

CAMPBELL

essential
biology

Detailed Contents

1 Learning About Life 36

CHAPTER THREAD
Swimming with the Turtles 37

BIOLOGY AND SOCIETY A Passion for Life 37

The Scientific Study of Life 38
An Overview of the Process of Science 38
Hypotheses, Theories, and Facts 41
Controlled Experiments 42

THE PROCESS OF SCIENCE Do Baby Turtles Swim? 42
Evaluating Scientific Claims 43

The Properties of Life 44

Major Themes in Biology 45
The Relationship of Structure to Function 46
Information Flow 46
Pathways That Transform Energy and Matter 47
Interactions within Biological Systems 48
Evolution 50

EVOLUTION CONNECTION Turtles in the Tree of Life 52

Unit 1 Cells 55

2 Essential Chemistry for Biology 56

CHAPTER THREAD
Helpful Radiation 57

BIOLOGY AND SOCIETY Nuclear Medicine 57

Some Basic Chemistry 58
Matter: Elements and Compounds 58
Atoms 59

THE PROCESS OF SCIENCE How Effective Is Radiation in Treating Prostate Cancer? 60

Chemical Bonding and Molecules 61
Chemical Reactions 62

Water and Life 63
Water 63
Acids, Bases, and pH 65

EVOLUTION CONNECTION Radioactivity as an Evolutionary Clock 67

3 The Molecules of Life 70

CHAPTER THREAD
Lactose Intolerance 71

BIOLOGY AND SOCIETY Got Lactose? 71

Organic Compounds 72
Carbon Chemistry 72
Giant Molecules from Smaller Building Blocks 73

Large Biological Molecules 74
Carbohydrates 74
Lipids 77
Proteins 80
Nucleic Acids 83

THE PROCESS OF SCIENCE Does Lactose Intolerance Have a Genetic Basis? 85

EVOLUTION CONNECTION The Evolution of Lactose Intolerance in Humans 85



4 A Tour of the Cell

CHAPTER THREAD
Humans Versus Bacteria

BIOLOGY AND SOCIETY Antibiotics: Drugs That Target Bacterial Cells

The Microscopic World of Cells

- The Two Major Categories of Cells
- An Overview of Eukaryotic Cells

Membrane Structure

- The Plasma Membrane
- Cell Surfaces

THE PROCESS OF SCIENCE How Was the First 21st-Century Antibiotic Discovered?

The Nucleus and Ribosomes: Genetic Control of the Cell

- The Nucleus
- Ribosomes
- How DNA Directs Protein Production

The Endomembrane System: Manufacturing and Distributing Cellular Products

- The Endoplasmic Reticulum
- The Golgi Apparatus
- Lysosomes
- Vacuoles

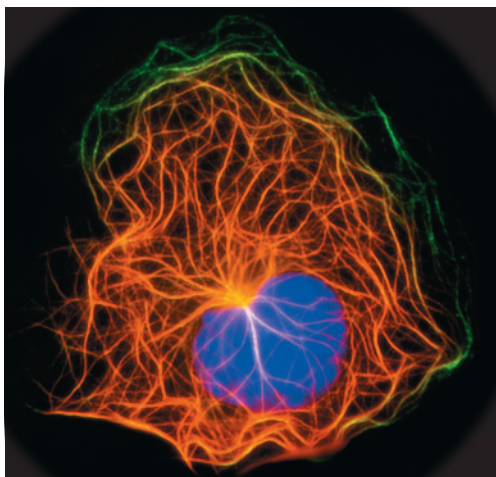
Chloroplasts and Mitochondria: Providing Cellular Energy

- Chloroplasts
- Mitochondria

The Cytoskeleton: Cell Shape and Movement

- Maintaining Cell Shape
- Flagella and Cilia

EVOLUTION CONNECTION The Evolution of Bacterial Resistance in Humans



5 The Working Cell

CHAPTER THREAD
Nanotechnology

BIOLOGY AND SOCIETY Harnessing Cellular Structures

Some Basic Energy Concepts

- Conservation of Energy
- Heat
- Chemical Energy
- Food Calories

ATP and Cellular Work

- The Structure of ATP
- Phosphate Transfer
- The ATP Cycle

Enzymes

- Activation Energy

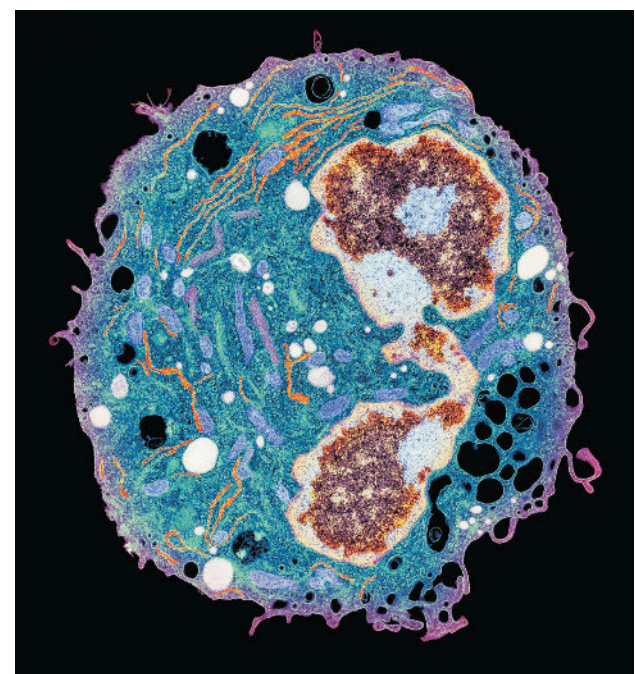
THE PROCESS OF SCIENCE Can Enzymes Be Engineered?

- Enzyme Activity
- Enzyme Inhibitors

Membrane Function

- Passive Transport: Diffusion across Membranes
- Osmosis and Water Balance
- Active Transport: The Pumping of Molecules across Membranes
- Exocytosis and Endocytosis: Traffic of Large Molecules

EVOLUTION CONNECTION The Origin of Membranes



6 Cellular Respiration: Obtaining Energy from Food 124

CHAPTER THREAD
Exercise Science 125

BIOLOGY AND SOCIETY Getting the Most Out of Your Muscles 125

Energy Flow and Chemical Cycling in the Biosphere 126
 Producers and Consumers 126
 Chemical Cycling between Photosynthesis and Cellular Respiration 126

Cellular Respiration: Aerobic Harvest of Food Energy 128
 An Overview of Cellular Respiration 128
 The Three Stages of Cellular Respiration 130
 The Results of Cellular Respiration 134

Fermentation: Anaerobic Harvest of Food Energy 135
 Fermentation in Human Muscle Cells 135

THE PROCESS OF SCIENCE What Causes Muscle Burn? 136
 Fermentation in Microorganisms 136

EVOLUTION CONNECTION The Importance of Oxygen 137

7 Photosynthesis: Using Light to Make Food 140

CHAPTER THREAD
Solar Energy 141

BIOLOGY AND SOCIETY A Solar Revolution 141

The Basics of Photosynthesis 142
 Chloroplasts: Sites of Photosynthesis 142
 An Overview of Photosynthesis 143

The Light Reactions: Converting Solar Energy to Chemical Energy 144
 The Nature of Sunlight 144

THE PROCESS OF SCIENCE What Colors of Light Drive Photosynthesis? 145

Chloroplast Pigments 145
 How Photosystems Harvest Light Energy 146
 How the Light Reactions Generate ATP and NADPH 147

The Calvin Cycle: Making Sugar from Carbon Dioxide 149

EVOLUTION CONNECTION Creating a Better Biofuel Factory 149



Unit 2 Genetics 153

8 Cellular Reproduction: Cells from Cells 154

CHAPTER THREAD
Life with and without Sex

BIOLOGY AND SOCIETY *Virgin Birth of a Shark*

What Cell Reproduction Accomplishes 156

The Cell Cycle and Mitosis 157

- Eukaryotic Chromosomes 157
- Duplicating Chromosomes 159
- The Cell Cycle 159
- Mitosis and Cytokinesis 160
- Cancer Cells: Dividing Out of Control 162

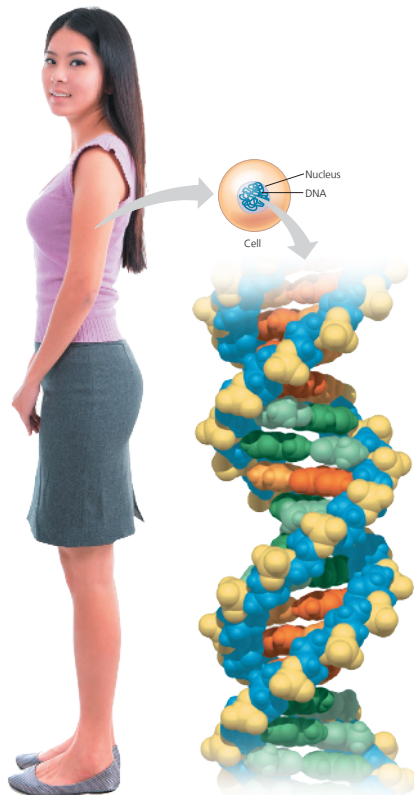
Meiosis, the Basis of Sexual Reproduction 164

- Homologous Chromosomes 164
- Gametes and the Life Cycle of a Sexual Organism 165
- The Process of Meiosis 166
- Review: Comparing Mitosis and Meiosis 168
- The Origins of Genetic Variation 169

THE PROCESS OF SCIENCE *Do All Animals Have Sex?* 171

- When Meiosis Goes Wrong 172

EVOLUTION CONNECTION *The Advantages of Sex* 174



9 Patterns of Inheritance 178

CHAPTER THREAD
Dog Breeding 179

BIOLOGY AND SOCIETY *Darwin's Dogs* 179

Genetics and Heredity 180

- In an Abbey Garden 180
- Mendel's Law of Segregation 181
- Mendel's Law of Independent Assortment 184
- Using a Testcross to Determine an Unknown Genotype 186
- The Rules of Probability 186
- Family Pedigrees 187
- Human Traits Controlled by a Single Gene 188

THE PROCESS OF SCIENCE *What Is the Genetic Basis of Short Legs in Dogs?* 190

Variations on Mendel's Laws 192

- Incomplete Dominance in Plants and People 192
- ABO Blood Groups: An Example of Multiple Alleles and Codominance 193
- Pleiotropy and Sickle-Cell Disease 194
- Polygenic Inheritance 194
- Epigenetics and the Role of Environment 195

The Chromosomal Basis of Inheritance 196

- Linked Genes 196
- Sex Determination in Humans 197
- Sex-Linked Genes 197

EVOLUTION CONNECTION *Barking Up the Evolutionary Tree* 199



10 The Structure and Function of DNA

204

CHAPTER THREAD
Deadly Viruses 205

BIOLOGY AND SOCIETY The Global Threat of Zika Virus 205

DNA: Structure and Replication 206
 DNA and RNA Structure 206
 Watson and Crick's Discovery of the Double Helix 207
 DNA Replication 209

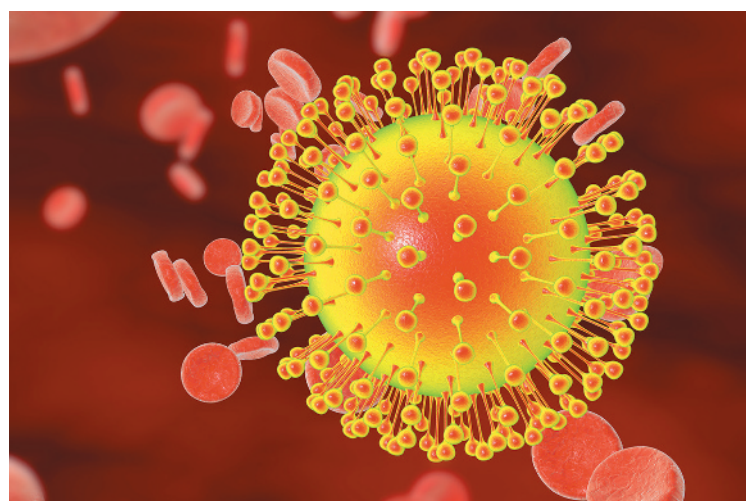
From DNA to RNA to Protein 210
 How an Organism's Genotype Determines Its Phenotype 210
 From Nucleotides to Amino Acids: An Overview 211
 The Genetic Code 212
 Transcription: From DNA to RNA 213
 The Processing of Eukaryotic RNA 214
 Translation: The Players 214
 Translation: The Process 216
 Review: DNA → RNA → Protein 217
 Mutations 218

Viruses and Other Noncellular Infectious Agents 220
 Bacteriophages 220
 Plant Viruses 222
 Animal Viruses 222

THE PROCESS OF SCIENCE Can DNA and RNA Vaccines Protect Against Viruses? 224

HIV, the AIDS Virus 224
 Prions 226

EVOLUTION CONNECTION Emerging Viruses 226



11 How Genes Are Controlled

230

CHAPTER THREAD
Cancer 231

BIOLOGY AND SOCIETY Breast Cancer and Chemotherapy 231

How and Why Genes Are Regulated 232
 Gene Regulation in Bacteria 232
 Gene Regulation in Eukaryotic Cells 234
 Cell Signaling 237
 Homeotic Genes 238
 Visualizing Gene Expression 238

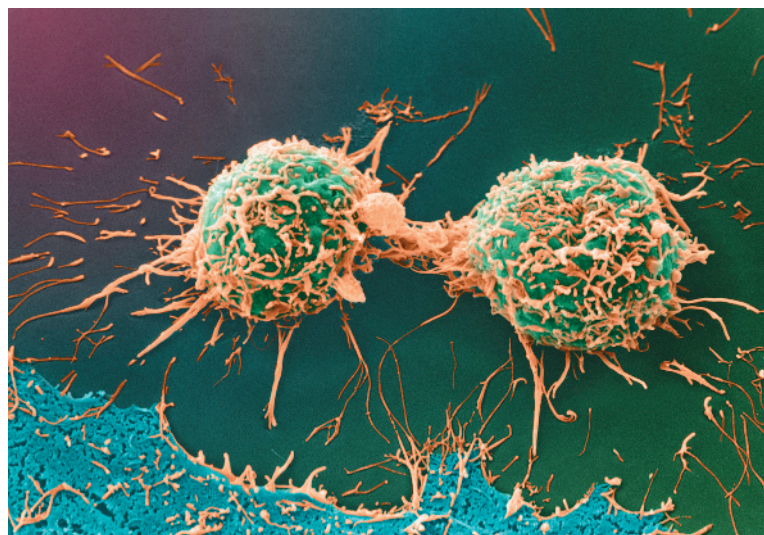
Cloning Plants and Animals 239
 The Genetic Potential of Cells 239
 Reproductive Cloning of Animals 240
 Therapeutic Cloning and Stem Cells 242

The Genetic Basis of Cancer 243
 Genes That Cause Cancer 243

THE PROCESS OF SCIENCE Can Avatars Improve Cancer Treatment? 244

Cancer Risk and Prevention 246

EVOLUTION CONNECTION The Evolution of Cancer in the Body 247



12 DNA Technology 250

CHAPTER THREAD
DNA Profiling 251

BIOLOGY AND SOCIETY Using DNA to Establish Guilt and Innocence 251

Genetic Engineering	252
Recombinant DNA Techniques	252
Gene Editing	254
Medical Applications	255
Genetically Modified Organisms in Agriculture	256
Human Gene Therapy	258

DNA Profiling and Forensic Science	259
DNA Profiling Techniques	259
Investigating Murder, Paternity, and Ancient DNA	262

Bioinformatics	263
DNA Sequencing	263
Genomics	264
Genome-Mapping Techniques	265
The Human Genome	265

THE PROCESS OF SCIENCE Did Nic Have a Deadly Gene? 267

Applied Genomics	267
Systems Biology	268

Safety and Ethical Issues	269
The Controversy over Genetically Modified Foods	269
Ethical Questions Raised by Human DNA Technologies	270

EVOLUTION CONNECTION The Y Chromosome as a Window on History 271



Unit 3 Evolution and Diversity 275

13 How Populations Evolve 276

CHAPTER THREAD
Evolution in Action 277

BIOLOGY AND SOCIETY Mosquitoes and Evolution 277

The Diversity of Life	278
Naming and Classifying the Diversity of Life	278
Explaining the Diversity of Life	279

Charles Darwin and <i>The Origin of Species</i>	280
Darwin's Journey	280
Darwin's Theory	282

Evidence of Evolution	282
Evidence from Fossils	282
Evidence from Homologies	284
Evolutionary Trees	285

Natural Selection as the Mechanism for Evolution	286
Natural Selection in Action	287
Key Points about Natural Selection	288

The Evolution of Populations	288
Sources of Genetic Variation	288
Populations as the Units of Evolution	289
Analyzing Gene Pools	290
Population Genetics and Health Science	291
Microevolution as Change in a Gene Pool	291

Mechanisms of Evolution	292
Natural Selection	292
Genetic Drift	292
Gene Flow	294
Natural Selection: A Closer Look	295

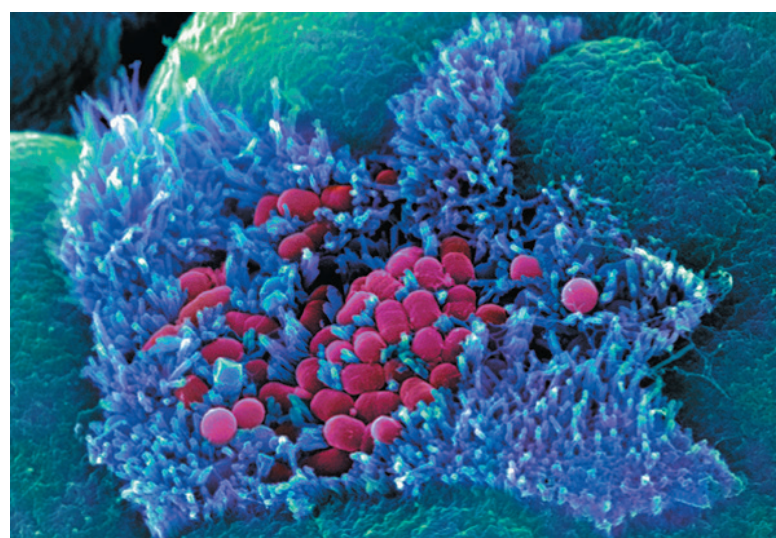
THE PROCESS OF SCIENCE Did Natural Selection Shape the Beaks of Darwin's Finches? 296

EVOLUTION CONNECTION The Rising Threat of Antibiotic Resistance 299



14	How Biological Diversity Evolves	302
	<p>CHAPTER THREAD Evolution in the Human-Dominated World</p>	
	<p>BIOLOGY AND SOCIETY Humanity's Footprint</p> <p>The Origin of Species 303</p> <p>What Is a Species? 304</p> <p>Reproductive Barriers between Species 305</p> <p>Mechanisms of Speciation 308</p>	
	<p>THE PROCESS OF SCIENCE Do Human Activities Facilitate Speciation?</p> <p>Earth History and Macroevolution 310</p> <p>The Fossil Record 313</p> <p>Plate Tectonics and Biogeography 313</p> <p>Mass Extinctions and Explosive Diversifications of Life 315</p> <p>Mechanisms of Macroevolution 317</p> <p>Large Effects from Small Genetic Changes 317</p> <p>The Evolution of Biological Novelty 318</p> <p>Classifying the Diversity of Life 320</p> <p>Classification and Phylogeny 320</p> <p>Classification: A Work in Progress 322</p>	
	<p>EVOLUTION CONNECTION Evolution in the Anthropocene 323</p>	

15	The Evolution of Microbial Life	326
	<p>CHAPTER THREAD Human Microbiota</p>	
	<p>BIOLOGY AND SOCIETY Our Invisible Inhabitants 327</p> <p>Major Episodes in the History of Life 328</p> <p>The Origin of Life 330</p> <p>A Four-Stage Hypothesis for the Origin of Life 330</p> <p>From Chemical Evolution to Darwinian Evolution 332</p> <p>Prokaryotes 333</p> <p>They're Everywhere! 333</p> <p>The Structure and Function of Prokaryotes 334</p> <p>The Ecological Impact of Prokaryotes 337</p> <p>The Two Main Branches of Prokaryotic Evolution: Bacteria and Archaea 338</p>	
	<p>THE PROCESS OF SCIENCE Are Intestinal Microbiota to Blame for Obesity? 340</p> <p>Protists 341</p> <p>Protozoans 342</p> <p>Slime Molds 343</p> <p>Unicellular and Colonial Algae 344</p> <p>Seaweeds 344</p>	
	<p>EVOLUTION CONNECTION The Sweet Life of <i>Streptococcus mutans</i> 345</p>	



16 The Evolution of Plants and Fungi 348

CHAPTER THREAD
Plant-Fungus Interactions 349

BIOLOGY AND SOCIETY The Diamond of the Kitchen 349

- Colonizing Land 350
 - Terrestrial Adaptations of Plants 350
 - The Origin of Plants from Green Algae 352

- Plant Diversity 352
 - Highlights of Plant Evolution 352
 - Bryophytes 353
 - Ferns 355
 - Gymnosperms 356
 - Angiosperms 358
 - Plant Diversity as a Nonrenewable Resource 361

- Fungi 362
 - Characteristics of Fungi 363

- THE PROCESS OF SCIENCE What Killed the Pines? 364
 - The Ecological Impact of Fungi 365
 - Commercial Uses of Fungi 365

- EVOLUTION CONNECTION A Pioneering Partnership 366



17 The Evolution of Animals 370

CHAPTER THREAD
Human Evolution 371

BIOLOGY AND SOCIETY Evolving Adaptability 371

- The Origins of Animal Diversity 372
 - What Is an Animal? 372
 - Early Animals and the Cambrian Explosion 373
 - Animal Phylogeny 374

- Major Invertebrate Phyla 375
 - Sponges 375
 - Cnidarians 376
 - Molluscs 377
 - Flatworms 378
 - Annelids 379
 - Roundworms 380
 - Arthropods 381
 - Echinoderms 387

- Vertebrate Evolution and Diversity 388
 - Characteristics of Chordates 388
 - Fishes 390
 - Amphibians 391
 - Reptiles 392
 - Mammals 394

- The Human Ancestry 395
 - The Evolution of Primates 395
 - The Emergence of Humankind 397

- THE PROCESS OF SCIENCE What Can Lice Tell Us About Ancient Humans? 400

- EVOLUTION CONNECTION Are We Still Evolving? 401



Unit 4 Ecology 405

18 An Introduction to Ecology and the Biosphere 406

CHAPTER THREAD
Climate Change 407

BIOLOGY AND SOCIETY Penguins, Polar Bears, and People in Peril 407

An Overview of Ecology 408

- Ecology and Environmentalism 408
- A Hierarchy of Interactions 409

Living in Earth's Diverse Environments 410

- Abiotic Factors of the Biosphere 410
- The Evolutionary Adaptations of Organisms 412
- Adjusting to Environmental Variability 412

Biomes 414

- Freshwater Biomes 414
- Marine Biomes 416
- How Climate Affects Terrestrial Biome Distribution 418
- Terrestrial Biomes 419
- The Water Cycle 425
- Human Impact on Biomes 426

Climate Change 428

- The Greenhouse Effect and Global Warming 428
- The Accumulation of Greenhouse Gases 429
- Effects of Climate Change on Ecosystems 430

THE PROCESS OF SCIENCE How Does Climate Change Affect Species Distribution? 431

- Looking to Our Future 432

EVOLUTION CONNECTION Climate Change as an Agent of Natural Selection 433



19 Population Ecology 436

CHAPTER THREAD
Biological Invasions 437

BIOLOGY AND SOCIETY Invasion of the Lionfish 437

An Overview of Population Ecology 438

- Population Density 439
- Population Age Structure 439
- Life Tables and Survivorship Curves 440
- Life History Traits as Adaptations 440

Population Growth Models 442

- The Exponential Population Growth Model: The Ideal of an Unlimited Environment 442
- The Logistic Population Growth Model: The Reality of a Limited Environment 443
- Regulation of Population Growth 444

Applications of Population Ecology 446

- Conservation of Endangered Species 446
- Sustainable Resource Management 446
- Invasive Species 447
- Biological Control of Pests 448

THE PROCESS OF SCIENCE Can Fences Stop Cane Toads? 449

- Integrated Pest Management 450

Human Population Growth 451

- The History of Human Population Growth 451
- Age Structures 452
- Our Ecological Footprint 453

EVOLUTION CONNECTION Humans as an Invasive Species 455



20	Communities and Ecosystems	458
	CHAPTER THREAD	
	Importance of Biodiversity	459
BIOLOGY AND SOCIETY	Why Biodiversity Matters	459
Biodiversity		460
Genetic Diversity		460
Species Diversity		460
Ecosystem Diversity		461
Causes of Declining Biodiversity		461
Community Ecology		462
Interspecific Interactions		462
Trophic Structure		466
Species Diversity in Communities		469
Disturbances and Succession in Communities		470
Ecological Succession		470
Ecosystem Ecology		471
Energy Flow in Ecosystems		472
Chemical Cycling in Ecosystems		474
Conservation and Restoration Biology		478
Biodiversity “Hot Spots”		478
Conservation at the Ecosystem Level		479
THE PROCESS OF SCIENCE	Does Biodiversity Protect Human Health?	480
Restoring Ecosystems		481
The Goal of Sustainable Development		482
EVOLUTION CONNECTION	Saving the Hot Spots	483

Appendices

A Metric Conversion Table	A-1
B The Periodic Table	A-3
C Credits	A-5
D Selected Answers	A-11

Glossary

G-1

Index

I-1

