

Environmental Science

A Study of Interrelationships

SIXTEENTH EDITION

ELDON D. ENGER

Delta College

BRADLEY F. SMITH

Western Washington University

Contributing Authors:

CRAIG D. PHELPS

Rutgers University

MAARTEN VONHOF

Western Michigan University

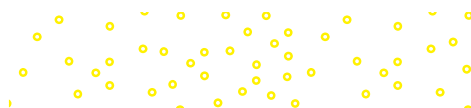
DAVID MURPHY

St. Lawrence University

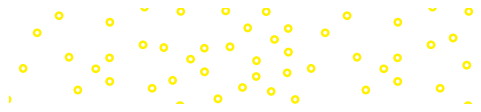
GRACE WANG

Western Washington University

**Mc
Graw
Hill**





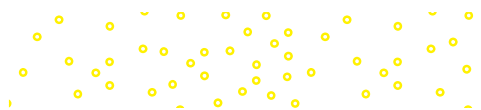


Environmental Science

A Study of Interrelationships

SIXTEENTH EDITION

**Mc
Graw
Hill**





ENVIRONMENTAL SCIENCE, SIXTEENTH EDITION

Published by McGraw Hill LLC, 1325 Avenue of the Americas, New York, NY 10121. Copyright © 2022 by McGraw Hill LLC. All rights reserved. Printed in the United States of America. Previous editions © 2019, 2016, and 2013. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of McGraw Hill LLC, including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 24 23 22 21

ISBN 978-1-260-72223-9 (bound edition)

MHID 1-260-72223-6 (bound edition)

ISBN 978-1-265-09613-7 ((loose-leaf edition))

MHID 1-265-09613-9 ((loose-leaf edition))

Portfolio Manager: *Jodi Rhomberg*

Product Developers: *Theresa Collins*

Marketing Manager: *Bitney Ross*

Content Project Managers: *Jessica Portz and Rachael Hillebrand*

Buyer: *Sandy Ludovissy*

Designer: *David W. Hash*

Content Licensing Specialist: *Beth Cray*

Cover Image: *Yellow Dog Productions/Digital Vision/Getty Images*

Compositor: *SPi Global*

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Names: Enger, Eldon D., author. | Smith, Bradley F., author.

Title: Environmental science : a study of interrelationships / Eldon D.

Enger, Delta College, Bradley F. Smith, Western Washington University.

Description: Sixteenth edition. | Dubuque : McGraw-Hill Education, [2022] |

Includes bibliographical references and index.

Identifiers: LCCN 2020042083 | ISBN 9781260722239 (hardcover)

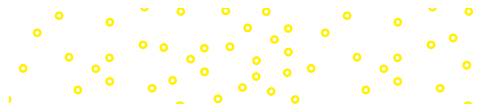
Subjects: LCSH: Environmental sciences—Textbooks.

Classification: LCC GE105 .E54 2022 | DDC 304.2—dc23

LC record available at <https://lcn.loc.gov/2020042083>

The Internet addresses listed in the text were accurate at the time of publication. The inclusion of a website does not indicate an endorsement by the authors or McGraw Hill LLC, and McGraw Hill LLC does not guarantee the accuracy of the information presented at these sites.

mheducation.com/highered

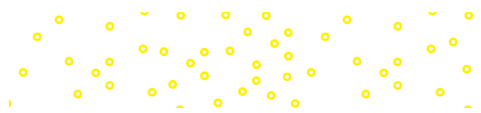


*To Judy, my wife and friend,
for sharing life's adventures*

ELDON ENGER

*For my lovely wife Daria,
who has survived 45 years with me
and 16 editions.*

BRAD SMITH



About the Authors

Eldon D. Enger is an emeritus professor of biology at Delta College, a community college near Saginaw, Michigan. He received his B.A. and M.S. degrees from the University of Michigan. Professor Enger has over 30 years of teaching experience, during which he has taught biology, zoology, environmental science, and several other courses. He has been very active in curriculum and course development. A major curriculum contribution was the development of an environmental technician curriculum and the courses that support it. He was also involved in the development of learning community courses in stream ecology, winter ecology, and plant identification. Each of these courses involved students in weekend-long experiences in the outdoors that paired environmental education with physical activity—stream ecology and canoeing, winter ecology and cross-country skiing, and plant identification with backpacking.

Professor Enger is an advocate for variety in teaching methodology. He feels that if students are provided with varied experiences, they are more likely to learn. In addition to the standard textbook assignments, lectures, and laboratory activities, his classes included writing assignments, student presentation of lecture material, debates by students on controversial issues, field experiences, individual student projects, and discussions of local examples and relevant current events. Textbooks are very valuable for presenting content, especially if they contain accurate, informative drawings and visual examples. Lectures are best used to help students see themes and make connections, and laboratory activities provide important hands-on activities.

Professor Enger received the Bergstein Award for Teaching Excellence and the Scholarly Achievement Award from Delta College and was selected as a Fulbright Exchange Teacher twice—to



Courtesy of Eldon D. Enger

Australia and Scotland. He has participated as a volunteer in several Earthwatch Research Programs. These include studying the behavior of a bird known as the long-tailed manakin in Costa Rica, participating in a study to assess the possibility of reintroducing endangered marsupials from off-shore islands to mainland Australia, helping with efforts to protect the nesting beaches of the leatherback turtle in Costa Rica, and assisting with on-going research on the sustainable use of fish, wildlife, and forest resources in the Amazon Basin in Peru. He also participated in a People to People program, which involved an exchange of ideas between U.S. and South African environmental professionals.

He has traveled extensively, which has allowed him first-hand experience with

coral reefs, ocean coasts, savannas, mangrove swamps, tundra, prairies, tropical rainforests, cloud forests, deserts, temperate rainforests, coniferous forests, deciduous forests, and many other special ecosystems. These experiences have provided opportunities to observe the causes and consequences of many environmental problems from a broad social and scientific perspective.

He volunteers at a local nature center, land conservancy, and Habitat for Humanity affiliate. Since 2005, he and his wife have spent a month each year with other volunteers from their church repairing houses damaged by tornados, floods, and hurricanes throughout the United States.

Professor Enger and his wife Judy have two married sons and four grandchildren. He enjoys a variety of outdoor pursuits such as cross-country skiing, snowshoeing, hiking, kayaking, hunting, fishing, camping, and gardening. Other interests include reading a wide variety of periodicals, beekeeping, singing in a church choir, picking wild berries, and preserving garden produce.

Bradley F. Smith is the Dean Emeritus of Western Washington University in Bellingham, Washington, having served as Dean from 1994 to 2012. Prior to assuming the position as Dean in 1994, he served as the first Director of the Office of Environmental Education for the U.S. Environmental Protection Agency in Washington, D.C., from 1991 to 1994. Dean Smith also served as the Acting President of the National Environmental Education and Training Foundation in Washington, D.C., and as a Special Assistant to the EPA Administrator.

Before moving to Washington, D.C., Dean Smith was a professor of political science and environmental studies for 15 years, and the executive director of an environmental education center and nature refuge for five years.

Dean Smith has considerable international experience. He was a Fulbright Exchange Teacher to England and worked as a research associate for Environment Canada in New Brunswick. He is a frequent speaker on environmental issues worldwide and serves on the International Scholars Program for the U.S. Information Agency. He also served as a U.S. representative on the Tri-Lateral Commission on environmental education with Canada and Mexico. He was awarded a NATO Fellowship to study the environmental problems associated with the closure of former Soviet military bases in Eastern Europe. He is a Fellow of the Royal Institute of Environmental Science in the U.K.



Courtesy of Bradley F. Smith

Dean Smith is a commissioner of the Washington State Fish and Wildlife Commission (served as Chair from 2015–2020). He is the chair of the board of trustees for Bellingham Technical College (BTC). BTC operates a fish hatchery as part of their aquaculture program that produces 5 million salmon a year for Puget Sound. Dean Smith is a member of the Governors Orca Whale Task Force. He also serves on the North Pacific Research Board and on the Bering Sea Fisheries Advisory Board and on the board of Washington Sea Grant. Previously, he served as chair of the Washington State Sustainability Council, as president of the Council of Environmental Deans and Directors, as a Trustee of the National Environmental Education Foundation, and as a

member of the National Advisory Council for Environmental Policy and Technology for the USEPA. He also served on President Bill Clinton's council for Sustainable Development (Education Task Force). From 2004 to 2013 he served on the Steering Committee of the Commission for Education and Communication for the International Union for the Conservation of Nature (IUCN) in Gland, Switzerland.

Dean Smith holds a Ph.D. from the School of Natural Resources and the Environment at the University of Michigan.

Dean Smith and his wife, Daria, live along the shores of Puget Sound in Bellingham, Washington, and spend part of the summer at their summer home on the shores of Lake Huron in the Upper Peninsula of Michigan. He has two married grown children and two grandchildren, and is an avid outdoor enthusiast.

Brief Contents

CHAPTER 1	Environmental Interrelationships 1
CHAPTER 2	Environmental Ethics 20
CHAPTER 3	Risk, Economics, and Environmental Concerns 43
CHAPTER 4	Interrelated Scientific Principles: Matter, Energy, and Environment 65
CHAPTER 5	Interactions: Environments and Organisms 84
CHAPTER 6	Kinds of Ecosystems and Communities 119
CHAPTER 7	Populations: Characteristics and Issues 152
CHAPTER 8	Energy and Civilization: Patterns of Consumption 184
CHAPTER 9	Nonrenewable Energy Sources 200
CHAPTER 10	Renewable Energy Sources 227
CHAPTER 11	Biodiversity Issues 249
CHAPTER 12	Land-Use Planning 287
CHAPTER 13	Soil and Its Uses 312
CHAPTER 14	Agricultural Methods and Pest Management 337
CHAPTER 15	Water Management 362
CHAPTER 16	Air Quality Issues 397
CHAPTER 17	Climate Change: A Twenty-First Century Issue 423
CHAPTER 18	Solid Waste Management and Disposal 444
CHAPTER 19	Environmental Regulations: Hazardous Substances and Wastes 462
CHAPTER 20	Environmental Policy and Decision Making 485

Appendix 1 507

Appendix 2 508

Glossary 510

Index 520

Contents

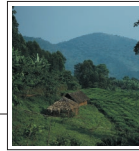
About the Authors vi
Preface xvi

Chapter 1

Environmental Interrelationships 1

The Important Role of Wolves in Yellowstone 2

- 1.1 The Nature of Environmental Science 3
 - Interrelatedness Is a Core Concept 3
 - An Ecosystem Approach 4
 - Political and Economic Issues 4
- 1.2 Sustainability 4
 - GOING GREEN: Individual Decisions Matter 5**
- 1.3 Human Welfare Issues 6
 - Population Growth 6
 - FOCUS ON: Campus Sustainability Initiative 6**
 - Food Security 7
 - Environment and Health 7
 - Personal Security 8
- 1.4 Maintaining Functional Ecosystems 9
 - Biodiversity Loss 9
 - Ecosystem Services 10
 - Climate Change 10
- 1.5 Resource Management Issues 10
 - Energy 10
 - Water 10
 - Land and Soil 10
 - Waste 11
 - SCIENCE, POLITICS, & POLICY: Federal Land-Use Policy in the West 12**
- 1.6 Urbanization and Globalization 13
 - FOCUS ON: COVID-19 Pandemic 15**
- 1.7 Environmental Governance Issues 16
 - ISSUES & ANALYSIS: Government Regulation and Personal Property 17**
 - The Earth Summit 17
 - Climate Change 18



Comstock/
Stockbyte/Getty
Images

Chapter 2

Environmental Ethics 20

Of Sea Lions and Salmon—An Environmental and Ethical Dilemma 21

- 2.1 The Call for a New Ethic 21
- 2.2 Environmental Ethics 22
 - Conflicting Ethical Positions 23
 - The Greening of Religion 23



Rich Carey/
Shutterstock

Three Philosophical Approaches to Environmental Ethics 23
Other Philosophical Approaches 24

2.3 Environmental Attitudes 25

Development 25
Preservation 26
Conservation 26
Sustainable Development 26

FOCUS ON: Early Philosophers of Nature 27

- 2.4 Environmental Justice 28
- 2.5 Environmental Disasters and Poverty 30
- 2.6 Societal Environmental Ethics 31
- 2.7 Corporate Environmental Ethics 32
 - Waste and Pollution 32
 - Is There a Corporate Environmental Ethic? 32
 - Green Business Concepts 34
- 2.8 Individual Environmental Ethics 34
- 2.9 The Ethics of Consumption 34
 - Food 35

SCIENCE, POLITICS, & POLICY: The Ethical and Political Dimensions of Climate Change 35

Energy 36

GOING GREEN: Do We Consume Too Much? 36

Water 37

Wild Nature 37

- 2.10 Personal Choices 37
- 2.11 Global Environmental Ethics 38

ISSUES & ANALYSIS: Major Environmental Issues and the Ethical Questions They Raise 40

Chapter 3

Risk, Economics, and Environmental Concerns 43

Drinking Water, Sanitation, and Disease 44

- 3.1 Making Decisions 44
- 3.2 Characterizing Risk 45
 - Risk Assessment 45
 - Risk Management 46
 - Perception of Risk 46
- 3.3 Environmental Economics 48
 - Resources 48
 - Supply and Demand 48
 - Assigning Value to Natural Resources and Ecosystem Services 49
 - Environmental Costs 51
 - The Economics of Pollution 52
 - GOING GREEN: Corporate Sustainability Reporting 54**
 - Cost-Benefit Analysis 55



Jupiterimages/Getty
Images

- 3.4 Comparing Economic and Ecological Systems 56
How Economic and Ecological Systems Differ 56
Common Property Resource Problems—The Tragedy of the Commons 58
- 3.5 Using Economic Tools to Address Environmental Issues 58
Subsidies 58
Market-Based Instruments 59
- SCIENCE, POLITICS, & POLICY: The Developing Green Economy 60**
Life Cycle Analysis and Extended Product Responsibility 61
- 3.6 Economics and Sustainable Development 61
ISSUES & ANALYSIS: The Economics and Risks of Mercury Contamination 62

Chapter 4

Interrelated Scientific Principles: Matter, Energy, and Environment 65

The Decline of Coal Use in the United States 66

- 4.1 The Nature of Science 66
Basic Assumptions in Science 67
Cause-and-Effect Relationships 67
Elements of the Scientific Method 67
- 4.2 Limitations of Science 69
- 4.3 Pseudoscience 71
GOING GREEN: Evaluating Green Claims 72
- 4.4 The Structure of Matter 72
Atomic Structure 72
The Molecular Nature of Matter 73
A Word About Water 74
Acids, Bases, and pH 74
Inorganic and Organic Matter 74
Chemical Reactions 75
Chemical Reactions in Living Things 75
Chemistry and the Environment 76
- 4.5 Energy Principles 77
Kinds of Energy 77
States of Matter 77
First and Second Laws of Thermodynamics 78
SCIENCE, POLITICS, & POLICY: Return of the Salmon 79
- 4.6 Environmental Implications
of Energy Flow 80
Entropy Increases 80
Energy Quality 80
Biological Systems and Thermodynamics 80
Pollution and Thermodynamics 80
ISSUES & ANALYSIS: The End of the Incandescent Lightbulb 81



Department of
Commerce/NOAA

Chapter 5

Interactions: Environments and Organisms 84

The Adaptation of Wildlife to Urban Environments 85

- 5.1 Ecological Concepts 85
Environment 86
Limiting Factors 87



Glow Images

SCIENCE, POLITICS, & POLICY: Emotion and Wolf Management 88

Habitat and Niche 88

- 5.2 The Role of Natural Selection and Evolution 91
Genes, Populations, and Species 92
Natural Selection 92
Evolutionary Patterns 94
- 5.3 Kinds of Organism Interactions 96
Predation 96
Competition 97
Symbiotic Relationships 99
Some Relationships are Difficult to Categorize 100
- 5.4 Community and Ecosystem Interactions 101
Keystone Species 102
Major Roles of Organisms in Ecosystems 102
Energy Flow Through Ecosystems 103
Food Chains and Food Webs 105
Nutrient Cycles in Ecosystems—Biogeochemical Cycles 105

FOCUS ON: Mass Balance: Applying the Law of Conservation of Mass in Environmental Science 106

FOCUS ON: Changes in the Food Chain of the Great Lakes 112

FOCUS ON: Good Environmental Stewardship Begins in Our Own Backyards 113

GOING GREEN: Phosphorus-Free Lawn Fertilizer 115

ISSUES & ANALYSIS: Wildlife and Climate Change 116

Chapter 6

Kinds of Ecosystems and Communities 119

Overfishing of Marine Ecosystems—

A Global Disaster 120

- 6.1 Succession 121
Primary Succession 121
Secondary Succession 123
Modern Concepts of Succession and Climax 124
- 6.2 Biomes Are Determined by Climate 125
Precipitation and Temperature 126
The Effect of Elevation on Climate and Vegetation 126
- 6.3 Major Biomes of the World 127
Desert 127
GOING GREEN: North American Wildlife Conservation Model 129
Temperate Grassland 129
Savanna 131
Mediterranean Shrublands (Chaparral) 132
Tropical Dry Forest 133
Tropical Rainforest 134
FOCUS ON: Grassland Succession 135
Temperate Deciduous Forest 136
Temperate Rainforest 137
Taiga, Northern Coniferous Forest, or Boreal Forest 137
Tundra 138
- 6.4 Major Aquatic Ecosystems 141
Marine Ecosystems 141
Freshwater Ecosystems 145
FOCUS ON: The Role of Fire in Natural Ecosystems 147



DonLand/
Shutterstock

SCIENCE, POLITICS, & POLICY: Preventing Asian Carp from Entering the Great Lakes 148

ISSUES & ANALYSIS: Effects of Climate Change on Fisheries 149

Chapter 7

Populations: Characteristics and Issues 152

Invasive Species 153

7.1 Population Characteristics 154

- Genetic Differences 154
- Natality—Birth Rate 154
- Mortality—Death Rate 154
- Population Growth Rate 155
- Sex Ratio 155
- Age Distribution 156
- Population Density and Spatial Distribution 157
- Summary of Factors that Influence Population Growth Rates 157

7.2 A Population Growth Curve 158

7.3 Factors That Limit Population Size 158

- Extrinsic and Intrinsic Limiting Factors 158
- Density-Dependent and Density-Independent Limiting Factors 159

7.4 Categories of Limiting Factors 159

- Availability of Raw Materials 159
- Availability of Energy 159
- Accumulation of Waste Products 159
- Interactions Among Organisms 160

7.5 Carrying Capacity 160

7.6 Reproductive Strategies and Population Fluctuations 161

- K-Strategists and r-Strategists 161

GOING GREEN: Species Success Stories 162

- Population Cycles 164

7.7 Human Population Growth 164

7.8 Human Population Characteristics and Implications 165

- Economic Development 165
- Measuring the Environmental Impact of a Population 166
- The Ecological Footprint Concept 167

7.9 Factors That Influence Human Population Growth 168

FOCUS ON: Thomas Malthus and His Essay on Population 168

- Biological Factors 169
- Social Factors 169
- Economic Factors 171
- Political Factors 171

FOCUS ON: Refugees—Involuntary Migrants 172

7.10 Population Growth Rates and Standard of Living 173

7.11 Hunger, Food Production, and Environmental

Degradation 174

- Environmental Impacts of Food Production 174

- The Human Energy Pyramid 174

- Economics and Politics of Hunger 175

- Solving the Problem 175

7.12 The Demographic Transition Concept 175

- The Demographic Transition Model 175

- Applying the Model 175

- The Demographic Dividend 176



Photodisc/Getty Images

7.13 The U.S. Population Picture 176

- Age Distribution 177

- Immigration Policy 177

SCIENCE, POLITICS, & POLICY: Funding the Unmet Need for Family Planning 178

7.14 What Does the Future Hold? 179

- Available Raw Materials 179

- Available Energy 179

- Waste Disposal 179

- Interaction with Other Organisms 179

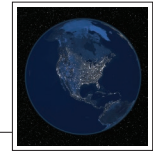
- Social Factors Influence Human Population 179

- Ultimate Size Limitation 179

ISSUES & ANALYSIS: Wolves and Moose on Isle Royale 180

Chapter 8

Energy and Civilization: Patterns of Consumption 184



NASA/NOAA/SPL/Getty Images

The Impact of Newly Industrialized Countries 185

8.1 History of Energy Consumption 185

- Biological Energy Sources 185

- Increased Use of Wood 186

- Fossil Fuels and the Industrial Revolution 186

- The Role of the Automobile 187

- Growth in the Use of Natural Gas 188

8.2 How Energy Is Used 189

- Residential and Commercial Energy Use 190

- Industrial Energy Use 190

- Transportation Energy Use 190

SCIENCE, POLITICS, & POLICY: Reducing Automobile Use in Cities 191

8.3 Electrical Energy 192

GOING GREEN: Saving Energy at Home 193

8.4 The Economics and Politics of Energy Use 194

- Fuel Economy and Government Policy 194

- Electricity Pricing 194

- The Importance of OPEC 195

8.5 Energy Consumption Trends 195

- Growth in Energy Use 195

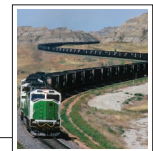
- Available Energy Sources 195

- Political and Economic Factors 196

ISSUES & ANALYSIS: Government Action and Energy Policy 198

Chapter 9

Nonrenewable Energy Sources 200



Mike Danneman/Getty Images

Hydraulic Fracturing 201

9.1 Major Energy Sources 202

9.2 Resources and Reserves 202

9.3 Fossil-Fuel Formation 203

- Coal 203

- Oil and Natural Gas 204

9.4 Issues Related to the Use of Fossil Fuels 205

Coal Use 205

Oil Use 207

FOCUS ON: Unconventional Sources of Oil and Natural Gas 208

Natural Gas Use 211

9.5 Nuclear Power 211

Forces That Influence the Growth of Nuclear Power 211

SCIENCE, POLITICS, & POLICY: The Arctic National Wildlife Refuge 212

The Current Status of Nuclear Power 212

9.6 The Nature of Nuclear Energy 213

9.7 Nuclear Chain Reaction 214

9.8 Nuclear Fission Reactors 215

9.9 The Nuclear Fuel Cycle 217

FOCUS ON: Measuring Radiation 218

9.10 Issues Related to the Use of Nuclear Fuels 219

The Biological Effects of Ionizing Radiation 219

Radiation Protection 219

Reactor Safety 220

GOING GREEN: Closure of Coal-Fired Power Plants 222

Terrorism 222

ISSUES & ANALYSIS: Subsidies for the Energy Sector 223

Nuclear Waste Disposal 223

Decommissioning Nuclear Power Plants 223

Chapter 10

Renewable Energy Sources 227

Which Renewable Energy Technologies Should We Use? 228

Energy Return on Investment and Net Energy 228

10.1 The Status of Renewable Energy 229

10.2 Major Kinds of Renewable Energy 230

Biomass Conversion 230

FOCUS ON: Biomass Fuels and the Developing World 232

SCIENCE, POLITICS, & POLICY: The Renewable Fuel Mandate 235

Hydroelectric Power 236

Solar Energy 237

Wind Energy 241

Geothermal Energy 242

Tidal Power 243

GOING GREEN: The Role of Hybrid and Electric Vehicles 244

10.3 Energy Conservation 245

Government Incentives 246

ISSUES & ANALYSIS: Does Corn Ethanol Fuel Make Sense? 247



Fabio Cardoso/
Corbis/Getty Images

Chapter 11

Biodiversity Issues 249

Prospecting and Medicine—One Aspect of the Value of Biodiversity 250

11.1 Biodiversity 250

Species Diversity 252



paula french/
Shutterstock

Genetic Diversity 254

Ecosystem Diversity 255

Beyond Counting the Number of Types or Variants 256

11.2 The Value of Biodiversity 257

Nature's Contributions to People 257

Variation in Biodiversity Affects Ecosystem Functioning 259

Assigning Value to Nature 259

11.3 Threats to Biodiversity 261

Habitat Loss 262

FOCUS ON: The Special Problem of Tropical Deforestation 266

Habitat Degradation 268

Overexploitation 269

FOCUS ON: Aquaculture 270

GOING GREEN: Sustainable Consumer Choices 271

Species Introductions 272

SCIENCE, POLITICS, & POLICY: The Cat Conundrum 273

Climate Change 276

Multiple Drivers Act Together 276

Broad Outcomes 277

FOCUS ON: New Zealand's Plan to Eradicate All Non-Native Predators 279

11.4 What Is Being Done to Preserve Biodiversity? 279

Species-Level Approaches 279

Ecosystem and Landscape Approaches 281

ISSUES & ANALYSIS: The Problem of Invasive Species 284

Chapter 12

Land-Use Planning 287

Oregon's Statewide Land Use Planning Program 288

12.1 The Need for Planning 288

12.2 Historical Forces That Shaped Land Use 289

Waterways and Development 289

The Rural-to-Urban Shift 289

Migration from the Central City to the Suburbs 289

Characteristics of Suburbs 291

Patterns of Urban Sprawl 291

FOCUS ON: Megacities 293

12.3 Factors That Contribute to Sprawl 294

Lifestyle Factors 294

Economic Factors 294

Planning and Policy Factors 294

12.4 Problems Associated with Unplanned Urban Growth 294

Transportation Problems 294

Death of the Central City 295

High Infrastructure and Energy Costs 295

Loss of Open Space and Farmland 295

Air and Water Pollution Problems 295

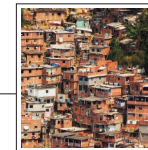
Floodplain Problems 296

Wetlands Misuse 297

Geology and Resource Limitations 298

Aesthetic Issues 298

12.5 Land-Use Planning Principles 298



dndavis/Getty
Images

12.6 Mechanisms for Implementing Land-Use Plans 300

Establishing State or Regional Planning Agencies 300
Restricting Use 300

12.7 Special Urban Planning Issues 302

Urban Transportation Planning 302
Urban Open Space and Recreation Planning 303
Redevelopment of Inner-City Areas 303
Urban Farming 304
Smart Growth Urban Planning 305

SCIENCE, POLITICS, & POLICY: Community Planning and Zoning and Conflicts of Interest 306

GOING GREEN: Using Green Building Techniques in Urban Planning 307

12.8 Federal Government Land-Use Issues 307

ISSUES & ANALYSIS: Smart Communities' Sustainability Planning Strategies 309

Chapter 13

Soil and Its Uses 312

The Living Soil 313

13.1 The Study of Soil as a Science 313

13.2 Geologic Processes 314

13.3 Soil and Land 316

13.4 Soil Formation 316

Soil Forming Factors 316

13.5 Soil Properties 318

13.6 Soil Profile 320

13.7 Soil Erosion 323

SCIENCE, POLITICS, & POLICY: Organic Crops, Healthy Soil, and Policy Debates 324

13.8 Soil Conservation Practices 326

Soil Quality Management Components 328

Contour Farming 329

Strip Farming 329

Terracing 329

GOING GREEN: Green Landscaping 330

Waterways 330

Windbreaks 331

13.9 Conventional Versus Conservation Tillage 331

13.10 Protecting Soil on Nonfarmland 333

FOCUS ON: Microplastics and Soil Pollution 334

ISSUES & ANALYSIS: Phytoremediation—Using Plants to Clean Up Polluted Soil 335



Alistair Berg/Getty Images

Chapter 14

Agricultural Methods and Pest Management 337

The Challenge for Agriculture—Feed More People 338

14.1 The Development of Agriculture 339

Shifting Agriculture 339

Labor-Intensive Agriculture 339

Mechanized Monoculture Agriculture 340



kampee patisena/Moment/Getty Images

14.2 Fertilizer and Agriculture 341

SCIENCE, POLITICS, & POLICY: Regulation of Pesticides 342

14.3 Agricultural Chemical Use 343

Insecticides 343

Herbicides 344

Fungicides and Rodenticides 345

Other Agricultural Chemicals 345

14.4 Problems with Pesticide Use 346

Persistence 346

Bioaccumulation and Biomagnification 346

Pesticide Resistance 346

FOCUS ON: The Dead Zone of the Gulf of Mexico 348

Effects on Nontarget Organisms 349

Human Health Concerns 349

14.5 Why Are Pesticides So Widely Used? 349

FOCUS ON: Honeybees 350

14.6 Alternatives to Conventional Agriculture 350

Techniques for Protecting Soil and Water Resources 352

Integrated Pest Management 352

GOING GREEN: Sustainability and Lawn Care 355

Genetically Modified Crops 356

FOCUS ON: Food Waste 357

Economic and Social Aspects of Sustainable Agriculture 358

ISSUES & ANALYSIS: What Is Organic Food? 359



Christopher E. Herbert/Shutterstock

Chapter 15

Water Management 362

Who Owns the Water? 363

15.1 The Global Water Challenge 364

15.2 The Water Issue 364

15.3 The Hydrologic Cycle 366

15.4 Human Influences on the Hydrologic Cycle 368

15.5 Kinds of Water Use 368

Domestic Use of Water 369

FOCUS ON: Cities Where the Water Taps Could Soon Run Dry 370

Agricultural Use of Water 372

FOCUS ON: The Bottled Water Boom 373

Industrial Use of Water 374

In-Stream Use of Water 375

SCIENCE, POLITICS, & POLICY: Water Wars 376

15.6 Kinds and Sources of Water Pollution 377

Municipal Water Pollution 379

FOCUS ON: Growing Demands for a Limited Supply of Water in the West 380

Agricultural Water Pollution 381

Industrial Water Pollution 382

Thermal Pollution 382

Marine Oil Pollution 383

Groundwater Pollution 383

15.7 Water-Use Planning Issues 384

Municipal Water Management 385

Water Diversion 385
Wastewater Treatment 387
Salinization 388
Groundwater Mining 388

GOING GREEN: From Toilet Water to Tap Water 389

ISSUES & ANALYSIS: Restoring the Everglades 392

Preserving Scenic Water Areas and Wildlife Habitats 392

Chapter 16

Air Quality Issues 397

Metropolitan Areas, Traffic, and Air Pollution 398

16.1 The Atmosphere 398

16.2 Pollution of the Atmosphere 399

16.3 Categories of Air Pollutants 400

Carbon Monoxide 401

Particulate Matter 402

Sulfur Dioxide 403

Nitrogen Dioxide 403

Lead 404

Volatile Organic Compounds 404

Ozone 404

Hazardous Air Pollutants 404

GOING GREEN: Going Solvent-Free 405

16.4 Photochemical Smog 405

How Smog Forms 406

Human Activity and the Pattern of Smog Development 406

The Role of Climate and Geography 407

16.5 Acid Deposition 408

Causes of Acid Precipitation 408

Effects on Structures 409

Effects on Terrestrial Ecosystems 409

Effects on Aquatic Ecosystems 410

16.6 Ozone Depletion 412

Why Stratospheric Ozone Is Important 412

Ozone Destruction 412

Actions to Protect the Ozone Layer 413

16.7 Control of Air Pollution 413

The Clean Air Act 413

SCIENCE, POLITICS, & POLICY: A History of Mercury Regulations 414

Actions That Have Reduced Air Pollution 415

16.8 Air Pollution in the Developing World 417

16.9 Indoor Air Pollution 417

Sources of Indoor Air Pollutants 417

Significance of Weatherizing Buildings 418

Secondhand Smoke 418

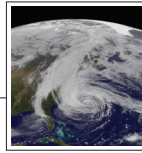
Radon 418

16.10 Noise Pollution 419

Effects of Noise on Humans 419

ISSUES & ANALYSIS: Pollution, Policy, and Personal Choice 420

Effect of Noise on Animals 420



NASA Earth Observatory image by Robert Simmon with data courtesy of the NASA/NOAA GOES Project Science team

Chapter 17

Climate Change: A Twenty-First Century Issue 423

Arctic Native People Confront Climate Change 424

17.1 Earth Is a Greenhouse Planet 424

17.2 Geologic Evidence for Global Warming and Climate Change 425

17.3 Growth in Knowledge of Climate Change 425

17.4 Sources and Impacts of Principal Greenhouse Gases 427

17.5 The Current State of Knowledge about Climate Change 429

17.6 Consequences of Climate Change 431

Climate Change and the Oceans 431

Effect of Ocean Acidity on Marine Organisms and Ecosystems 431

Disruption of the Hydrologic Cycle 431

FOCUS ON: Doubters, Deniers, Skeptics, and Ignorers 432

Rising Sea Level 433

Changes to Ecosystems 434

Health Effects 434

Challenges to Agriculture and the Food Supply 434

17.7 Addressing Climate Change 434

Energy Efficiency and Green Energy 434

The Role of Biomass 435

FOCUS ON: Decline in Arctic Sea Ice 436

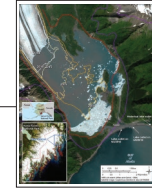
Technological Approaches 437

International Agreements 437

SCIENCE, POLITICS, & POLICY: Policy Responses to Climate Change 438

GOING GREEN: How Countries Respond to Climate Change 440

ISSUES & ANALYSIS: Who Should Reduce CO₂ Emissions? 442



National Park Service

Chapter 18

Solid Waste Management and Disposal 444

Innovative Approaches to Solid Waste Problems 445

18.1 Kinds of Solid Waste 445

18.2 Municipal Solid Waste 447

FOCUS ON: New York City's Garbage Challenge 448

18.3 Methods of Waste Disposal 448

Landfills 449

Incineration 451

GOING GREEN: Garbage Goes Green 452

Composting 453

Source Reduction 453

SCIENCE, POLITICS, & POLICY: Dealing with e-Waste 454

FOCUS ON: Resins Used in Consumer Packaging 455

Recycling 456

ISSUES & ANALYSIS: Plastics in Our Environment 458



Al Franklin/Corbis/Alamy Stock Photo

Chapter 19

Environmental Regulations: Hazardous Substances and Wastes 462

Hazardous Materials Incidents and Regulatory Response 463

19.1 Hazardous and Toxic Materials in Our Environment 464

19.2 Characterizing Hazardous and Toxic Materials 464

Identifying Hazardous Materials 464

Hazardous Waste—A Special Category of Hazardous Material 464

19.3 Controlling Hazardous Materials and Waste 466

Laws and Regulations 466

Voluntary Standards 467

19.4 Managing Health Risks Associated with Toxic Substances 467

Acute and Chronic Toxicity 467

Synergism 467

Persistent and Nonpersistent Pollutants 467

Setting Exposure Limits 468

19.5 How Hazardous Wastes Enter the Environment 468

FOCUS ON: Determining Toxicity 469

19.6 Hazardous-Waste Dumps—The Regulatory Response 469

Resource Conservation and Recovery Act (RCRA) 470

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) 471

19.7 Hazardous-Waste Management Choices 472

Reducing the Amount of Waste at the Source 472

Recycling Wastes 473

Treating Wastes 473

Disposal Methods 473

GOING GREEN: Household Hazardous-Waste Disposal 474

19.8 Toxic Chemical Releases 474

19.9 International Trade in Hazardous Wastes 475

19.10 Nuclear Waste Disposal 475

Sources of Nuclear Waste 476

Disposal Methods 477

FOCUS ON: The Hanford Facility: A Storehouse of Nuclear Remains 478

SCIENCE, POLITICS, & POLICY: Disposal of Waste from Nuclear Power Plants 480

ISSUES & ANALYSIS: PFAS: A Class of Persistent Organic Pollutants 482



DOE Photo

Urbanization 487

Globalization and International Networks 487

Disproportionate Consumption 487

Climate Change 488

Biodiversity Loss 488

20.2 Development of Environmental Policy in the United States 488

Historical Background 488

The Process of Setting Policy 491

Role of the Legislative Branch 491

Role of the Executive Branch 491

The Role of the Judicial Branch 494

The Special Role of Administrative Law 494

FOCUS ON: The Precautionary Principle 495

The Development of the Environmental Protection Agency 495

SCIENCE, POLITICS, & POLICY: The Endangered Species Act—Two Perspectives 496

The Role of Nongovernmental Organizations 497

The Role of Lobbying in the Development of Environmental Policy 497

20.3 The Development and Management of Environmental Policy 498

Landmark Legislation—National Environmental Policy Act 498

Other Important Environmental Legislation 498

GOING GREEN: Principles for Responsible Investment 499

20.4 The Global Commons 499

The Role of the United Nations 499

Earth Summit on Environment and Development 500

Sustainable Development Goals 500

International Environmental Treaties 501

Obstacles to International Cooperation 502

20.5 It All Comes Back to You 503

ISSUES & ANALYSIS: The Future Has Yet To Be Written 504

APPENDIX 1 507

APPENDIX 2 508

GLOSSARY 510

INDEX 520

Chapter 20

Environmental Policy and Decision Making 485

An Historical Look at Attitudes Toward the Environment 486

20.1 Environmental Policy Issues 486

World Population Growth 486



Image Source, all rights reserved.

Preface

The Role of Environmental Science in Society

We live in a time of great change and challenge. Our species has profoundly altered the Earth. Our use of fossil fuels to provide energy is altering climate, our use of Earth's soil resources to feed ourselves results in extinctions, overexploitation of fish populations has resulted in the population declines of many marine species, and freshwater resources are becoming scarce. At the same time, we see significant improvement in other indicators. Energy-efficient and alternative energy technologies are becoming mainstream, population growth is beginning to slow, air and water pollution problems are being addressed in many parts of the world, and issues of biodiversity loss, climate change, and human health are beginning to be addressed on a worldwide basis.

However, there are still major challenges, and there are additional opportunities to lighten our impact on Earth. Understanding the fundamental principles that describe how the Earth's systems work is necessary knowledge for everyone, not just scientists who study these systems. It is particularly important for political, industrial, and business leaders because the political, technical, and economic decisions they make affect the Earth.

Why “A Study of Interrelationships”?

Environmental science is an interdisciplinary field. Because environmental problems occur as a result of the interaction between humans and the natural world, we must include both scientific and social aspects when we seek solutions to environmental problems. Therefore, the central theme of this book is interrelatedness. It is important to have a historical perspective, to appreciate economic and political realities, to recognize the role of different social experiences and ethical backgrounds, and to integrate these with the science that describes the natural world and how we affect it. *Environmental Science: A Study of Interrelationships* incorporates all of these sources of information when discussing any environmental issue.

Environmental science is also a global science. While some environmental problems may be local in nature—pollution of a river, cutting down a forest, or changing the flow of a river for irrigation—other problems are truly global—climate change, overfishing of the oceans, or loss of biodiversity. In addition, individual local events often add together to cause a worldwide problem—the actions of farmers in China or Africa can result in dust storms that

affect the entire world, or the individual consumption of energy from fossil fuels increases carbon dioxide concentrations in the Earth's atmosphere. Therefore, another aspect of the interrelationships theme of this text is to purposely include features that highlight problems, issues, and solutions involving a variety of cultures.

This text has been translated and published in Spanish, Chinese, and Korean. Therefore, students in Santiago, Shanghai, Seoul, or Seattle are learning the “hows and whys” involved in thinking and acting sustainably. At the end of the day, we all share the same air, water, and one not-so-big planet. It's important for all of us to make it last.

What Makes This Text Unique?

We present a balanced view of issues, diligently avoiding personal biases and fashionable philosophies.

It is not the purpose of this textbook to tell readers what to think. Rather, our goal is to provide access to information and the conceptual framework needed to understand complex issues so that readers can comprehend the nature of environmental problems and formulate their own views. Two features of the text encourage readers to think about issues and formulate their own thoughts:

- The **Issues & Analysis** feature at the end of each chapter presents real-world, current issues and provides questions that prompt students to think about the complex social, political, and scientific interactions involved.



Issues & Analysis

Major Environmental Issues and the Ethical Questions They Raise

It is very difficult to prioritize the major environmental issues facing our planet today. The following list includes many of our pressing problems and some of the ethical questions each of the problems raises. You will learn more about each of the issues as you proceed through this text. Do you agree with the problems that are listed? What would you add to the list? Can you identify several ethical questions that each of the problems listed raises?

1. **Population**
The world's population has tripled in the last 60 years, placing stress on every aspect of the environment. In 1950, the population of the world was 2,555,900,000; by 2018, it was over 7,000,000,000. All other major environmental issues stem from the fact that we are overpopulating the planet.
2. **Climate Change**
Climate scientists believe that human activities are currently affecting the climate and that the tipping point has already been passed. In other words, it is too late to undo the damage that climate change has done to the environment.
3. **Loss of Biodiversity**
The loss of biodiversity on the planet can be directly related to the behaviors of humans. Humans have destroyed and continue to destroy the habitats of species. The catastrophic impact of biodiversity loss is likely to affect the planet for millions of years to come. The current loss of biodiversity is also being called “the sixth extinction.”
4. **Water**
Many experts believe that in the near future water will become a commodity like gold and oil. Some experts say that wars will be fought over who owns the water supply. Currently, one-third of

humans have inadequate access to clean, fresh water. That number is expected to increase to two-thirds by 2050.

5. **Ocean Acidification**
Over the last 250 years, surface acidity of the ocean has increased by an estimated 30 percent. The acidity is expected to increase by 150 percent by 2100. The effect of overacidification of the oceans on sea creatures such as shellfish and plankton is similar to osteoporosis in humans. The acid effectively is dissolving the skeletons of the creatures.
6. **Pollution**
Pollution of air, water, and soil is caused by chemical compounds that take many years to break down. Most of these chemicals are by-products of our modern lifestyle. The World Health Organization reports that nearly a quarter of all deaths in the world, about 12.6 million, are caused by environmental problems such as poor sanitation and air pollution.
7. **Overfishing**
Some scientists have said that by 2050 there will be no fish left in the sea. The extinction of many fish species is due to humans overfishing the oceans to supply an ever-increasing demand for seafood. The collapse of the Atlantic Cod fishery is one example of how humans have exploited the planet's natural resources to the brink of extinction.
 - Many statements in the preceding list might be considered dramatic, but they were made to get you thinking about what your future could look like.
 - We are faced with ethical choices daily. What are the ethical choices you see raised by the preceding seven global concerns? What concerns are missing from the list?

Illustration: iStockphoto.com/Steve Haggard

- The **What's Your Take?** feature found in each chapter asks students to take a stand on a particular issue and develop arguments to support their position, helping students develop and enhance their critical thinking skills.



What's Your Take?

The grizzly bear (*Ursus arctos horribilis*) has been receiving federal protection under the U.S. Endangered Species Act for over 30 years. The federal government has now proposed removing that protection on the basis of increasing numbers of bears in the Greater Yellowstone ecosystem and elsewhere. There is considerable disagreement among conservation biologists about how many bears are needed for the species to be

Plant icon: ©Bear Dances Studios/Mark Dinkler

"recovered." When a species is delisted, management is handed over to individual states. If it proposes an acceptable plan, a state may introduce a management plan that includes the hunting of the previously listed species. What kind of ethic underlies the Endangered Species Act? What kind of ethic underlies a management plan that includes hunting? Develop an ethical argument for or against the delisting of the grizzly bear.

We recognize that environmental problems are global in nature.

Three features of the text support this concern:

- Throughout the text, the authors have made a point to use **examples** from around the world as well as those from North America.
- Many of the boxed readings—**Focus On; Going Green; Science, Politics, & Policy;** and **Issues & Analysis**—are selected to provide a global flavor to the basic discussion in the text.



Focus On

Refugees—Involuntary Migrants

Refugees are involuntary migrants who flee their home countries because they fear persecution, war, or violence. It is also possible for persons to leave their home country because of natural disasters (drought, floods, etc.) that endanger their lives. Refugees are essentially international migrants who are seeking a safe place to live. According to the Office of the United Nations High Commissioner for Refugees (UNHCR), there were about 30 million refugees in the world at the end of 2019. Over half of them were from Afghanistan, Syria, and South Sudan, where war caused people to flee their home country.

When refugees cross borders, they have limited rights and protections because they are not citizens of the countries they enter. While most host countries recognize a humanitarian responsibility to help these people, the refugees are a significant social and economic burden. After

all, refugees are generally poor, have not paid taxes to the host country, and are unlikely to be able to pay for services. Thus governments seek to control the entry of refugees and may restrict their movement, require settlement in refugee camps, and limit their access to health care, education, and other services.

The influx of a large number of people disrupts the local social structure of the host country. Any funding that is shifted to helping refugees reduces the amount of money available to fund programs for legal citizens. In addition, if refugees remain in an area, they will try to find jobs to earn money. Others may beg or steal. One of the outcomes of this tension between local citizens and refugees is the development of nationalistic or anti-immigrant groups among the host countries' citizens.



A sign from a demonstration in London, England October 2016
Razvan La Coste/AP Images



A camp in Turkey for Syrian refugees.
SOPA Images/Getty Images

Butterfly icon: ©Kris Bradley/Flickr RF/Getty Images

We recognize that many environmental issues involve complex social, economic, and cultural aspects.

- The first three chapters focus on the underlying social, economic, health, and ethical aspects involved in understanding how people view environmental issues.
- The **Science, Politics, & Policy** feature shows how the scientific understanding of environmental problems is filtered through the lens of social and political goals to determine policy.
- Critical Thinking questions appear at the end of each chapter and require students to evaluate information, recognize bias, characterize the assumptions behind arguments, and organize information.



Science, Politics, & Policy

A History of Mercury Regulations

Science Facts

Mercury is a metal that is liquid at room temperature. It has been known to be toxic for centuries. However, when mercury enters aquatic ecosystems it can be converted to methylmercury by the action of bacteria. The methylmercury becomes concentrated in aquatic food chains and becomes a human health problem when certain species of fish are eaten by humans. The toxic effects of methylmercury have been known since the 1930s. Since methylmercury impairs brain development, fetuses, infants, and children are particularly susceptible. Because of the level of methylmercury and other toxic materials in fish, every state has advisories against eating certain kinds of fish from certain locations.

Because of the known health effects of elemental mercury and methylmercury, the EPA successfully regulated several of the major sources of mercury emissions such as cement plants and those industries that use mercury in their manufacturing processes. The primary remaining source of mercury in the environment is the stack gases from power plants that burn coal or oil. Mercury from power plants is released into the atmosphere and enters watersheds, where it is converted to methylmercury and becomes incorporated into the bodies of organisms.

Politics and Court Actions

The George W. Bush administration (2001–2009) in essence allowed power plants to be exempt from the Clean Air Act, which enabled power plants to avoid the cost of retrofitting their equipment to reduce mercury emissions. In 2008, a lawsuit was filed by several environmental organizations in the U.S. Circuit Court of Appeals in Washington, D.C. The appeals court overturned the Bush administration's mercury regulations and instructed the EPA to come up with a new rule. In 2009, an electric power industry group, Utility Air Regulatory Group, asked the Supreme Court to review the ruling by the appeals court, arguing that the Bush administration had legally decided not to regulate power plants under the Clean Air Act. The Supreme Court denied the request.

During the Obama administration (2009–2017) there were several regulatory and court actions. In December 2011, in response to the appeals court order to produce a new rule on mercury releases from power plants, the EPA published the Mercury and Air Toxics Standards (MATS) rule. MATS set a limit on the amount of mercury that power plants could release. Power plants were given four years in which to comply with the rule. The rule would have ultimately reduced mercury emissions by 90 percent. Because there are several kinds of power plants that use different kinds of coal and other fuels, the setting of rules was a complicated process. In general, new plants must meet much more stringent requirements than existing plants.

In 2015, as a result of a lawsuit by Michigan and 20 other states and industry groups, the Supreme Court ruled 5 to 4 that the EPA should have considered the cost to industry of implementing the rule. The Washington D.C. circuit court reviewed the Supreme Court's ruling and decided that the EPA did not need to stop enforcement of the MATS rule while they completed the cost-benefit analysis. The states appealed the circuit court's ruling to the Supreme Court. In March 2016, Chief Justice John Roberts rejected a request to stay the Mercury and Air Toxics Standards rule. So the EPA could proceed with its enforcement actions while it conducted its investigations of the cost of implementing the rule. The Trump administration began in 2017. President Trump had promised more jobs in the coal

Rock icon: ©Shutterstock/Alga

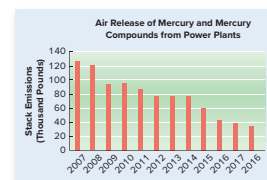
industry, and less regulation on industry. In December 2018, in response to the Supreme Court ruling that the cost to industry should have been considered when the MATS rule was established, the EPA determined that the cost to industry was greater than the value of the health benefits of reducing mercury in the environment. Therefore, it was not "appropriate and necessary" to regulate mercury emissions from power plants. By 2020, the rule had not been finalized.



Emissions from coal-fired power plants are the major source of mercury in the environment.
Lars Lien Photography/Alga Images

Power Industry Reaction

Despite years of political maneuvering and court challenges, there is still no clear policy on mercury releases from power plants. However, the power industry has reacted to the availability of natural gas and the MATS rule by cancelling plans to build new coal-fired power plants and by shutting down many older (more polluting) coal-fired plants. Between 2010 and 2018 the amount of electricity generated by coal-fired power plants declined by 38 percent as many coal-fired plants were shut down. This resulted in a reduction in the demand for coal. Between 2013 and 2019, coal production fell by nearly 25 percent, and thousands of jobs were lost as several coal companies filed for bankruptcy. However, there is a silver lining. Throughout the years this issue has been fermenting, the actual mercury emissions from power plants have fallen by 70 percent, primarily because of the reduction in the number of coal-fired power plants. (See graph.)



We recognize that it is important to focus on the positive.

Environmental science often seems to focus on the negative, since one of the outcomes of any analysis of an environmental situation is to highlight problems and point out where change is needed. We often overlook the many positive actions of individuals and organizations. Therefore, each chapter has two features that call attention to the positive:

- **Going Green** boxes describe actions that are having a positive environmental impact. Some of these actions are taken by governments, some are by corporations, and some are individual efforts.



Going Green

From Toilet Water to Tap Water

Reuse of wastewater to recover water is becoming an important strategy in water-stressed areas. Options for water sources used for drinking water continue to evolve. All water, to some extent, is recycled. River water often is withdrawn and used by one city, which returns treated wastewater to the river. A town downstream uses this water as a source for drinking water for its citizens. In situations where municipalities are experiencing shortages of water, many have identified treated wastewater as a source of water that can be reused for other purposes.

Many wastewater recycling programs provide water for agriculture, landscape, or industrial use. Using wastewater for irrigation accounts for 10 percent of irrigation water in developing countries. This is known as nonpotable reuse. However, many municipalities are now using treated wastewater as a source for drinking water. No federal laws govern reusing treated wastewater for drinking. However, wastewater destined for reuse as potable water typically undergoes two additional steps not usually part of a typical wastewater treatment plant. Microfiltration and reverse osmosis can remove tiny particles (bacteria, viruses, sediment) and dissolved molecules from the wastewater. In most cases, a city's treated wastewater doesn't go directly into the tap but is piped into the ground, or released into lakes or reservoirs that the municipality uses as its source of drinking water. It mixes with the groundwater or surface water and enters a water treatment plant, where it is processed to meet drinking water standards before being funneled to consumers' taps. This process is known as indirect potable reuse. Orange County, California, and St. Petersburg, Florida, use treated wastewater to recharge groundwater. Fairfax County, Virginia, releases its treated wastewater into a reservoir used as a source of drinking water. About 20 percent of the water entering the reservoir is wastewater. The country of Singapore uses treated wastewater for industrial needs, and during water shortages it is added to a reservoir that is a water supply for drinking water.

A few cities, in areas with severe water shortages, send treated wastewater directly to a water treatment plant. This is known as direct potable reuse. Windhoek, Namibia, is an extremely water-stressed part of Africa and has been recycling wastewater since 1968. Today,

Tree icon: ©Shutterstock/Flickr RF/Getty Images



May Knox Merrill/Getty Images

with the construction of a new treatment plant, about 35 percent of its drinking water comes from recycled wastewater. In the United States, Big Spring, Texas, and Wichita Falls, Texas, have both constructed wastewater treatment plants that supply water directly to drinking water treatment plants.

Yet, because of the controversy surrounding this type of water recycling, public acceptance has become as crucial as politics or cost in whether it's implemented. In Toowoomba, Australia, about 100 kilometers (60 miles) west of Brisbane, residents soundly defeated a 2006 proposal to add recycled wastewater to the drinking water supply, despite the area's perpetual water shortage. As periodic drought and population growth create conditions of water shortage and knowledge about wastewater recycling grows, more cities will be looking to wastewater as a source of drinking water. Would you have difficulty drinking "recycled" wastewater? In truth, don't you drink such water already?

- **Acting Green** is an end-of-chapter feature that asks students to consider making personal changes that are relatively simple and will have a positive environmental impact.

Acting Green

1. Learn to identify five plants native to your area.
2. Visit a nature center, wildlife refuge, or state nature preserve. List 10 organisms you identified.
3. Participate in a local program to restore a habitat or eliminate invasive species.
4. Participate in Earth Day (April 22) and Arbor Day (in the spring, but the date varies by state) activities in your community.
5. Visit the National Wildlife Federation website and learn about its Backyard Wildlife Habitat Program.
6. Visit a disturbed site—vacant lot, roadside, abandoned farmland. What evidence do you see that succession is taking place?
7. Participate in a local river or shoreline cleanup program.
8. Make an attempt to spend some time every week in nature. When you do, do so “unplugged.”

New to This Edition

The sixteenth edition of *Environmental Science: A Study of Interrelationships* is the result of extensive analysis of the text and the evaluation of input from environmental science instructors who conscientiously reviewed chapters during the revision. We have used the constructive comments provided by these professionals in our continuing efforts to enhance the strengths of the text.

Current Content As with previous editions, the authors have incorporated the most recent information available at the time of publication.

Revised Art Program Over 120 illustrations, graphs, and charts are new or revised to present detailed information in a form that is easier to comprehend than if that same material were presented in text form.

Several Significantly Revised Chapters

Chapter 1 Environmental Interrelationships The chapter has been completely reorganized to provide a better conceptual flow of information. There is greater emphasis on urbanization, globalization, and governance. There is also a new **Issues & Analysis** on federal land-use in the American West and a new **Focus On** dealing with COVID-19.

Chapter 2 Environmental Ethics There is a new **Science, Politics, & Policy** feature on the ethical and political dimensions of climate change.

Chapter 3 Risk, Economics, and Environmental Concerns The **Science, Politics, & Policy**: The Developing Green Economy and the **Issues & Analysis**: The Economics and Risks of Mercury Contamination were significantly revised and updated.

Chapter 5 Interactions: Environments and Organisms There is a new **Focus On** feature dealing with the concept of mass balance, and the **Science, Politics, & Policy** feature on attitudes toward wolves was revised to reflect recent changes in policy.

Chapter 6 Kinds of Ecosystems and Communities A new **Focus On** reading deals with the role of fire in natural ecosystems, and a new **Going Green** feature discusses the North American model of wildlife conservation.

Chapter 7 Populations: Characteristics and Issues The content was updated with the most recent data from the Population Reference Bureau. There is a new **Issues & Analysis**: The Wolves and Moose on Isle Royale with graph of population changes of moose and wolves.

Chapters 8, 9, and 10 all deal with aspects of energy. These chapters have been updated with the most current data available. In **chapter 9 Nonrenewable Energy Sources**, There is a new **Going Green**: Closure of Coal-Fired Power Plants. **Issues & Analysis**: Subsidies for the Energy Sector has been updated to 2016, and material has been reorganized into a table to make it easier to

follow. **chapter 10 Renewable Energy Sources**, has a new introduction that compares EROI and Net Energy. There is new material on the nature of solar cells, geothermal heat pump systems, and a tidal current system with accompanying illustrations.

Chapter 11 Biodiversity Issues This chapter has been completely rewritten and reorganized with 25 new illustrations. The new organization focuses on the various levels of biodiversity, the value of biodiversity, threats to biodiversity, and efforts to combat the loss of biodiversity.

Chapter 12 Land-Use Planning There is a new **Science, Politics, & Policy**: Community Planning and Zoning and Conflicts of Interest.

Chapter 14 Agricultural Methods and Pest Management There is a new **Focus On**: Honeybees.

Chapter 15 Water Management There is a new **Focus On**: Cities Where the Water Taps Could Soon Run Dry.

Chapter 16 Air Quality Issues The introductory material on Metropolitan Areas, Traffic, and Air Pollution was significantly rewritten with subheads added to make things easier to understand.

The section on photochemical smog was rewritten and illustrations were revised to include more recent changes in the chemical mechanisms involved in the development of smog.

Science, Politics, & Policy: A History of Mercury Regulations was modified to highlight the different approaches of Bush, Obama, and Trump administrations. In addition, several subheads were added to make it easier to follow the flow. A graph showing the reduction in mercury emissions from power plants was added.

Chapter 17 Climate Change: A Twenty-First Century Issue The chapter has been updated with material on the Madrid climate meeting and a new section on the effect of climate change on oceans was added. There is a new **Going Green**: How Countries Respond to Climate Change.

Chapter 18 Solid Waste Management and Disposal The chapter includes a new section on the impact of China's decision to stop purchase of recycled materials and the impact this has on the recycling industry. There is a new **Issues and Analysis**: Plastics in our Environment.

Chapter 19 Environmental Regulations: Hazardous Substances and Wastes The chapter has been updated throughout. There is a new **Issues & Analysis**: PFAS: A Class of Persistent Organic Pollutants. The **Focus On**: The Hanford Facility: A Storehouse of Nuclear Remains has a new table showing the magnitude of the original problem and the current degree of cleanup.

Chapter 20 Environmental Policy and Decision Making The chapter has been completely rewritten. It begins with a discussion of major global environmental issues needing policy initiatives. This is followed by a discussion of the process of establishing environmental policy with the United States political system as a model and the significance of major U.S. environmental legislation. This is followed by a discussion of the role of the United Nations in fostering international environmental agreements and the difficulties involved in reaching consensus.

There is a new chapter introduction that describes changes in attitudes to environmental policy. There are also new **Science, Politics, & Policy**: The Endangered Species Act—Two Perspectives; a new **Going Green**: Principles for Responsible Investment; and a new **Issues & Analysis**: The Future Has Yet To Be Written.

Acknowledgments

The creation of a textbook requires a dedicated team of professionals who provide guidance, criticism, and encouragement. It is also important to have open communication and dialogue to deal with the many issues that arise during the development and production of a text. Therefore, we would like to thank Portfolio Manager and Product Developer Jodi Rhomberg, Project Manager Jessica Portz, Buyer Sandy Ludovissy, Content Licensing Specialist Beth Cray and Designer David Hash for their suggestions and kindnesses. We would like to thank the following individuals who wrote and/or reviewed learning goal-oriented content for LearnSmart.

Sylvester Allred, *Northern Arizona University*
 Ray Beiersdorfer, *Youngstown State University*
 Anne H. Bower, *Philadelphia University*
 Michelle Cawthorn, *Georgia Southern University*
 Kathleen Dahl, *University of Kansas*

Dani DuCharme, *Waubensee Community College*
 Tristan Kloss, *University of Wisconsin–Milwaukee*
 Arthur C. Lee, *Roane State Community College*
 Trent McDowell,
 Jessica Miles, *Florida Atlantic University*
 Brian F. Mooney, *Johnson & Wales University at Charlotte*
 Noelle J. Relles, *State University of New York at Cortland*
 Gigi Richard, *Colorado Mesa University*
 Elise Uphoff
 Amy J. Wagner, *California State University at Sacramento*

Finally, we'd like to thank our many colleagues who have reviewed all, or part, of *Environmental Science: A Study of Interrelationships*. Their valuable input has continued to shape this text and help it meet the needs of instructors around the world.

Eldon D. Enger
 Bradley F. Smith

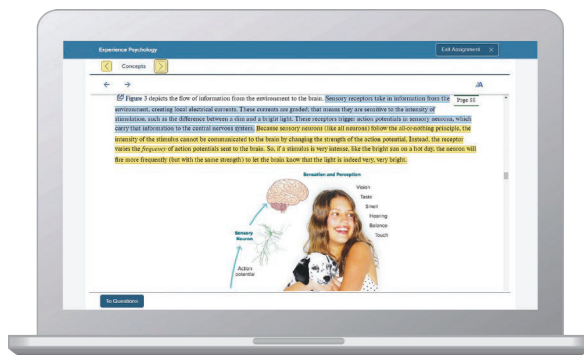


Instructors: Student Success Starts with You

Tools to enhance your unique voice

Want to build your own course? No problem. Prefer to use our turnkey, prebuilt course? Easy. Want to make changes throughout the semester? Sure. And you'll save time with Connect's auto-grading too.

65%
Less Time
Grading



Laptop: McGraw Hill; Woman/dog: George Doyle/Getty Images

Study made personal

Incorporate adaptive study resources like SmartBook® 2.0 into your course and help your students be better prepared in less time. Learn more about the powerful personalized learning experience available in SmartBook 2.0 at www.mheducation.com/highered/connect/smartbook

Affordable solutions, added value



Make technology work for you with LMS integration for single sign-on access, mobile access to the digital textbook, and reports to quickly show you how each of your students is doing. And with our Inclusive Access program you can provide all these tools at a discount to your students. Ask your McGraw Hill representative for more information.

Padlock: Jobalou/Getty Images

Solutions for your challenges



A product isn't a solution. Real solutions are affordable, reliable, and come with training and ongoing support when you need it and how you want it. Visit **www.supportateverystep.com** for videos and resources both you and your students can use throughout the semester.

Checkmark: Jobalou/Getty Images

SUPPORT AT
every step

Students: Get Learning that Fits You

Effective tools for efficient studying

Connect is designed to make you more productive with simple, flexible, intuitive tools that maximize your study time and meet your individual learning needs. Get learning that works for you with Connect.

Study anytime, anywhere

Download the free ReadAnywhere app and access your online eBook or SmartBook 2.0 assignments when it's convenient, even if you're offline. And since the app automatically syncs with your eBook and SmartBook 2.0 assignments in Connect, all of your work is available every time you open it. Find out more at www.mheducation.com/readanywhere

"I really liked this app—it made it easy to study when you don't have your textbook in front of you."

- Jordan Cunningham,
Eastern Washington University



Calendar: owattaphotos/Getty Images

Everything you need in one place

Your Connect course has everything you need—whether reading on your digital eBook or completing assignments for class, Connect makes it easy to get your work done.

Learning for everyone

McGraw Hill works directly with Accessibility Services Departments and faculty to meet the learning needs of all students. Please contact your Accessibility Services Office and ask them to email accessibility@mheducation.com, or visit www.mheducation.com/about/accessibility for more information.

Top: Jenner Images/Getty Images, Left: Hero Images/Getty Images, Right: Hero Images/Getty Images





chapter

1

Environmental Interrelationships



Environmental science is the study of interrelationships between humans and the natural world. This farmer in Uganda has cleared a portion of the original forest to create this small farm, which supplies food and income for the family.

Comstock/Stockbyte/Getty Images

OBJECTIVES

After reading this chapter, you should be able to:

- Recognize that the field of environmental science includes social, political, and economic aspects in addition to science.
- Describe examples that illustrate the interrelated nature of environmental science.
- Understand why most social and political decisions are made with respect to political jurisdictions, but environmental problems do not necessarily coincide with these human-made boundaries.
- Understand the concept of sustainability.
- Recognize that human population growth contributes to environmental problems.
- Recognize that people rely on the services provided by ecosystems.
- Understand that food security is an issue for many people in the less-developed world.
- Recognize that there are governance issues that make it difficult to solve environmental problems.
- Recognize that the quality of the environment has an important impact on human health.
- Understand that personal security incorporates economic, political, cultural, social, and environmental aspects.
- Describe environmental impacts of globalization.
- Recognize the central role energy use has on environmental problems.
- Understand that land, soil, and water are resources that need to be managed.
- Recognize that human activities produce waste product that need to be managed.
- State examples of both positive and negative effects of globalization.
- Recognize that the human population is becoming increasingly urbanized.
- List three reasons it is difficult to develop laws and regulations governing environmental issues.

CHAPTER OUTLINE

The Important Role of Wolves in Yellowstone

- 1.1 The Nature of Environmental Science
- 1.2 Sustainability
- 1.3 Human Welfare Issues
- 1.4 Maintaining Functional Ecosystems
- 1.5 Resource Management Issues
- 1.6 Urbanization and Globalization
- 1.7 Environmental Governance Issues

GOING GREEN Individual Decisions Matter 5

FOCUS ON Campus Sustainability Initiative 6

FOCUS ON COVID-19 Pandemic 15

SCIENCE, POLITICS, & POLICY Federal Land-Use Policy in the West 12

ISSUES & ANALYSIS Government Regulation and Personal Property 17

The Important Role of Wolves in Yellowstone

Early explorers of the lands west of the Mississippi River told of a place with fantastic geysers, mud pots, and other thermal features. They also told of abundant wildlife and rivers filled with fish. After several official government expeditions confirmed these tales, Yellowstone National Park was established as the world's first national park in 1872. As more people settled in the west and ranches and farms were established, there was pressure from farmers and ranchers as well as hunters to reduce the number of predator species on public lands in the west. It was also a generally held idea that predators reduced the numbers of elk, deer, and other species preferred by hunters. Thus the U.S. Congress in 1914 provided funding to eliminate wolves and other predators on public lands, including national parks. By 1926 wolves had been eliminated from Yellowstone. The lack of wolves led to a cascade of unintended consequences:

- Since hunting of species other than predators was prohibited in the park, the population of elk increased. In addition, coyotes, which are normally killed by wolves, increased greatly. By 1935, park managers felt that overgrazing by the large population of elk was beginning to destroy the park's habitat. Therefore, a program of harvesting elk, bison, and pronghorns was instituted to protect the habitat. This program was discontinued in the 1960s as better knowledge of the habitat indicated that it was not overgrazed.
- Coyotes greatly reduced the number of small mammal species such as mice, squirrels, and rabbits.
- The number of pronghorn antelope also decreased because coyotes killed newborn pronghorns.
- Populations of cottonwood and willows along streams declined substantially due to browsing by elk.

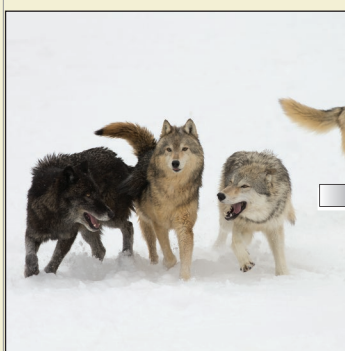
Eventually, as park managers and biologists began to understand the profound changes caused by the elimination of wolves, the decision was made to reintroduce wolves to Yellowstone National Park. The initial introduction of 31 wolves in 1995 and 1996 has resulted in a current population of about 80 wolves in the park. Several changes to the Yellowstone ecosystem can be directly attributed to the alterations brought about by the return of wolves:

- Wolves kill and eat elk. This has contributed to a significant reduction in the size of the elk herd from about 19,000 prior to wolf reintroduction to about 5,000 now.

- The presence of wolves also has modified the behavior of elk. Because they must be more vigilant and move about more because of the predatory behavior of wolves, elk are organized into smaller herds and spend less time feeding on willow, cottonwood, and aspen. Both the change in behavior and the reduced size of the elk herd have allowed the regeneration of stands of cottonwood and willow along rivers. This has in turn resulted in increased numbers of beavers that use these streamside trees for food and as building materials for their dams. In 1995, there was one beaver colony in Yellowstone. In 2019, there were nine. The dams built by beavers tend to slow the flow of water and increase the recharge of groundwater. Furthermore, the stands of willow along the banks of streams cool the water and improve fish habitat. The stands of willow also provide needed habitat for some songbirds.
- Wolves directly compete with coyotes and kill them if they have the opportunity. Thus, since the reintroduction of wolves the coyote population has fallen significantly. There is evidence that the populations of the prey of coyotes—voles, mice, and other rodents—have increased. The increased availability of this food source has resulted in an increase in the number of foxes, hawks, and owls.
- Predation by wolves has affected the lives of many other kinds of animals. The carcasses of animals killed by wolves are a food source for scavengers such as ravens, eagles, bears, wolverines, and magpies. So, the presence of wolves has had a positive effect. Conversely, wolves usurp the kills of cougars, and cougars have migrated to areas without wolves.

Thus, it is fair to say that the reintroduction of the wolf has changed how water flows through the landscape and has led to increased populations of many organisms—willow, cottonwood, beaver, songbirds, foxes, certain rodents, hawks, and owls; and to the decline in the population of other organisms—coyote and elk. Truly this is a story that illustrates the point made by the early naturalist John Muir (1838–1914)—*When we try to pick out anything by itself, we find it hitched to everything else in the Universe.*

Source: John Muir, *My First Summer in the Sierra*, Boston and New York: Houghton Mifflin and Company, 1911.



Wolves reintroduced



Elk decline



Willows increase



Beavers increase

(a): Dennis W Donohue/Shutterstock.com; (b): Source: U.S. National Park Services (NPS); (c): Judy Enger; (d): Yenwen Lu/E+/Getty Images

1.1 The Nature of Environmental Science

Environmental science is an interdisciplinary field that includes both scientific and social aspects of human impact on the world. The word *environment* is usually understood to mean the surrounding conditions that affect organisms. In a broader definition, **environment** is everything that affects an organism during its lifetime. In turn, all organisms including people affect many components in their environment. **Science** is an approach to studying the natural world that involves formulating hypotheses and then testing them to see if the hypotheses are supported or refuted. However, because humans are organized into complex societies, environmental science also must deal with politics, social organization, economics, ethics, and philosophy. Thus, environmental science is a mixture of traditional science, individual and societal values, economic factors, and political realities that are important to solving environmental problems. (See figure 1.1.)

Although environmental science as a field of study is evolving, it is rooted in the early history of civilization. Many ancient cultures expressed a reverence for the plants, animals, and geographic features that provided them with food, water, and transportation. These features are still appreciated by many modern people. Although the following quote from Henry David Thoreau (1817–62) is over a century old, it is consistent with current environmental philosophy:

I wish to speak a word for Nature, for absolute freedom and wildness, as contrasted with a freedom and culture merely civil . . . to regard man as an inhabitant, or a part and parcel of Nature, rather than a member of society.

The current interest in the state of the environment began with philosophers like Thoreau and scientists like Rachel Carson and received emphasis from the organization of the first Earth Day on April 22, 1970. Subsequent Earth Days reaffirmed this commitment. As a result of this continuing interest in the state of the world and how people both affect it and are affected by it, environmental science is now a standard course or program at many colleges. It is also included in the curriculum of high schools. Most of the concepts covered by environmental science courses had previously been taught in ecology, conservation, biology, or geography courses. Environmental science incorporates the scientific aspects of these courses with input from the social sciences, such as economics, sociology, and political science, creating a new interdisciplinary field.

FIGURE 1.1 Environmental Science The field of environmental science involves an understanding of scientific principles, economic influences, and political action. Environmental decisions often involve compromise. A decision that may be supportable from a scientific or economic point of view may not be supportable from a political point of view without modification. Often political decisions relating to the environment may not be supported by economic analysis.

Interrelatedness Is a Core Concept

A central factor that makes the study of environmental science so interesting/frustrating/challenging is the high degree of interrelatedness among seemingly unrelated factors. The opening story about the relationship between wolves and elk in Yellowstone National Park illustrates the theme of interrelatedness very well. The absence of wolves led to an increase in elk and coyotes but to a decrease in beaver, streamside stands of willow and cottonwood, and habitat for some birds. The return of wolves resulted in a decrease in elk numbers and changes in elk behavior that allowed the vegetation to rebound and for beaver to increase in numbers. However, this interrelatedness theme does not just relate to the animal and plant actors in this drama. There is an important human-dominated drama as well that involves philosophical, economic, and political actors.

For example, although many biologists and environmentalists argued that it was important to restore the wolf to its former habitat for biological reasons, others looked at the issue in terms of ethics. They felt that humans had an ethical obligation to restore wolves to their former habitat. While park managers could easily see the problems created by a lack of wolves and a huge elk population, they could not simply make the decision to bring back the wolf. A long

