

CONTENTS

Preface 13

CHAPTER 1

The Nature of Ecology 17

- 1.1 Ecology Is the Study of the Relationship between Organisms and Their Environment 18
- 1.2 Organisms Interact with the Environment in the Context of the Ecosystem 18
- 1.3 Ecological Systems Form a Hierarchy 19
- 1.4 Ecologists Study Pattern and Process at Many Levels 20
- 1.5 Ecologists Investigate Nature Using the Scientific Method 21
 - **QUANTIFYING ECOLOGY 1.1:** Classifying Ecological Data 23
 - **QUANTIFYING ECOLOGY 1.2:** Displaying Ecological Data: Histograms and Scatter Plots 24
- 1.6 Models Provide a Basis for Predictions 26
- 1.7 Uncertainty Is an Inherent Feature of Science 26
- 1.8 Ecology Has Strong Ties to Other Disciplines 27
- 1.9 The Individual Is the Basic Unit of Ecology 27
 - **ECOLOGICAL ISSUES & APPLICATIONS:** Ecology Has a Rich History 28
 - Summary 30 • Study Questions 31
 - Further Readings 31

PART 1 THE PHYSICAL ENVIRONMENT

CHAPTER 2

Climate 32

- 2.1 Surface Temperatures Reflect the Difference between Incoming and Outgoing Radiation 33
- 2.2 Intercepted Solar Radiation and Surface Temperatures Vary Seasonally 35
- 2.3 Geographic Difference in Surface Net Radiation Result in Global Patterns of Atmospheric Circulation 35
- 2.4 Surface Winds and Earth's Rotation Create Ocean Currents 38
- 2.5 Temperature Influences the Moisture Content of Air 39
- 2.6 Precipitation Has a Distinctive Global Pattern 40

- 2.7 Proximity to the Coastline Influences Climate 41
- 2.8 Topography Influences Regional and Local Patterns of Climate 42
- 2.9 Irregular Variations in Climate Occur at the Regional Scale 43
- 2.10 Most Organisms Live in Microclimates 44
 - **ECOLOGICAL ISSUES & APPLICATIONS:** Rising Atmospheric Concentrations of Greenhouse Gases Are Altering Earth's Climate 46
- Summary 49 • Study Questions 50
- Further Readings 50

CHAPTER 3

The Aquatic Environment 51

- 3.1 Water Cycles between Earth and the Atmosphere 52
- 3.2 Water Has Important Physical Properties 53
- 3.3 Light Varies with Depth in Aquatic Environments 55
- 3.4 Temperature Varies with Water Depth 56
- 3.5 Water Functions as a Solvent 57
- 3.6 Oxygen Diffuses from the Atmosphere to the Surface Waters 58
- 3.7 Acidity Has a Widespread Influence on Aquatic Environments 60
- 3.8 Water Movements Shape Freshwater and Marine Environments 61
- 3.9 Tides Dominate the Marine Coastal Environment 62
- 3.10 The Transition Zone between Freshwater and Saltwater Environments Presents Unique Constraints 63
 - **ECOLOGICAL ISSUES & APPLICATIONS:** Rising Atmospheric Concentrations of CO₂ Are Impacting Ocean Acidity 64
- Summary 66 • Study Questions 67
- Further Readings 67

CHAPTER 4

The Terrestrial Environment 68

- 4.1 Life on Land Imposes Unique Constraints 69
- 4.2 Plant Cover Influences the Vertical Distribution of Light 70
 - **QUANTIFYING ECOLOGY 4.1:** Beer's Law and the Attenuation of Light 72

PART 2 THE ORGANISM AND ITS ENVIRONMENT

CHAPTER 5 Adaptation and Natural Selection 85

- 5.1 Adaptations Are a Product of Natural Selection 86
 - 5.2 Genes Are the Units of Inheritance 87
 - 5.3 The Phenotype Is the Physical Expression of the Genotype 87
 - 5.4 The Expression of Most Phenotypic Traits Is Affected by the Environment 88
 - 5.5 Genetic Variation Occurs at the Level of the Population 90
 - 5.6 Adaptation Is a Product of Evolution by Natural Selection 91
 - 5.7 Several Processes Other than Natural Selection Can Function to Alter Patterns of Genetic Variation within Populations 94
 - 5.8 Natural Selection Can Result in Genetic Differentiation 95
 - **QUANTIFYING ECOLOGY 5.1: Hardy-Weinberg Principle** 96
 - **FIELD STUDIES: Hopi Hoekstra** 100
 - 5.9 Adaptations Reflect Trade-offs and Constraints 102
 - **ECOLOGICAL ISSUES & APPLICATIONS: Genetic Engineering Allows Humans to Manipulate a Species' DNA** 104
- Summary 106 • Study Questions 107
• Further Readings 108

CHAPTER 6 Plant Adaptations to the Environment 109

- 6.1 Photosynthesis Is the Conversion of Carbon Dioxide into Simple Sugars 110
 - 6.2 The Light a Plant Receives Affects Its Photosynthetic Activity 111
 - 6.3 Photosynthesis Involves Exchanges between the Plant and Atmosphere 112
 - 6.4 Water Moves from the Soil, through the Plant, to the Atmosphere 112
 - 6.5 The Process of Carbon Uptake Differs for Aquatic and Terrestrial Autotrophs 115
 - 6.6 Plant Temperatures Reflect Their Energy Balance with the Surrounding Environment 115
 - 6.7 Constraints Imposed by the Physical Environment Have Resulted in a Wide Array of Plant Adaptations 116
 - 6.8 Species of Plants Are Adapted to Different Light Environments 117
 - **FIELD STUDIES: Kaoru Kitajima** 118
 - **QUANTIFYING ECOLOGY 6.1: Relative Growth Rate** 122
 - 6.9 The Link between Water Demand and Temperature Influences Plant Adaptations 123
 - 6.10 Plants Exhibit Both Acclimation and Adaptation in Response to Variations in Environmental Temperatures 128
 - 6.11 Plants Exhibit Adaptations to Variations in Nutrient Availability 130
 - 6.12 Plant Adaptations to the Environment Reflect a Trade-off between Growth Rate and Tolerance 132
 - **ECOLOGICAL ISSUES & APPLICATIONS: Plants Respond to Increasing Atmospheric CO₂** 133
- Summary 136 • Study Questions 137
• Further Readings 138

CHAPTER 7 Animal Adaptations to the Environment 139

- 7.1 Size Imposes a Fundamental Constraint on the Evolution of Organisms 140
- 7.2 Animals Have Various Ways of Acquiring Energy and Nutrients 143
- 7.3 In Responding to Variations in the External Environment, Animals Can Be either Conformers or Regulators 144
- 7.4 Regulation of Internal Conditions Involves Homeostasis and Feedback 145

■ **FIELD STUDIES: Martin Wikelski** 146

- 7.5 Animals Require Oxygen to Release Energy Contained in Food 148
- 7.6 Animals Maintain a Balance between the Uptake and Loss of Water 149
- 7.7 Animals Exchange Energy with Their Surrounding Environment 151
- 7.8 Animal Body Temperature Reflects Different Modes of Thermoregulation 152
- 7.9 Poikilotherms Regulate Body Temperature Primarily through Behavioral Mechanisms 153
- 7.10 Homeotherms Regulate Body Temperature through Metabolic Processes 156
- 7.11 Endothermy and Ectothermy Involve Trade-offs 157
- 7.12 Heterotherms Take on Characteristics of Ectotherms and Endotherms 158
- 7.13 Some Animals Use Unique Physiological Means for Thermal Balance 159
- 7.14 An Animal's Habitat Reflects a Wide Variety of Adaptations to the Environment 161

■ **ECOLOGICAL ISSUES & APPLICATIONS: Increasing Global Temperature Is Affecting the Body Size of Animals** 162

- Summary 164 • Study Questions 165
- Further Readings 166

PART 3 POPULATIONS

CHAPTER 8 Properties of Populations 167

- 8.1 Organisms May Be Unitary or Modular 168
- 8.2 The Distribution of a Population Defines Its Spatial Location 169
 - **FIELD STUDIES: Filipe Alberto** 170
- 8.3 Abundance Reflects Population Density and Distribution 174
- 8.4 Determining Density Requires Sampling 176
- 8.5 Measures of Population Structure Include Age, Developmental Stage, and Size 178
- 8.6 Sex Ratios in Populations May Shift with Age 180
- 8.7 Individuals Move within the Population 181
- 8.8 Population Distribution and Density Change in Both Time and Space 182

■ **ECOLOGICAL ISSUES & APPLICATIONS: Humans Aid in the Dispersal of Many Species, Expanding Their Geographic Range** 183

- Summary 186 • Study Questions 186
- Further Readings 187

CHAPTER 9 Population Growth 188

- 9.1 Population Growth Reflects the Difference between Rates of Birth and Death 189
- 9.2 Life Tables Provide a Schedule of Age-Specific Mortality and Survival 191
 - **QUANTIFYING ECOLOGY 9.1: Life Expectancy** 193
- 9.3 Different Types of Life Tables Reflect Different Approaches to Defining Cohorts and Age Structure 193
- 9.4 Life Tables Provide Data for Mortality and Survivorship Curves 194
- 9.5 Birthrate Is Age-Specific 196
- 9.6 Birthrate and Survivorship Determine Net Reproductive Rate 196
- 9.7 Age-Specific Mortality and Birthrates Can Be Used to Project Population Growth 197
 - **QUANTIFYING ECOLOGY 9.2: Life History Diagrams and Population Projection Matrices** 199
- 9.8 Stochastic Processes Can Influence Population Dynamics 201
- 9.9 A Variety of Factors Can Lead to Population Extinction 201

■ **ECOLOGICAL ISSUES & APPLICATIONS: The Leading Cause of Current Population Declines and Extinctions Is Habitat Loss** 202

- Summary 206 • Study Questions 207
- Further Readings 207

CHAPTER 10 Life History 208

- 10.1 The Evolution of Life Histories Involves Trade-offs 209
- 10.2 Reproduction May Be Sexual or Asexual 209
- 10.3 Sexual Reproduction Takes a Variety of Forms 210
- 10.4 Reproduction Involves Both Benefits and Costs to Individual Fitness 211
- 10.5 Age at Maturity Is Influenced by Patterns of Age-Specific Mortality 212
- 10.6 Reproductive Effort Is Governed by Trade-offs between Fecundity and Survival 215

Intraspecific Population Regulation 235

- 11.1** The Environment Functions to Limit Population Growth 236
- **QUANTIFYING ECOLOGY 11.1:** Defining the Carrying Capacity (K) 237
 - **QUANTIFYING ECOLOGY 11.2:** The Logistic Model of Population Growth 238
- 11.2** Population Regulation Involves Density Dependence 238
- 11.3** Competition Results When Resources Are Limited 239
- 11.4** Intraspecific Competition Affects Growth and Development 239
- 11.5** Intraspecific Competition Can Influence Mortality Rates 241
- 11.6** Intraspecific Competition Can Reduce Reproduction 242
- 11.7** High Density Is Stressful to Individuals 244
- **FIELD STUDIES: T. Scott Sillett** 246
- 11.8** Dispersal Can Be Density Dependent 248
- 11.9** Social Behavior May Function to Limit Populations 248

- 10.7** There Is a Trade-off between the Number and Size of Offspring 218
- 10.8** Species Differ in the Timing of Reproduction 219
- **QUANTIFYING ECOLOGY 10.1:** Interpreting Trade-offs 220
- 10.9** An Individual's Life History Represents the Interaction between Genotype and the Environment 220
- 10.10** Mating Systems Describe the Pairing of Males and Females 222
- 10.11** Acquisition of a Mate Involves Sexual Selection 224
- **FIELD STUDIES: Alexandra L. Basolo** 226
- 10.12** Females May Choose Mates Based on Resources 228
- 10.13** Patterns of Life History Characteristics Reflect External Selective Forces 229
- **ECOLOGICAL ISSUES & APPLICATIONS:** The Life History of the Human Population Reflects Technological and Cultural Changes 231
- Summary 233 • Study Questions 234
• Further Readings 234

- 11.10** Territoriality Can Function to Regulate Population Growth 249
- 11.11** Plants Preempt Space and Resources 250
- 11.12** A Form of Inverse Density Dependence Can Occur in Small Populations 251
- 11.13** Density-Independent Factors Can Influence Population Growth 253
- **ECOLOGICAL ISSUES & APPLICATIONS:** The Conservation of Populations Requires an Understanding of Minimum Viable Population Size and Carrying Capacity 255
- Summary 256 • Study Questions 257
• Further Readings 258

PART 4 SPECIES INTERACTIONS

Species Interactions, Population Dynamics, and Natural Selection 259

- 12.1** Species Interactions Can Be Classified Based on Their Reciprocal Effects 260
- 12.2** Species Interactions Influence Population Dynamics 261
- **QUANTIFYING ECOLOGY 12.1:** Incorporating Competitive Interactions in Models of Population Growth 263
- 12.3** Species Interactions Can Function as Agents of Natural Selection 263
- 12.4** The Nature of Species Interactions Can Vary across Geographic Landscapes 267
- 12.5** Species Interactions Can Be Diffuse 268
- 12.6** Species Interactions Influence the Species' Niche 270
- 12.7** Species Interactions Can Drive Adaptive Radiation 272
- **ECOLOGICAL ISSUES & APPLICATIONS:** Urbanization Has Negatively Impacted Most Species while Favoring a Few 273
- Summary 275 • Study Questions 276
• Further Readings 276

Interspecific Competition 278

- 13.1** Interspecific Competition Involves Two or More Species 279
- 13.2** The Combined Dynamics of Two Competing Populations Can Be Examined Using the Lotka–Volterra Model 279

- 13.3 There Are Four Possible Outcomes of Interspecific Competition 280
 - 13.4 Laboratory Experiments Support the Lotka–Volterra Model 282
 - 13.5 Studies Support the Competitive Exclusion Principle 283
 - 13.6 Competition Is Influenced by Nonresource Factors 284
 - 13.7 Temporal Variation in the Environment Influences Competitive Interactions 285
 - 13.8 Competition Occurs for Multiple Resources 285
 - 13.9 Relative Competitive Abilities Change along Environmental Gradients 287
 - **QUANTIFYING ECOLOGY 13.1:** Competition under Changing Environmental Conditions: Application of the Lotka–Volterra Model 290
 - 13.10 Interspecific Competition Influences the Niche of a Species 291
 - 13.11 Coexistence of Species Often Involves Partitioning Available Resources 293
 - 13.12 Competition Is a Complex Interaction Involving Biotic and Abiotic Factors 296
 - **ECOLOGICAL ISSUES & APPLICATIONS:** Is Range Expansion of Coyote a Result of Competitive Release from Wolves? 296
- Summary 298 • Study Questions 299
• Further Readings 300

CHAPTER 14 Predation 301

- 14.1 Predation Takes a Variety of Forms 302
- 14.2 Mathematical Model Describes the Interaction of Predator and Prey Populations 302
- 14.3 Predator-Prey Interaction Results in Population Cycles 304
- 14.4 Model Suggests Mutual Population Regulation 306
- 14.5 Functional Responses Relate Prey Consumed to Prey Density 307
 - **QUANTIFYING ECOLOGY 14.1:** Type II Functional Response 309
- 14.6 Predators Respond Numerically to Changing Prey Density 310
- 14.7 Foraging Involves Decisions about the Allocation of Time and Energy 313
 - **QUANTIFYING ECOLOGY 14.2:** A Simple Model of Optimal Foraging 314
- 14.8 Risk of Predation Can Influence Foraging Behavior 314

- 14.9 Coevolution Can Occur between Predator and Prey 315
 - 14.10 Animal Prey Have Evolved Defenses against Predators 316
 - 14.11 Predators Have Evolved Efficient Hunting Tactics 318
 - 14.12 Herbivores Prey on Autotrophs 319
 - **FIELD STUDIES:** Rick A. Relyea 320
 - 14.13 Plants Have Evolved Characteristics that Deter Herbivores 322
 - 14.14 Plants, Herbivores, and Carnivores Interact 323
 - 14.15 Predators Influence Prey Dynamics through Lethal and Nonlethal Effects 324
 - **ECOLOGICAL ISSUES & APPLICATIONS:** Sustainable Harvest of Natural Populations Requires Being a “Smart Predator” 325
- Summary 327 • Study Questions 328
• Further Readings 329

CHAPTER 15 Parasitism and Mutualism 330

- 15.1 Parasites Draw Resources from Host Organisms 331
- 15.2 Hosts Provide Diverse Habitats for Parasites 332
- 15.3 Direct Transmission Can Occur between Host Organisms 332
- 15.4 Transmission between Hosts Can Involve an Intermediate Vector 333
- 15.5 Transmission Can Involve Multiple Hosts and Stages 333
- 15.6 Hosts Respond to Parasitic Invasions 334
- 15.7 Parasites Can Affect Host Survival and Reproduction 335
- 15.8 Parasites May Regulate Host Populations 336
- 15.9 Parasitism Can Evolve into a Mutually Beneficial Relationship 337
- 15.10 Mutualisms Involve Diverse Species Interactions 338
- 15.11 Mutualisms Are Involved in the Transfer of Nutrients 339
 - **FIELD STUDIES:** John J. Stachowicz 340
- 15.12 Some Mutualisms Are Defensive 342
- 15.13 Mutualisms Are Often Necessary for Pollination 343
- 15.14 Mutualisms Are Involved in Seed Dispersal 344
- 15.15 Mutualism Can Influence Population Dynamics 345

- **QUANTIFYING ECOLOGY 15.1: A Model of Mutualistic Interactions** 346
- **ECOLOGICAL ISSUES & APPLICATIONS: Land-use Changes Are Resulting in an Expansion of Infectious Diseases Impacting Human Health** 347

Summary 349 • Study Questions 350
 • Further Readings 351

PART 5 COMMUNITY ECOLOGY

CHAPTER 16 Community Structure 352

- 16.1 Biological Structure of Community Defined by Species Composition 353
- 16.2 Species Diversity Is defined by Species Richness and Evenness 354
- 16.3 Dominance Can Be Defined by a Number of Criteria 356
- 16.4 Keystone Species Influence Community Structure Disproportionately to Their Numbers 357
- 16.5 Food Webs Describe Species Interactions 358
- 16.6 Species within a Community Can Be Classified into Functional Groups 363
- 16.7 Communities Have a Characteristic Physical Structure 363
- 16.8 Zonation Is Spatial Change in Community Structure 367
- 16.9 Defining Boundaries between Communities Is Often Difficult 368
- **QUANTIFYING ECOLOGY 16.1: Community Similarity** 370

16.10 Two Contrasting Views of the Community 370

- **ECOLOGICAL ISSUES & APPLICATIONS: Restoration Ecology Requires an Understanding of the Processes Influencing the Structure and Dynamics of Communities** 372

Summary 374 • Study Questions 374
 • Further Readings 375

CHAPTER 17 Factors Influencing the Structure of Communities 376

- 17.1 Community Structure Is an Expression of the Species' Ecological Niche 377
- 17.2 Zonation Is a Result of Differences in Species' Tolerance and Interactions along Environmental Gradients 379
- **FIELD STUDIES: Sally D. Hacker** 380
- 17.3 Species Interactions Are Often Diffuse 385

- 17.4 Food Webs Illustrate Indirect Interactions 387
- 17.5 Food Webs Suggest Controls of Community Structure 390
- 17.6 Environmental Heterogeneity Influences Community Diversity 392
- 17.7 Resource Availability Can Influence Plant Diversity within a Community 393
- **ECOLOGICAL ISSUES & APPLICATIONS: The Reintroduction of a Top Predator to Yellowstone National Park Led to a Complex Trophic Cascade** 396

Summary 398 • Study Questions 399
 • Further Readings 400

CHAPTER 18 Community Dynamics 401

- 18.1 Community Structure Changes through Time 402
- 18.2 Primary Succession Occurs on Newly Exposed Substrates 404
- 18.3 Secondary Succession Occurs after Disturbances 405
- 18.4 The Study of Succession Has a Rich History 407
- 18.5 Succession Is Associated with Autogenic Changes in Environmental Conditions 410
- 18.6 Species Diversity Changes during Succession 412
- 18.7 Succession Involves Heterotrophic Species 413
- 18.8 Systematic Changes in Community Structure Are a Result of Allogenic Environmental Change at a Variety of Timescales 415
- 18.9 Community Structure Changes over Geologic Time 416
- 18.10 The Concept of Community Revisited 417

- **ECOLOGICAL ISSUES & APPLICATIONS: Community Dynamics in Eastern North America over the Past Two Centuries Are a Result of Changing Patterns of Land Use** 421

Summary 423 • Study Questions 424
 • Further Readings 424

CHAPTER 19 Landscape Dynamics 426

- 19.1 A Variety of Processes Gives Rise to Landscape Patterns 427
- 19.2 Landscape Pattern Is Defined by the Spatial Arrangement and Connectivity of Patches 429

19.3 Boundaries Are Transition Zones that Offer Diverse Conditions and Habitats 431

19.4 Patch Size and Shape Influence Community Structure 434

19.5 Landscape Connectivity Permits Movement between Patches 438
■ **FIELD STUDIES: Nick A. Haddad** 440

19.6 The Theory of Island Biogeography Applies to Landscape Patches 442

19.7 Metapopulation Theory Is a Central Concept in the Study of Landscape Dynamics 444

■ **Quantifying Ecology 19.1: Model of Metapopulation Dynamics** 445

19.8 Local Communities Occupying Patches on the Landscape Define the Metacommunity 447

19.9 The Landscape Represents a Shifting Mosaic of Changing Communities 448

■ **ECOLOGICAL ISSUES & APPLICATIONS: Corridors Are Playing a Growing Role in Conservation Efforts** 449

Summary 452 • Study Questions 453
• Further Readings 454

PART 6 ECOSYSTEM ECOLOGY

CHAPTER 20 Ecosystem Energetics 455

20.1 The Laws of Thermodynamics Govern Energy Flow 456

20.2 Energy Fixed in the Process of Photosynthesis Is Primary Production 456

20.3 Climate and Nutrient Availability Are the Primary Controls on Net Primary Productivity in Terrestrial Ecosystems 457

20.4 Light and Nutrient Availability Are the Primary Controls on Net Primary Productivity in Aquatic Ecosystems 460

20.5 External Inputs of Organic Carbon Can Be Important to Aquatic Ecosystems 463

20.6 Energy Allocation and Plant Life-Form Influence Primary Production 464

20.7 Primary Production Varies with Time 465

20.8 Primary Productivity Limits Secondary Production 466

20.9 Consumers Vary in Efficiency of Production 468

20.10 Ecosystems Have Two Major Food Chains 469

■ **FIELD STUDIES: Brian Silliman** 470

20.11 Energy Flows through Trophic Levels Can Be Quantified 472

20.12 Consumption Efficiency Determines the Pathway of Energy Flow through the Ecosystem 472

20.13 Energy Decreases in Each Successive Trophic Level 473

■ **ECOLOGICAL ISSUES & APPLICATIONS: Humans Appropriate a Disproportionate Amount of Earth's Net Primary Productivity** 474

■ **QUANTIFYING ECOLOGY 20.1: Estimating Net Primary Productivity Using Satellite Data** 476

Summary 477 • Study Questions 479
• Further Readings 479

CHAPTER 21 Decomposition and Nutrient Cycling 480

21.1 Most Essential Nutrients Are Recycled within the Ecosystem 481

21.2 Decomposition Is a Complex Process Involving a Variety of Organisms 482

21.3 Studying Decomposition Involves Following the Fate of Dead Organic Matter 484

■ **QUANTIFYING ECOLOGY 21.1: Estimating the Rate of Decomposition** 485

21.4 Several Factors Influence the Rate of Decomposition 486

21.5 Nutrients in Organic Matter Are Mineralized During Decomposition 489

■ **FIELD STUDIES: Edward (Ted) A. G. Schuur** 490

21.6 Decomposition Proceeds as Plant Litter Is Converted into Soil Organic Matter 493

21.7 Plant Processes Enhance the Decomposition of Soil Organic Matter in the Rhizosphere 495

21.8 Decomposition Occurs in Aquatic Environments 496

21.9 Key Ecosystem Processes Influence the Rate of Nutrient Cycling 497

21.10 Nutrient Cycling Differs between Terrestrial and Open-Water Aquatic Ecosystems 498

21.11 Water Flow Influences Nutrient Cycling in Streams and Rivers 500

21.12 Land and Marine Environments Influence Nutrient Cycling in Coastal Ecosystems 501

21.13 Surface Ocean Currents Bring about Vertical Transport of Nutrients 502

■ **ECOLOGICAL ISSUES & APPLICATIONS:**

Agriculture Disrupts the Process of Nutrient Cycling 503

- Summary 506 • Study Questions 507
• Further Readings 508

CHAPTER

22 Biogeochemical Cycles 509

- 22.1** There Are Two Major Types of Biogeochemical Cycles 510
- 22.2** Nutrients Enter the Ecosystem via Inputs 510
- 22.3** Outputs Represent a Loss of Nutrients from the Ecosystem 511
- 22.4** Biogeochemical Cycles Can Be Viewed from a Global Perspective 511
- 22.5** The Carbon Cycle Is Closely Tied to Energy Flow 511
- 22.6** Carbon Cycling Varies Daily and Seasonally 513
- 22.7** The Global Carbon Cycle Involves Exchanges among the Atmosphere, Oceans, and Land 514
- 22.8** The Nitrogen Cycle Begins with Fixing Atmospheric Nitrogen 515
- 22.9** The Phosphorus Cycle Has No Atmospheric Pool 517
- 22.10** The Sulfur Cycle Is Both Sedimentary and Gaseous 518
- 22.11** The Global Sulfur Cycle Is Poorly Understood 519
- 22.12** The Oxygen Cycle Is Largely under Biological Control 520
- 22.13** The Various Biogeochemical Cycles Are Linked 521

■ **ECOLOGICAL ISSUES & APPLICATIONS:**

Nitrogen Deposition from Human Activities Can Result in Nitrogen Saturation 521

- Summary 523 • Study Questions 525
• Further Readings 525

PART 7 ECOLOGICAL BIOGEOGRAPHY

CHAPTER

23 Terrestrial Ecosystems 526

- 23.1** Terrestrial Ecosystems Reflect Adaptations of the Dominant Plant Life-Forms 528
- 23.2** Tropical Forests Characterize the Equatorial Zone 530
- **QUANTIFYING ECOLOGY 23.1:**
Climate Diagrams 531

- 23.3** Tropical Savannas Are Characteristic of Semiarid Regions with Seasonal Rainfall 533

- 23.4** Grassland Ecosystems of the Temperate Zone Vary with Climate and Geography 535

- 23.5** Deserts Represent a Diverse Group of Ecosystems 538

- 23.6** Mediterranean Climates Support Temperate Shrublands 540

- 23.7** Forest Ecosystems Dominate the Wetter Regions of the Temperate Zone 542

- 23.8** Conifer Forests Dominate the Cool Temperate and Boreal Zones 544

- 23.9** Low Precipitation and Cold Temperatures Define the Arctic Tundra 546

■ **ECOLOGICAL ISSUES & APPLICATIONS:**

The Extraction of Resources from Forest Ecosystems Involves an Array of Management Practices 549

- Summary 552 • Study Questions 553
• Further Readings 554

CHAPTER

24 Aquatic Ecosystems 555

- 24.1** Lakes Have Many Origins 556

- 24.2** Lakes Have Well-Defined Physical Characteristics 556

- 24.3** The Nature of Life Varies in the Different Zones 558

- 24.4** The Character of a Lake Reflects Its Surrounding Landscape 559

- 24.5** Flowing-Water Ecosystems Vary in Structure and Types of Habitats 560

- 24.6** Life Is Highly Adapted to Flowing Water 561

■ **QUANTIFYING ECOLOGY 24.1:**
Streamflow 562

- 24.7** The Flowing-Water Ecosystem Is a Continuum of Changing Environments 564

- 24.8** Rivers Flow into the Sea, Forming Estuaries 565

- 24.9** Oceans Exhibit Zonation and Stratification 567

- 24.10** Pelagic Communities Vary among the Vertical Zones 568

- 24.11** Benthos Is a World of Its Own 569

- 24.12** Coral Reefs Are Complex Ecosystems Built by Colonies of Coral Animals 570

- 24.13** Productivity of the Oceans Is Governed by Light and Nutrients 572

■ **ECOLOGICAL ISSUES & APPLICATIONS:** Inputs of Nutrients to Coastal Waters Result in the Development of “Dead Zones” 572

- Summary 574 • Study Questions 576
• Further Readings 576

CHAPTER

25

Coastal and Wetland Ecosystems 577

- 25.1** The Intertidal Zone Is the Transition between Terrestrial and Marine Environments 578

- 25.2** Rocky Shorelines Have a Distinct Pattern of Zonation 578

- 25.3** Sandy and Muddy Shores Are Harsh Environments 580

- 25.4** Tides and Salinity Dictate the Structure of Salt Marshes 581

- 25.5** Mangroves Replace Salt Marshes in Tropical Regions 582

- 25.6** Freshwater Wetlands Are a Diverse Group of Ecosystems 583

- 25.7** Hydrology Defines the Structure of Freshwater Wetlands 585

- 25.8** Freshwater Wetlands Support a Rich Diversity of Life 587

■ **ECOLOGICAL ISSUES & APPLICATIONS:** Wetland Ecosystems Continue to Decline as a Result of Land Use 587

- Summary 589 • Study Questions 590
• Further Readings 590

CHAPTER

26

Large-Scale Patterns of Biological Diversity 591

- 26.1** Earth’s Biological Diversity Has Changed through Geologic Time 592

- 26.2** Past Extinctions Have Been Clustered in Time 593

- 26.3** Regional and Global Patterns of Species Diversity Vary Geographically 594

- 26.4** Various Hypotheses Have Been Proposed to Explain Latitudinal Gradients of Diversity 596

- 26.5** Species Richness Is Related to Available Environmental Energy 598

- 26.6** Large-scale Patterns of Species Richness Are Related to Ecosystem Productivity 600

- 26.7** Regional Patterns of Species Diversity Are a Function of Processes Operating at Many Scales 603

■ **ECOLOGICAL ISSUES & APPLICATIONS:** Regions of High Species Diversity Are Crucial to Conservation Efforts 604

- Summary 606 • Study Questions 607
• Further Readings 607

CHAPTER

27

The Ecology of Climate Change 608

- 27.1** Earth’s Climate Has Warmed over the Past Century 609

- 27.2** Climate Change Has a Direct Influence on the Physiology and Development of Organisms 611

- 27.3** Recent Climate Warming Has Altered the Phenology of Plant and Animal Species 614

- 27.4** Changes in Climate Have Shifted the Geographic Distribution of Species 615

- 27.5** Recent Climate Change Has Altered Species Interactions 618

- 27.6** Community Structure and Regional Patterns of Diversity Have Responded to Recent Climate Change 621

- 27.7** Climate Change Has Impacted Ecosystem Processes 623

- 27.8** Continued Increases in Atmospheric Concentrations of Greenhouse Gases Is Predicted to Cause Future Climate Change 624

- 27.9** A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change 626

■ **FIELD STUDIES: Erika Zavaleta** 628

- 27.10** Predicting Future Climate Change Requires an Understanding of the Interactions between the Biosphere and the Other Components of the Earth’s System 633

- Summary 635 • Study Questions 636
• Further Readings 637

References 639

Glossary 657

Credits 673

Index 683