

Daniel B. Botkin | Edward A. Keller

ENVIRONMENTAL SCIENCE

EARTH AS A LIVING PLANET

Ninth Edition



WILEY

This page intentionally left blank

WileyPLUS

WileyPLUS is a research-based online environment for effective teaching and learning.

WileyPLUS builds students' confidence because it takes the guesswork out of studying by providing students with a clear roadmap:

- what to do
- how to do it
- if they did it right

It offers interactive resources along with a complete digital textbook that help students learn more. With *WileyPLUS*, students take more initiative so you'll have greater impact on their achievement in the classroom and beyond.



For more information, visit www.wileyplus.com

Now available for



Blackboard

WileyPLUS

ALL THE HELP, RESOURCES, AND PERSONAL SUPPORT YOU AND YOUR STUDENTS NEED!

www.wileyplus.com/resources

1st DAY OF
CLASS
... AND BEYOND!

2-Minute Tutorials and all of the resources you and your students need to get started

WileyPLUS

Student
Partner
Program

Student support from an experienced student user

Wiley Faculty Network



Collaborate with your colleagues, find a mentor, attend virtual and live events, and view resources

www.WhereFacultyConnect.com

WileyPLUS

Quick
Start

Pre-loaded, ready-to-use assignments and presentations created by subject matter experts



Technical Support 24/7
FAQs, online chat,
and phone support

www.wileyplus.com/support



© Courtney Keating/Stockphoto

Your *WileyPLUS* Account Manager,
providing personal training
and support

NINTH EDITION

Environmental Science

Earth as a Living Planet

Daniel B. Botkin

Professor (Adjunct)
Department of Biology
University of Miami
Coral Gables, FL

Professor Emeritus
Department of Ecology, Evolution, and Marine Biology
University of California, Santa Barbara

Edward A. Keller

Professor of Environmental Studies and Earth Science
University of California, Santa Barbara

WILEY

VICE PRESIDENT AND PUBLISHER Petra Recter
EXECUTIVE EDITOR Ryan Flahive
ASSISTANT EDITOR Elizabeth Baird
EDITORIAL ASSISTANT Chloe Moffett
CONTENT MANAGER Juanita Thompson
MARKETING MANAGER Clay Stone
CREATIVE DIRECTOR Harry Nolan
SENIOR PRODUCTION EDITOR Trish McFadden
DESIGNER Wendy Lai
SENIOR PHOTO EDITOR Billy Ray

COVER PHOTOS: Main photo: ©Hal Bergman Photography/Flickr/Getty Images
Inset photos (from left to right): Stock Image ©Anton Balazh 2011/istock;
©ssguy/Shutterstock; ©Sean Randall/Getty Images, Inc.; ©George Doyle/Getty Images, Inc.

This book was set in Adobe Garamond by cMPreparé and printed and bound by Courier/Kendallville. The cover was printed by Courier/Kendallville.

This book is printed on acid-free paper.

Founded in 1807, John Wiley & Sons, Inc. has been a valued source of knowledge and understanding for more than 200 years, helping people around the world meet their needs and fulfill their aspirations. Our company is built on a foundation of principles that include responsibility to the communities we serve and where we live and work. In 2008, we launched a Corporate Citizenship Initiative, a global effort to address the environmental, social, economic, and ethical challenges we face in our business. Among the issues we are addressing are carbon impact, paper specifications and procurement, ethical conduct within our business and among our vendors, and community and charitable support. For more information, please visit our website: www.wiley.com/go/citizenship.

Copyright © 2014, 2011, 2010, 2008 John Wiley & Sons, Inc. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (website www.copyright.com). Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030-5774, (201) 748-6011, fax (201) 748-6008, or online at: www.wiley.com/go/permissions.

Evaluation copies are provided to qualified academics and professionals for review purposes only, for use in their courses during the next academic year. These copies are licensed and may not be sold or transferred to a third party. Up on completion of the review period, please return the evaluation copy to Wiley. Return instructions and a free of charge return shipping label are available at www.wiley.com/go/returnlabel. Outside of the United States, please contact your local representative.

Library of Congress Cataloging-in-Publication Data:

ISBN-13: 978-1-118-42732-3
BRV ISBN: 978-1-118-29197-9

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Preface

What Is Environmental Science?

Environmental science is a group of sciences that attempt to explain how life on the Earth is sustained, the causes of environmental problems, and how these problems can be solved.

Why Is This Study Important?

- We depend on our environment. We enjoy it and the condition of our environment has a large effect on the quality of our lives. People can only live in an environment with certain kinds of characteristics and within certain ranges of availability of resources. Because modern science and technology give us the power to affect the environment, we have to understand how the environment works, so that we can live within its constraints.
- People have always been fascinated with nature, which, in its broadest view, is our environment. As long as people have written, they have asked three questions about ourselves and nature:
 - What is nature like when it is undisturbed by people?
 - What are the effects of people on nature?
 - What are the effects of nature on people?

Environmental science is our modern way of seeking answers to these questions.

What Is the “Science” in Environmental Science?

Many sciences are important to environmental science. These include biology (especially ecology, the part of biology that deals with the relationships among living things and their environment), geology, hydrology, climatology, meteorology, oceanography, and soil science.

How Is Environmental Science Different from other Sciences?

It involves many sciences.

It includes sciences, but also involves related nonscientific fields that have to do with how we value the environment, from environmental philosophy to environmental economics.

It deals with many topics that have great emotional effect on people, and therefore are subject to political debate and to strong feelings that often ignore scientific information.

What Is Your Role as a Student and as a Citizen?

Your role is to understand how to think through environmental issues so that you can arrive at your own conclusions.

What Are the Professions That Grow Out of Environmental Science?

Many professions have grown out of the modern concern with environment, or have been extended and augmented by modern environmental sciences. These include park, wildlife, and wilderness management; urban planning and design; landscape planning and design; conservation and sustainable use of our natural resources; pollution control; environmental energy engineering.

Goals of This Book

Environmental Science: Earth as a Living Planet provides an up-to-date introduction to the study of the environment. Information is presented in an interdisciplinary perspective necessary to deal successfully with environmental problems. The goal is to teach you, the student, how to think through environmental issues.

Critical Thinking

We must do more than simply identify and discuss environmental problems and solutions. To be effective, we must know what science is and is not. Then, we need to develop critical thinking skills. Critical thinking is so important that we have made it the focus of its own chapter, Chapter 2. With this need in mind, we have also developed *Environmental Science* to present the material in a factual and unbiased format. Our goal is to help you think through the issues, not tell you what to think. To this purpose, at the end of each chapter, we present “Critical Thinking Issues.” Critical thinking is further emphasized throughout the text in analytical discussions of topics, evaluation of perspectives, and integration of important themes, which are described in detail later.

Interdisciplinary Approach

The approach of *Environmental Science* is interdisciplinary in nature. Environmental science integrates many disciplines, including the natural sciences, in addition to fields such as anthropology, economics, history, sociology, and philosophy of the environment. Not only do we need the best ideas and information to deal successfully with our environmental problems, but we also must be aware of the cultural and historical contexts in which we make decisions about the environment. Thus, the field of environmental science also integrates the natural sciences with environmental law, environmental impact, and environmental planning.

Themes

Our book is based on the philosophy that six threads of inquiry are of particular importance to environmental science. These key themes—human population, sustainability, global perspective, urban world, people and nature, and science and values—are woven throughout the book.

These six key themes are discussed in more detail in Chapter 1. They are also revisited at the end of each chapter and are emphasized in the Closer Look boxes, each of which is highlighted by an icon suggesting the major underlying theme of the discussion. In many cases, more than one theme is relevant.

Human Population



Underlying nearly all environmental problems is the rapidly increasing human population. Ultimately, we cannot expect to solve environmental problems unless the total number of people on Earth is an amount the environment can sustain. There is considerable debate about what are practical limits to what can be sustained.

Sustainability



Sustainability means that a resource is used in a way that it continues to be available. However, the term is used vaguely, and it is a concept experts continually struggle to clarify. Some would define it as ensuring that future generations have equal opportunities to access the resources that our planet offers. Others would argue that sustainability refers to types of developments that are economically viable, do not harm the environment, and are socially just. We all agree that we must learn how to sustain our environmental resources so that they continue to provide benefits for people and other living things on our planet.

A Global Perspective



Until recently, it was common to believe that human activity caused only local, or at most regional, environmental change. We now know that human activities can affect the environment globally. An emerging science known as Earth System Science seeks a basic understanding of how our planet's environment works as a global system. This understanding can then be applied to help solve global environmental problems. The emergence of Earth System Science has opened up a new area of inquiry for faculty and students.

The Urban World



An ever-growing number of people are living in urban areas. Unfortunately, our urban centers have long been neglected, and the quality of the urban environment has suffered. It is here that we experience the worst of air pollution, waste-disposal problems, and other stresses on the environment. In the past our studies of the environment have focused more on wilderness than on the urban environment. In the future we must place greater emphasis on towns and cities as livable environments.

People and Nature



People seem to be always interested—amazed, fascinated, pleased, curious—in our environment. Why is it suitable for us? How can we keep it that way? We know that people and our civilizations are having major effects on the environment, from local effects (the street where you live) to the entire planet (we have created a hole in the Earth's ozone layer), which can affect us and many forms of life.

Science and Values



Finding solutions to environmental problems involves more than simply gathering facts and understanding the scientific issues of a particular problem. It also has much to do with our systems of values and issues of social justice. To solve our environmental problems, we must understand what our values are and which potential solutions are socially just. Then we can apply scientific knowledge about specific problems and find acceptable solutions.

Special Features

In writing *Environmental Science* we have designed a text that incorporates a number of special features that we believe will help teachers to teach and students to learn. These include the following:

A **Case Study** introduces each chapter. The purpose of this feature is to interest students in the chapter's subject and to raise important questions on the subject matter. For example, in Chapter 11, Agriculture, Aquaculture, and Environment, the opening case study tells about a farmer feeding his pigs trail mix, banana chips, yogurt-covered raisins, dried papaya, and cashews because growing corn for biofuels is raising the costs of animal feed so much.

Learning Objectives at the beginning of each chapter challenge students to apply the knowledge in the chapter to solve some problems and to integrate the chapter's materials.

A **Closer Look** is the name of special learning modules that present more detailed information concerning a particular concept or issue. For example, A Closer Look 13.2 discusses the reasons for conserving endangered species.

Many of these special features contain **figures** and **data** designed to enrich the reader's understanding and relate back to the book themes.

Near the end of each chapter, a **Critical Thinking Issue** encourages critical thinking about the environment, helping students understand how the issue may be studied and evaluated. For example, Chapter 22 presents a critical thinking issue title "How Can Urban Sprawl Be Controlled?"

Following the Summary, a special section, **Reexamining Themes and Issues**, reinforces the six major themes of the textbook.

Study Questions for each chapter provide a study aid, emphasizing critical thinking.

Further Readings are provided with each chapter so that students may expand their knowledge by reading additional sources of information (both print and electronic) on the environment.

References cited in the text are provided at the end of each chapter as notes for each chapter. These are numbered according to their citation in the text. We believe it's important that introductory textbooks carefully cite sources of information used in the writing. These sources are provided to help students recognize those scholars whose work we depend on, and to encourage students to draw upon these references as needed for additional reading and research.

Changes in the Ninth Edition

Environmental science is a rapidly developing set of fields and our scientific understanding of the environment is also changing rapidly. Even the kinds of connections between science and our ways of life change. In addition, the environment itself is changing rapidly: Populations grow; species become threatened or released from near extinction; our actions change. To remain contemporary, a textbook in environmental science requires frequent updating, and with this edition we have examined the entire text and worked to streamline and update every chapter.

Other changes in the ninth edition include the following:

- Several chapters have been deleted and their material integrated into other chapters, to shorten the book and make it more readable.
- Biological Production and Ecosystem Energy Flow material now integrated into new Ecosystems and Ecological Restoration chapters.
- Economics and Environment Chapter has been moved to the third chapter, because this is so basic to the entire discussion of environmental science applications.
- Revision of the basic energy and fossil fuel chapters to reflect the tremendous changes that have occurred as a result of exploiting the oil and natural gas resources that have become available in the United States.
- An updated Global Change that presents a balanced coverage of this important Environmental Science topic.
- New Case Studies have been added, including “Conservation Concessions: How to Save 200,000 Acres of Tropical Rainforest,” “Pacific Salmon: Iconic Fish of the Pacific Northwest,” and “Air Pollution in China 2013.”
- An in-depth discussion about the processes of learning and discovery in Environmental Science, with steps to creative thinking and higher cognitive abilities.
- New and updated Closer Look Boxes, and Critical Thinking Issues.
- Learning Objectives for each chapter have been completely revised to provide the student with challenging activities.

Updated features help engage students in the key issues and topics of environmental science, and provide resources for instructors to foster dynamic in-class discussion

Augmentation of WebSite References

Valid information is becoming increasingly available via the Web, and easy access to this data is of great value. Government data that used to take weeks of library research to find are available almost instantly on the Internet Web site. For this reason, we have greatly augmented the number of website references and have gathered them all on the book's companion site.

Updated Case Studies

Each chapter begins with a case study that helps the student learn about the chapter's topic through a specific example. A major improvement in the ninth edition is the replacement of some older case studies with new ones that discuss current issues and are more closely integrated into the chapter.

Updated Critical Thinking Issues

Each chapter ends with a discussion of an environmental issue, with critical thinking questions for the students. This is one of the ways that the text is designed to help students learn to think for themselves about the analysis of environmental issues. Answers to the end of chapter questions are available for instructor use with the Instructors Manual.

Support

Environmental Science, Ninth Edition, features a full line of teaching and learning resources developed to help professors create a more dynamic and innovative learning environment. For students, we offer tools to build their ability to think clearly and critically.

For Students WileyPLUS

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

Integrated multimedia resources include:

- **Environmental Science Basics** provides a suite of animated concepts and tutorials to give students a solid grounding in key basic environmental concepts. Concepts ranging from global climate change to sustainable agriculture are presented across 21 modules in easy-to-understand language.
- **Environmental Science Videos** cover the current key stories relating to environmental science; they include clips from the BBC and CBS news.
- **Virtual Field Trip Videos** allow students to go to different places around the world and gain a better understanding of

the environment and our impact on it. Through these video-based field trips, students gain virtual on-the-ground experience using their WileyPLUS course

- **Animations.** Select text concepts are illustrated using flash animations for student self-study or classroom presentation.
- **Virtual Discovery Labs.** These select Virtual Labs bring core laboratory concepts to life in an online lab setting.

For Instructors

Instructor's Manual

The Instructor's Manual (IM), prepared by James Yount of Brevard Community College, highlights and discusses key concepts, definitions, equations, and examples from each chapter. It also provides answers to the in-text critical thinking and end-of-chapter study questions.

Test Bank

The Test Bank, updated and revised by Anthony Gaudin of Ivy Tech Community College, includes approximately 2,000 questions, in multiple-choice, short-answer, and essay formats. The Test Bank is provided in a word.doc format for your convenience to use and edit for your individual needs. For this edition, the author has created many new questions and has labeled the boxed applications according to the six themes and issues set forth in the text. In addition, the author has created questions for the theme boxes and emphasized the themes in many of the questions throughout the test bank.

Respondus Test Bank

The Respondus Test Bank provides tests and quizzes for *Environmental Science* Ninth Edition for easy publication into your LMS course, as well as for printed tests. The Respondus Test Bank includes all of the files from the Test Bank, Practice Quizzes, and Pre and Post Lecture Questions in a dynamic computerized format. *For schools without a campus-wide license to Respondus, Wiley will provide one for no additional cost.

Video Lecture Launchers

A rich collection of videos have been selected to accompany key topics in the text. Accompanying each of the videos are contextualized commentary and questions in PowerPoint format that facilitate easy in-class use.

PowerPoint™ Presentations

Prepared by Donald Williams of Park University, these presentations are tailored to the text's topical coverage and are designed to convey key concepts, illustrated by embedded text art.

Advanced Placement® Guide for Environmental Science

Prepared by Brian Kaestner of Saint Mary's Hall, this resource is available on the Instructor's Resource Web site (www.wiley.com/college/botkin). The Advanced Placement Guide provides a useful tool for high school instructors who are teaching the AP® Environmental Science course. This guide will help teachers to focus on the key concepts of every chapter to prepare students for the Advanced Placement® Exam. Each chapter includes a Chapter Overview that incorporates critical thinking questions, Key Topics important to the exam, and Web links to Laboratories and Activities that reinforce key topics.

Book Companion Site

All instructor resources (the Test Bank, Instructor's Manual, PowerPoint presentations, and all textbook illustrations and photos in jpg format) are housed on the book companion site (www.wiley.com/college/botkin). Student resources include self quizzes and flashcards.

Also Available

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

Brief Contents

Chapter 1 Key Themes in Environmental Sciences	1	Chapter 14 Energy: Some Basics	317
Chapter 2 Science as a Way of Knowing: Critical Thinking about the Environment	22	Chapter 15 Fossil Fuels and the Environment	336
Chapter 3 Dollars and Environmental Sense: Economics of Environmental Issues	43	Chapter 16 Alternative Energy and the Environment	365
Chapter 4 The Big Picture: Systems of Change	60	Chapter 17 Nuclear Energy and the Environment	387
Chapter 5 The Human Population and the Environment	81	Chapter 18 Water Supply, Use, and Management	412
Chapter 6 Ecosystems: Concepts and Fundamentals	103	Chapter 19 Water Pollution and Treatment	444
Chapter 7 The Biogeochemical Cycles	131	Chapter 20 The Atmosphere and Climate Change	478
Chapter 8 Environmental Health, Pollution, and Toxicology	157	Chapter 21 Air Pollution	514
Chapter 9 Biological Diversity and Biological Invasions	185	Chapter 22 Urban Environments	552
Chapter 10 Ecological Restoration	214	Chapter 23 Materials Management	576
Chapter 11 Agriculture, Aquaculture, and the Environment	233	Chapter 24 Our Environmental Future	611
Chapter 12 Landscapes: Forests, Parks and Wilderness	260	Appendix	A-1
Chapter 13 Wildlife, Fisheries, and Endangered Species	285	Glossary	G-1
		Index	I-1

Contents

Chapter 1 Key Themes in Environmental Sciences 1



CASE STUDY Pacific Salmon: Iconic Fish of the Pacific Northwest 2

1.1 Major Themes of Environmental Science 4

1.2 Human Population Growth 5

Our Rapid Population Growth 5

■ A CLOSER LOOK 1.1 A Little Environmental History 5

Famine and Food Crisis 6

Human Population and the Incidence of Natural Disasters 7

The Age of Abundance and Human Population Increase 8

1.3 Sustainability and Carrying Capacity 8

Sustainability: The Environmental Objective 8

Moving Toward Sustainability: Some Criteria 9

The Carrying Capacity of Earth 10

1.4 A Global Perspective 10

1.5 An Urban World 11

Cities Can Help with Some of Our Environmental Problems 11

1.6 People and Nature 12

1.7 Science and Values 13

Selected Intellectual Standards 13

Learning and Discovery in Environmental Science 14

The Precautionary Principle 15

Placing a Value on the Environment 16



CRITICAL THINKING ISSUE EASTER ISLAND 17

Summary 19

Reexamining Themes and Issues 19

Key Terms 20

Study Questions 20

Further Reading 20

Chapter 2 Science as a Way of Knowing: Critical Thinking about the Environment 22



CASE STUDY Birds at Mono Lake: Applying Science to Solve an Environmental Problem 23

2.1 Understanding What Science Is—and What It Isn't 24

Science as a Way of Knowing 26

Disprovability 26

■ A CLOSER LOOK 2.1 The Case of the Mysterious

Crop Circles 27

2.2 Observations, Facts, Inferences, and Hypotheses 28

Controlling Variables 28

The Nature of Scientific Proof 29

Theory in Science and Language 30

Models and Theory 31

Some Alternatives to Direct Experimentation 31

Uncertainty in Science 32

Leaps of Imagination and Other Nontraditional Aspects of the Scientific Method 32

2.3 Measurements and Uncertainty 32

A Word about Numbers in Science 32

Dealing with Uncertainties 33

Accuracy and Precision 33

■ A CLOSER LOOK 2.2 Measurement of Carbon Stored in Vegetation 34

2.4 Misunderstandings about Science and Society 35

Science and Decision Making 35

Science and Technology 35

Science and Objectivity 35

Science, Pseudoscience, and Frontier Science 37

2.5 Environmental Questions and the Scientific Method 37



CRITICAL THINKING ISSUE HOW DO WE DECIDE WHAT TO BELIEVE ABOUT ENVIRONMENTAL ISSUES? 38

Summary 39

Reexamining Themes and Issues 39

Key Terms 40

Study Questions 40

Further Reading 41

Chapter 3 Dollars and Environmental Sense: Economics of Environmental Issues 43



CASE STUDY How Conservation Can Be an Economic Benefit 44

3.1 Overview of Environmental Economics 45

3.2 Public-Service Functions of Nature 45

3.3 The Environment as a Commons 46

3.4 Low Growth Rate and Therefore Low Profit as a Factor in Exploitation 48

Scarcity Affects Economic Value 49

3.5 Externalities 49

3.6 Valuing the Beauty of Nature 50

3.7 How Is the Future Valued? 51

3.8 Risk-Benefit Analysis 52



CRITICAL THINKING ISSUE GEORGES BANK: HOW CAN U.S. FISHERIES BE MADE SUSTAINABLE? 55

Summary 56

Reexamining Themes and Issues 56

Key Terms 57

Study Questions 57

Chapter 4

The Big Picture: Systems of Change 60



CASE STUDY **Amboseli National Reserve: A Story of Change** 61

- 4.1 Basic Systems Concepts** 63
 - Static and Dynamic Systems 63
 - Open Systems 64
- **A CLOSER LOOK 4.1** Simple Systems 64
 - The Balance of Nature: Is a Steady State Natural? 68
 - Residence Time 69
 - Feedback 69
- 4.2 System Responses: Some Important Kinds of Flows** 71
 - Linear and Nonlinear Flows 71
 - Lag Time 71
 - Selected Examples of System Responses 71
- 4.3 Overshoot and Collapse** 73
- 4.4 Irreversible Consequences** 74
- 4.5 Environmental Unity** 74
- 4.6 Uniformitarianism** 75
- 4.7 Earth as a System** 75
- 4.8 Types of Change** 76



CRITICAL THINKING ISSUE IS THE GAIA HYPOTHESIS SCIENCE? 77

- Summary** 77
- Reexamining Themes and Issues** 78
- Key Terms** 79
- Study Questions** 79
- Further Reading** 79

Chapter 5

The Human Population and the Environment 81



CASE STUDY **Your Future** 82

- 5.1 Basic Concepts of Population Dynamics** 82
 - The Human Population as an Exponential Growth Curve 83
- **A Closer Look 5.1** A Brief History of Human Population Growth 85
- 5.2 Analyzing and Estimating Future Population Growth** 86
 - Exponential Growth and Doubling Time 86
 - Human Population as a Logistic Growth Curve 86
- **A CLOSER LOOK 5.2** The Prophecy of Malthus 88
- 5.3 Age Structure** 89
- 5.4 The Demographic Transition** 90
 - Potential Effects of Medical Advances on the Demographic Transition 92
- 5.5 Longevity and Its Effect on Population Growth** 92
 - Human Death Rates and the Rise of Industrial Societies 93

■ **A CLOSER LOOK 5.3** Pandemics And World Population Growth: West Nile Virus 93

- 5.6 The Human Population's Effects on the Earth** 95
- 5.7 Estimating How Many People Could Live on Earth** 95
- 5.8 Can We Achieve Zero Population Growth?** 97
 - Age of First Childbearing 97
 - Birth Control: Biological and Societal 97
 - National Programs to Reduce Birth Rates 97



CRITICAL THINKING ISSUE WILL THE DEMOGRAPHIC TRANSITION HOLD IN THE UNITED STATES? 98

- Summary** 99
- Reexamining Themes and Issues** 99
- Key Terms** 100
- Study Questions** 100
- Further Reading** 101

Chapter 6

Ecosystems: Concepts and Fundamentals 103




CASE STUDY **The Acorn Connection** 104

- 6.1 The Ecosystem: Sustaining Life on Earth** 106
 - Basic Characteristics of Ecosystems 106
 - 6.2 Ecological Communities and Food Chains** 107
 - A Simple Ecosystem 107
 - **A CLOSER LOOK 6.1** Sea Otters, Sea Urchins, and Kelp: Indirect Effects of Species on One Another 109
 - An Oceanic Food Chain 111
 - Food Webs Can Be Complex: The Food Web of the Harp Seal 111
 - 6.3 Ecosystems as Systems** 112
 - **A CLOSER LOOK 6.2** Land and Marine Food Webs 113
 - 6.4 Biological Production and Ecosystem Energy Flow** 114
 - The Laws of Thermodynamics and the Ultimate Limit on the Abundance of Life 116
 - 6.5 Biological Production and Biomass** 118
 - Measuring Biomass and Production 118
 - 6.6 Energy Efficiency and Transfer Efficiency** 119
 - 6.7 Ecological Stability and Succession** 120
 - Patterns in Succession 121
 - 6.8 Chemical Cycling and Succession** 124
 - 6.9 How Species Change Succession** 125
 - Facilitation 125
 - Interference 125
 - Life History Differences 126
- **CRITICAL THINKING ISSUE** SHOULD PEOPLE EAT LOWER ON THE FOOD CHAIN? 126
- Summary** 127
 - Reexamining Themes and Issues** 127
 - Key Terms** 128
 - Study Questions** 129
 - Further Reading** 129

Chapter 7 The Biogeochemical Cycles 131

 **CASE STUDY** Recent Decline and Rise of Oysters in The Pacific Northwest 132

- 7.1 Earth, Life, and Chemistry** 133
 - Earth is a Peculiar Planet 133
 - Space Travelers and Our Solar System 134
 - The Fitness of the Environment 135
 - The Rise of Oxygen 135
 - Life Responds to an Oxygen Environment 135
- 7.2 Life and Global Chemical Cycles** 137
- 7.3 General Aspects of Biogeochemical Cycles** 138
 - **A CLOSER LOOK 7.1** Basic Chemistry for Environmental Science 138
- 7.4 The Geologic Cycle** 141
 - The Tectonic Cycle 142
 - The Hydrologic Cycle 143
 - The Rock Cycle 144
- 7.5 Some Major Global Biogeochemical Cycles** 145
 - The Carbon Cycle 145
 - The Carbon–Silicate Cycle 148
 - The Nitrogen Cycle 148
 - The Phosphorus Cycle 150

 **Critical Thinking Issue** HOW ARE HUMAN ACTIVITIES LINKED TO THE PHOSPHORUS AND NITROGEN CYCLES? 152

- Summary** 153
- Reexamining Themes and Issues** 154
- Key Terms** 155
- Study Questions** 155
- Further Reading** 155

Chapter 8 Environmental Health, Pollution, and Toxicology 157

 **CASE STUDY** Toxic Air Pollution and Human Health: Story of a Southeast Houston Neighborhood 158

- 8.1 Some Basics** 159
 - Environmental Health 159
 - Terminology 159
 - Synergism 159
 - Point, Area, and Mobile Sources 159
 - Toxic Pathways 161
- 8.2 Categories of Pollutants and Toxins** 161
 - Infectious Agents 161
 - Toxic Heavy Metals 162
- **A CLOSER LOOK 8.1** Mercury and Minamata, Japan 164
 - Organic Compounds 165
 - Hormonally Active Agents (HAAs) 166
 - Nuclear Radiation 167
 - Thermal Pollution 167
- **A CLOSER LOOK 8.2** Demasculinization and Feminization of Frogs 168
 - Particulates 169
 - Asbestos 170

- Electromagnetic Fields 170
- Noise Pollution 171

- 8.3 Measuring the Amount of Pollution** 172
- 8.4 Old and New Environmental Health Problems** 172
 - Epidemics and Pandemics 172
 - Social Conditions and the Spread of Disease 173
- 8.5 General Effects of Pollutants** 174
 - Concept of Dose and Response 175
 - Dose-Response Curve (LD-50, ED-50, and TD-50) 175
 - Threshold Effects 176
 - Ecological Gradients 177
 - Tolerance 177
 - Acute and Chronic Effects 177

8.6 Risk Assessment 177



CRITICAL THINKING ISSUE IS LEAD IN THE URBAN ENVIRONMENT CONTRIBUTING TO ANTISOCIAL BEHAVIOR AND HEALTH PROBLEMS IN

- CHILDREN? 178
- Summary** 180
- Reexamining Themes and Issues** 181
- Key Terms** 181
- Study Questions** 182
- Further Reading** 182

Chapter 9 Biological Diversity and Biological Invasions 185

 **CASE STUDY** Citrus Greening 186

- 9.1 What Is Biological Diversity?** 187
 - Why Do People Value Biodiversity? 188
- 9.2 Biological Diversity Basics** 189
 - The Number of Species on Earth 189
- 9.3 Biological Evolution** 191
 - The Four Key Processes of Biological Evolution 192
- **A CLOSER LOOK 9.1** Natural Selection: Mosquitoes and the Malaria Parasite 193
 - Biological Evolution as a Strange Kind of Game 196
- 9.4 Competition and Ecological Niches** 197
 - The Competitive Exclusion Principle 197
 - Niches: How Species Coexist 198
 - Measuring Niches 199
- 9.5 Symbiosis** 200
 - A Broader View of Symbiosis 200
 - A Practical Implication 200
- 9.6 Predation and Parasitism** 201
 - A Practical Implication 201
- 9.7 How Geography and Geology Affect Biological Diversity** 201
 - Wallace's Realms and Biotic Provinces 202
 - Biomes 204
 - Convergent and Divergent Evolution 204
- 9.8 Invasions, Invasive Species, and Island Biogeography** 206
 - Biogeography and People 207

 **CRITICAL THINKING ISSUE** POLAR BEARS AND THE REASONS PEOPLE VALUE BIODIVERSITY 208

- Summary 210
- Reexamining Themes and Issues 210
- Key Terms 211
- Study Questions 211
- Further Reading 212

Chapter 10 Ecological Restoration 214

-  **CASE STUDY** The Florida Everglades 215
- 10.1 What Is Ecological Restoration?** 217
- 10.2 Goals of Restoration: What Is “Natural”?** 218
- 10.3 What Is Usually Restored?** 219
 - Rivers, Streams, and Wetlands Restoration: Some Examples 219
 - Prairie Restoration 223
- **A CLOSER LOOK 10.1** Island Fox on Santa Cruz Island 224
- 10.4 Applying Ecological Knowledge to Restore Heavily Damaged Lands and Ecosystems** 225
- 10.5 Criteria Used to Judge the Success of Restoration** 227
-  **CRITICAL THINKING ISSUE** HOW CAN WE EVALUATE CONSTRUCTED ECOSYSTEMS? 227

- Summary 229
- Reexamining Themes and Issues 229
- Key Terms 230
- Study Questions 230
- Further Reading 231

Chapter 11 Agriculture, Aquaculture, and the Environment 233

-  **CASE STUDY** No-Till Versus the Plow 234
- 11.1 An Ecological Perspective on Agriculture** 234
- 11.2 Can We Feed the World?** 236
 - How We Starve 237
- 11.3 What We Grow on the Land** 238
 - Crops 238
 - Livestock: The Agriculture of Animals 240
- 11.4 Soils** 243
 - Restoring Our Soils 244
- **A CLOSER LOOK 11.1** The Great American Dust Bowl 245
 - Agricultural Sustainability 246
- 11.5 Controlling Pests** 247
 - Pesticides 247
- 11.6 The Future of Agriculture** 249
 - Increased Production per Acre 249
 - Increased Farmland Area 249
 - New Crops and Hybrids 250

- Better Irrigation 250
- Organic Farming 250
- Eating Lower on the Food Chain 251

- 11.7 Genetically Modified Food: Biotechnology, Farming, and Environment** 251
 - The Terminator Gene 252
 - Transfer of Genes from One Major Form of Life to Another 253

- 11.8 Aquaculture** 253
 - Some Negatives 254

 **CRITICAL THINKING ISSUE** SHOULD RICE BE GROWN IN A DRY CLIMATE? 254

- Summary 255
- Reexamining Themes and Issues 256
- Key Terms 257
- Study Questions 258
- Further Reading 258

Chapter 12 Landscapes: Forests, Parks, and Wilderness 260

 **CASE STUDY** Jamaica Bay National Wildlife Refuge: Nature and the Big City 261

- 12.1 Forests** 262
 - How People Have Viewed Forests 262
- 12.2 Forestry** 262
 - Modern Conflicts over Forestland and Forest Resources 262
- 12.3 World Forest Area and Global Production and Consumption of Forest Resources** 264
- 12.4 How Forests Affect the Whole Earth** 265
- 12.5 The Ecology of Forests** 266
- **A CLOSER LOOK 12.1** The Life of a Tree 267
- 12.6 Forest Management** 268
 - A Forester’s View of a Forest 268
 - Harvesting Trees 268
 - Plantations 269
- 12.7 Can We Achieve Sustainable Forestry?** 270
 - Certification of Forest Practices 270
- 12.8 Deforestation** 270
 - History of Deforestation 271
 - Causes of Deforestation 272
- 12.9 Dealing with Forest Fires** 272
- 12.10 Parks, Nature Preserves, and Wilderness** 274
 - What’s the Difference between a Park and a Nature Preserve? 274
- **A CLOSER LOOK 12.2** A Brief History of Parks Explains Why Parks Have Been Established 275
 - Conflicts Relating to Parks 277
- 12.11 Conserving Wilderness** 278
 - What It Is, and Why It Is of Growing Importance 278
 - Conflicts in Managing Wilderness 279
-  **CRITICAL THINKING ISSUE** CAN TROPICAL FORESTS SURVIVE IN BITS AND PIECES? 280

- Summary 281

Reexamining Themes and Issues 281
Key Terms 282
Study Questions 282
Further Reading 283

Chapter 13 Wildlife, Fisheries, and Endangered Species 285

 **CASE STUDY** *How Can There Be Both Too Few and Too Many Wildlife?* 286

13.1 Traditional Single-Species Wildlife Management 286
 Carrying Capacity and Sustainable Yields 286
 An Example of Problems with the Logistic Curve 288

13.2 Improved Approaches to Wildlife Management 289
 Time Series and Historical Range of Variation 289
 Age Structure as Useful Information 290

■ **A CLOSER LOOK 13.1** *Stories Told by the Grizzly Bear and the Bison* 291
 Harvests as an Estimate of Numbers 293

13.3 Fisheries 294
 The Decline of Fish Populations 296

■ **A CLOSER LOOK 13.2** *Chesapeake Bay, One of the World's Great Fisheries* 296
 Can Fishing Ever Be Sustainable? 298

■ **A CLOSER LOOK 13.3** *Reasons for Conserving Endangered Species—and All Life on Earth* 299

13.4 Endangered Species: Current Status 301

13.5 How a Species Becomes Endangered and Extinct 303
 Causes of Extinction 304

13.6 The Good News: We Have Improved the Status of Some Species 304


■ **A CLOSER LOOK 13.4** *Conservation of Whales and Other Marine Mammals* 306

13.7 Can a Species Be Too Abundant? If So, What to Do? 308

13.8 How People Cause Extinctions and Affect Biological Diversity 308

13.9 Ecological Islands and Endangered Species 308

13.10 Using Spatial Relationships to Conserve Endangered Species 309

 **CRITICAL THINKING ISSUE** *SHOULD WOLVES BE REESTABLISHED IN THE ADIRONDACK PARK?* 310

Summary 311
Reexamining Themes and Issues 312
Key Terms 313
Study Questions 313
Further Reading 314

Chapter 14 Energy: Some Basics 317

 **CASE STUDY** *Racing with the Sun (Power)* 318

14.1 Outlook for Energy 318
 Energy Today and Tomorrow 318
 Can the United States Achieve Energy Independence? When? How? 319

14.2 Energy Basics 320

14.3 Energy Efficiency 321

■ **A CLOSER LOOK 14.1** *Energy Units* 322

14.4 Energy Sources and Consumption 324
 Fossil Fuels and Alternative Energy Sources 324


14.5 Energy Conservation, Increased Efficiency, and Cogeneration 326
 Building Design 327
 Industrial Energy 327
 Values, Choices, and Energy Conservation 328

14.6 Sustainable-Energy Policy 329
 Energy for Tomorrow 329

 **CRITICAL THINKING ISSUE** *USE OF ENERGY TODAY AND IN 2030* 331

Summary 332
Reexamining Themes and Issues 333
Key Terms 334
Study Questions 334
Further Reading 334

Chapter 15 Fossil Fuels and the Environment 336

 **CASE STUDY** *Oil Boom in North Dakota* 337

15.1 Fossil Fuels 338

15.2 Oil 338
 Conventional and Continuous Oil and Gas Resources 338
 Continuous Oil Resources 338
 Tar Sands and Shale Oil 340
 Production of Oil 341
 Oil in the 21st Century 341

15.3 Natural Gas 342
 Shale Gas 343
 Methane 343

■ **A CLOSER LOOK 15.1** *Hydrologic Fracturing To Recover Oil And Gas* 344
 Tight Gas 347
 Coal-bed Methane 347
 Methane Hydrates 348

15.4 The Environmental Effects of Oil and Natural Gas 348
 Recovery 348
 Refining 349
 Delivery and Use 349

■ **A CLOSER LOOK 15.2** *The Oil Spill in the Gulf of Mexico, 2010* 350

15.5 Coal 354
 Coal Mining and the Environment 354
 Mountaintop Removal 357
 Underground Mining 358
 Transporting Coal 358
 The Future of Coal 358


 **CRITICAL THINKING ISSUE** U.S. OIL SUPPLY FOR THE FUTURE 361

- Summary** 361
Reexamining Themes and Issues 362
Key Terms 363
Study Questions 363
Further Reading 363

Chapter 16

Alternative Energy and the Environment 365

 **CASE STUDY** Alternative Energy on Public Lands in the American Southwest: Good Idea or a Conflict Among Environmentalists? 366


- 16.1 Introduction to Alternative Energy Sources** 367
- 16.2 Solar Energy** 367
 Passive Solar Energy 368
 Active Solar Energy 369
 Solar Thermal Generators 371
 Solar Energy and the Environment 372
- 16.3 Converting Electricity from Renewable Energy into a Fuel for Vehicles** 372
 Producing Liquid and Gaseous Fuels from Electricity. 372
- **A CLOSER LOOK 16.1** Fuel Cells—An Attractive Alternative 372
- 16.4 Water Power** 373
 Small-Scale Hydropower Systems 373
 Water Power and the Environment 374
- 16.5 Ocean Energy** 375
 New Ocean Energy Technologies 375
- 16.6 Wind Power** 377
 Basics of Wind Power 377
 Wind Power and the Environment 379
 The Future of Wind Power 379
- 16.7 Biofuels** 379
 Biofuels and Human History 379
 Biofuels and the Environment 380
- 16.8 Geothermal Energy** 381
 Geothermal Systems 381
 Geothermal Energy and the Environment 382
 The Future of Geothermal Energy 382
-  **CRITICAL THINKING ISSUE** SHOULD GOVERNMENTS SUPPORT RENEWABLE ENERGY? 383

- Summary** 384
Reexamining Themes and Issues 384
Key Terms 385
Study Questions 385
Further Reading 386

Chapter 17

Nuclear Energy and the Environment 387

 **CASE STUDY** JAPAN 2011: AFTERMATH OF A NUCLEAR DISASTER 388

- 17.1 Current Role of Nuclear Power Plants in World Energy Production** 390
- 17.2 What Is Nuclear Energy?** 390
 Conventional Nuclear Reactors 390
- **A CLOSER LOOK 17.1** Radioactive Decay 393
- 17.3 Nuclear Energy and the Environment** 396
 Problems with the Nuclear Fuel Cycle 396
- 17.4 Nuclear Radiation in the Environment and Its Effects on Human Health** 397
 Ecosystem Effects of Radioisotopes 397
- **A CLOSER LOOK 17.2** Radiation Units and Doses 399
 Radiation Doses and Health 401
- 17.5 Nuclear Power Plant Accidents** 401
 Three Mile Island 401
 Chernobyl 402
 Japan's Nuclear Accident, 2011 403
- 17.6 Radioactive-Waste Management** 404
 Low-Level Radioactive Waste 404
 High-Level Radioactive Waste 404
 What Should the United States Do with Its Nuclear Wastes? 404
- 17.7 The Future of Nuclear Energy** 405
 New Kinds of Fission Reactors 406
 Fusion Reactors 406
-  **CRITICAL THINKING ISSUE** INDIAN POINT: SHOULD A NUCLEAR POWER INSTALLATION OPERATE NEAR ONE OF AMERICA'S MAJOR CITIES? 407

- Summary** 408
Reexamining Themes and Issues 409
Key Terms 410
Study Questions 410
Further Reading 410

Chapter 18

Water Supply, Use, and Management 412

 **CASE STUDY** Singapore Water Supply: Emergence of a Water Ethic 413

- 18.1 Water** 415
 A Brief Global Perspective 415
 Groundwater and River/Stream Flow 416
 Interactions between Surface Water and Groundwater 418
- 18.2 Water Resources** 418
 Surface Runoff 419
 Groundwater Resources 420
 Water Reuse as a Water Resource 420
 Water Conservation as a Water Source 421
 Desalination as a Water Resource 421
- 18.3 Water Use** 421
 Transport of Water 423
 Transfer of Water: Real and Virtual 423
 Real Water 424
 Virtual Water 424
 Water Footprint 425
 Some Trends in Water Use 425
- 18.4 Water Conservation** 428
 Agricultural Use—Suggestions 428
 Public Supply and Domestic Use 428
 Industry and Manufacturing Use 430


18.5 Sustainability and Water Management 430
Sustainable Water Use 430

■ **A CLOSER LOOK 18.1** Palm Beach County, Florida: Water Use, Conservation, and Reuse 431
Water Management 431
Water Management and the Environment 432

18.6 Wetlands 432
Natural Service Functions of Wetlands 432
Restoration of Wetlands 434


18.7 Dams and the Environment 434
Removal of Dams 436

18.8 Global Water Shortage Linked to Food Supply 437

 **CRITICAL THINKING ISSUE** WHAT IS YOUR PERSONAL WATER USE? 438

Summary 440
Reexamining Themes and Issues 440
Key Terms 441
Study Questions 441
Further Reading 442

Chapter 19 Water Pollution and Treatment 444

 **CASE STUDY** America's "First River": A Success Story in Progress 445

19.1 Water Pollution 447

■ **A CLOSER LOOK 19.1** What Is the Value of Clean Water to New York City? 449

19.2 Biochemical Oxygen Demand (BOD) 450

19.3 Nutrients 451
Eutrophication 451

■ **A CLOSER LOOK 19.2** Cultural Eutrophication in the Gulf of Mexico 453

19.4 Waterborne Disease 454
Fecal Coliform Bacteria 454

19.5 Oil 455

19.6 Sediment 456

19.7 Acid Mine Drainage 456

19.8 Surface-Water Pollution 457

■ **A CLOSER LOOK 19.3** Water Pollution from Industrial Livestock Farms 458
Reducing Surface-Water Pollution 459

19.9 Groundwater Pollution 460

■ **A CLOSER LOOK 19.4** Water for Domestic Use: How Safe Is It? 461
Principles of Groundwater Pollution: An Example 462
Long Island, New York 463

19.10 Wastewater Treatment 464
Septic-Tank Disposal Systems 464
Wastewater Treatment Plants 464
Primary Treatment 465
Secondary Treatment 465
Advanced Wastewater Treatment 466


■ **A CLOSER LOOK 19.5** Boston Harbor: Cleaning Up a National Treasure 466
Chlorine Treatment 467

19.11 Land Application of Wastewater 467
Wastewater and Wetlands 468
Louisiana Coastal Wetlands 468
Phoenix, Arizona: Constructed Wetlands 469

19.12 Water Reuse 469


19.13 Conditions of Stream Ecosystems in the United States 470

19.14 Water Pollution and Environmental Law 471

 **CRITICAL THINKING ISSUE** CAN SAFE DRINKING WATER AND SANITATION BE PROVIDED FOR ALL PEOPLE ON EARTH? 472

Summary 473
Reexamining Themes and Issues 473
Key Terms 474
Study Questions 475
Further Reading 475

Chapter 20 The Atmosphere and Climate Change 478

 **CASE STUDY** What Does History Tell Us about Global Warming's Potential Consequences for People? 479

20.1 Origin of the Global Warming Issue 480

20.2 Twentieth-Century Methods to Reconstruct Past Temperatures 481
Historical Documents 481
Discovery of Continental Glaciation and Ice Ages: What the Rocks Told Swiss Farmers 482
Sediments 483
Tree Rings 483
Ice Cores 484
Corals 484
Carbon 14 484

20.3 How the Atmosphere Works 485
Structure of the Atmosphere 485
Atmospheric Processes: Temperature, Pressure, and Global Zones of High and Low Pressure 486
Energy and the Atmosphere: What Makes the Earth Warm? 488
Milankovitch Cycles 488
Solar Cycles 491

20.4 How Earth's Atmosphere, Oceans, and Land Affect Climate 491
Atmospheric Transparency Affects Climate and Weather 491
The Surface of Earth and Albedo Effects 491
Roughness of Earth's Surface Affects the Atmosphere 491
The Chemistry of Life Affects the Atmosphere 491

20.5 The Greenhouse Effect 492
How the Greenhouse Effect Works 492

20.6 The Major Greenhouse Gases 493
Carbon Dioxide 493
Methane 493
Chlorofluorocarbons 494
Nitrous Oxide 494

20.7 Greenhouse Gases and Climate 494

- 20.8 The Oceans and Climate Change** 494
- 20.9 Forecasting Climate Change Using Computer Simulation** 494
- 20.10 Climate Change and Feedback Loops** 496
Possible Negative Feedback Loops for Climate Change 496
Possible Positive Feedback Loops for Climate Change 497
Climate Forcing 497
- 20.11 New Understanding of the Interplay Between the Oceans and the Atmosphere** 497
El Niño and Climate 499
The “Ocean Conveyor Belt” 499
- 20.12 New Insights from the Fossil Record** 500
The Paleocene-Eocene Thermal Maximum 500
- 20.13 New Insights into Glaciers and Sea Ice** 500
- 20.14 Potential Rates of Global Climate Change** 503
How Fast Has Climate Changed in the Past? 504
- 20.15 Potential Changes in River Flow and Sea Levels** 504
Rise in Sea Level 504
- 20.16 Changes in Biological Diversity** 505
Corals 505
Agricultural Productivity 506

■ **A CLOSER LOOK 20.1** Some Animals and Plants in Great Britain Are Adjusting to Global Warming 506
Human Health Effects 507

- 20.18 Adjusting to Potential Global Warming** 507
International Agreements to Mitigate Global Warming 507



CRITICAL THINKING ISSUE GLOBAL CHANGE: CRITICAL THINKING ELEMENT 508

Summary 509

Reexamining Themes and Issues 510

Key Terms 511

Study Questions 511

Further Reading 511

Chapter 21 Air Pollution 514



CASE STUDY Beijing Air Pollution 2013 515

- 21.1 Air Pollution in the Lower Atmosphere** 515
A Brief Overview 515
Stationary and Mobile Sources of Air Pollution 515
General Effects of Air Pollution 516
The Major Air Pollutants 517
Criteria Pollutants 517

■ **A CLOSER LOOK 21.1** Acid Rain 519

■ **A CLOSER LOOK 21.2** High-Altitude (Stratospheric) Ozone Depletion 522
Air Toxics 530
Variability of Air Pollution 531
Urban Air Pollution: Chemical and Atmospheric Processes 532
Future Trends for Urban Air Pollution 534
Developing Countries 535

- 21.2 Controlling Common Pollutants of the Lower Atmosphere** 535
Particulates 535
Automobiles 535
Sulfur Dioxide 536
Air-Pollution Legislation and Standards 536
The Cost of Controlling Outdoor Air Pollution 539
Sustainable Air Quality 539

- 21.3 Indoor Air Pollution** 539
Sources of Indoor Air Pollution 541
Pathways, Processes, and Driving Forces 542
Symptoms of Indoor Air Pollution 544

- 21.4 Controlling Indoor Air Pollution** 544
Making Homes and Other Buildings Radon Resistant 545
Designing Buildings to Minimize Indoor Air Pollution 546



CRITICAL THINKING ISSUE SHOULD CARBON DIOXIDE BE REGULATED ALONG WITH OTHER MAJOR AIR POLLUTANTS? 546

Summary 547

Reexamining Themes and Issues 547

Key Terms 548

Study Questions 549

Further Reading 549

Chapter 22 Urban Environments 552



CASE STUDY Rivers, Seacoasts, And Cities 553

- 22.1 City Life** 554

- 22.2 The City as a System** 556

- 22.3 The Location of Cities: Site and Situation** 557
The Importance of Site and Situation 557

■ **A CLOSER LOOK 22.1** Should We Try to Restore New Orleans? 558
Site Modification 560

- 22.4 An Environmental History of Cities** 561
The Rise of Towns 561
The Urban Center 561
The Industrial Metropolis 561
The Center of Civilization 561

- 22.5 City Planning and the Environment** 561
City Planning for Defense and Beauty 562

■ **A CLOSER LOOK 22.2** A Brief History of City Planning 562
The City Park 563

- 22.6 The City as an Environment** 564
The Energy Budget of a City 564
The Urban Atmosphere and Climate 564
Solar Energy in Cities 564
Water in the Urban Environment 565
Soils in the City 566
Pollution in the City 566

■ **A CLOSER LOOK 22.3** Design with Nature 566

- 22.7 Cities and Their Rivers** 567
Vegetation in Cities 567
Urban “Wilds”: The City as Habitat for Wildlife and Endangered Species 568
Animal Pests 570



CRITICAL THINKING ISSUE HOW CAN URBAN SPRAWL BE CONTROLLED? 571

Summary 572
Reexamining Themes and Issues 573
Key Terms 574
Study Questions 574
Further Reading 574

Chapter 23 Materials Management 576

 **CASE STUDY Treasures of the Cell Phone** 577

23.1 The Importance of Resources to Society 578

23.2 Materials Management: What It Is 578

23.3 Mineral Resources 580
How Mineral Deposits Are Formed 580

23.4 Figuring Out How Much Is Left 581
Mineral Resources and Reserves 581
Availability and Use of Our Mineral Resources 582
U.S. Supply of Mineral Resources 582

23.5 Impacts of Mineral Development 582
Environmental Impacts 582
Social Impacts 583
Minimizing the Environmental Impact of Mineral Development 584

■ **A CLOSER LOOK 23.1 Golden, Colorado: Open Pit Mine Becomes a Golf Course** 585

23.6 Materials Management and Our Waste 586
History of Waste Disposal 586

23.7 Integrated Waste Management 586
Reduce, Reuse, Recycle 587
Recycling of Human Waste 589

23.8 Municipal Solid-Waste Management 589

■ **A CLOSER LOOK 23.2 Life of A Plastic Water Bottle** 590
Composition of Solid Waste 591
Onsite Disposal 591
Composting 591
Incineration 591
Open Dumps (Poorly Controlled Landfills) 592
Sanitary Landfills 592
Reducing the Waste that Ends Up in a Landfill 595

23.9 Hazardous Waste 596

■ **A CLOSER LOOK 23.3 “e-waste”: A Growing Environmental Problem** 597

23.10 Hazardous Waste Legislation 598
Resource Conservation and Recovery Act 598
Comprehensive Environmental Response, Compensation, and Liability Act 598

23.11 Hazardous Waste Management: Land Disposal 599

23.12 Alternatives to Land Disposal of Hazardous Waste 601
Source Reduction 601
Recycling and Resource Recovery 601
Treatment 601
Incineration 601

23.13 Ocean Dumping 601

■ **A CLOSER LOOK 23.4 Plastics in the Ocean** 603

23.14 Pollution Prevention 604

23.15 Sustainable Resource Management 604



CRITICAL THINKING ISSUE SHOULD WE BUY A NEW CAR OR KEEP THE OLD ONE? 605

Summary 606

Reexamining Themes and Issues 607

Key Terms 608

Study Questions 608

Further Reading 608

Chapter 24 Our Environmental Future 611

 **CASE STUDY Imagine an Ecotopia** 612

24.1 The Process of Planning a Future 612

24.2 Environment and Law: A Horse, a Gun, and a Plan 614
The Three Stages in the History of U.S. Environmental Law 614

24.3 Planning to Provide Environmental Goods and Services 615

24.4 Planning for Recreation on Public Lands 616
Who Stands for Nature? Skiing at Mineral King 617
How Big Should Wildlands Be? Planning a Nation's Landscapes 618

24.5 Planning For Disasters 619

24.6 How You Can Be an Actor in the Environmental Law Processes 620
Citizen Actions 620
Mediation 621

24.7 International Environmental Law and Diplomacy 621

24.8 Global Security and Environment 622

24.9 Challenges to Students of the Environment 623



CRITICAL THINKING ISSUE IS IT POSSIBLE TO DERIVE SOME QUANTITATIVE STATEMENTS ABOUT THRESHOLDS BEYOND WHICH UNACCEPTABLE ENVIRONMENTAL CHANGE WILL OCCUR? 623

Summary 624

Study Questions 625

Notes 625

Appendix A-1

Glossary G-1

Notes N-1

Acknowledgments

Completion of this book was possible only through the cooperation and work of many people. To all those who so freely offered their advice and encouragement in this endeavor, we offer our most sincere appreciation. We are indebted to our colleagues who made contributions.

We greatly appreciate the work of our editors at John Wiley & Sons, Rachel Falk and Ryan Flahive, for support, encouragement, assistance, and professional work. We extend thanks to our production editor Trish McFadden, who did a great job and made important contributions in many areas; to Wendy Lai for a beautiful interior design; and to Billy Ray for photo research. Thanks go out also for editorial assistance from Elizabeth Baird and Chloe Moffett.

Reviewers of This Edition

Renée E. Bishop Pierce, Penn State Worthington Scranton
Ron Cisar, Iowa Western Community College
James Kubicki, Penn State
Bryan Mark, Ohio State University
Stephen Overmann, Southeast Missouri State University
Dork Sahagian, Lehigh University
Santhosh Seelan, University of North Dakota
Don Williams, Park University

Reviewers of Previous Editions

David Aborn, University of Tennessee, Chattanooga
Marc Abrams, Pennsylvania State University
John All, Western Kentucky University
Diana Anderson, Northern Arizona University
Mark Anderson, University of Maine
Robert J. Andres, University of North Dakota
Walter Arenstein, Ohlone College
Daphne Babcock, Collin County Community College
Marvin Baker, University of Oklahoma
Kevin Baldwin, Monmouth College
Michele Barker-Bridges, Pembroke State University (NC)
James W. Bartolome, University of California, Berkeley
Colleen Baxter, Georgia Military College
Laura Beaton, York College
Susan Beatty, University of Colorado, Boulder
David Beckett, University of Southern Mississippi
Brian Beeder, Morehead State University

About the Authors



Photo by Maguire Neblet

Daniel B. Botkin is Professor (Adjunct), Department of Biology, University of Miami, Coral Gables, Florida, and Professor Emeritus of Ecology, Evolution, and Marine Biology, University of California, Santa Barbara, where he joined the faculty in 1978, serving as chairman of the Environmental Studies Program from 1978 to 1985. For more than four decades, Professor Botkin has been active in the application of ecological

science to environmental management. He is winner of Santa Barbara Botanic Garden's John C. Pritzlaff Conservation Award in 2012, in recognition of his career contributions to conservation of biodiversity. Other awards include Oxford University Astor Lectureship, 2007; the Mitchell International Prize for Sustainable Development, and the Fernow Prize for International Forestry; he has also been elected to the California Environmental Hall of Fame.

Trained in physics and biology, Professor Botkin is a leader in the application of advanced technology to the study of the environment. The originator of widely used forest gap-models, he has conducted research on endangered species, characteristics of natural wilderness areas, the biosphere, and global environmental problems, including possible ecological effects of global warming. During his career, Professor Botkin has advised the World Bank about tropical forests, biological diversity and sustainability; the Rockefeller Foundation about global environmental issues; the government of Taiwan about approaches to solving environmental problems; and the state of California

on the environmental effects of water diversion on Mono Lake. He served as the primary advisor to the National Geographic Society for its centennial edition map on "The Endangered Earth." He directed a study for the states of Oregon and California concerning salmon and their forested habitats.

He has published many articles and books about environmental issues. His latest books are: *The Moon in the Nautilus Shell: Discordant Harmonies Reconsidered* (Oxford University Press, 2012) and *Powering the Future: A Scientist's Guide to Energy Independence* (FT Press, 2010). His other books are: *Beyond the Stoney Mountains: Nature in the American West from Lewis and Clark to Today* (Oxford University Press) and available as an ebook (Croton River Publishers); *Strange Encounters: Adventures of a Renegade Naturalist* (Penguin/Tarcher), *The Blue Planet* (Wiley), available as an ebook (Croton River Publishers); *No Man's Garden: Thoreau and a New Vision for Civilization and Nature* (Island Press; now available as an ebook (Croton River Publishers); *Passage of Discovery: The American Rivers Guide to The Missouri River of Lewis and Clark* (Perigee Books (a Division of Penguin-Putnam, now available as an ebook (Croton River Publisher); *Our Natural History: The Lessons of Lewis and Clark* (Oxford University Press), *Discordant Harmonies: A New Ecology for the 21st Century* (Oxford University Press), and *Forest Dynamics: An Ecological Model* (Oxford University Press).

Professor Botkin was on the faculty of the Yale School of Forestry and Environmental Studies (1968–1974) and was a member of the staff of the Ecosystems Center at the Marine Biological Laboratory, Woods Hole, MA (1975–1977). He received a B.A. from the University of Rochester, an M.A. from the University of Wisconsin, and a Ph.D. from Rutgers University.



Edward A. Keller was chair of the Environmental Studies and Hydrologic Sciences Programs from 1993 to 1997 and is Professor of Earth Science at the University of California, Santa Barbara, where he teaches earth surface processes, environmental geology, environmental science, river processes, and engineering geology. Prior to joining the faculty at Santa Barbara, he

taught geomorphology, environmental studies, and earth science at the University of North Carolina, Charlotte. He was the 1982–1983 Hartley Visiting Professor at the University of Southampton, a Visiting Fellow in 2000 at Emmanuel College of Cambridge University, England, and recipient of the Easterbrook Distinguished Scientist award from the Geological Society of America in 2004.

Professor Keller has focused his research efforts into three areas: studies of Quaternary stratigraphy and tectonics as they relate to earthquakes, active folding, and mountain building processes; hydrologic process and wildfire in the chaparral environment of Southern California; and physical habitat requirements for the endangered Southern California steelhead trout. He is the recipient of various Water Resources Research Center grants to study fluvial processes and U.S. Geological Survey and Southern California Earthquake Center grants to study earthquake hazards.

Professor Keller has published numerous papers and is the author of the textbooks *Environmental Geology; Introduction to Environmental Geology; Natural Hazards* (with Duane DeVecchio); and *Active Tectonics* (with Nicholas Pinter). He holds bachelor's degrees in both geology and mathematics from California State University, Fresno, an M.S. in geology from the University of California, and a Ph.D. in geology from Purdue University.

Dedications

For my sister, Dorothy B. Rosenthal

who has been a source of inspiration, support, ideas, and books to read, and is one of my harshest and best critics.

Dan Botkin

For Valery Rivera

who contributed so much to this book and is a fountain of inspiration in our work and lives.

Ed Keller

This page intentionally left blank

Key Themes in Environmental Sciences

LEARNING OBJECTIVES

Certain themes are basic to environmental science. After reading this chapter, you should be able to . . .

- Construct an argument to support the idea that people and nature are intimately connected
- Defend or criticize the statement that human environmental health problems are largely caused by social phenomena and human population increase
- Differentiate between the ways we place value on the environment
- Define sustainability and list the major criteria to assist in achieving sustainability
- Critically appraise the statement “think globally and act locally”
- Compare and contrast positive and negative aspects of the urban environment
- Support the idea that value judgments are necessary to adopt a solution to human population based on scientific knowledge
- Argue in support of the Precautionary Principle and then criticize your argument
- Synthesize the environmental implications of the history of Easter Island

CASE STUDY



Pacific Salmon: Iconic Fish of the Pacific Northwest

Legend has it that 9,000 years ago the Pacific Northwest tribe, the Chinook People (First People) needed some help with a sustainable food supply. Coyote, a mythological character found in the legends of many Indian tribes, came to the rescue. He connected the Columbia River to an upstream pond where women were keeping two fish. Coyote knew more people would come, so he decreed that the fish would swim from the pond to the ocean and return to become food for the people.

The fish returned, and Coyote taught the people how to fish; the people prospered. When Meriwether Lewis and William Clark reached the mouth of the Columbia River in November of 1805 with the Corps of Discovery, they observed the celebration of the first catch of king salmon (chinook salmon) of the season. The fish were eaten fresh and preserved by drying. The Chinook People then pounded the dried fish into a powder that they pressed into loaves that could be used for several years.

Salmon fishing in the United States by people of European descent started after the Civil War. The catch increased rapidly, peaking in the 1920s, and then declined to much lower levels (Figure 1.1). Today, some salmon runs are listed as endangered or threatened under the U.S. Endangered Species Act of 1973, and billions of dollars are being invested to restore runs of salmon.¹

There are six species of salmon along the Pacific coast of the United States, ranging from California to Alaska. These are called anadromous fish because they spend part of their lives in fresh water and part in the ocean. Eggs are

hatched and the young grow in fresh waters; then the fish migrate to the ocean, where they feed and grow, returning to the river of their origin in four to six years to spawn. About 85% of salmon return to a place on the river that is very close to where they first emerged as eggs (Figure 1.2). (The life cycle of salmon is shown in Figure 1.3.)

Salmon affect their freshwater habitats. The young are predators on insects and are themselves the food of birds, river otters, bears, and other predators of fish. Adult salmon that return from the ocean provide an annual food for large animals and birds, from bears to eagles. Also, many forests and their streams in salmon country are phosphorus poor. During the ocean phase of their lives, salmon take up phosphorus in their food. When the salmon die in fresh water after spawning, their phosphorus is added to the river, and, if the fish are taken from the river by bears and eagles, then the phosphorus is spread more widely.

There are six salmon species that return to inland waterways from the Pacific: chinook (king), sockeye, chum, pink, coho (silver), and steelhead. Each has different freshwater habitats and travels different distances from the ocean. Chum salmon spawn just inland, in estuaries or near mouths of stream. In contrast, sockeye, which is common far north, such as in the Frazier River, Alaska, migrate as far as 1,000 km upstream. On their river travels, salmon often endure warm river temperatures, and, as famously seen in so many photographs and movies, often must leap high to travel up rapids and falls and

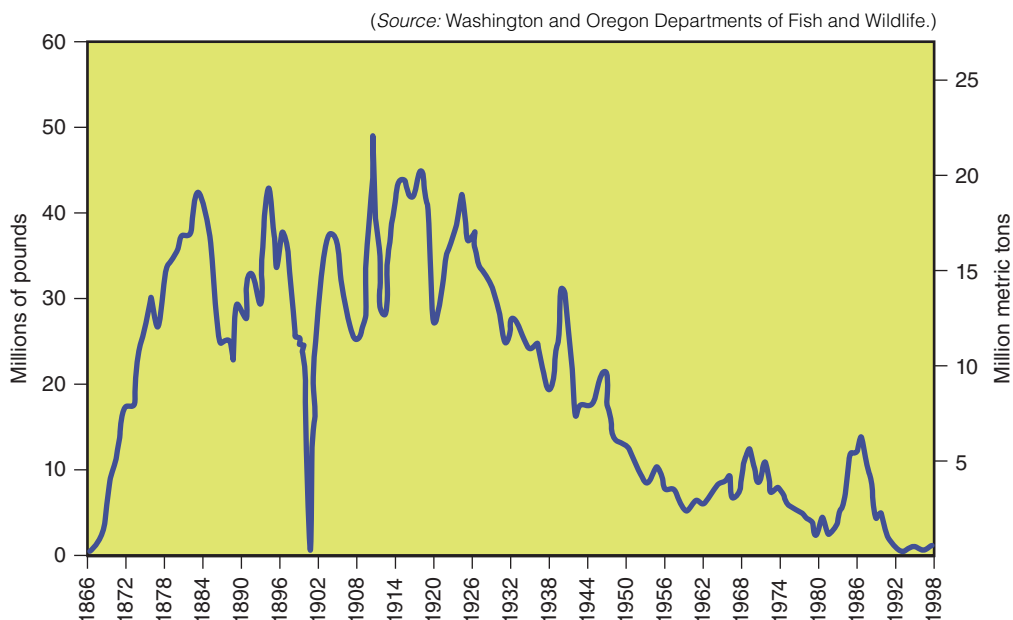


FIGURE 1.1 Commercial salmon catch in the Columbia River, 1866–2000. There is no data for 1901. The catch in 2011 was about 1–2 million tons (0.45–0.90 metric tons).



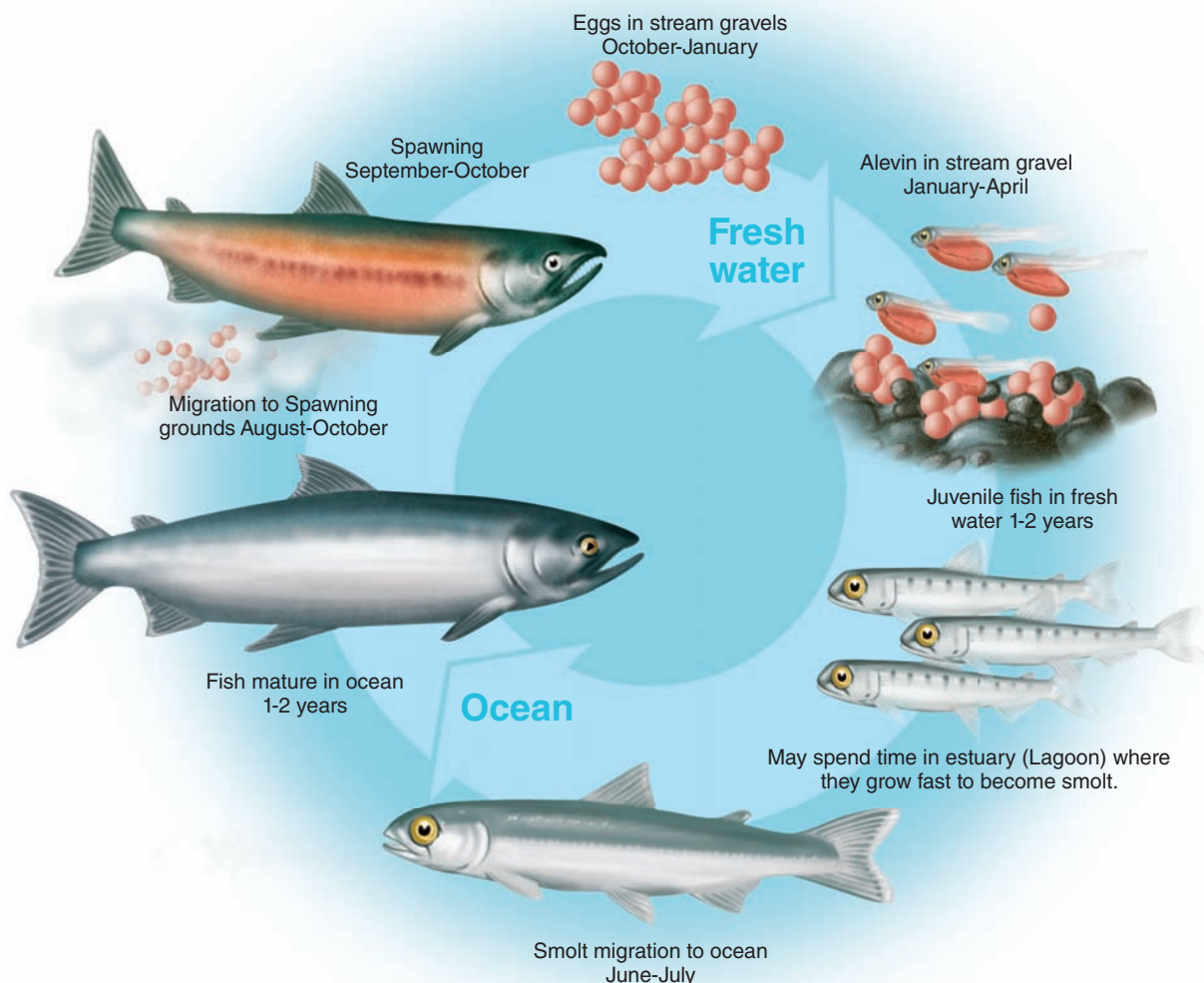
Steven Kazlowski/ING Image Collection

FIGURE 1.2 Sockeye salmon spawning in an Alaskan River.

swim through very fast-running water. Because salmon tend to return to the same stream where they were born, each stream's population can be genetically isolated from

others long enough so that different populations differ genetically from each other. The American Fisheries Society has listed up to 500 genetically distinct salmon populations among the six species. Unfortunately, numerous populations of salmon have declined in many rivers in northern California, Oregon, Washington, British Columbia, and Alaska.

Salmon are important to various ecosystem food chains. They have been long vital to the cultures of Native Americans, as we see in the Coyote legend. Salmon fishing is also a major recreational activity benefiting many towns along the Pacific coast. Moreover, there is a worldwide market for salmon. As a result, many attempts have been made to increase the size of salmon populations. The four culprits usually listed as causes of decline in salmon populations are overfishing by people, forest logging that destroys spawning and the breeding habitat, construction of dams that interfere with salmon migration, and harvests of salmon by sea lions.



(Source: Based on figures from Alaskan Department of Fish and Game and the US Fish and Wildlife Service).

FIGURE 1.3 Life cycle of Pacific salmon.

But other factors, which receive less attention, may also be important. These include problems arising from hatchery-bred fish intermixing with wild fish, thereby mixing genotypes that may be less well adapted to a stream; pollution of streams and therefore salmon habitat from agricultural chemical runoff; and introduction of exotic species, such as parasites, predators, and competitors with native species and populations.² Deforestation also leads to warmer waters and the addition of fine sediment that plugs stream gravel, reducing oxygen and egg vitality.

So what is the future of salmon, these iconic fish of the Pacific Northwest, often viewed as an indicator of the health of our rivers? Large amounts of money have been spent to study the life cycle of salmon in various rivers and to develop management plans. In general, these efforts have varied from unsuccessful to moderately successful.

The history of salmon exploitation around the world, from Europe to the United States, as it is with most fish species, seems to follow a similar pattern: discovery of a very abundant source; habitat degradation; and then overfishing that leads to great declines, sometimes leaving

populations so low as to make harvests impractical. The good news is that it is very likely that many salmon populations will recover, although probably not to pre-European settlement levels.³

The story of Pacific Northwest salmon emphasizes the six major themes of *Environmental Science*:

1. Human population increase has impacted salmon habitat.
2. We are concerned for the future (sustainability) of salmon.
3. Climate change, with warming river water and changing flows, is impacting the future of salmon.
4. Urbanization of coastal areas impacts some rivers where salmon are present.
5. People and salmon in the Pacific Northwest have shared a common history for thousands of years.
6. While science can provide choices to manage salmon, the choices we make will reflect our values.

1.1 Major Themes of Environmental Science

The study of environmental problems and their solutions has never been more important. Modern society is hooked on oil. Production has declined, while demand has grown, and the population of the world has been increasing by more than 70 million each year. The emerging energy crisis is producing an economic crisis, as the prices of everything produced from oil (fertilizer, food, and fuel) rises beyond what some people can afford to pay. Energy and economic problems come at a time of unprecedented environmental concerns, from the local to global level.

At the beginning of the modern era—in A.D. 1—the number of people in the world was probably about 100 million, one-third of the present population of the United States. In 1960, the world contained 3 billion people. Our population has more than doubled in the last 50 years to about 7 billion people in 2013. In the United States, population increase is often apparent when we travel. Urban traffic snarls, long lines to enter national parks, and difficulty getting tickets to popular attractions are all symptoms of a growing population. If recent human population growth rates continue, our numbers could reach 9.4 billion by 2050.⁴ The problem is that the Earth has not grown any larger, and the abundance of its resources has not increased—in many cases, quite the

opposite. How, then, can Earth sustain all these people? And what is the maximum number of people that could live on Earth, not just for a short time but *sustained* over a long period?

Estimates of how many people the planet can support range from 2.5 billion to 40 billion (a population not possible with today's technology). Why do the estimates vary so widely? Because the answer depends on what quality of life people are willing to accept. Beyond a threshold world population of about 4–6 billion, the quality of life declines. How many people the Earth can sustain depends on *science and values* and is also a question about *people and nature*. The more people we pack onto the Earth, the less room and resources there are for wild animals and plants, wilderness, areas for recreation, and other aspects of nature—and the faster Earth's resources will be used. The answer also depends on how the people are distributed on the Earth—whether they are concentrated mostly in cities or spread evenly across the land.

Although the environment is complex and environmental issues seem sometimes to cover an unmanageable number of topics, the science of the environment comes down to the central topics just mentioned: the human population, urbanization, and sustainability within a global perspective. These issues have to be evaluated in light of the interrelations between people and nature, and the answers ultimately depend on both science and nature.

This book therefore approaches environmental science through six interrelated themes:

1. *Human population growth* (the environmental problem)
2. *Sustainability* (the environmental goal)
3. *A global perspective* (many environmental problems require a global solution)
4. *An urbanizing world* (most of us live and work in urban areas)
5. *People and nature* (we share a common history with nature)
6. *Science and values* (science provides solutions; which ones we choose are in part value judgments)

You may ask, “If this is all there is to it, what is in the rest of this book?” (See A Closer Look 1.1.) The answer lies with the old saying “The devil is in the details.” The solution to specific environmental problems requires specific knowledge. The six themes listed above help us see the big picture and provide a valuable background. The opening case study illustrates linkages among the themes, as well as the importance of details.

In this chapter we introduce the six themes with brief examples, showing the linkages among them and touch-

ing on the importance of specific knowledge that will be the concern of the rest of the book. We start with human population growth.

1.2 Human Population Growth

Our Rapid Population Growth

The most dramatic increase in the history of the human population occurred in the last part of the 20th century and continues today into the early 21st century. As mentioned, in merely the past 50 or so years, the human population of the world has more than doubled—to more than 7 billion. Figure 1.4 illustrates this population explosion, sometimes referred to as the “population bomb.” The figure shows that the expected decrease in population in the developed regions (for example, the United States and western Europe) is more than offset by rapid population growth in the developing regions (for example, Africa, India, and South America).

A CLOSER LOOK 1.1

A Little Environmental History

A brief historical explanation will help clarify what we seek to accomplish. Before 1960, few people had ever heard the word *ecology*, and the word *environment* meant little as a political or social issue. Then came the publication of Rachel Carson’s landmark book, *Silent Spring* (Boston: Houghton Mifflin, 1960, 1962). At about the same time, several major environmental events occurred, such as oil spills along the coasts of Massachusetts and southern California and highly publicized threats of extinction of many species, including whales, elephants, and songbirds. The environment became a popular issue.

As is true of any new social or political issue, at first relatively few people recognized its importance. Those who did found it necessary to stress the problems—to emphasize the negative—in order to bring public attention to environmental concerns. Adding to the limitations of the early approach to environmental issues was a lack of scientific knowledge and practical know-how. Environmental sciences were in their infancy. Some people even saw science as part of the problem.

The early days of modern environmentalism were dominated by confrontations between those labeled environmentalists and those labeled anti-environmentalists. Stated in the simplest terms, environmentalists believed that the world was in peril. To them, economic and social development

meant destruction of the environment and ultimately the end of civilization, the extinction of many species, and perhaps the extinction of human beings. Their solution was a new world-view that depended only secondarily on facts, understanding, and science. In contrast, again in simplest terms, the anti-environmentalists believed that whatever the environmental effects, social and economic health and progress were necessary for people and civilization to prosper. From their perspective, environmentalists represented a dangerous and extreme view with a focus on the environment to the detriment of people, a focus they thought would destroy the very basis of civilization and lead to the ruin of our modern way of life.

Today, the situation has changed. Public-opinion polls now show that people around the world rank the environment among the most important social and political issues. There is no longer a need to prove that environmental problems are serious.

We have made significant progress in many areas of environmental science (although our scientific understanding of the environment still lags behind our need to know). We have also begun to create legal frameworks for managing the environment, thus providing a new basis for addressing environmental issues. The time is now ripe to seek truly lasting, more rational solutions to environmental problems.

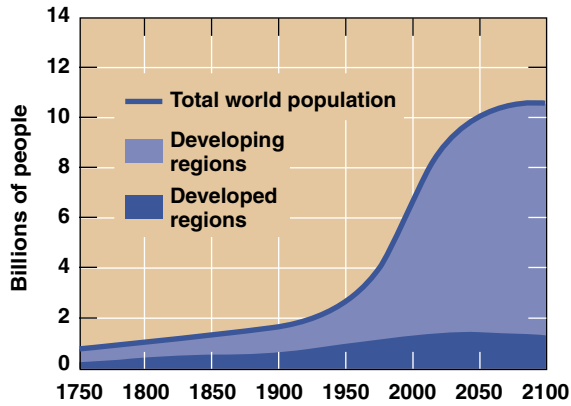


FIGURE 1.4 Population growth in developed and developing nations. 1750 projected to 2100.

Human population growth is, in some important ways, *the* underlying issue of the environment. Much current environmental damage is directly or indirectly the result of the very large number of people on Earth and our rate of increase. As you will see in Chapter 5, where we consider the human population in more detail, for most of human history, the total population was small and the average long-term rate of increase was low relative to today's growth rate.⁴

Although it is customary to think of the population as increasing continuously without declines or fluctuations, the growth of the human population has not been a steady march. For example, great declines occurred during the time of the Black Death in the 14th century. At that time, entire towns were abandoned, food production declined,

and in England one-third of the population died within a single decade.⁵

Famine and Food Crisis

Famine is one of the phenomena that happen when a human population exceeds its environmental resources. Famines have occurred in recent decades in Africa. In the mid-1970s, following a drought in the Sahel region, 500,000 Africans starved to death and several million more were permanently affected by malnutrition.⁶ Starvation in African nations gained worldwide attention some ten years later, in the 1980s.^{7, 8}

Famine in Africa has had multiple interrelated causes. One, as suggested, is drought. Although drought is not new to Africa, the size of the population affected by drought is unprecedented. In addition, deserts in Africa appear to be spreading, in part because of changing climate but also because of human activities. Poor farming practices have increased erosion, and deforestation may be helping to make the environment drier. In addition, the control and destruction of food have sometimes been used as a weapon in political disruptions (Figure 1.5). Today, malnutrition contributes to the death of about 6 million children per year. Low- and middle-income countries suffer the most from malnutrition, as measured by low weight for age (underweight, as shown in Figure 1.6).⁹

The emerging global food crisis in the first decade of the 21st century has not been caused by war or drought but by rising food costs. The cost of basic items, such as rice, corn, and wheat, has risen to the point where



Peter Turnley/© Corbis



dbimages/Alamy

FIGURE 1.5 Science and values. Social conditions affect the environment, and the environment affects social conditions. Political disruption in Somalia (illustrated by a Somali boy with a gun, left photo) interrupted farming and food distribution, leading to starvation. Overpopulation, climate change, and poor farming methods also lead to starvation, which in turn promotes social disruption. Famine has been common in parts of Africa since the 1980s, as illustrated by gifts of food from aid agencies.

(Source: World Population Data Sheet [Washington, DC: Population Reference Bureau, 2007. Accessed 5/19/08 @www.prb.org].)



FIGURE 1.6 Underweight children under the age of five by region. Most are in low- and middle-income countries.

low- and moderate-income countries are experiencing a serious crisis. In 2007 and 2008, food riots occurred in many locations, including Mexico, Haiti, Egypt, Yemen, Bangladesh, India, and Sudan (Figure 1.7). The rising cost of oil used to produce food (in fertilizer, transportation, working fields, etc.) and the conversion of some corn production to biofuels have been blamed. This situation involves yet another key theme: science and values. Scientific knowledge has led to increased agricultural production and to a better understanding of population growth and what is required to conserve natural resources. With this knowledge, we are forced to confront a choice: which is more important, the survival of people alive today or conservation of the environment on which future food production and human life depend?¹⁰

Answering this question requires both *value judgments* and the information and knowledge with which to make such judgments. For example, we must determine whether we can continue to increase agricultural production without destroying the very environment on which agriculture and, indeed, the persistence of life on Earth depend. Put another way, a technical, scientific investigation provides a basis for a value judgment.

Human Population and the Incidence of Natural Disasters

It is difficult to pick up a paper without hearing about a natural disaster striking some part of the world. It might be tornadoes in the midwestern United States, flooding in China or Indonesia, a tsunami in Japan, or hurricanes and typhoons around various locations in the Pacific and Atlantic oceans. What is clear is that the number of natural events has not dramatically increased, but the impacts certainly have. Going back a few hundred years, human population on Earth was much less, and when hazardous events struck an area, there was less chance of loss of structures and lives. As human population has grown, more people are in harm's way. A disaster that occurred before the planet was widely populated might have affected a few people in a small, isolated community. Today, a similar natural event is likely to be a catastrophe in which damages may exceed billions of dollars and take hundreds of lives (Figure 1.8). And with growing human population, more people are forced to live on marginal lands where hazardous events are more likely to occur. Thus, increasing population and poor land-use choices (some of which



FIGURE 1.7 Food riots over the rising cost of food in 2007. (a) Haiti and (b) Bangladesh.



FIGURE 1.8 Tsunami waves in 2011 produced by a very large off-shore earthquake inundating part of east coastal Japan (about 400 km or 250 miles north of Tokyo). More than 20,000 people died, and entire coastal communities were destroyed. High population density of about 300 people per square kilometer (800 per square mile) was achieved during the 19th and early 20th centuries, contributing to the large loss of life in the hazardous coastal zone where very large tsunamis happen about every 1,000 years.

are difficult to avoid) are leading to greater property damage and loss of life.

The Age of Abundance and Human Population Increase

Human population on Earth is increasing exponentially (see Working it Out 4.2 on exponential growth in Chapter 4), and on one hand, the general consensus is that this growth is not sustainable from a resource perspective. On the other hand, it has been argued that, along with the exponential growth of population, there has been an exponential growth of technology that has resulted in a much improved environment for people. The idea is that, as population continues to increase, people have a greater chance of making important innovations that will eventually provide clean water and energy on Earth, with affordable housing and education and good health care for all citizens.¹¹

Let's explore this hypothesis in more detail. A lot of research has been done on innovation and what makes for creative environments. It certainly appears that large numbers of people working collaboratively in urban centers are more productive, and innovation and creativity occur at higher rates in cities. Thus, it appears that, as the urban regions have grown, so have technological advances and creativity. However, this is not true across the board, particularly for developing countries where the increase in population is most apparent and where large urban regions are developing.

Our large urban centers must provide a quality environment for people to be truly successful. Certainly,

people move to large cities for economic reasons. There, even in the developing world, they will find more jobs and better health care. However, the apparent relationship between population and technology may not be so clear cut. Certainly, urban centers in developed countries with high-quality research labs and many people working collaboratively may experience an increased rate of inventions, innovations, and creative activity. This does not mean that there would be a similar increase in large urban areas where most of the population is just at or beyond the subsistence level. What might be said is that as urban centers in the developing world become more connected to the greater world through the Internet and other technology, they might be able to move forward more quickly. However, an ever-growing human population that exceeds the ability of the planet to support it will eventually lead to a failure of ecosystems and cause problems for humans. Later in this chapter and in Chapter 22 on urban environments, we will return to this discussion when we consider the principle that we live in an urban world.

1.3 Sustainability and Carrying Capacity

The story of recent famines and food crises brings up one of the central environmental questions of our day: What is the maximum number of people the Earth can sustain? That is, what is the sustainable human carrying capacity of the Earth? Much of this book will deal with information that helps answer this question. However, there is little doubt that we are using many renewable environmental resources faster than they can be replenished—in other words, we are using them *unsustainably*. In general, we are using forests and fish faster than they can regrow, and we are eliminating habitats of endangered species and other wildlife faster than they can be replenished. We are also extracting minerals, petroleum, and groundwater without sufficient concern for their limits or the need to recycle them. As a result, there is a shortage of some resources and a probability of more shortages in the future. Clearly, we must learn how to sustain our environmental resources so that they continue to provide benefits for people and other living things on our planet.³

Sustainability: The Environmental Objective

The environmental catchphrase of the 1990s was “saving our planet.” Are all life and the environments on which life depends really in danger? Will we leave behind a dead planet?

In the long view of planetary evolution, it is certain that planet Earth will survive us. Our sun is likely to last

another several billion years, and if all humans became extinct in the next few years, life would still flourish here on Earth. The changes we have made—in the landscape, the atmosphere, the waters—would last for a few hundred or thousands of years but in a modest length of time would be erased by natural processes. What we are concerned with, as environmentalists, is the quality of the *human* environment on Earth, for us today and for our children.

Environmentalists agree that sustainability must be achieved, but we are unclear about how to achieve it, in part because the word is used to mean different things, often leading to confusion that causes people to work at cross-purposes. **Sustainability** has two formal scientific meanings with respect to environment: (1) *sustainability of resources*, such as a species of fish from the ocean, a kind of tree from a forest, or coal from mines; and (2) *sustainability of an ecosystem*. Strictly speaking, harvesting a resource at a certain rate is sustainable if we can continue to harvest that resource at that same rate for some specified time well into the future. An ecosystem is sustainable if it can continue its primary functions for a specified time in the future. (Economists refer to the specified time in the future as a “planning time horizon.”) Commonly, in discussions about environmental problems, the time period is not specified and is assumed to be very long—mathematically an infinite planning time, but in reality as long as it could possibly matter to us. For conservation of the environment and its resources to be based on quantitative science, both a rate of removal and a planning time horizon must be specified. However, ecosystems and species are always undergoing change, and a completely operational definition of *sustainability* will have to include such variation over time.

Economists, political scientists, and others also use the term *sustainability* in reference to types of development that are economically viable, do not harm the environment, and are socially just (fair to all people). We should also point out that the term *sustainable growth* is an oxymoron (i.e., a contradictory term) because any steady growth (fixed-percentage growth per year) produces large numbers in modest periods of time (see Working it Out 4.2 on exponential growth in Chapter 4).

One of the environmental paradigms of the 21st century will be sustainability, but how will it be attained? Economists have begun to consider what is known as the *sustainable global economy*: the careful management and wise use of the planet and its resources, analogous to the management of money and goods. Those focusing on a sustainable global economy generally agree that under present conditions the global economy is *not* sustainable. Increasing numbers of people have resulted in so much pollution of the land, air, and water that the ecosystems that people depend on are in danger of collapse. What, then, are the attributes of a sustainable economy in the information age?¹²

- Populations of humans and other organisms living in harmony with the natural support systems, such as air, water, and land (including ecosystems)
- An energy policy that does not pollute the atmosphere, cause climate change (such as global warming), or pose unacceptable risk (a political or social decision)
- A plan for renewable resources—such as water, forests, grasslands, agricultural lands, and fisheries—that will not deplete the resources or damage ecosystems
- A plan for nonrenewable resources that does not damage the environment, either locally or globally, and ensures that a share of our nonrenewable resources will be left to future generations
- A social, legal, and political system that is dedicated to sustainability, equity, and justice for all people, with a democratic mandate to produce such an economy

Recognizing that population is *the* environmental problem, we should keep in mind that a sustainable global economy will not be constructed around a completely stable global population. Rather, such an economy will take into account the fact that the size of the human population will fluctuate within some stable range necessary to maintain healthy relationships with other components of the environment. To achieve a sustainable global economy, we need to do the following:¹²

- Develop an effective population-control strategy. This will at least require more education of people, since literacy and population growth are inversely related.
- Completely restructure our energy programs. A sustainable global economy is probably impossible if it is based on the use of fossil fuels. New energy plans will be based on an integrated energy policy, with more emphasis on renewable energy sources (such as solar and wind) and on energy conservation.
- Institute economic planning, including a tax structure that will encourage population control and wise use of resources. Financial aid for developing countries is absolutely necessary to narrow the gap between rich and poor nations.
- Implement social, legal, political, and educational changes that help to maintain a quality local, regional, and global environment. This must be a serious commitment that all the people of the world will cooperate with.

Moving Toward Sustainability: Some Criteria

Stating that we wish to develop a sustainable future acknowledges that our present practices are not sustainable. Indeed, continuing on our present paths of overpopulation, resource consumption, and pollution will not lead to sustainability. We will need to develop new concepts that