

Brief Contents

CHAPTER 1 The Science of Plant Ecology 1

PART I Individuals and Their Environments 19

CHAPTER 2 Photosynthesis and Light 21

CHAPTER 3 Water Relations and Thermal Energy Balance 53

CHAPTER 4 Soil and Terrestrial Plant Life 83

CHAPTER 5 Ecosystem Processes 111

PART II From Individuals to Populations 141

CHAPTER 6 Individual Growth and Reproduction 143

CHAPTER 7 Plant Life Histories 177

CHAPTER 8 Population Structure, Growth, and Decline 199

CHAPTER 9 Evolution: Processes and Change 231

PART III Population Interactions and Communities 259

CHAPTER 10 Competition and Other Plant Interactions 261

CHAPTER 11 Herbivory and Other Trophic Interactions 297

CHAPTER 12 Community Diversity and Structure 333

CHAPTER 13 Community Dynamics and Succession 371

CHAPTER 14 Local Abundance, Diversity, and Rarity 397

PART IV From Landscapes to Planet Earth 419

CHAPTER 15 Landscapes: Pattern and Scale 421

CHAPTER 16 Climate, Plants, and Climate Change 447

CHAPTER 17 Paleoecology 495

CHAPTER 18 Biomes and Physiognomy 513

CHAPTER 19 Global Biodiversity Patterns, Loss, and Conservation 543

Contents

1 The Science of Plant Ecology 1

1.1 Ecology Is a Science 2

Where does scientific knowledge come from? 2

Scientific research involves objectivity, subjectivity, choice, and chance 5

Observational studies detect and quantify patterns 5

Experiments are central to research 5

In ecology, “controls” are what you are using for baseline comparisons 8

How do we test theories? 10

Studies can lead to specific results but contribute to general understanding 12

Science is ultimately consistent, but getting to consistency is a challenge 12

1.2 Ecological Phenomena Are Heterogeneous in Many Ways 12

1.3 Plant Ecology Has Developed through the Interaction of Observation, Measurement, Analysis, Technology, and Theory 14

Plant ecology is situated in the more general theoretical framework of ecology 16

Ecology has a range of subdisciplines 17

Science is a human endeavor 18

PART I Individuals and Their Environments 19

2 Photosynthesis and Light 21

2.1 Photosynthesis Is the Engine of Life on Earth 22

■ BOX 2A The Discovery and Elucidation of Photosynthetic Carbon Reduction 26

2.2 Photosynthesis Is Affected by the Environment and by Plant Adaptations 28

The amount of light available limits photosynthesis 28

Carbon uptake is limited by the ways plants respond to their environments 31

Photosynthetic rates can vary among species in different habitats 32

2.3 There Are Three Photosynthetic Pathways:

C_3 , C_4 , and CAM 33

C_3 photosynthesis is the most common and original type of photosynthesis 33

■ BOX 2B Photorespiration 34

C_4 photosynthesis is a specialized adaptation for rapid carbon uptake in warm, bright environments 35

■ BOX 2C Stable Isotopes and Photosynthesis 37

Crassulacean acid metabolism (CAM photosynthesis) is a specialized adaptation for minimizing water loss but at the cost of reduced photosynthesis and slow growth 38

2.4 C_3 Photosynthesis Is the Foundation for the Evolution of C_4 and CAM 39

C_4 and CAM evolved from C_3 photosynthesis many different times in many different plant families 39

Photosynthesis first evolved about 2.5 billion years ago and has continued to evolve over Earth’s history 39

2.5 C_3 , C_4 , and CAM Plants Each Have Distinct Growth Forms, Phenology, and Distributions 42

The three photosynthetic types dominate in different habitats and differ in growth form 42

C_3 and C_4 plants grow most actively in different seasons 43

C_3 , C_4 , and CAM species have different geographic distributions 44

2.6 Plants Possess Many Different Adaptations to Their Light Environments 46

Many plants can detect the length of daylight and how it is changing seasonally 46

Leaves grown in sunlit and shaded conditions can differ in structure and function 47

■ BOX 2D Blue Color and Iridescence, Structural Coloration, and Anthocyanin Pigments 50

3 Water Relations and Thermal Energy Balance 53

The ancestors of modern plants evolved to live in terrestrial environments 54

3.1 Water Potential Provides a Framework for Understanding How Plants Interact with Water in Their Environment 55

■ BOX 3A Measuring Photosynthesis, Transpiration, and Water Potential 56

3.2 Water Moves through a Soil-Plant-Atmosphere Continuum 57

3.3 Plants Manage Transpiration and Water Loss 59

Plants have different strategies for adapting to water availability 60

Water use efficiency is a measure of carbon gain versus water loss 62

Plants have different adaptations for coping with reduced water availability 62

Plants have complex physiological adaptations to drought 65

The anatomy and physiology of stomata shape plant responses to water loss 67

Leaf anatomy can be adaptive for survival and growth in arid environments 68

Roots, stems, and their tissues have adaptations for controlling plant water relations 71

3.4 Everything in the Universe Has a Thermal Energy Balance 75

Radiant energy is always being exchanged between plants and their surroundings 76

■ **BOX 3B Why the Sky Is Blue and the Setting Sun Is Red 77**

Energy flows between plants and air, water and soil via conduction and convection 77

Water loss is accompanied by latent heat loss 78

Putting it all together: what determines leaf and whole-plant temperature? 78

Plants may have adaptations to extreme temperature regimes 80

4 Soil and Terrestrial Plant Life 83

4.1 Soils Have Distinct and Varied Composition, Characteristics, and Structure 84

It takes many thousands of years to create soil 85

■ **BOX 4A Serpentine Soils 85**

Soil texture determines many of the properties of soils that affect plants 89

Soil pH has profound but indirect effects 92

Soils are characterized by horizons—layers with distinctive properties 94

■ **BOX 4B Soil Conservation Is a Major Global Environmental Issue 96**

Soils are the unique product of living organisms acting on soil parent material 97

4.2 The Rhizosphere Is a Unique Environment Created by Roots and Their Interaction with Microorganisms 98

4.3 Water Moves through the Soil to Reach Plants 99

4.4 The Basic Building Blocks of Plants are C, H, and O from Air and Water, and Macronutrients and Micronutrients from the Soil 101

The stoichiometry of elements in plants and soils regulates many ecological processes 104

Nitrogen is often the limiting nutrient for plant growth 104

In some plants nitrogen comes from fixation by symbiotes 105

■ **BOX 4C Symbioses and Mutualisms 105**

Phosphorus is limiting for plant growth in many environments 108

5 Ecosystem Processes 111

5.1 Ecosystem Processes Set the Stage for Life in a Salt Marsh 112

5.2 Ecosystem Pools and Fluxes Form Cycles of Nutrients and Energy 114

■ **BOX 5A Biogeochemical Cycles: Quantifying Pools and Fluxes 114**

5.3 Carbon Is the Foundation of Life on Earth 116

Productivity measures how carbon moves between living things and their nonliving environment 116

Carbon is stored in the living and nonliving components of ecosystems 119

Soil food webs are the recycling engine of terrestrial ecosystems 122

Soil organic matter revisited: Bacteria are an essential component of soil organic matter 125

Primary productivity can be measured or estimated in a variety of ways 125

■ **BOX 5B Using Remote Sensing and Eddy Covariance Methods to Estimate NPP 126**

5.4 The Nitrogen Cycle Is an Essential Component of Ecosystems 127

Bacteria mineralize organic N to inorganic forms taken up by plants 129

Nitrogen is lost from ecosystems through denitrification and leaching 131

Decomposition can immobilize soil nitrogen when NO_3^- or NH_4^+ are sequestered in bacterial biomass 132

5.5 Nitrogen Deposition and Acid Precipitation Can Alter Ecosystems 132

■ **BOX 5C The Haber Process, the Green Revolution, and Nitrogen in Ecosystems 134**

5.6 Cycles of Phosphorus and Other Elements Play Important Roles in Ecosystems 135

Microorganisms make phosphorus available for plants 135

Sulfur is critical for certain plant compounds 136

Calcium is necessary for many plant processes and structures 136

5.7 The Water Cycle Is Central to Life and Climate 137

Water cycles at local and regional scales 137

Local water cycles can affect global cycles 139

PART II From Individuals to Populations 141

6 Individual Growth and Reproduction 143

6.1 Growth Begins with Seed Germination 144

6.2 Plants Grow by Adding Repeated Units to Their Bodies 144

6.3 Plant Growth Affects Resource Acquisition 146

Shoot architecture determines light interception 146

The growth of clonal plants affects their ability to take up patchy resources 147

6.4 Plants Reproduce both Sexually and Asexually 149

Many plants reproduce vegetatively 149

Some plants produce seeds asexually 150

The sexual life cycles of plants involve alternation of generations 150

6.5 The Movement of Pollen Is an Important Aspect of a Plant's Life Cycle 153

The pollen of many plants is moved by the wind 153

Visual displays are important for attracting animal visitors 154

Animal visitors are attracted to plants with floral odors or acoustic guides 156

Plants often need to limit unwanted visits 158

How strongly are floral characteristics associated with particular pollinators? 158

■ **BOX 6A Specialized Plants and Pollinators 159**

■ **BOX 6B Some Complex Plant-Pollinator Interactions 160**

Aquatic plants have special adaptations for pollination 161

■ **BOX 6C Is There a Pollinator Crisis? 161**

6.6 Plants Have Complicated Mating Systems 162

Inbreeding is mating between close relatives 162

Plants may vary in gender 163

■ **BOX 6D Pollination Experiments 164**

Competition occurs among plants and among pollen grains 165

Most mating is between neighboring individuals 166

Plants may mate preferentially with individuals with similar phenotypes 166

Fitness can depend on a population's composition 167

Mating systems have other important consequences 168

6.7 Fruit and Seed Characteristics Affect Dispersal across Space and Time 170

The structures of seeds and fruits affect their dispersal 170

Plants can disperse across time via seed banks 174

7 Plant Life Histories 177

7.1 Trade-Offs Are a Central Cause of Variation in Life History Patterns 178

Trade-offs are difficult to measure 178

An important trade-off is in the size and number of seeds 179

7.2 Evolution Acts on the Schedule of Survival and Reproduction 181

How long a plant lives and when it does its growing is part of its life history strategy 182

7.3 Several Theories Address Life History Strategies 184

Demographic life history theory is based on evolutionary principles 184

r- and *K*-selection theory was influential in earlier thinking about life histories 184

r- and *K*-strategy theory was extended to the ecology of plants 185

Grime's triangular model focuses on the ecological conditions favoring different life history strategies 185

Demographic life history theory has been tied to patterns of reproductive allocation 186

Other theories of life history strategies are based on examining plant traits 188

7.4 Year-to-Year Variation in the Environment Shapes Life Histories 189

Among-year demographic variation reduces fitness 189

Bet-hedging strategies can reduce the variance in fitness 190

Seed germination is triggered by many factors 191

Masting can result in synchronization of flowering among individuals 192

7.5 Phenology Is the Within-Year Schedule of Growth and Reproduction 193

The timing of growth is driven by both abiotic and biotic factors 194

The timing of reproduction may be due to abiotic factors 195

The timing of reproduction may be due to biotic factors 196

8 Population Structure, Growth, and Decline 199

8.1 Plant Biology Creates Special Issues for Population Studies 200

■ **BOX 8A** Genets and Ramets: What Is an Individual? 201

8.2 Plant Populations Are Structured by Age, Size, and Developmental Stage 202

Plant population structure is complicated because plants can change size or form at variable rates 203

8.3 Studying Population Growth Usually Involves Models of Changes in Population Structure 205

Life cycle graphs are useful models of plant demography and its relationship to data acquisition 206

Estimating vital rates can be done several ways 207

■ **BOX 8B** How to Construct a Life Table 208

■ **BOX 8C** Borrowing the Mark-Recapture Method from Animal Ecology 209

■ **BOX 8D** Obtaining Data for Survival Studies 210

There are several approaches to building models for structured populations 211

■ **BOX 8E** Constructing Matrix Models 212

Analyzing demographic models gives information on population growth rates and population composition 213

■ **BOX 8F** Demography of an Endangered Cactus 213

■ **BOX 8G** Multiplying a Population Vector by a Matrix 214

Measuring lifetime reproduction gives us the net reproductive rate of the population 215

Reproductive value is the contribution of each stage to population growth 215

■ **BOX 8H** Reproductive Value 216

Sensitivity and elasticity indicate how individual matrix elements affect population growth 217

Life table response experiments can examine the demographic differences among populations 218

■ **BOX 8I** How Do Changes in Transition Probabilities Affect the Population Growth Rate? 219

Ecologists are beginning to study demography at larger spatial scales 219

There are additional approaches to modeling plant demography 220

Plant populations are heterogeneous 220

8.4 Demographic Studies of Long-Lived Plants Require Creative Methods 221

8.5 Population Growth Fluctuates Randomly over Time 222

There are two general types of random variation 223

Random fluctuations reduce long-term growth rates 225

Studying variable population growth requires data recorded over many years 227

8.6 Demographic Models Have Strengths and Limitations 228

9 Evolution: Processes and Change 231

9.1 Natural Selection Is a Primary Cause of Evolutionary Change 232

Variation in phenotype is necessary for natural selection 233

Three conditions are necessary for evolution by natural selection 234

9.2 Heritability Measures the Genetic Basis of Phenotypic Variation 235

Heritability is a measure of resemblances among relatives 235

■ **BOX 9A** A Simple Genetic System and the Resemblance of Relatives 237

■ **BOX 9B** Using Genes to Track Pollen and Seeds and to Identify Species 238

Phenotypic variation can be partitioned into genetic and nongenetic components 238

The environment can interact with the genome to determine the phenotype 239

Genotypes are often nonrandomly distributed among environments 240

9.3 Patterns of Adaptation Are the Result of Natural Selection 240

Heavy-metal tolerance is an example of genetic differentiation 241

Adaptation to different light conditions is an example of adaptive plasticity 243

Environmental effects can extend over generations 245

Phenotypic plasticity is important for understanding other ecological concepts 245

9.4 Natural Selection Can Occur at Levels Other Than the Individual 246

9.5 Other Processes Can Cause Evolutionary Change 247

Mutation, migration, and sexual reproduction are processes that increase genetic variation 248

Genetic drift is a process that decreases genetic variation 248

These evolutionary processes have important conservation implications 250

- 9.6 Evolutionary Processes Can Affect Variation among Populations 250
- 9.7 Ecotypes Are Different Forms of a Species That Are Adapted to Different Environments 250

- 9.8 Natural Selection Can Cause the Origin of New Species 254
- 9.9 Adaptation and Speciation Can Happen through Hybridization 256

PART III Population Interactions and Communities 259

10 Competition and Other Plant Interactions 261

10.1 Individuals Compete for Limited Resources 262

What are the mechanisms of resource competition? 263

Resource competition often depends on plant size 266

Plant competition frequently occurs between seedlings 266

Seedling competition can lead to self-thinning 269

10.2 There Are Several Approaches to Experiments for Studying Competition 270

How we quantify competition can affect experimental results 270

Competition experiments were originally conducted in greenhouse or garden environments 271

10.3 Interactions among Species Range from Competition to Facilitation 273

Different theories attempt to explain how competitive trade-offs lead to strategies 274

Are there fixed competitive hierarchies? 275

■ BOX 10A Plant Traits and the Worldwide Leaf Economic Spectrum: Attempts to Simplify Understanding of Plant Diversity 276

Does allelopathy between species explain patterns in nature? 276

Plants can change the environment to the advantage of other plants 279

Competitive exclusion sometimes determines species distributions 281

10.4 Competition and Facilitation May Vary along Environmental Gradients 282

There are conflicting models of how productivity affects the importance of competition and facilitation 282

Experimental evidence provides a mixed picture about the roles of competition and facilitation along productivity gradients 284

Research syntheses provide some help in interpreting the evidence 286

Can we resolve the conflicting results? 287

■ BOX 10B Research Synthesis, Systematic Reviews, and Meta-Analysis: Tools for Summarizing Results across Studies 289

Models of plant competition can help us to better understand competitive processes and the role of competition in species coexistence 289

Modern coexistence theory is a framework for understanding how competition affects coexistence 290

Models within the framework of modern coexistence theory have stimulated research and discovery 291

New research can extend our understanding of coexistence 293

11 Herbivory and Other Trophic Interactions 297

11.1 The Effects of Herbivores on Individual Plants Depend on What Is Eaten 298

11.2 Herbivores Can Alter Plant Population Composition and Dynamics 300

Herbivores can change where plants grow 302

Herbivory on seeds has both negative and positive consequences for plant populations 303

People use insect herbivores for biological control 303

11.3 Herbivores Affect Plant Communities in Different Ways 305

Herbivore behavior can change plant community composition 305

Herbivory might result in apparent competition among plants 308

Domesticated and introduced herbivores can shape plant communities 308

How important is herbivory in shaping the natural world? 310

11.4 Plants Defend Themselves against Herbivores by Different Means 310

Plants use a variety of physical defenses to protect themselves 310

Plants have evolved a wide range of chemical defenses against herbivores 312

Plant chemical defenses can be constant or be induced by herbivory 314

Evolutionary consequences of plant-herbivore interactions 316

11.5 Plants Are Involved in Many Kinds of Trophic Interactions 317

Some plants are parasites of other plants 317

11.6 Plants Interact with Pathogens, Endophytes, and Mycorrhizae in Complex Ways 318

■ **BOX 11A “Broken” Tulips and the Tulip Mania of the 1600s 319**

Plants are attacked by many different disease-causing organisms 319

■ **BOX 11B Effects of Plant Disease on Humans: Potato Blight and the Irish Potato Famine (the Great Famine) 319**

Plants have immediate defenses and long-term evolutionary responses to pathogens 321

Pathogens can shape plant populations and communities 322

Plant pathogens can interact in complex ways with other organisms 324

Endophytes are symbiotic organisms that live inside plant cells 324

Mycorrhizae are essential for terrestrial life 325

Arbuscular mycorrhizae and ectomycorrhizae are the two most ecologically important groups 326

Specialized mycorrhizal interactions include those associated with the Ericaceae and Orchidaceae 328

Mycorrhizae function in other ways in addition to nutrient uptake 329

Are mycorrhizal fungi mutualists or parasites? 329

The influence of mycorrhizae can depend on plant-plant interactions as well as on soil nutrients 330

12 Community Diversity and Structure 333

12.1 There Are Many Ways of Thinking about Communities 334

■ **BOX 12A Communities, Taxa, Guilds, and Functional Groups 335**

The debate between Henry Gleason and Frederic Clements shaped modern ideas about plant communities 336

Today’s ecologists have a different perspective on the issues in contention 338

■ **BOX 12B A Deeper Look at Some Definitions: Abiotic Factors and Emergent Properties 340**

The concept of communities is useful but has often been debated 340

12.2 Biodiversity Describes Variation in Biological Organisms and Systems 341

Biodiversity metrics can be built from different types of information 342

Inventory diversity is the variation of types of objects 342

■ **BOX 12C A Unified Measure of Diversity 344**

Differentiation diversity is the variation among units 345

Phylogenetic diversity is variation in evolutionary relationships 345

Functional diversity is variation in traits 347

Different types of biodiversity information can be combined 349

12.3 Communities Can Be Measured in Many Ways 349

Measuring species richness can involve simple sampling procedures or complex mathematical estimates 349

There are many ways to sample communities 354

One measure of a plant community is its physiognomy 357

Long-term studies are important for measuring communities 357

■ **BOX 12D The Long-Term Ecological Research Network 358**

12.4 Plant Communities Can Be Compared by Many Methods 358

Non-numerical techniques were the first methods for comparing communities 359

Communities can be compared by single factors using univariate techniques 360

Most community comparisons use multivariate techniques 360

12.5 Communities Are Distributed across Landscapes 362

Ordination is a group of techniques for describing landscape patterns 362

Patterns of species difference among communities are caused by variation in the environment 364

What types of data are used? 365

Classification is an alternative approach to describing communities in a landscape 366

13 Community Dynamics and Succession 371

13.1 Conflicting Theories Have Attempted to Explain the Mechanisms of Succession 372

Are communities dynamic mosaics or regulated by predictable processes? 372

■ **BOX 13A History of the Development of Modern Succession Theory 373**

Scientific understanding can be influenced by methodology 374

13.2 Successional Change Has Three General Causes 377

Disturbance size affects which species can colonize 377

Fire can cause disturbance 379

Wind can cause disturbance 381

Water can cause disturbance 381

Animals can cause disturbance 382

Earthquakes and volcanoes can cause disturbance 382

■ **BOX 13B The Dust Bowl of the 1930s 383**

- Disease can cause disturbance 384
Humans can cause disturbance 384
- 13.3 Which Species Are Available for Colonization Affects Succession 385**
The dispersal capacity of species affects their colonization capability 385
Species can emerge from the propagule pool 387
- 13.4 Species Performance Determines the Pattern of Successional Change 390**
Species vary in their life histories 390
Species interactions are central to species replacement during succession 391
Resource availability can change during succession 392
- 13.5 The Pathway of Succession Can Vary 393**
Succession may or may not be predictable 393
Understanding successional processes is critical for community restoration 394
- 13.6 Ecologists Have Reconsidered the Concept of Climax 395**
- 14 Local Abundance, Diversity, and Rarity 397**
- 14.1 Are Dominant Species Competitively Superior? 398**
There are many ways to be rare but few ways to be common 398
- Being rare can vary over space and time 399
What makes a species common or rare? 402
- 14.2 Biological Invasions Are a Worldwide Concern 403**
Why do some species become invasive? 404
What makes a community susceptible to invasion? 405
Efforts have been made to integrate explanations for invasiveness and susceptibility to invasion 409
Invasive species may alter many community properties and threaten biodiversity 410
- 14.3 Species Richness and Abundances Differ Greatly among Communities 411**
Abundance curves illustrate community structure graphically 411
Productivity and diversity are related in complex ways within communities 412
Trade-offs and specialization contribute to diversity in heterogeneous environments 414
Disturbances might maintain community diversity 415
- 14.4 Does Increased Diversity Enhance Community Productivity or Stability? 416**
Community dominance and diversity can affect ecosystem processes 417
Diversity has been hypothesized to increase stability 417
Diversity, rarity, and commonness vary with spatial extent 417

PART IV From Landscapes to Planet Earth 419

15 Landscapes: Pattern and Scale 421

- 15.1 Understanding Scale Is Critical to Understanding Ecological Processes 422**
Patterns and processes can vary with scale 422
Scale interacts with environmental heterogeneity 424
Processes and patterns may vary as grain and extent change 425
Spatial pattern and scale can be analyzed using graphical and statistical methods 426
- 15.2 Landscape Ecology Involves Measuring Spatial Patterns and Looking at Their Effects 427**
Defining patches is a key step in measuring patterns 427
- **BOX 15A Differentiating Vegetation Based on Spectral Quality 428**
Patches can be quantified by their sizes, shapes, and spatial arrangement 429
Spatial patterns determine many ecological processes 430
- How one analyzes landscape data affects whether the landscape appears to be continuous or discrete 430
- 15.3 Ecological Processes Occur across Landscapes 431**
Island biogeography theory 431
Ecologists have debated whether there is a set of rules that determines how communities are put together 433
Metapopulation theory 434
- **BOX 15B Metapopulation Models 435**
Demographic processes occur across landscapes 436
Metacommunity theory 437
- 15.4 Ecological Processes at the Level of Landscapes Is Important for Plant Conservation 439**
Fragmentation of landscapes is a major threat to biodiversity 439
Key landscape characteristics are edges, connectivity, and nestedness 443
Ecological theory can help guide reserve design 445

16 Climate, Plants, and Climate Change 447

16.1 There Are Important Differences between Climate and Weather 448

16.2 The Kinetic Energy of Molecules Determines Heat and Temperature 448

The sun's angle is the main factor determining the radiant energy received at Earth's surface 451

There are long-term cycles in Earth's path around the sun that affect radiant energy at Earth's surface 455

16.3 Precipitation Patterns Vary across the Earth 457

Global patterns are determined by air moving in three dimensions at huge spatial scales 457

BOX 16A The Coriolis Effect 460

Continental-scale movement of air and water explain regional differences in snow and rain 464

Seasonal variation in precipitation is an important component of climate 465

The El Niño Southern Oscillation affects rainfall at large spatial scales and intermediate time scales 468

Temperature and rainfall predictability affect plant ecology and evolution 470

16.4 Anthropogenic Global Climate Change Is Caused by Humans and Is Affecting Vegetation 471

The global carbon cycle is central to Earth's climates 472

Increasing atmospheric CO₂ has direct effects on plants 474

The greenhouse effect warms the Earth due to greenhouse gases 475

BOX 16B The Ozone Hole and the Greenhouse Effect 476

16.5 Humans Are Changing the Global Carbon Cycle 477

Fossil fuel combustion is the most important factor changing the greenhouse effect 477

Deforestation and land use change also affect climate 481

16.6 Agriculture Is a Major Source of Greenhouse Gases 482

16.7 Global Climate Change Is Already Occurring 483

16.8 Large Changes Are Predicted for Earth's Climates, but Some Impacts Can Still Be Mitigated 486

BOX 16C Understanding Past Climates and Predicting Future Climates 486

16.9 Changing Climates Are Affecting Species and Ecological Systems 489

16.10 Responses to Ongoing and Predicted Climate Change 492

17 Paleocology 495

17.1 Plants Invaded the Land in the Paleozoic Era 496

17.2 The Mesozoic Era Was Dominated by Gymnosperms and Saw the Origin of the Angiosperms 499

Gymnosperms were the first group of dominant seed plants 499

The breakup of Pangaea happened as the angiosperms rose to dominance 501

The boundary between the Cretaceous and Tertiary periods resulted in big changes in the flora and fauna 503

17.3 The Cenozoic Era Was Dominated by Angiosperms 503

17.4 Many Different Methods Are Used to Uncover the Past 504

17.5 Vegetation Change in the Recent Past Has Been Dominated by the Waxing and Waning of Glaciers 505

At the glacial maximum, climates and habitats were very different from today 506

Modern plant communities began to appear as the glaciers retreated 508

Climatic fluctuations of the recent past continue to shape the vegetation 510

18 Biomes and Physiognomy 513

18.1 Vegetation Can Be Categorized by Its Structure and Function 514

Plant physiognomy varies across the globe 514

Forests are closed canopy systems dominated by trees 516

Tree line defines the edge between treed and treeless landscapes 518

Grasslands and woodlands dominate in areas of lower precipitation 518

Shrublands and deserts are found in very dry or cool regions 519

18.2 Biomes with Similar Vegetation Forms May Be the Result of Convergent Evolution 520

18.3 Moist Tropical Forests 523

Tropical rainforest 523

Tropical montane forest 526

18.4 Seasonal Tropical Forests and Woodlands 526

Tropical deciduous forest 526

Thorn forest 527

Tropical woodland 527

18.5 Temperate Deciduous Forest 528

18.6 Other Temperate Forests and Woodlands 529

- Temperate rainforest 529
- Temperate evergreen forest 530
- Temperate woodland 531

18.7 Taiga 532**18.8 Temperate Shrubland 533****18.9 Grasslands 534**

- Temperate grassland 534
- Tropical savanna 536

18.10 Deserts 537

- Hot desert 537
- Cold desert 538

18.11 Alpine and Arctic Vegetation 539

- Alpine grassland and shrubland 539
- Tundra 540

19 Global Biodiversity Patterns, Loss, and Conservation 543**19.1 Biodiversity Varies Enormously across the Earth 544**

- Global biodiversity increases toward the tropics 545

19.2 What Explains Global Biodiversity Patterns? 546

- Explanations for the latitudinal diversity gradient include energy, water, and environmental heterogeneity, but all explanations have limitations 546

BOX 19A The Fynbos and the Cape Region of Africa Have Some of the World's Highest Plant Diversity 547

- There are also regional and global patterns of β -diversity 550

19.3 There Are Distinctive Regional and Continental Patterns of Plant Biodiversity 550

- Continents at the same latitudes differ in species diversity 551

- Transition zones may have higher diversity due to overlaps in species' distributions 553

- Mountains and mountainous regions have distinct but complex patterns of species diversity 554

19.4 Regional Diversity and Local Diversity Can Influence One Another 556

- Endemism, isolation, and global biodiversity hotspots 557

19.5 Patterns of Species Diversity May Be Explained in General Terms 561

- Null models and the neutral theory of biodiversity and biogeography pose a different approach to explaining patterns of species diversity 562

- Other explanations have been posed to explain variation in biodiversity, but patterns are scale dependent 562

BOX 19B Explaining Diversity along Ecological Gradients 564**19.6 Biodiversity Is Rapidly Being Lost Globally 566**

- What is being lost? 566

- Biodiversity is threatened by human activity 567

- Does human domination require a new definition of the biomes? 570

- Both rare and common species face threats in a range of communities 570

- Human population growth and land use contribute to biodiversity loss 570

19.7 Ecosystem Services Are One Way of Quantifying the Benefits of Natural Systems to Humans 572

- Why should anyone care about plant biodiversity? 572

- Conservation and restoration of biodiversity: a ray of hope? 573

Glossary G-1**Index I-1**