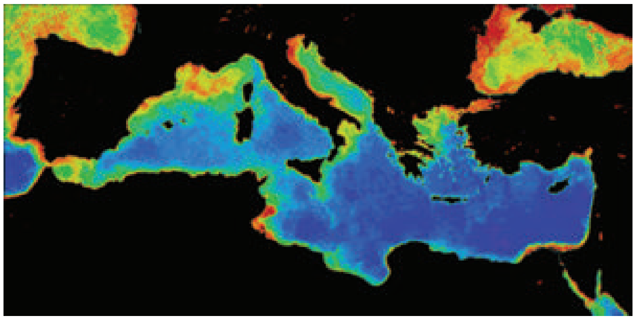


FIGURE 1.13 A computer-enhanced image of pollution in the Mediterranean Sea. Red, yellow, and orange areas are concentrations of plankton growth promoted by discharge of raw sewage. (Blue indicates clear water.) Many coastal cities lack sewage treatment.

Courtesy of Gene Carl Feldman/NASA Goddard Space Flight Center.

Many nations share commons. The international nature of many environmental problems adds greatly to the complexity of solving them because international agreements are required. Consider the Mediterranean Sea. A confined shallow ocean basin surrounded by many nations, this sea is one of the most overfished and polluted large bodies of water on Earth (**FIGURE 1.13**).

1.6 Saving the Commons

If we are to save the environmental commons, the throughput of matter and energy through all societies must be reduced. This will slow both depletion and pollution. Increasing population (*P*) and consumption (*C*) have driven increased impact (*I*), so their growth must be reduced.

As noted earlier, we are in the transition stage. Environmental problems have become so widespread that they demand large-scale regional and global solutions involving many aspects of society. Furthermore, countries such as China and India are in the process of rapid industrialization, which consumes a tremendous amount of Earth's resources. It is important that these economies learn to work in a sustainable manner instead of using their resources in a wasteful and inefficient manner. The United States and other countries are doing a good job, but need to improve as well. Beginning in the early 1980s, a sustainability movement emerged to try to deal with these problems. Unlike the conservation and antipollution movements of the past that emphasized specific problems rather than a global approach, the sustainability movement seeks long-term coexistence with the environment. As mentioned earlier, sustainability means meeting the needs of today without reducing the quality of life for future generations.

The sustainability movement uses three approaches not attempted by previous environmental movements. First, it focuses explicitly on trying to reduce society's use of all resources; therefore, emphasis is on input reduction, as opposed to end-of-pipe solutions. *Waste is viewed as a symptom, not a cause, of the environmental crisis.*

Second, the sustainability movement is more holistic. It realizes the necessity of addressing the social, and especially economic, causes of environmental degradation. This has led to an increasing appreciation of the role of poverty and other economic factors that encourage people to deplete resources and pollute. Market-based solutions are becoming more popular, and less emphasis is placed on the legal solutions used in the past. For example, many experts now agree that it is often more effective and cheaper for society to tax coal, gasoline, and other polluting substances than to pass laws specifying how much pollution may be emitted. For instance, higher gasoline prices encourage people to drive less or buy fuel-efficient cars.

Third, the sustainability movement has encouraged the growth of thousands of local community action groups, as opposed to the national groups that dominated the conservationism and environmentalism periods. Many of the national and international environmental organizations arose well before 1980. For instance, the Sierra Club was founded in 1892, the National Audubon Society in 1905, the National Wildlife Federation in 1936, and the World Wildlife Fund in 1961. Since the exposure of the toxic dump at Love Canal, New York (1978), and the Three Mile Island nuclear accident in Pennsylvania (1979), residents of communities have become increasingly active in addressing local environmental problems. Vocal debates over incinerators, landfills, land development, mountaintop removal, water contamination, and many other environmental issues now often dominate the local news (**FIGURE 1.14**). Such local participation is often called **grassroots activism**. Recently, grassroots groups with common interests have begun to network by establishing regional and national newsletters and computer nets. By the mid-1990s, many of the national organizations had begun to experience a decline in membership. Although some people suggest that this decline means environmental interest is waning in the United States, others argue that it simply reflects the transfer of environmental allegiance from national to grassroots organizations. Today, environmental issues are often the focus of major news stories and popular movements. In 2017 the biggest climate march in U.S. history occurred in Washington, D.C. with more than 200,000 demonstrators attending the Peoples Climate March. Also in 2017, the first March for Science event inspired tens of thousands of people across the globe to rally for environmental concerns.

FIGURE 1.14 Citizen protest is an effective and growing way to promote local environmental sustainability.
Courtesy of Appalachian Voices.

All three characteristics of the sustainability movement historically arose from the desire to find better ways to solve widespread environmental problems. Grassroots activism is often the best way to deal with local issues. The rise of input reduction and economic approaches reflects the need to reduce social costs. Although litigation and lobbying are still used, the sustainability movement also uses direct action and lifestyle changes. In keeping with its more holistic approach, many members of the sustainability movement are also **ecocentric** ("environment centered") instead of **anthropocentric** ("human centered"). In other words, they seek to preserve nature for reasons beyond simply improving the quality of human life. Nature is viewed as having a high intrinsic value that is not related to human needs; that is, nature is worth protecting for its own sake. As the sustainability movement spreads, addressing the needs of the 21st century, it will continue to develop many new strategies and approaches to further the goal of sustaining the environment for the generations that follow.

The budding sustainability movement reflects a reenvisioning of the commons. The work of famed economist and political theorist Elinor Ostrom demonstrates that groups of people attempting to manage their common resources, such as farmers, fishermen, or foresters, with the help of resource managers and environmental scientists are not only capable, but often very successful at sustainable use of the commons. Today, human dimensions and ideas of adaptive governance and stakeholder approaches to natural resource management are regularly practiced among resource professionals.

Reducing Consumption: Defusing the Bomb of the North

Rapid population growth is often described as a "time bomb" that will greatly degrade the environment in coming years. Although population growth is especially rapid in the Southern Hemisphere, the industrialized nations of the Northern Hemisphere are also contributing to environmental degradation through their habit of excessive and wasteful resource consumption developed during a time of abundant resources. Consumption may be viewed as the environmental "time bomb" of the Global North. The solution is to reduce consumption, or C, in the impact equation $I = P \times C$.

Three strategies can be used to reduce consumption. None of them need to involve painful self-sacrifice or a decreased quality of life. In fact, reducing consumption can improve quality of life in many ways by improving human health and the environment:

- *Reduce material needs.* Psychological studies have statistically documented what many religions have long taught: increasing a person's material wealth will rarely produce an increase in happiness or contentment. The "treadmill of wealth" says that the more we accumulate, the more we want. When Americans are surveyed, most respond that they have far too much "stuff."
- *Use less technology to meet our needs.* Long before Thoreau, many people observed that some machines might have detrimental effects on people. Riding bicycles to work (instead of driving cars), buying products with fewer artificial chemicals and less superfluous packaging, and using fewer unnecessary convenience appliances are but a few ways that people have reduced their reliance on technology.
- *Use sustainable technology to meet our needs.* Another way to reduce technology's impact is to use technologies that are much more "environmentally friendly" than the fossil fuel–based, industrial technologies of the past. **Sustainable technology** permits people to meet their needs with minimum impact on the environment. It produces a sustainable economy that provides jobs for many generations without degrading the environment.

Many kinds of sustainable technologies are available, ranging from direct solar and wind power to recycling. Although advances in pollution cleanup technologies are often heralded, true sustainability results from input reduction: slowing resource depletion also slows pollution. The three basic ways that sustainable technologies achieve input reduction, or conservation, are (1) efficiency improvements, (2) reuse and recycle, and (3) substitution.

Efficiency improvements reduce the flow of throughput by decreasing per capita resource use. The United States, more than almost any other country, uses technologies that were developed during periods of abundant resources. As a result, it generates much waste, providing enormous opportunities to save many resources by relatively simple changes in existing technologies. The amount of waste is so great that, in many cases, the large amount of resources saved will more than compensate for the cost of investment to make the change.

Let us use the example of energy, which drives all economies. It is estimated that changes in U.S. technology, ranging from high-mileage cars to superefficient heating and cooling systems to new lighting technologies, could reduce overall energy consumption by as much as 80%. For example, the incandescent light bulb converts 95% of the electricity it uses to waste heat instead of light. Compact fluorescent bulbs (CFLs) generate 70% less heat and use between 50 and 80% less energy to produce light. According to the EPA, if every U.S. household replaced incandescent lights with compact fluorescent lights, the society would benefit by a reduction of greenhouse gas equivalent to removing 800,000 cars from the road. Recent discussion about the use of compact fluorescent bulbs often mentions that the bulbs contain mercury. Although it is true that the bulbs contain a small amount of mercury (5 grams; a little less than the weight of a modern quarter), the Union of Concerned Scientists points out that the bulbs can be recycled and that the energy savings must take into account that "the average coal-fired power plant emits only 3.2 milligrams of mercury for each CFL running six hours per day for five years, but emits nearly 15 milligrams of mercury for an incandescent bulb running the same amount of time." Even more efficient are light-emitting diode (LED) lights that are becoming more readily available as costs decrease, making them more attractive to consumers. LEDs can last as long as 50,000 hours, more than eight times as long as CFLs, and also contain no mercury, making this evolution of technology a promising answer to home energy-efficiency challenges.

In addition to reducing environmental damage, efficiency improvements have two immediate economic advantages. First, as noted, the improvement usually pays for itself. The cost of a technological change that increases efficiency is usually recovered within a few years and sometimes almost immediately. For instance, a study by a major beverage company found that each reduction of one thousandth of an inch (0.001 inch) reduces aluminum costs by $1 million. (Of course, there is a limit to how thin aluminum cans can be and remain structurally sound.) In addition, increased efficiency tends to produce many more jobs than do wasteful technologies. The traditional energy industries, such as oil, coal, and nuclear power, are much less labor intensive than the energy-conservation industry that designs and maintains many kinds of energy-conservation equipment.

Many other resources in the United States could be used much more efficiently. Here are just a couple of examples:

- *Wood.* The United States converts only about 50% of raw timber (compared with 70% in Japan) directly into furniture and other refined timber products. The rest is disposed of as waste or simply abandoned.
- *Water.* The United States uses more than twice as much water per person as most other nations on Earth. The average U.S. farmer typically could cut water use by more than half by adopting water-conservation measures, such as microirrigation that pipes water directly to crops instead of using evaporation-prone irrigation ditches. In the home, installing a low-flow toilet can save a family of four more than 1,350 gallons of water per month.

Reuse and recycling are the second best ways to accomplish input reduction. **Reuse** refers to using the same resource over and over in the same form. An example would be soda bottles that are returned, sanitized, and refilled. **Recycling** refers to using the same resource over and over but in modified form. For instance, the soda bottles could be melted to produce new soda bottles. Wastewater, paper, plastics, and many other resources can be recycled. In general, reuse is less costly than recycling because the resource is not modified. Both measures are often less costly than extracting "virgin" resources, such as aluminum ore or cutting trees for paper, because they usually consume less energy and fewer natural resources than does making products from virgin materials (**FIGURE 1.15**). For example, recycling aluminum cans saves as much as 95% of the energy cost of cans made from newly mined aluminum. Recycling and reuse are less costly in both economic and environmental terms than is using natural raw materials.

FIGURE 1.15 Yard waste in a biodegradable plastic bag waiting for recycle pick up.

Substitution of one resource for another can benefit the environment in a number of ways. A renewable resource can be substituted for a nonrenewable one, or a less-polluting resource can substitute for a highly polluting resource. Often the newly substituted resource provides both benefits. Substituting renewable, cleaner alternative fuels, such as solar and wind energy, for fossil fuels is an example. Another example is making products from paper instead of plastics, which are generally made from fossil fuels and last longer in the environment (although there are now biodegradable plastics, and plastics produced from plants have been developed recently). Like conservation, reuse, and recycling, substitution often yields economic benefits. Studies routinely show that substitution of solar and wind power technologies for the fossil fuel energy now consumed in the United States would produce three to five times as many jobs as now exist in fossil fuel industries.

Some people are surprised to learn that many sustainable technologies were invented centuries ago. Wind power and water power are examples. The solar cell was invented in the 1950s. These technologies have failed to become widespread largely for social and economic reasons, not technical ones. When nonrenewable resources are cheap, they will be wasted because people have no incentive to increase efficiency, recycle/reuse, and substitute renewable resources. The current interest in solar energy has reached record highs, with industry journals indicating a 20% increase in jobs in the solar industry throughout 2014. This is particularly impressive when considering the current average unemployment rate (2017) is 4.3% nationally in the United States. Combining other renewable energy industry data results in trends predicting that by 2025 approximately 2.5 million people will have jobs related to renewable energy. Cost of installation is becoming more attractive to consumers, as are incentive plans and infrastructure improvements. For instance, more than 42 states and the District of Columbia now have net metering rules that allow an individual owner of a solar energy system to sell excess electricity back to the grid. In other nations, such as Germany and Japan, where governmental and private incentive plans are in place, growth in renewable energy has soared in recent years.

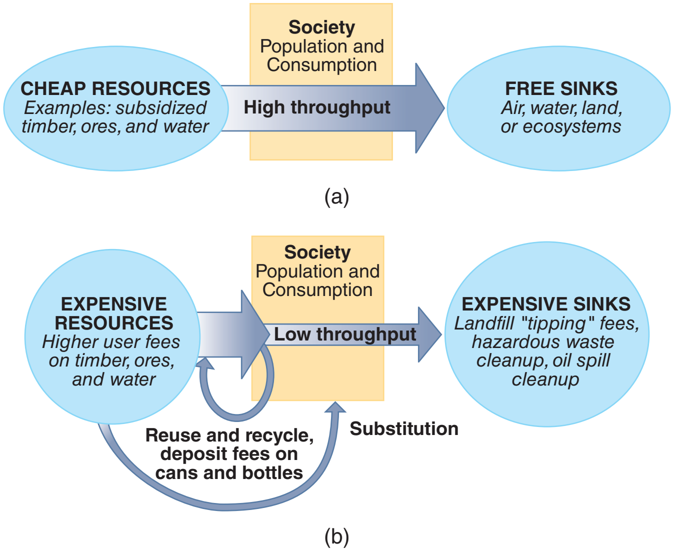


FIGURE 1.16 **(a)** Excluding environmental costs by allowing cheap resources and free sinks promotes high throughput (and thus much depletion and pollution). **(b)** Including environmental costs by imposing user fees and deposits promotes efficiency, recycling, and all other forms of input reduction.

1.7 Promoting Sustainability by Paying the True Costs of Nature's Benefits

The economic forces that promote population growth and overconsumption have arisen because the goods and services that the environment provides, such as water purification, erosion control, and carbon sequestration, have been undervalued in the past. These and other benefits provided to human populations from ecosystems simply by their existence are collectively known as **ecosystem services**. Essentially, the true costs of using the environment as both a source and a sink have not been incorporated into global economic activity. This trend, according to the Millennium Ecosystem Assessment (a 2005 United Nations–sponsored report designed to assess the state of the world's ecosystems), has led to the degradation of more than 60% of ecosystem services that were evaluated over the past 50 years. **FIGURE 1.16a** shows that when resources are artificially cheap and sinks are free, there is much throughput, which leads to high rates of resource depletion and pollution. Increased throughput also contributes greatly to the rapid population growth of developing nations. Poverty is strongly correlated with high population growth rates, and people in resource-rich developing nations are often underpaid for their resources (as compared with prices in many developed nations).

Market failure (or *externality*) occurs when market prices do not reflect all the true costs of a product or service. Most ecosystem services are either undervalued or considered free in our current economic system. Many environmental problems ultimately can be traced to market failures:

- The cost of gasoline does not include the cost of smog and other urban air pollutants, contamination of groundwater by leaking underground oil tanks, oil spills, and many other well-known impacts of gasoline use.
- Electricity from nuclear energy does not include the cost of disposing of nuclear waste; electricity produced by coal burning omits the cost of most air pollution.
- Water use by many U.S. farmers does not reflect the fact that in many regions the groundwater is being depleted much faster than it is being replenished by rainfall.

A number of ideas have been proposed on how best to approach market failures, and each deserves time for debate in the public arena. For example, many economists suggest that society can correct market failures by imposing **green fees** that incorporate the environmental costs into the final costs of products and services (**FIGURE 1.16b**). Fees that increase the price of a resource are particularly effective because they promote conservation of the resource and also reduce pollution by reducing throughput. For example, a gas tax or carbon tax covering all fossil fuels would encourage reduced and more efficient use of these fuels. Similarly, charging for garbage by the bag motivates people to reduce the waste they produce.

Another emerging solution to address market failures is known as *payments for ecosystem services* (PES), which involves offering incentives to landowners in exchange for managing their land to provide an ecological service, such as carbon sequestration and storage, endangered species habitat, and wetlands protection. PES programs are contracts between the consumers of ecosystem services and the suppliers of these services. The beneficiaries of the ecosystem services are willing to pay a price that is lower than their welfare gain because of service benefits. The providers of the service are willing to accept a payment that is greater than the cost of delivering the services.

Reducing Population: Defusing the Bomb of the South

More than 90% of world population growth occurs in developing nations. Most developing nations are in the Southern Hemisphere; thus the cause of throughput is especially important there. To defuse this so-called **population bomb**, we must address its central causes, which often are economic. **FIGURE 1.17** illustrates how population growth is often driven by poverty. Poor people tend to have more offspring for a variety of reasons, including lack of education about and easy access to birth control, lack of economic opportunities for women, and the need for children to perform chores and care for the aged. The result is a "vicious circle" in which population growth leads to poverty because increasing numbers of people reduce the standard of living. Impoverished people tend not to focus on environmental concerns but must turn their attention to simply surviving from one day to the next.

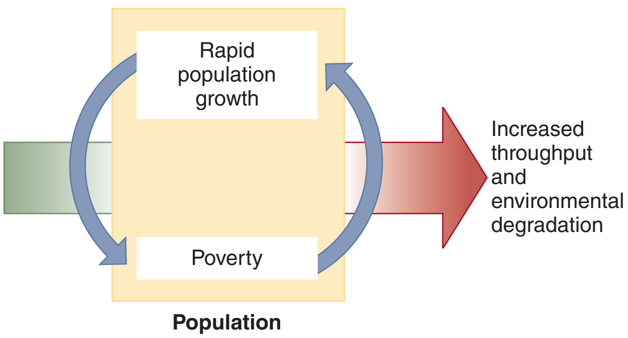


FIGURE 1.17 Poverty and population growth feed on each other, and both produce environmental degradation.

Can this cycle of poverty, population growth, and environmental degradation be broken? Many people still subscribe to the **fallacy of enlightenment**, or the idea that education will solve the problem. Education is very important, but often it is not enough; realistic solutions that remove the root causes of the problem must be found. Attempting to protect the environment by legal means, such as creating game reserves, often is not effective because desperate people will break laws. Decades of experience show that the economic causes of this cycle must be addressed. Eliminating poverty will not only reduce many causes of population growth, but it also will reduce environmental degradation.

Reducing Population Growth by Paying True Costs

The gap in wealth between developed and developing nations is wide, and the gap continues to grow because developing countries are required to pay large amounts of interest on money that was lent to them many years ago. Developing countries owe their creditors more than $2 trillion. As a result of the interest on this debt, the net flow of money has been from South to North since 1982. Rich countries now receive more money from poor countries (variously estimated at more than $50 billion per year) than they transfer to them. This is sometimes referred to as the **debt bomb**.

Some economists argue that foreign aid to poor countries should not be viewed as charity. They note that these poor but resource-rich nations would not need charity if they were paid the true value for their resources. They maintain that if people in the developed Northern Hemisphere wish to save rain forests, they should pay for the environmental goods and services the forests produce. Although it is often difficult to estimate the true environmental costs and values in most cases, nearly all estimates indicate that developing nations are greatly underpaid for their resources. As payments for ecosystem service markets develop, the true costs of environmental goods and services will be better valued in the economic system. Programs such as the United Nations Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) are structured to help alleviate the debt bomb issue. However, programs such as REDD often have unintended consequences. In many areas, REDD inadvertently promotes the total exploitation of natural areas simply because regulation diverts resource extraction to unprotected land/seascapes.

Appropriate payment for ecosystem services could help eliminate poverty, probably much more effectively than foreign aid donations. These payments would break the vicious cycle of poverty and population growth. A key necessity is that this increased wealth be used to buy sustainable technologies that focus on efficiency, recycling/reuse, and renewable resources rather than nonsustainable practices.

1.8 The Role of the Individual

The environmentalist Wendell Berry said that the roots of all environmental problems ultimately lie in the values of the individuals who comprise society. As the writer Paul Hawken put it, "The environment is not being degraded by corporate presidents; it is being degraded by popular demand." By this, he means that companies produce only things that people buy, and they cause depletion and pollution only as long as society permits such behavior to be profitable.

Values on the Here and Now: Why We Avoid True Costs

Why do individuals have values that lead to environmental degradation by "popular demand"? Many writers have argued that most large-scale problems arise because individuals are not good at dealing with problems beyond their own immediate situation. We tend to focus on the here and now.

Discounting the future results from focusing on the "now": the environmental costs of our actions on future generations are not fully paid, mostly because they are not fully valued in the current economic system. For instance, cheap gasoline and minerals lead to rapid depletion of these nonrenewable resources, making them unavailable to future generations. These resources are cheap because their current cost does not include the future effects of their use, such as global climate change or other pollution hazards. **Discounting by distance** results from focusing on the "here": environmental costs of our actions on people living in another area are not fully paid. For instance, cheap ivory, imported animals, and tropical timber lead to rapid depletion of those tropical resources, thereby degrading the environment for the people who live there. These resources are so cheap because their cost does not incorporate their full value to their local environment.

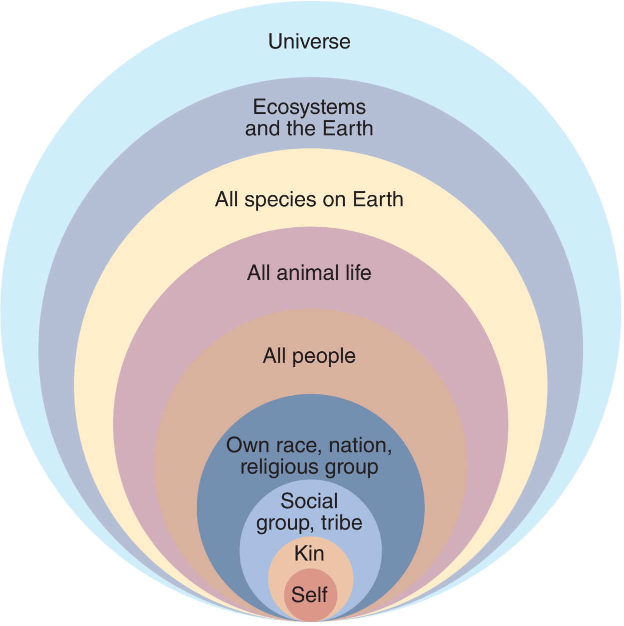


FIGURE 1.18 An ethical sequence in which the individual concerns extend outward beyond the self to progressively more inclusive levels.

Modified from Noss, R. (1992). Issues of Scale, in P.L. Fideler & S. Jain (Eds.), *Conservation biology* (pp. 396-431). Chapman & Hall. With permission of Springer Nature.

A Solution: Values Beyond the Self and Recognizing the True Value of Ecosystem Services

It can be argued that the single greatest obstacle to building a sustainable society is this tendency of the human mind to focus on the here and now. It limits our ability to make the systemic social changes needed to solve regional and global problems.

FIGURE 1.18 illustrates how people can extend their sphere of concern, beginning with close relatives and progressing through other social groupings to include all people. Ultimately, all living things can be included, as reflected by the philosophy of **deep ecology**. If we are to place a higher value on the environment of the future and in other parts of the world, such extended spheres of concern are needed. If many people adopt this view, society will be more willing to promote solutions that require looking beyond the here and now.

Most sociologists believe that the trend has been in the opposite direction until now. Large cities have fostered a loss of community and the fragmentation of social groups, including families. Can this trend be reversed? No one knows, but some encouraging signs have appeared. For example, the grassroots activism of the current sustainability movement is based

CASE STUDY 1.2 WHAT ARE YOUR VALUES? WOULD YOU DECLINE $600,000 TO SAVE A RAIN FOREST?

Although many of us say that we are "pro environment," we never really know how strong our values are until we are asked to make personal sacrifices for them. For example, in this chapter we have asserted that the environment of future generations is often discounted or devalued. Most of us would like to change that situation, but just how much are we willing to sacrifice?

Consider the case of Miguel Sanchez, a subsistence farmer in Costa Rica. He was offered $600,000 for a piece of land that he and his family have tended for many years. This land consists of a spectacular old-growth rain forest and a beautiful black sand beach in an area where land is rapidly being developed. A hotel developer offered the money. Sanchez declined, knowing that this was more money than he, his children, and all of his grandchildren would ever accumulate. Sanchez explained his decision: "I have no desire to live anywhere else. Money can be evil. People will ask me for money."

Miguel knows that cleared forest means less rain, less water in the rivers, less escape from the blazing tropical sun; however, he is reluctant to talk about his decision. Hundreds of other farmers and fishermen in his area feel the same way and are fighting development.

Critical Thinking

1. How does Miguel's sacrifice compare with sacrifices that you have made to promote long-term environmental health? What would you do if you were in Miguel's position?
2. Comment on the following statement from writer Andre Carothers: America has "a skewed moral universe, where people regularly swoon over each other's negligible acts of charity." The writer's point is that we make a big deal about recycling cans, buying organic foods, and giving tiny donations to environmental funds. Is this a fair criticism or unjustified cynicism?

Modified from A. Carothers, "Letters from Costa Rica," *E Magazine,* September 1993.

on community concerns. Many examples of exceptional unselfishness in individuals can be highlighted (**CASE STUDY 1.2**).

Payments for ecosystem service markets, whereby the true cost of an environmental service or benefit is incorporated into the costs of decision making, can help people realize more directly the value of environmental services. Other initiatives, such as fair-trade labeling, organic food, and green products, are also making it easier for people to become more environmentally literate and make choices that result in less environmental harm.

1.9 Toward a Sustainable World

Although no one knows if sustainability will be attained, there is certainly no shortage of debate and speculation. Historically, two schools of thought have existed on the urgency of overpopulation and resource limitation, and they tend to be polarized. At one extreme are **cornucopians**, who argue that human ingenuity has always overcome environmental limitations. They suggest, for example, that inventions such as genetic engineering could make agriculture more productive so that the planet will be able to support many more people at a high standard of living. At the other extreme are **cassandras** (also known as *neo-Malthusians*), who argue that people have always altered the environment and managed things poorly; they insist that exponential growth of populations and consumptive technology will finally degrade the environment so much that it will lead to overshoot (see Figure 1.11). Cornucopian and cassandran views have been common, in various forms, throughout history.

As is often the case, extreme views can be counterproductive. Too much optimism, such as a cornucopian view, can lull people into inactivity because they think that the future will take care of itself. Too much pessimism, such as a cassandran view, can cause despair, which leads to inaction because people think that the future is bleak no matter what they do. Thus, many writers suggest a more moderate view that acknowledges that urgent environmental problems exist and that these problems need to be addressed within the next few years, or at least decades, or they may lead to large-scale environmental degradation and overshoot. This moderate view relies on the **precautionary principle**, which states that in the face of uncertainty the best course of action is to assume that a potential problem is real and should be addressed. In other words, we are better safe than sorry. The worst that can happen with this approach is that society will become more efficient, less wasteful, and less polluting, even if environmental problems prove to be not as bad as some people argue. On the other hand, the results can be disastrous if the precautionary principle is not used and problems are indeed as urgent as some people believe.

Assuming that a person wishes to rely on the precautionary principle, which specific environmental problems should be of most concern? A good starting place is the following priority list based on material published by the EPA and other sources:

- *Highest priority:* Species extinction, ecological disruption and habitat destruction, stratospheric ozone depletion, and global climate change.
- *Middle priority*: Problems associated with pesticides and herbicides, lake and river pollution, acid rain, and airborne toxics.
- *Lowest priority*: Oil spills, groundwater pollution and depletion, airborne radiation, waste dumping, thermal pollution to water bodies, and acid runoff.

The highest-priority problems are global and are very long term in scope. Lower-priority problems tend to be geographically more localized and can (in theory) be solved within shorter time spans.

Visualizing a Sustainable World

Recall that sustainability means meeting the needs of today without degrading the environment for future generations. **TABLE 1.1** summarizes many of the changes that are necessary to create a sustainable society. Note the following major points. First, many aspects of our society are affected: scientific paradigms; role of the human; and values toward nature, land, and people. Second, many of our social institutions are affected: religion, education, political systems, and economic systems. Third, technology and agriculture are affected. Fourth, many of these changes ultimately are based on increasing the importance of our communities, from encouraging community values among individuals to creating decentralized, community-based economies and political systems.

The need for such pervasive changes is reflected in academic disciplines such as the social sciences and humanities, which traditionally have studied society as an entity distinct from the natural environment or at most only moderately influenced by the natural world. For example, economics once (and still largely does) focused almost exclusively on the flow of goods through society, ignoring the costs of depletion and pollution that the flows impose on the environment. Similarly, other disciplines, such as ecology, studied the environment as a largely separate entity. The new field of environmental economics is a more holistic discipline that includes both society and the environment. It incorporates externalities into the overall profit or loss of the product. It studies not just the flow of goods within society but also the effects on the environment and makes an effort to value the true costs of ecosystem services. Other social science–oriented disciplines are also rapidly developing an interest in studies that incorporate the environment.

Supporting Services

Supporting services are those that are necessary for the production of all other ecosystem services. They differ from provisioning, regulating, and cultural services in that their impacts on people are often indirect or occur over a long time, whereas changes in the other categories have relatively direct and short-term impacts on people. (Some services, such as erosion regulation, can be categorized as both a supporting and a regulating service, depending on the time scale and immediacy of their impact on people). Consider the following supporting services:

- *Soil formation.* Because many provisioning services depend on soil fertility, the rate of soil formation influences human well-being in many ways.
- *Photosynthesis.* Photosynthesis produces oxygen necessary for most living organisms.
- *Primary production.* Organisms assimilate or accumulate energy and nutrients.
- *Nutrient cycling.* Approximately 20 nutrients essential for life, including nitrogen and phosphorus, cycle through ecosystems and are maintained at different concentrations in different parts of ecosystems.
- *Water cycling.* Water cycles through ecosystems and is essential for living organisms. (Millennium Ecosystem Assessment, 2005)

TABLE 1.1 Transition from the Industrial to the Ecological Age*

	Industrial Age	Sustainability or Ecological Age
Scientific paradigms	Mechanistic Earth as inert matter Determinism Atomism	Organismic Gaia: Earth as a superorganism Indeterminacy, probability Holism/systems theory
Role of the human	Conquest of nature Individual versus world Resource management	Living as part of nature Extended sense of self Ecological stewardship
Values in relationship to nature	Nature as resource Exploit or conserve Anthropocentric/humanist Nature has instrumental value	Preserve biodiversity Protect ecosystem integrity Biocentric/ecocentric Nature has intrinsic value
Relation to land	Land use; farming, herding Competing for territory Owning "real estate"	Land ethic: think like mountain Dwelling in place Reinhabiting the bioregion
Human/social values	Sexism, patriarchy Racism, ethnocentrism Hierarchies of class and caste	Ecofeminism, partnership Respect and value differences Social ecology, egalitarianism
Theology and religion	Nature as background Nature as demonic/frightening Transcendent divinity Monotheism and atheism	Animism: everything lives Nature as sacred Immanent divinity Pantheism and panentheism
Education and research	Specialized disciplines	Multidisciplinary, integrated
Political systems	Nation-state sovereignty Centralized national authority Cultural homogeneity National security focus Militarism	Multinational federations Decentralized bioregions Pluralistic societies Humans and environment focus Commitment to nonviolence
Economic systems	Multinational corporations Competition Limitless progress "Economic development" No accounting of nature	Community-based economies Cooperation Limits to growth Steady state, sustainability Economics based on ecology
Technology	Addiction to fossil fuels Profit-driven technologies Waste overload Exploitation/consumerism	Reliance on renewables Appropriate technologies Recycling, reusing Protect and restore ecosystems
Agriculture	Monoculture farming Agribusiness, factory farms Chemical fertilizers and pesticides Vulnerable high-yield hybrids	Polyculture and permaculture Community and family farms Biological pest control Preservation of genetic diversity

*Some of these may be considered speculative attempts to understand the personal and humanistic aspects of sustainable living.
Modified from Metzner, R. (1993). The emerging ecological world view. In M. Tucker & J. Grim (Eds.), *World views and ecology* (pp. 170–171). Cranbury, NJ: Associated University Presses.