



ISBN:978-0-9863935-0-1

1 Introduction to Plant Biology 1–1

- 1.1 What are plants? 1–2
 - Essay 1.1 Devilish Dodder 1–3
- 1.2 Bacteria, fungi, and algae are included in the scientific study of plant life 1–6
- 1.3 Plants and other organisms have scientific names 1–8
- 1.4 Scientific methods are used to learn about plants and other aspects of nature 1–10
 - Science has an error-correction capacity 1–11
 - The process of science may be inductive or deductive 1–12
- 1.5 Plants and microbes play essential roles in maintaining Earth's environment 1–13
 - Plants and microbes maintain Earth's atmospheric chemistry and climate 1–13
 - Essay 1.2 Global Warming: Too Much of a Good Thing 1–15
 - Plants display close associations with other organisms 1–16
 - Food webs 1–16
 - Beneficial symbioses 1–17
 - Co-evolution 1–17
- 1.6 Plants and microbes are important in human affairs 1–19

2 Plants and People 2–1

- 2.1 Ethnobotany and economic botany focus on human uses of plants 2–2
 - Essay 2.1 Ethnobotany 2–3
- 2.2 The origin of agriculture 2–5
 - When and why did agriculture rise? 2–6
 - Where were plants first domesticated? 2–6
 - Ecological adaptations are responsible for the useful features of cereals and legumes 2–8
 - How were cereals and legumes domesticated? 2–9
- 2.3 Food plant genetic resources and traditional agricultural knowledge need to be preserved 2–12
- 2.4 Natural plant products are useful to humans as medicine and in other ways 2–14
 - Plants are sources of medicine and dietary supplements 2–15
 - Plants are sources of psychoactive drugs 2–17

3 Atoms, Molecules, and Water—The Basis of Life 3–1

- 3.1 All physical matter is made up of elements composed of distinct atoms 3–2
 - Plants contain and require more of some elements than others 3–2
 - Atoms are made up of three subatomic particles: protons, neutrons, and electrons 3–3
 - Every element has an atomic number and a mass number 3–3
- 3.2 Several types of bonds link atoms to form molecules 3–5
 - Ionic bonds form when atoms gain or lose electrons 3–5
 - Acids and bases contain ionic bonds 3–5
 - In covalent bonds, two or more atoms share electrons 3–6
 - Hydrogen bonds are weak attractions between molecules 3–7
- 3.3 Water has unique properties because it forms hydrogen bonds 3–8
 - Essay 3.1 Molecules: Keys to the Search for Extraterrestrial Life 3–9

4 Molecules of Life 4–1

- 4.1 Carbohydrates include sugars, starches, and cellulose 4–2

- 4.2 Lipids include fats and oils, waxes, phospholipids, and steroids 4–6
- 4.3 Proteins are large molecules composed of amino acids 4–10
 - Storage proteins are important in human nutrition 4–12
 - Enzymes are proteins that act as biological catalysts 4–12
- 4.4 DNA and RNA are nucleic acids composed of nucleotides 4–14
- 4.5 Plants produce a wide range of secondary compounds 4–17
 - Terpenes and terpenoids repel insects 4–18
 - Phenolics have antiseptic properties and flavonoids color flowers and fruits 4–19
 - Many alkaloids are widely used as medicines 4–20

5 Cells 5–1

- 5.1 Organisms are composed of one to many microscopic cells 5–2
- 5.2 Microscopes are used to study cells 5–3
 - Light microscopes use glass lenses and visible light to enlarge images 5–3
 - Electron microscopes use magnetic lenses to focus beams of electrons 5–4
- 5.3 Two major types of cells are eukaryotic cells and prokaryotic cells 5–7
 - Cell membranes, cytoplasm, DNA, and ribosomes occur in all cells 5–7
 - The cell membrane functions in communication and transport of materials 5–8
 - Some cell-membrane proteins perceive environmental information 5–8*
 - Some cell-membrane proteins transport materials into or out of cells 5–8*
 - Selective membrane permeability is the basis for osmosis 5–9*
 - Some plants are adapted to salty environments 5–10*
 - Essay 5.1 Plant “Psi”chological Stress 5–11**
 - Endocytosis and exocytosis also transport materials across cell membranes 5–12*
 - Eukaryotic cells share some features that prokaryotic cells lack 5–12
 - Nuclei contain most of the eukaryotic cell’s genetic information 5–13
 - The endomembrane system constructs and transports cell materials 5–13
 - The endoplasmic reticulum 5–14*
 - The Golgi apparatus 5–14*
 - The cytoskeleton and associated motor proteins generate cell movements 5–15
 - Cytoskeletal components 5–15*
 - Types of motor proteins 5–16*
 - Flagella 5–16*
 - Mitochondria are major cellular sites of chemical energy transformations 5–16
 - Peroxisomes contain protective enzymes 5–17
- 5.4 Plant cells have the general features of eukaryotic cells and additional components 5–18
 - Cellulose-rich plant cell walls provide support and protection 5–19
 - Cellulose 5–19*
 - Noncellulose components of plant cell walls 5–20*
 - Primary and secondary plant cell walls 5–20*
 - Plant cells are connected by plasmodesmata 5–21
 - Plastids are sites of photosynthesis and other functions 5–21
 - Starch is formed in plastids of plants and green algae 5–22*
 - Chromoplasts are non-green, pigmented plastids of flowers and fruits 5–22*
 - Vacuoles play several important roles in plant cells 5–22

6 Photosynthesis and Respiration 6–1

- 6.1 Photosynthesis and respiration are the processes by which living organisms capture solar energy and release it to sustain life on Earth 6–2
- 6.2 Metabolism includes many kinds of chemical reactions organized into series called pathways 6–4
 - Chemical reactions may be exergonic or endergonic 6–4

Oxidation–reduction reactions are highly important in cell metabolism 6–5

In metabolism, chemical reactions are organized into pathways 6–6

6.3 Photosynthesis harvests solar energy to sustain life on Earth 6–8

Photosynthesis changed the early Earth so that multicellular life became possible 6–8

Photosynthesis provides the food and fuel that power life on Earth 6–9

The interaction between light and pigments is crucial to the capture of solar energy 6–10

Photosynthesis occurs in the chloroplasts of algae and plants 6–12

Photosynthesis converts light energy into chemical energy stored in sugars 6–12

The light reactions capture solar energy 6–13

Essay 6.1 A Bent Chair Breaks Water Molecules 6–16

Chemiosmosis and photophosphorylation produce ATP molecules in the chloroplast 6–17

The carbon-fixation reactions reduce carbon dioxide to simple sugars 6–17

Photorespiration makes the pathway inefficient 6–19

C₄ plants and CAM plants have mechanisms to reduce photorespiration 6–20

C₄ plants reduce photorespiration by preconcentrating CO₂ 6–20

CAM plants reduce photorespiration by fixing CO₂ at night 6–21

6.4 Respiration and fermentation release energy for cellular metabolism 6–24

Respiration occurs in the cytoplasm and mitochondria of cells 6–25

Glycolysis is the splitting of glucose into two molecules of pyruvate 6–25

Fermentation extracts energy from organic compounds without oxygen 6–26

Essay 6.2 The Botany of Beer 6–27

Pyruvate is split into CO₂ and an acetyl group attached to coenzyme A 6–27

In the Krebs cycle, the acetyl group is broken into two carbon dioxide molecules 6–27

The electron transport chain generates a proton gradient across the inner mitochondrial membrane 6–29

Chemiosmosis and oxidative phosphorylation generate ATP in the mitochondrion 6–30

7 DNA and RNA—Genetic Material, Protein Synthesis, and Gene Regulation 7–1

7.1 DNA contains two nucleotide strands that wind about each other in a double helix 7–2

7.2 DNA replicates by separating its two strands and synthesizing two new complementary strands 7–5

Stability of genetic information depends on efficient mechanisms for DNA repair 7–6

7.3 Genetic information is coded in DNA as groups of three nucleotides 7–8

7.4 Protein synthesis involves three forms of RNA in the cytoplasm 7–9

Instructions for protein synthesis coded in DNA are first transcribed into a coded mRNA molecule 7–10

The coded information in mRNA is translated into a protein with the aid of ribosomes and tRNAs 7–12

7.5 Gene regulation can occur at any step in protein synthesis 7–17

In bacteria and archaea regulatory transcription factors and small effector molecules regulate gene expression 7–18

In eukaryotes general transcription factors and changes in chromatin structure regulate gene expression 7–21

In eukaryotes gene expression may also be regulated by RNA processing and at translation 7–23

Alternative splicing 7–25

Small RNAs 7–25

7.6 Differences in DNA account for differences among organisms and even among individuals 7–27

Essay 7.1 Molecular Detectives: DNA Fingerprinting Solves Crimes 7–31

8 Cell Division 8–1

8.1 Cell division and the cell cycle 8–2

8.2 Division in bacteria, archaea, mitochondria, and plastids occurs by binary fission 8–3

8.3 Eukaryotic cells have separate processes of nuclear and cytoplasmic division 8–5

Preparation for cell division occurs during interphase 8–7

The G₁ phase is a period of intense synthesis of molecules and structures 8–7

DNA replication occurs during the S phase 8–8

The G₂ phase completes preparations for cell division 8–9

Essay 8.1 Chromosome Cohesion and the Cell Cycle 8–10

Mitosis consists of four phases 8–12

In prophase, chromosomes condense until they appear as sister chromatids 8–12

In metaphase, chromosomes align on the equator of the mitotic spindle 8–13

Sister chromatids separate in anaphase 8–14

In telophase, chromosomes become indistinct 8–15

In cytokinesis, cytoplasm is divided between daughter cells 8–15

9 Plant Structure, Growth, and Development 9–1

9.1 Plant structural variation is ecologically and economically important 9–2

9.2 Plant bodies are composed of organ systems, organs, tissues, and specialized cells 9–4

Plant organs occur in organ systems 9–4

Essay 9.1 Supermarket Botany 9–5

Plant organs are composed of tissues whose cells are linked by plasmodesmata 9–6

Plant tissues are composed of one to several types of specialized cells 9–8

Specialized cells arise by the process of differentiation 9–9

9.3 Plant bodies grow by producing new cells and by cell enlargement 9–11

Apical meristems produce primary tissues 9–11

Shoot architecture is based upon alternating nodes and internodes 9–12

Secondary meristems produce wood and bark 9–12

Cell expansion is a distinctive component of plant growth 9–12

9.4 Plants acquire polarity during development from zygotes or small pieces 9–14

Plant bodies have polarity, radial symmetry, and indeterminate growth 9–14

Plant bodies can develop from unicellular zygotes or spores, or excised tissue 9–16

10 Stems and Materials Transport 10–1

10.1 Stems are fundamental plant organs having multiple functions 10-2

Essay 10.1 Weird and Wonderful Stems 10–4

10.2 The structure of conducting tissues helps explain their functions 10-7

Vascular bundles of herbaceous plants are scattered through the stem or organized into a ring 10–7

Living phloem tissues conduct organic compounds in a watery solution 10–8

Phloem conducts sugars from their source to the sites of utilization by a pushing mechanism 10–9

Dead xylem tissues are structured to facilitate water transport 10–11

Water and solutes move within xylem as the result of transpiration, a pulling mechanism 10–12

Wood and bark arise in woody stems by the activity of secondary meristems 10–13

The vascular cambium produces wood and inner bark 10–13

Essay 10.2 Growth Rings: Mirrors Into the Past 10–15

The cork cambium produces a protective covering for older woody stems 10–16

Some plants can grow tall without extensive wood 10–18

10.3 Humans use stems in many ways 10-19

Paper 10–19

Cork 10–20

Bamboo 10–20

Wood 10–21

11 Roots and Plant Nutrition 11–1

11.1 Roots play a variety of roles in plants 11–2

- Roots anchor plants and absorb water and minerals 11–2
- Some roots are useful as human food because they store carbohydrates 11–3
- Roots are important sites of hormone and secondary compound production in plants 11–3

Essay 11.1 The Root of the Matter: Human Uses of Roots 11–4

- The roots of some plants help support stems 11–5
 - Pneumatophores help provide oxygen to underwater roots of some mangroves 11–5
 - Some plants produce other types of specialized roots 11–5
- 11.2 Taproots, fibrous roots, and feeder roots are major types of underground root formations 11–7**
- 11.3 Root external and internal structure are intimately related to function 11–9**
- External root structures include branch roots, root hairs, and the root tip 11–9
 - An internal view of root tissues reveals how root cells arise, grow, and specialize 11–10
 - The root apical meristem produces primary tissues 11–10*
 - Root cells enlarge and begin to specialize in the zone of elongation 11–10*
 - Specialized cells and tissues are present above the zone of maturation 11–11*
 - Selective root mineral absorption uses energy generated by cell respiration 11–15
 - Plants require several types of soil minerals, but other minerals may actually harm plants 11–15*
 - Plant roots require organic food and oxygen 11–17
- 11.4 Plant roots are associated with beneficial microbes 11–18**

12 Leaves—Photosynthesis and Transpiration 12–1

- 12.1 As photosynthetic organs, leaves occur in a vast range of forms 12–2**
- Leaves vary in blade structure 12–3
 - Leaves occur in different patterns along stems 12–4
- 12.2 The major tissues of leaves are epidermis, mesophyll, xylem, and phloem 12–5**
- The leaf epidermis provides structural support and retards water loss 12–6
 - Mesophyll is the photosynthetic tissue of leaves 12–9
 - Xylem and phloem are the conducting tissues of leaf veins 12–10
- 12.3 Plants move large quantities of water by means of transpiration 12–12**
- Stomatal movements control transpiration 12–12
 - Environmental factors can affect stomatal movements 12–13
- Essay 12.1 Plant Leaves Track CO₂ Levels in the Atmosphere 12–14**
- 12.4 The cohesion-tension theory explains movement of water through plants 12–15**
- 12.5 Senescence and leaf fall are a normal part of plant development 12–17**
- Autumn leaf abscission is preceded by a period of senescence 12–18
 - Leaf abscission is preceded by formation of an abscission zone 12–18
- 12.6 Leaves perform many functions in addition to photosynthesis 12–19**
- Some leaves are specialized for water or food storage 12–20
 - Leaves may be modified to play a role in plant defense 12–21
 - Leaves of some plants capture animal prey 12–21
- 12.7 Humans use leaves in many ways 12–24**

13 Plant Behavior 13–1

- 13.1 Plants sense and respond to external and internal stimuli 13–2**
- 13.2 Hormones regulate plant growth and development 13–3**
- There are several types of plant hormones 13–4
 - Auxins 13–4*
 - Cytokinins 13–7*
 - Gibberellins 13–8*
 - Ethylene 13–9*
 - Several plant hormones play protective roles 13–9

Essay 13.1 Aspen Aspirin 13–11

13.3 Plants use pigment-containing molecules to sense their light environments 13–12

Phytochrome controls seed and spore germination 13–12

Phytochrome helps control the timing of flowering and dormancy 13–13

Plant shoots can sense shading and grow into the light 13–14

13.4 Plants respond to gravity and touch 13–15

13.5 Plants can respond to flooding, heat, drought, and cold stress 13–16

13.6 Plants can defend themselves against attack 13–19

14 Reproduction, Meiosis, and Life Cycles 14–1

14.1 Sexual and asexual reproduction confer different advantages 14–2

Sexual reproduction accelerates adaptation 14–2

Asexual reproduction can occur rapidly 14–3

Many organisms that reproduce only asexually evolved from sexually reproducing ancestors 14–4

Many organisms reproduce by both asexual and sexual means 14–5

14.2 Meiosis is essential to sexual reproduction 14–7

Essay 14.1 The Perfect Date 14–8

Meiosis prevents buildup of chromosomes as the result of sexual reproduction over many generations 14–8

Meiosis contributes to genetic variability by mixing parental chromosomes and genes 14–9

14.3 Meiosis resembles mitosis in some respects, but differs in important ways 14–10

Meiosis follows DNA replication and uses a spindle apparatus, as does mitosis 14–11

Homologous chromosomes pair, then separate during meiosis I 14–11

Essay 14.2 The Guardian Spirit 14–14

Chromatids are separated during meiosis II 14–15

14.4 Life cycles link one generation to the next 14–16

Gametic life cycles are typical of animals and some algae 14–17

Zygotic life cycles are typical of fungi and are also common among protists 14–17

Sporic life cycles are characteristic of land plants and some algae 14–18

15 Genetics and the Laws of Inheritance 15–1

15.1 Gregor Mendel's experiments with garden peas revealed the pattern of inheritance of genetic traits 15–2

Before Mendel, people assumed hereditary material blended in the offspring 15–2

Mendel's use of garden peas had many advantages 15–3

Mendel's experiments focused on seven distinct traits in peas 15–5

The F_1 generations revealed dominant and recessive traits 15–5

The F_2 generations had dominant and recessive forms for each trait in a 3:1 ratio 15–6

Mendel's model of the pattern of inheritance 15–6

The testcross revealed the true nature of dominant traits 15–7

15.2 Mendel's model in terms of genes, alleles, and chromosomes 15–9

Essay 15.1 Pseudoscience and the Lysenko Affair 15–12

15.3 Variations on Mendelian genetics 15–13

In incomplete dominance, the heterozygote has an intermediate phenotype 15–13

In pleiotropy, a single gene affects several traits 15–14

In polygenic inheritance, several genes combine to affect a single trait 15–14

The environment can alter the expression of the phenotype 15–15

15.4 Genes and chromosomes 15–16

Linked genes tend to be inherited together 15–16

Genetic maps show the order and position of genes on chromosomes 15–17

In a dihybrid cross, genes segregate independently if they are on separate chromosomes 15–17

In epistasis two or more genes interact to produce a trait 15–18

In some plants, genes located on sex chromosomes determine separate male and female organisms 15–20

Essay 15.2 Hybrid Corn and Hybrid Orchids 15–21

16 Genetic Engineering 16–1

16.1 What is genetic engineering? 16–2

Genetic engineers use tools that are common in nature 16–3

Some genetic engineering tools are derived from bacteria and viruses 16–

Plants contribute other molecular tools 16–4

Essay 16.1 PCR: The Gene Copier 16–5

16.2 Plant genetic engineering resembles crop breeding but is faster and more versatile 16–6

Humans have long altered the genetics of domesticated plants and animals 16–6

Genetic engineering overcomes some drawbacks of traditional breeding methods 16–7

16.3 Bacteria can be genetically engineered to produce useful materials 16–8

Restriction enzymes are used to prepare DNA and vectors for cloning 16–9

Foreign DNA is “glued” into the vector 16–9

Modified vectors are incorporated into bacterial cells, which are then grown to large populations 16–10

16.4 Plants can be genetically engineered to increase productivity and utility 16–12

The roots of some GM crops can more effectively obtain soil phosphate 16–13

Plants can be genetically tailored to produce particular types of starch 16–13

GM plants can produce proteins for use in medicine 16–14

16.5 Genetically engineered crops pose some societal concerns 16–15

Will genetic engineering help solve world food sufficiency problems? 16–15

Might GM crops have harmful environmental effects? 16–16

Evolution of resistance to pest and weed control measures might offset the value of some GM crops 16–16

GM crops might have harmful effects on non-pest species 16–17

GM crop plants might interbreed with organic crops or wild relatives 16–17

17 Biological Evolution 17–1

17.1 Pre-Darwinian science held that species were unchanging 17–2

17.2 During the voyage of the *Beagle*, Darwin made observations that revolutionized biology 17–5

Over the next two decades, Darwin developed his theory of evolution by natural selection 17–6

The theory of evolution by natural selection can be summarized as a chain of logical statements 17–7

17.3 Many areas of science provide evidence for evolution 17–9

Artificial selection demonstrates that species can be modified 17–9

Comparative anatomy reveals many evolutionary relationships 17–10

Changes in proteins and DNA trace evolutionary changes 17–12

Fossils provide a record of large-scale evolutionary changes 17–13

17.4 Evolution occurs when forces change allele frequencies in the gene pool of a population 17–14

Mutation provides new variation to a gene pool 17–15

Nonrandom mating alters the frequency of alleles 17–16

In small populations, genetic drift can cause alleles to be lost 17–16

Migration causes alleles to flow into or out of a population 17–16

Through natural selection, allele frequencies change such that populations become better adapted to their environment 17–17

Directional selection 17–17

Stabilizing selection 17–17

Disruptive selection 17–18

17.5 New plant species originate through reproductive isolation and polyploidy 17–19

The concept of species is based on genetic isolation 17–19

Allopatric speciation requires geographic isolation 17–20

Polyploidy fosters sympatric speciation in plants 17–21

Essay 17.1 Major Beneficial Gene Changes Can Separate Species 17–24

Microbial species can evolve in the lab 17–24

18 Naming, Identifying, and Classifying Plants 18–1

18.1 Naming, identifying, and archiving plants 18–2

Essay 18.1 Viruses—Extreme Minimalists 18–3

Each species has a unique scientific name 18–4

Scientific names are structured to provide useful information 18–5

Resources for identifying plants include keys, DNA barcodes, and herbaria 18–7

Essay 18.2 Botanical Gardens: Science and Art All in One! 18–10

18.2 Plants and other organisms are classified according to their relationships 18–11

Species are classified into larger categories 18–13

Classifications change as new discoveries are made 18–14

19 Origin of Life on Earth; Archaea and Bacteria 19–1

19.1 The nature of life, Earth's suitability for life, and how early life changed the Earth 19–2

The Earth's position in space is important to life 19–3

Earth's early history influenced the rise of life 19–4

19.2 The Origin of Life on Earth 19–7

The chemical-biological theory explains the origin of life as a series of stages 19–7

Macromolecules can form from simple organic compounds 19–8

Macromolecules in water can form cell-like structures 19–9

19.3 Bacteria and Archaea are Earth's oldest, smallest, simplest life forms 19–10

Bacteria and Archaea are generally smaller and simpler than eukaryotes 19–10

Prokaryotic cells are relatively simple in structure 19–11

Prokaryotic DNA 19–11

Prokaryotic enzymes 19–12

Other cell components 19–12

Some microbes swim or glide 19–13

Slimy polysaccharides often coat microbial surfaces 19–13

Essay 19.1 Microbial Metropolis: Microbiomes of Photosynthesizers 19–14

Bacterial and archaeal cell walls differ in structure and chemistry 19–15

Peptidoglycan forms part of bacterial cell walls 19–15

The Gram stain is useful in describing bacteria and predicting responses to antibiotics 19–15

Bacteria and archaea reproduce by binary fission or budding 19–16

Many microbes survive harsh conditions as tough spores 19–16

Bacteria and archaea lack sex, but can acquire new genes 19–17

19.4 Prokaryotic diversity is important in nature and human affairs 19–18

Proteobacteria are related to eukaryotic mitochondria 19–19

Cyanobacteria are related to eukaryotic plastids 19–20

Gram-positive bacteria include important disease agents and antibiotic producers 19–21

Prokaryotic nutrition is ecologically important 19–21

Microbes have useful applications in human affairs 19–22

20 Protists and the Origin of Eukaryotic Cells 20–1

20.1 Defining protists, their evolutionary importance, and habitats 20–2

Why is it important to distinguish protists from plants, fungi, and animals? 20–3

Microscopes must be used to observe most protists 20–4

Protists are common and numerous in aquatic and moist habitats 20–4

- Microscopic protists move in several ways 20–5
- 20.2** Protists can be classified into eukaryotic supergroups 20–7
- 20.3** Algal diversity reflects the occurrence of key evolutionary events 20–12
- Mitochondria are derived from endosymbiotic proteobacteria 20–13
 - Primary plastids originated from endosymbiotic cyanobacteria 20–14
- 20.4** Protist nutritional, chemical, and reproductive diversity 20–16
- Nutritional diversity 20–16
 - Essay 20.1 Algae Have Many Useful Biotechnological Applications** 20–17
 - Cell coverings and food storage diversity 20–17
 - Asexual reproduction 20–18
 - Sexual reproduction 20–19

21 Fungi and Lichens 21–1

- 21.1** Distinctive features of the Fungi 21–2
- 21.2** Major fungal groups differ in reproduction 21–6
- Sexual spores are produced in diverse types of fruiting bodies 21–11
 - Essay 21.1 Fungal Gold: Mining Truffles** 21–12
 - Asexual spores are used to disperse well-adapted genetic types 21–12
- 21.3** Fungi live in beneficial associations with most plants 21–13
- Endophytic fungal partners provide benefits to plants 21–14
 - Mycorrhizae and partnerships between fungi and plant roots 21–14
 - Some heterotrophic plants obtain organic food from fungi 21–16
- 21.4** Fungi are relevant to humans in many ways 21–16
- Fungi function as decomposers 21–17
 - Fungi are useful as foods and in industrial production 21–17
 - Some fungi are poisonous or psychogenic 21–18
- 21.5** Lichens are partnerships between fungi and photosynthetic microbes 21–19
- Lichen evolution and diversity 21–19
 - Lichen reproduction and development 21–20
 - Lichen ecology 21–20
 - Human uses of lichens 21–21

22 Seedless Plants 22–1

- 22.1** What are plants? 22–2
- Plants are multicellular autotrophs that are adapted to life on land 22–2
 - Plant diversity is important in global ecology and human affairs 22–4
 - Essay 22.1 Plants That Changed the World** 22–5
- 22.2** DNA and fossils help trace the history of plants 22–7
- DNA data reveal relationships of modern plants 22–8
 - Land plants evolved from ancestral streptophyte green algae* 22–8
 - DNA and other evidence reveals the order in which the modern plant groups appeared* 22–8
 - Fossils reveal important events in the early evolutionary history of plants 22–9
 - The origin of land-adapted plants* 22–10
 - The rise of vascular plants* 22–10
- 22.3** Early plant evolution illustrates the concept of descent with modification 22–12
- The plant sporophyte probably originated by delaying zygote meiosis 22–12
 - Leaves of ferns arose from branched stem systems 22–13
- 22.4** Modern seedless plant groups include bryophytes, lycophytes, and pteridophytes 22–14
- Bryophytes are the earliest-divergent modern land plants 22–15
 - Bryophyte bodies are simpler than those of vascular plants* 22–15
 - Bryophytes reproduce by wind-dispersed spores, breakage, or asexual structures* 22–16

Mosses are diverse, ecologically significant, and economically useful 22–19

Lycophytes and pteridophytes are modern phyla of seedless vascular plants 22–21

Lycophytes have simple leaves and magnificent pasts 22–21

Most pteridophytes have conspicuous leaves with branched vascular systems 22–23

Lycophyte and pteridophyte reproduction illustrates early steps toward seed evolution 22–24

23 Gymnosperms, the First Seed Plants 23–1

23.1 Gymnosperms include several modern groups and diverse extinct forms 23–2

Modern gymnosperms are useful to humans 23–3

Diverse groups of extinct gymnosperms were ecologically significant in the past 23–4

23.2 Gymnosperms produce ovules and seeds in cones, rather than within fruits 23–4

An ovule is an integument-covered megasporangium 23–5

Seeds develop from ovules whose egg cells have been fertilized 23–7

Ovule evolution illustrates Darwin's concept of descent with modification 23–8

23.3 Seeds provide ecological advantages to present and past plants 23–10

23.4 Diversity of modern gymnosperms 23–12

Cycads are widely planted, but endangered in the wild 23–12

Ginkgo biloba is the maidenhair tree 23–13

Essay 23.1 Plants That Changed the World 23–14

Conifers are the most diverse living gymnosperms 23–14

Pines illustrate the major features of conifers 23–15

Gnetophytes are of evolutionary significance 23–19

24 Angiosperm Diversity and Reproduction 24–1

24.1 Flowering plants are enormously diverse, but share a suite of defining features 24–2

24.2 The structure and diversity of flowers 24–6

Flowers parts occur in concentric whorls 24–6

Essay 24.1 The ABCs of Floral Organ Development 24–7

Flowers vary greatly in number, position, and arrangement of parts 24–9

Flowers have evolved many different types of inflorescences 24–10

24.3 The angiosperm sexual life cycle involves an alternation of generations 24–13

Pollen and ovules arise within anthers and ovaries 24–13

Double fertilization produces a zygote and an endosperm 24–15

Apomixis produces seeds without fertilization 24–16

24.4 Angiosperm embryos and seeds pass through stages of development 24–17

Angiosperm embryo development 24–18

The mature seed is nutritionally independent of the parent plant 24–19

24.5 A fruit is a mature ovary containing seeds 24–20

Simple fruits are the most common type 24–21

Complex fruits develop from multiple pistils or multiple flowers 24–23

24.6 Seed germination and seedling variation 24–24

Seed germination requirements are closely linked to the environment 24–24

After germination, seedlings display various patterns of development 24–25

25 Flowering Plant Co-evolution With Animals 25–1

25.1 Co-evolutionary interactions are important in nature and human affairs 25–2

Flowering plant-animal co-evolutionary interactions are important in agriculture 25–3

Co-evolution is important in global ecology 25–4

25.2 Cross-pollination benefits plants 25–5

Out-breeding enhances genetic variability 25–5

25.3 Animal pollination benefits plants and pollinators 25–7

Co-evolved animals and plants influence each other's traits 25–7

Essay 25.1 Pollination by Wind and Water 25–8

Plants attract pollinators by flower scent and color 25–8

Flowers control pollinator access by flower shapes and positions 25–10

Plant food rewards to animal pollinators include nectar, pollen, and oil 25–11

Flowers and pollinators have coordinated traits known as pollination syndromes 25–12

Beetles and beetle-pollinated flowers 25–12

Bees and bee-pollinated flowers 25–14

Nectar-feeding flies, carrion flies, and fly-pollinated flowers 25–16

Butterflies, moths, and coevolved flowers 25–16

Birds and bird-pollinated flowers 25–18

Bats and bat-pollinated flowers 25–19

25.4 Animal seed dispersal benefits plants 25–20

26 Principles of Ecology and the Biosphere 26–1

26.1 Ecology focuses on populations, communities, ecosystems, biomes, and the biosphere 26–2

26.2 Populations show patterns of distribution and age structure, grow and decline, occupy specific niches, and interact with other populations 26–3

Plants in a population may be distributed in a random, uniform, or clumped pattern 26–3

Age distribution and survivorship curves describe the age structure of populations 26–4

Populations show distinct patterns of growth 26–5

The ecological niche includes the abiotic factors that determine the area the population occupies 26–7

The ecological niche includes interactions between populations of different species 26–7

In mutualism, two populations exchange benefits 26–8

In parasitism, herbivory, and predation, one population benefits and the other is harmed 26–8

In competition, individual organisms have a negative impact on each other 26–9

26.3 Communities are composed of individuals of many different species 26–10

Communities can be characterized by their species diversity 26–10

Ecological succession is the change in community composition over time 26–12

Primary succession begins on areas not previously occupied by organisms 26–12

Essay 26.1 Determining Past Climate and Vegetation From Pollen Data 26–13

Secondary succession occurs on areas where a community has been removed 26–14

26.4 Ecosystem studies focus on trophic structure and energy flow 26–15

Organisms may be grouped into functional categories 26–15

The flow of energy through a food chain is linear 26–15

Only a small fraction of energy passes between trophic levels 26–16

26.5 Global climatic patterns determine the distribution of biomes 26–18

The distribution of biomes is determined primarily by global patterns of atmospheric circulation 26–18

Continentality, ocean currents, and mountain ranges also affect the distribution of biomes 26–20

26.6 Matter moves between biomes and the physical environment in large-scale biogeochemical cycles 26–22

Water cycles through the oceans, atmosphere, lands, and organisms 26–22

Microorganisms largely control the nitrogen cycle 26–23

Carbon dioxide cycles between the atmosphere and the biosphere 26–25

27 Arid Terrestrial Ecosystems 27–1

27.1 Arid terrestrial ecosystems are diverse 27–2

27.2 Polar deserts have the most severe climates on Earth 27–3

Arctic herb barrens contain few species of plants 27–4

Continental Antarctica contains only sparse populations of mosses, lichens, and algae 27–4

In the maritime Antarctic, bryophytes and lichens are dominant 27–5

Essay 27.1 Building Biomes on Mars 27–6

27.3 Temperate and subtropical deserts are characterized by low annual precipitation 27–7

- Four physical factors determine the locations of temperate and subtropical deserts 27–8
- Desert plants have adapted to acquire water 27–8
- Plants using the deep-water table must put down long roots 27–9
- A great variety of desert plants use surface water 27–9
 - Desert algae, mosses, and lichens are tolerant of high temperatures* 27–9
 - Desert annuals and herbaceous perennials grow when water is available* 27–10
 - Deciduous perennials maintain significant aboveground biomass* 27–11
- Desert succulents have a number of adaptive features to survive aridity 27–13
 - Succulents conserve water by a low surface-to-volume ratio and CAM metabolism* 27–13
 - Much of the volume of succulents is available for water storage* 27–13
 - Cacti are extremely tolerant of high temperatures* 27–14
 - Water uptake in desert succulents may be very rapid* 27–14
- Stem succulents have cylindrical, globose, or paddlelike stems 27–14
- Leaf succulents include the agaves, aloes, and stone plants 27–15
- Human impacts on deserts include mining, depletion of aquifers, and urban sprawl 27–16

27.4 Grasslands are temperate areas dominated by grasses 27–17

- Grasslands are ecologically, evolutionarily, and economically important 27–18
 - Grasslands occupy vast areas of land and support immense populations of animals* 27–18
 - Grasslands store vast amounts of organic carbon in their soils* 27–18
 - Grasslands support the world's most productive agriculture* 27–19
 - Grasslands have had a major impact on the evolution of grazer animals and humans* 27–20
- Climate, fire, and herbivores shape grassland environments 27–20
 - Grassland climate is drier and more extreme than that of most forests* 27–21
 - Fire plays an important role in maintaining grasslands* 27–21
 - Large animal grazers also influence grassland environments* 27–22
- Grassland plants are adapted to cope with environmental stresses 27–22

Essay 27.2 Restoring Prairies 27–23

- Dominant grass species vary through the year and by region* 27–23
- Grass plants are adapted for fast growth, high productivity, and resistance to fire and grazing* 27–24
- Grass flowers and fruits are adapted for efficient reproduction* 27–24
- Forbs are diverse grassland plants that are not grasses, trees, or shrubs* 27–26
- Grassland trees and shrubs are adapted to survive fire and provide important resources for some grazers* 27–27
- Grassland improvement, restoration, and preservation yield benefits for people 27–28
 - Dry grasslands can degrade into deserts* 27–29
 - Mesic grasslands have mostly been transformed into farmlands* 27–29
 - Wet grasslands provide valuable ecological services* 27–30

27.5 The chaparral ecosystem has hot, dry summers and cool, wet winters 27–31

- Evergreen shrubs with sclerophyllous leaves dominate the chaparral 27–32
- Fire is a major ecological force in the chaparral 27–33
 - Some shrubs require fire to establish new seedlings* 27–34
 - Other shrubs require an absence of fire to establish seedlings* 27–34
 - Trees in the chaparral are adapted to survive wildfires* 27–35
- Human impact has been severe on Mediterranean scrub ecosystems 27–35

28 Moist Terrestrial Ecosystems 28–1

28.1 Moist terrestrial ecosystems cover a wide range of climates 28–2

28.2 Polar and alpine ecosystems have arisen since the retreat of the last glaciation 28–3

- Tundra can be characterized by the absence of trees 28–4
- Tundra plants show a number of adaptations in form and function 28–5
- Tundra plants show a number of reproductive adaptations 28–5

28.3 Coniferous trees dominate the taiga 28–7

- Alpine tundra and montane coniferous forest are southern extensions of arctic tundra and taiga 28–8
- Alpine tundra and arctic tundra have many species in common 28–9

Dominant conifer species differ among mountain ranges 28–9

Mining, logging, grazing, and recreation affect polar and alpine ecosystems at local and regional scales 28–10

Global warming is affecting montane coniferous forests and taiga 28–11

28.4 Temperate deciduous forests are ecosystems with seasonality and abundant precipitation 28–13

Eight genera of trees define the eastern temperate deciduous forest 28–14

Plants in the temperate deciduous forest are adapted to cold winters and competition for light 28–15

Humans have had a major impact on many features of the eastern temperate deciduous forest 28–17

Essay 28.1 Native American Uses of Temperate Forest Plants 28–18

Many exotic species have invaded the temperate deciduous forest 28–19

Plant rustling from national forests is a serious problem 28–19

Research at Hubbard Brook was undertaken to determine how temperate forest ecosystems function 28–20

Acid rain is damaging the eastern temperate deciduous forest 28–21

28.5 Tropical rain forests have a non-seasonal climate and abundant precipitation 28–23

Tropical rain forests have high biotic diversity and important global climate effects 28–24

Great age, rapid evolution, and complex structure may foster high biodiversity 28–24

Tropical rain forests store much of the Earth's carbon 28–25

Tropical rain forests play an important role in global water cycling 28–25

Tropical forest vegetation is distinctive 28–26

Tropical forests are tall, evergreen, and layered 28–26

Tropical forests are richer in tree species than other forests 28–26

Tropical forests contain plant forms that are rare elsewhere 28–26

Tropical rain forests are among the most productive ecosystems on Earth 28–27

Warm, moist tropical climates favor lush plant growth 28–27

Essay 28.2 Fascinating Orchids 28–28

Tropical plants compete for light 28–29

Some tropical plants are adapted to drought 28–29

Heavy rainfall and high winds can damage tropical plants 28–29

Paradoxically, lush rain forests grow on poor soils 28–29

Tropical forest soils are low in nutrients and organic materials 28–30

Tropical forest mineral nutrients are held within tissues of living organisms 28–30

Nitrogen-fixing bacteria and mycorrhizal fungi help tropical rain forest plants cope with poor soils 28–31

Early tropical forest farmers learned to cope with poor soils 28–31

Temperate-style agriculture is often difficult to practice in the tropics 28–32

Essay 28.3 Restoring a Lost Forest 28–33

Tropical forest plants are adapted to numerous environmental stresses 28–33

Canopy trees are well adapted to intercept light, but are vulnerable to fire and forest fragmentation 28–33

Tropical tree stem architecture is amazingly diverse 28–34

Buttress roots provide structural support 28–34

Leaves of tropical trees are surprisingly uniform in shape 28–35

Tree reproduction is adapted to forest conditions 28–35

Lianas' growth and reproduction reflect their clinging lifestyle 28–36

29 Aquatic Ecosystems 29–1

29.1 Aquatic ecosystems are essential to humans 29–2

People and wildlife depend on freshwaters and wetlands for many services 29–3

29.2 Lake ecosystems: habitats, seasonal changes, and primary producers 29–4

Lakes contain three major types of habitats and communities 29–4

Mineral nutrient availability in temperate lakes varies with seasonal temperature change 29–5

Spring 29–5

Summer 29–5

Fall 29–6

Winter 29–6

Freshwater algae and plants are adapted to aquatic habitats 29–6

Algae and cyanobacteria 29–6

Floating plants 29–7

Rooted macrophytes 29–7

Human activities have degraded freshwaters 29–8

Oligotrophic freshwaters are low in nutrients and productivity but high in species diversity 29–8

Eutrophic freshwaters are high in nutrients and productivity but low in species diversity 29–9

Phosphorus availability controls growth of freshwater plants, algae, and cyanobacteria 29–10

Lake and stream eutrophication can be prevented or reversed 29–10

29.3 Wetland ecosystems 29–12

Common freshwater wetlands include riparian wetlands, deep-water swamps, marshes, acid bogs, and sedge meadows 29–13

Wetlands play important roles in global carbon cycling 29–13

Wetland plants are adapted in ways that help them overcome stresses of wetland habitats 29–14

Humans have destroyed many of the world's wetlands 29–16

Wetland delineation, invasive species, and restoration are issues in wetland protection and restoration 29–16

29.4 Oceans are essential to humans and life on Earth 29–18

Seawater and freshwater differ in the amount of dissolved substances 29–18

Ocean basins contain a varied terrain 29–20

Atmospheric circulation and the Coriolis force drive ocean currents 29–21

Ocean temperatures vary with depth, season, and latitude 29–22

The oceans can be divided into realms 29–23

29.5 The epipelagic ecosystem contains plankton and nekton communities 29–24

Bacterioplankton are the most important group in terms of productivity 29–25

Phytoplankton are very diverse in form 29–26

Diatoms 29–26

Dinoflagellates 29–27

Haptophytes 29–27

The planktonic food web begins with picoplankton 29–28

29.6 The sublittoral zone includes kelp forests, seagrass beds, and coral reefs 29–30

Kelp forests are dominated by large photosynthetic protists 29–30

Seagrasses stabilize soft, sandy sediments and provide shelter for many marine animals 29–32

Coral reefs are among the most beautiful and diverse ecosystems on Earth 29–33

Essay 29.1 Jamaican Coral Reefs: Going, Going, ... Gone 29–35

29.7 The littoral zone includes rocky intertidal areas, estuaries, salt marshes, and mangrove forests 29–36

Rocky intertidal ecosystems have many species of organisms 29–36

Estuaries have relatively few species of organisms 29–37

Salt marshes contain herbs, grasses, and shrubs rooted in soils washed by tides 29–37

In mangrove forests the trees grow in shallow seawater 29–38

30 Human Impacts and Sustainability 30–1

30.1 Sustainability is the maintenance of humans together with healthy environments 30–2

30.2 Humans impact the global environment in many ways 30–4

How many people can Earth sustain? 30–5

Human population growth is correlated with environmental degradation 30–6

Global warming is affecting every ecosystem on Earth 30–7

Humans impact the global environment in a number of other ways 30–9

Acid rain 30–9

Depletion of soil fertility and erosion 30–9

Deforestation 30–9

Pollution of coastal zones 30–10

Overfishing 30–11

Transformation of ecosystems leads to loss of biodiversity 30–11

30.3 The concept of sustainability has many different dimensions 30–15

Stable human populations are necessary for sustainability 30–15

Innovative technologies may improve energy sustainability 30–17

Hydroelectric power 30–17

Wind power 30–17

Photovoltaics 30–18

Biomass 30–19

Alternatives to gasoline 30–20

Sustainable agriculture reduces erosion, nutrient and organic carbon loss, and chemical use 30–21

Sustainable use of ocean resources and restoration of coastal zones are future goals 30–22

Sustainability requires maintaining ecosystem services and biodiversity 30–23

Essay 30.1 Sustainable Use of Neotropical Forests 30–24

Biodiversity “hotspots” are regions of high endemism 30–24

Biomes differ in their vulnerability to extinction 30–25

Everyone can contribute to global sustainability 30–25

Glossary G1

Answers A1

Geological Time Scale