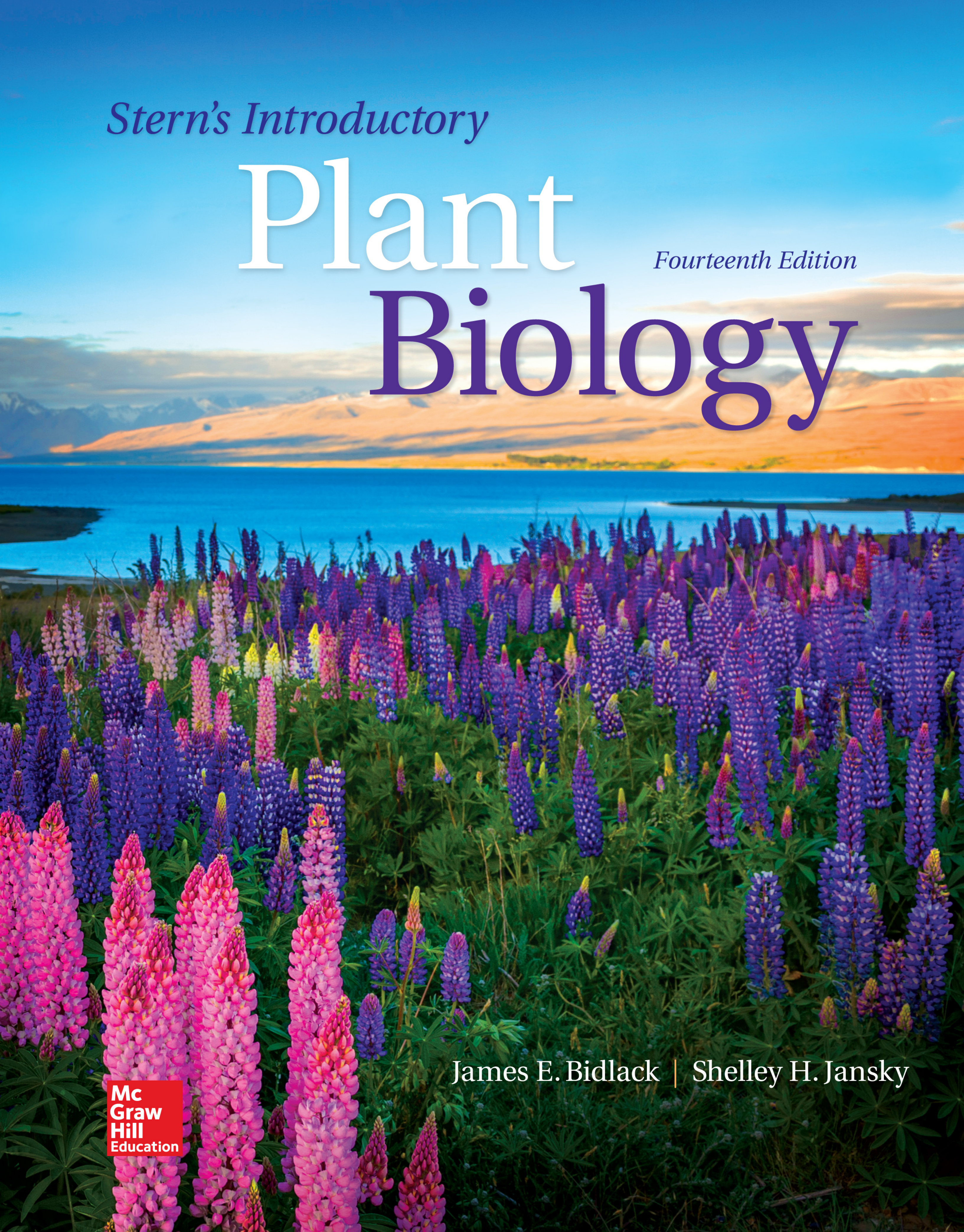

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Plant Biology

Fourteenth Edition

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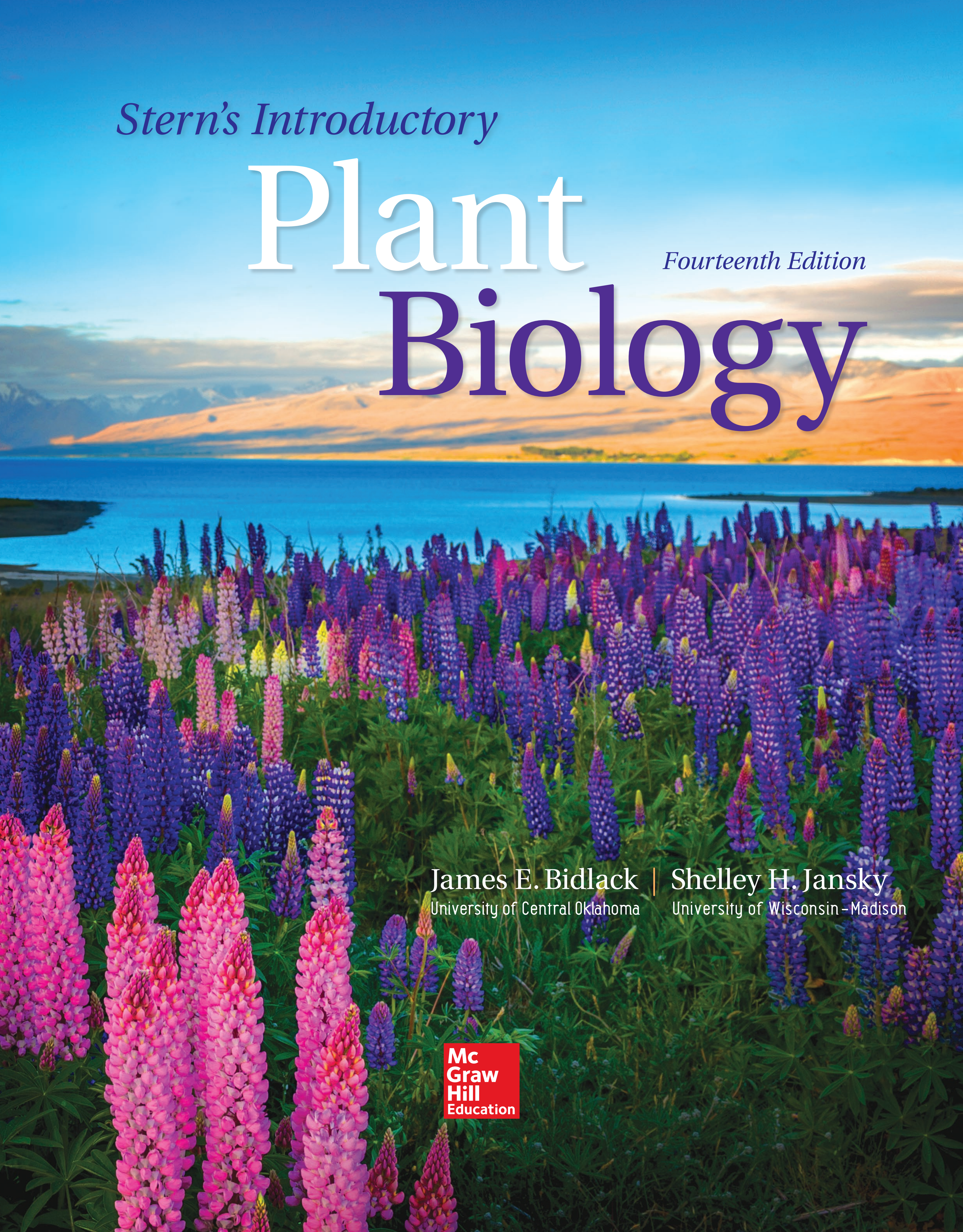

Stern's Introductory

Plant Biology

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James E. Bidlack
University of Central Oklahoma

Shelley H. Jansky
University of Wisconsin–Madison

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STERN'S INTRODUCTORY PLANT BIOLOGY, FOURTEENTH EDITION

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Contents in Brief

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About the Authors

Jim Bidlack, Kingsley Stern, and Shelley Jansky at Kingsley's office residence in Paradise, California. © Jan Monelo

Introductory Plant Biology was originally written by Kingsley R. Stern (1927–2006), who spent more than 40 years as a devoted botanist and teacher. It is estimated that Dr. Stern educated 15,000 students through classroom/laboratory teaching and inspired thousands of botanists as the author of this book, which has sold more than 275,000 copies since the first edition was published in 1979. Kingsley's enthusiasm for the botanical world captivated those around him for many decades. He will long be remembered for his attention to detail and dedication to high standards, along with a refreshing sense of humor. It was always Kingsley's aspiration that those who read *Stern's Introductory Plant Biology* will share his lifelong love of botany.

In late 1999 and early 2000, Drs. Jim Bidlack and Shelley Jansky joined Kingsley Stern in editing and updating this textbook. They worked with him on several editions and have since carried Dr. Stern's legacy forward to educate and inspire young botanists. This fourteenth edition reflects the same accuracy, content, and enthusiasm of the Stern writing style, along with revisions and updates to make it an up-to-date and enjoyable resource and textbook for plant biology.

James E. Bidlack

© James E. Bidlack

Jim Bidlack received a bachelor of science degree in agronomy, with a soil and crop option, from Purdue University in 1984 and continued his education with a master's degree in crop physiology at the University of Arkansas in 1986. Upon completing a Ph.D. in plant physiology at Iowa State University in 1990, Jim joined the teaching faculty at the University of Central Oklahoma (UCO) where he is a professor of biology. His first paper was published from undergraduate research at Purdue University on the use of synthetic growth regulators to stimulate seed germination. Subsequent work in Arkansas, Iowa, and Oklahoma focused on soybean physiology, cell wall chemistry, alternative crops, and photovoltaic cells, as well as teaching responsibilities in botany. Equipment and student salaries for Jim's research projects have been funded by grants from the National Science Foundation and the United States Department of Agriculture. About 20 refereed publications, as well as hundreds of abstracts and popular articles, have resulted from this work. Jim has been recognized with UCO's Presidential Partner's Excellence in Teaching Award; University Merit Awards in Service, Research, and Teaching; the Biology Club Teaching Award; and the Pre-Med Teaching Award. Some of Jim's additional responsibilities have included participation on NSF and USDA review panels, editor of the Biology Discipline for the Multimedia Educational Resource for Learning and Online Teaching (MERLOT), vice president of The Genome Registry, and president of Metabolism Foundation.

Shelley H. Jansky

© Shelley H. Jansky

Shelley Jansky received a bachelor's degree in biology from the University of Wisconsin–Stevens Point in 1982, and a master of science degree and Ph.D. in plant breeding and plant genetics from the University of Wisconsin–Madison in 1984 and 1986, respectively. Her graduate work focused on developing methods to incorporate genes from wild relatives of potato into the cultivated potato. Then, she spent four years as an assistant professor at North Dakota State University, teaching courses in plant breeding and plant propagation, and performing research in the potato breeding program. She taught courses in botany, genetics, and horticulture, and continued to perform potato genetics research at the University of Wisconsin–Stevens Point from 1990 until 2004. She was the chair of the Department of Biology and was promoted to associate professor in 1992 and professor in 1995. In 2004, she moved to Madison, where she is a research geneticist with the U.S. Department of Agriculture and an associate professor in the Department of Horticulture at the University of Wisconsin–Madison. Her research program focuses on using disease resistance and nutritional quality genes from wild relatives for the improvement of cultivated potato varieties. She received the University of Wisconsin–Stevens Point Excellence in Teaching Award in 1992 and the University Scholar Award in 2000. She has published 87 refereed research articles and seven book chapters.

Preface

Plants and algae are essential for life on earth as it exists today. They provide our world with oxygen and food, contribute an essential part of water and nutrient cycling in ecosystems, provide clothing and shelter, and add beauty to our environment. Some scientists believe that if photosynthetic organisms exist on planets beyond our solar system, it would be possible to sustain other forms of life that depend upon them to survive.

Botany today plays a special role in many interests of both major and nonmajor students. For example, in this text, topics such as global warming, ozone layer depletion, acid rain, genetic engineering, organic gardening, Native American and pioneer uses of plants, pollution and recycling, house plants, backyard vegetable gardening, natural dye plants, poisonous and hallucinogenic plants, nutritional values of edible plants, and many other topics are discussed. To intelligently pursue such topics, one needs to understand how plants are constructed, and how they function. To this end, the text assumes little prior knowledge of the sciences on the part of the student, but covers basic botany, without excessively resorting to technical terms. The coverage, however, includes sufficient depth to prepare students to go further in the field, should they choose to do so.

The text is arranged so that certain sections can be omitted in shorter courses. Such sections may include topics such as soils, molecular genetics, and phylum Bryophyta. Because botany instructors vary greatly in their opinions about the depth of coverage needed for photosynthesis and respiration in an introductory botany course open to both majors and nonmajors, these topics are presented at three different levels. Some instructors will find one or two levels sufficient, whereas others will want to include all three.

Both majors in botany and nonmajors who may initially be disinterested in the subject matter of a required course frequently become engrossed if the material is related repeatedly to their popular interests. This is reflected, as intimated above, in the considerable amount of ecology and ethnobotany included with traditional botany throughout the book.

Organization of the Text

A relatively conventional sequence of botanical subjects is followed. Chapters 1 and 2 cover introductory and background information; Chapters 3 through 11 deal with structure and function; Chapters 12 and 13 introduce meiosis, genetics, and molecular biology. Chapter 14 discusses plant propagation and biotechnology; Chapter 15 introduces evolution; Chapter 16 deals with classification; Chapters 17 through 23 stress, in phylogenetic sequence, the diversity of organisms traditionally regarded as plants; and Chapter 24 deals with ethnobotanical aspects and other information of general interest pertaining to 16 major plant families or groups of families. Chapters 25 and 26 present an overview of the vast topic of ecology, although ecological topics and applied botany are included in the preceding chapters as well. Some of these topics are broached in anecdotes that introduce the chapters, while others are mentioned in text boxes as well as the appendices.

Learning Aids

A chapter outline, review questions, discussion questions, and additional reading lists are provided for each chapter. New terms are defined as they are introduced, and those that are boldfaced are included, with their pronunciation, in a glossary. A list of the scientific names of all organisms mentioned throughout the text is given in Appendix 1. Appendix 2 deals with biological controls and companion planting. Appendix 3 includes wild edible plants, poisonous plants, medicinal plants, hallucinogenic plants, spices, tropical fruits, and natural dye plants. Appendix 4 gives horticultural information on house plants, along with brief discussions on how to cultivate vegetables. Nutritional values of the vegetables are included. Appendix 5 covers metric equivalents and conversion tables.

New to this Edition

The fourteenth edition is an exciting one, with dozens of new/replacement photographs and updates in the text to make it a modern textbook with great new topics. Most of the major changes in the book have been made as a result of new discoveries and technologies in plant biology. This edition still retains the hallmark style and pedagogy that make it one of the most enduring and popular introductory plant biology books on the market, and it now has a more contemporary look and presentation style. All chapters incorporate measurable learning outcomes and updated additional readings. For instructors using Internet resources such as Connect and the textbook website offered by McGraw-Hill, all learning outcomes are directly tied to assessment within the question and test banks. With encouragement from reviewers, the new material has been eloquently incorporated directly into the textbook narrative and as text boxes, to provide a blend of historically important principles as well as modern developments in plant biology. Some of the more interesting components that make this fourteenth edition more accurate and up-to-date with our current understanding of plant biology include:

Chapter 1 (What Is Plant Biology?): The scientific method section has been extensively revised. The Plant Biology and the Internet text box has been updated with information about how the Internet has affected the scientific community.

Chapter 2 (The Nature of Life): New examples have been added and text has been updated and revised for clarity.

Chapter 3 (Cells): Several photographs have been replaced with higher-quality images.

Chapter 4 (Tissues): The introduction has been rewritten in language relevant to today's college students. A flowchart has been added to show how meristems give rise to tissues. Trichomes have been defined and added to the index.

Chapter 5 (Roots and Soils): The soil profile caption has been enhanced.

Chapter 6 (Stems): The caption for the cover image has been expanded.

Chapter 7 (Leaves): Some discussion on incorporation of plant pigments in photovoltaic cells has been added to the introduction.

Chapter 8 (Flowers, Fruits, and Seeds): The role of respiration in seed germination is described in more detail.

Chapter 9 (Water in Plants): The description of active transport has been revised.

Chapter 10 (Plant Metabolism): A more straightforward introduction is provided at the beginning of the chapter.

Chapter 11 (Growth and Development): The distinction between determinate and indeterminate growth has been clarified. The caption for the photograph on photoperiodism has been expanded.

Chapter 12 (Meiosis and Alternation of Generations): The introduction has been re-written to describe the consequences of meiosis and how it results in variability when farmers save seeds from hybrid crops. The distinction between x (ploidy) and n (gametophyte versus sporophyte generation) has been clarified. The idea that the sporophyte becomes more dominant in advanced plant lineages is introduced.

Chapter 13 (Genetics and Molecular Biology): The description of a DNA molecule has been enhanced. The description of $2n$ gametes has been expanded. The role of the monohybrid cross in illustrating the law of segregation is discussed. A section has been added to describe genetic engineering technologies to develop herbicide-resistant plants.

Chapter 14 (Plant Breeding, Propagation, and Biotechnology): A new text box on "genome editing," as a clever method for recombinant DNA technology with endless possibilities, has been added to the chapter. Additional updates on transgenic plants and rewording of the text has also been completed to make the content more current.

Chapter 15 (Evolution): Some strategic rewording of the text was done to provide a more straightforward presentation of evolutionary concepts.

Chapter 16 (Plant Names and Classification): More precise information is presented to show the global estimate of existing species to be about 8.7 million, and some other tactful changes were made in the text to bring it up to date.

Chapter 17 (Domain (Kingdom) Bacteria, Domain (Kingdom) Archaea, and Viruses): Some of the information on human diseases (such as AIDS and tuberculosis), as well as human uses of archaebacteria (such as methane production) has been updated. Additionally, a text box on cyanobacteria and algae blooms has been added to the chapter to show the huge impact algae can have on ecosystems.

Chapter 18 (Kingdom Protista): Two important and innovative text boxes have been added to this chapter—one on green plant phylogeny and another on biofuels made from algae. The text box on green plant phylogeny, in particular, is an exciting new topic presented to introduce readers to the new approaches being used in taxonomy using DNA technology. Other modifications have also been made to this chapter to focus on the basic differences among life cycles and how these can be used to describe and distinguish among the algae phyla.

Chapter 19 (Kingdom Fungi): More direct language was incorporated into this chapter to make concepts easier to understand. A great new picture of a puffball was also added to the chapter.

Chapter 20 (Introduction to the Plant Kingdom: Bryophytes): Antheridiophores and archegoniophores have been more accurately described and pointed out in one of the figures. Additionally, the important feature of hornworts having stomata has been added to the section on Phylum Anthocerophyta.

Chapter 21 (The Seedless Vascular Plants: Ferns and Their Relatives): The concept that seedless vascular plants are sporophyte dominant, and the spores produced germinate into a free-living gametophye generation, is emphasized at the beginning of the chapter. More direct language was also incorporated into this chapter to make it more straightforward.

Chapter 22 (Introduction to Seed Plants: Gymnosperms): The phrase "common ancestor" is introduced in this chapter to convey the more modern approach to plant classification using DNA technology. New information is also presented on the production of paclitaxel (also known by its trade name Taxol) from new lines (derived from tissue culture) of yew trees.

Chapter 23 (Seed Plants: Angiosperms): More direct language was incorporated into this chapter to make it more straightforward and easier to understand.

Chapter 26 (Biomes): Some of the climatological data and specific information about biomes have been updated.

Appendix 2 (Biological Controls): The introduction has been rewritten to discuss the consequences of improper use of pesticides. The section on the use of resistant plant varieties has been updated. The section on the control of weeds has also been updated.

Appendix 4 (House Plants and Home Gardening): This appendix has been extensively updated. New information is presented on LED lights, transplanting of seedlings, direct seeding, temperature and seed germination, the effect of overwatering on root growth, fertilizer application, pest control, and inoculation of soil with *Rhizobia*.

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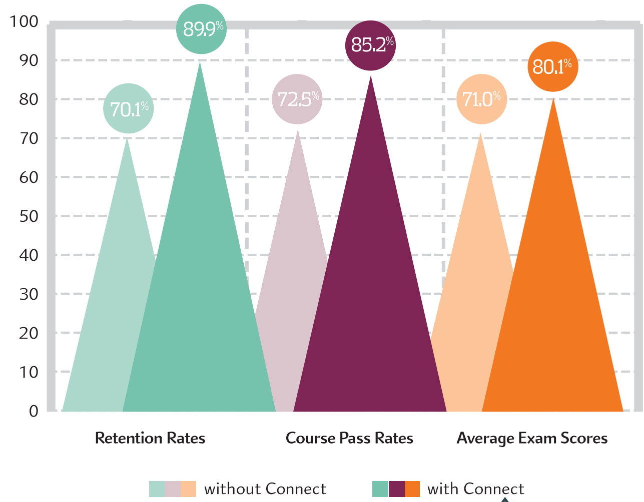

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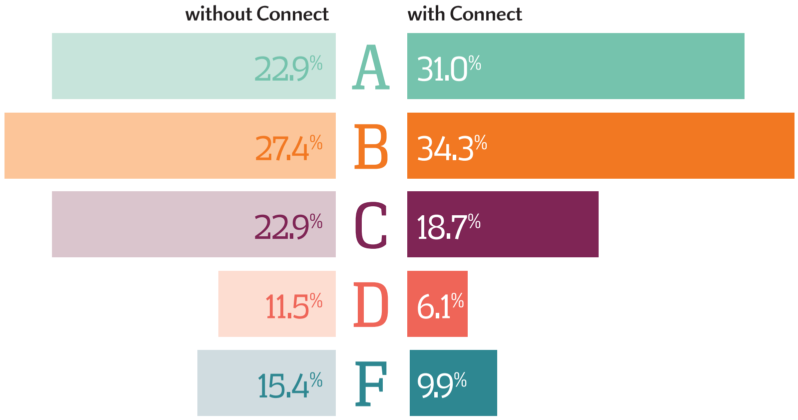

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Upon reaching this milestone fourteenth edition, we would also like to once again extend gratitude to the reviewers of earlier editions, who have provided considerable comments and suggestions. Although too numerous to include here, their contributions have been much appreciated. The following is a list of reviewers for recent editions:

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Teaching and Learning Supplements

Stern's Introductory Plant Biology Lab Manual, 14th Edition by James Bidlack

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MHID: 1260030148)

The laboratory manual that accompanies *Stern's Introductory Plant Biology* has been revised and updated. It is written for the student who is entering the study of botany. The exercises utilize plants to introduce biological principles and the scientific method. They are written to allow for maximum flexibility in sequencing.

CHAPTER

1

What Is Plant Biology?

A mountain iris (*Iris missouriensis*) growing along a slope near the roadside in the Carson National Forest, New Mexico.
© Cliff Pelchat

OVERVIEW

This chapter introduces you to botany: what it is, how it developed, how it relates to our everyday lives, and its potential for the future. The discussion includes a brief introduction to some common questions about plants and their functions, an examination of the scientific method, and a brief look at botany after the invention of the microscope. It concludes with a brief survey of the major disciplines within the field of botany.

Learning Outcomes

1. Explain how humans have impacted their environment, particularly during the past century.
2. Describe how hypotheses are formulated and used in the scientific method.
3. Explain how and why all life is dependent on green organisms.
4. List the aspects of botany with which each of the major botanical disciplines is concerned.

While in high school in southern Africa, the famous botanist, Kingsley Stern, was invited to a friend's farm during spring break. One particular day, Kingsley was returning to the farmhouse from a walk around the farm, and heard groaning coming from inside. He learned that his friend's father had been clearing cactus-like *Euphorbia* plants from some land. The plants produce a poisonous, milky latex, which the father had taken great care to wash thoroughly from his hands. Absentmindedly, however, the man had splashed some of the water in his face, and traces of the poison had gotten into his eyes, causing great pain. Another family member immediately ran to the nearby barn and obtained some colostrum milk from a cow that had just given birth. The man's eyes were bathed in the milk, which contains an antidote for that poison, and the pain subsided. Kingsley was told that if the milk had not been quickly available, the man would have been blind within half an hour. In Venezuela and Brazil, however, cow trees (e.g., *Brosimum utile; Mimusops huberi*) produce a sweet, nutritive latex that is relished by the natives of the region. Still other plants such as opium poppies produce latex that contains narcotic and medicinal drugs (Fig. 1.1). Why do plants such as *Euphorbia* species produce poisons, while parts of so many other plants are perfectly edible, and some produce spices, medicines, and a myriad of products useful to humans?

In the popular story "Little Shop of Horrors," Audrey II is a plant that thrives on human blood. While this scenario makes for an interesting piece of dark comedy, there are plants that feed on insects and occasionally frogs, rodents, and birds (Fig. 1.2). What do these plants gain from their carnivorous diet?

Occasionally we hear or read of experiments—often associated with school science fairs—that suggest plants respond in some positive way to music or soothing talk; conversely, some plants are said to grow poorly when they are harshly yelled at. Do plants really respond to their surroundings, and, if so, how and to what extent?

California's huge coastal redwoods and Tasmania's giant gum trees can grow to heights of 90 or more meters (300 or more feet). When these giant trees are cut down, there is no evidence of pumps of any kind within them. How, then, does water get from the roots below ground to the tops of these and other trees? Do they have to expend large amounts of energy to carry water such long distances (Fig. 1.3)?

Figure 1.1 Immature opium poppy capsules that were gashed with a razor blade. Note the opium-containing latex oozing from the gashes.

Figure 1.2 Pitcher plants. Pitcher plants are carnivorous plants that grow in nutrient-poor environments. Small insects trapped in their pitchers are digested and used as a source of minerals. © *2009 Pia Liikala/Getty Images*

Figure 1.3 California coastal redwoods (*Sequoia sempervirens*). Coastal redwoods may grow for thousands of years and some reach heights of nearly 100 meters (330 feet). © *Kingsley Stern*

Our tropical rain forests, which once covered 14% of the earth's land surface, now occupy only 6% of land area. They are disappearing at the rate of several acres a minute as the plant life is cleared for agriculture, wood supplies (primarily for fuel), cattle ranching, and other human activities such as mining for gold. Experts estimate that all rain forests may be destroyed within 40 years. Rain forests are home to 50% of all the species of living organisms; it is estimated that 137 species are destroyed every day due to rain-forest deforestation. What will be the long-term impacts of these activities, and can they be reversed?

There is no doubt that our climate is changing. There is much debate, though, about the effects that global warming will have on life as we know it. Are those who proclaim that global warming will eventually have disastrous effects on modern civilization and living organisms simply exaggerating, or is there a scientific basis for the claims? Plant life constitutes more than 98% of the total *biomass* (collective dry weight of living organisms) of the earth. Plants and other green organisms have the exclusive capacity to produce oxygen while converting the sun's energy into forms vital to the existence of both plant and animal life. At the same time, plants remove the large amounts of carbon dioxide given off by all living organisms as they respire. In other words, virtually all living organisms are totally dependent on green organisms for their existence. If some major disease were to kill off all or most of the green organisms on land and in the oceans and lakes, all the animals on land, in the sea, and in the air would soon starve. Even if some alternative source of energy were available, animal life would suffocate within 11 years—the time estimated for all the earth's oxygen to be completely used up if it were not replaced. Just how do green plants capture the sun's energy, use carbon dioxide, and give off oxygen?

This book tries to answer these and other questions about living organisms—particularly those pertaining to plants, algae, fungi, and bacteria. Moreover, additional information about plant biology related to future societies, conservation, and human benefits is discussed.

KEY THEME: ecology

Who Needs Plants?

Human existence depends on plants. In fact, we need plants more than we need animals. In addition to providing oxygen essential to all aerobic organisms, plants act as the foundations of our civilizations, providing food, animal feed, shelter, clothing, industrial products, and medicines. Despite our dependence on plants, though, human activities threaten their survival. Given the fundamental need for plants by humans, it is surprising that conservation efforts in past decades have instead focused on so-called charismatic megafauna (large mammals such as tigers and whales). In recent years, though, there has been a refocusing of conservation strategies to be more inclusive of all members of the biotic world, including plants, fungi, bacteria, and algae. This new direction reflects the growing recognition that preservation of all biological diversity is important for the survival of the human race.

The Relationship of Humans to Their Environment

It has been estimated that the total human population of the world was less than 20 million in 6000 B.C. During the next 7,750 years, it rose to 500 million; by 1850, it had doubled to 1 billion; and 70 years later, it had doubled again to 2 billion. The 4.48-billion mark was reached in 1980, and within 5 years it had grown to 4.89 billion. In 2011, the human population size reached a milestone, exceeding 7 billion people. The earth remains constant in size, but the human population continues to grow.

In feeding, clothing, and housing ourselves, we have had a major impact on our environment. We have drained wetlands and cleared natural vegetation from vast areas of land. California, for example, now has less than 5% of the wetland it had 100 years ago. We have dumped wastes and other pollutants into our waters and added pollutants to the atmosphere. We have killed pests and plant disease organisms with poisons. These poisons have also killed natural predators and other useful organisms and, in general, have disrupted the delicate balance of nature that existed before humans began degrading their natural surroundings.

If we are to survive on this planet beyond the 21st century, there is little question that humans have to stop increasing in numbers, and the many unwise agricultural and industrial practices that have accompanied the mushrooming of human populations must be replaced with practices more in tune with restoring some ecological balance. Agricultural practices of the future will have to include the return of organic material to the soil after each harvest, instead of adding only inorganic fertilizers. Harvesting of timber and other crops will have to be done in a manner that prevents topsoil erosion, and the practice of clearing brush with chemicals will have to be abolished. Industrial pollutants will have to be rendered harmless and recycled whenever possible.

Many products that now are still largely discarded (e.g., garbage, paper products, glass, metal cans) will also have to be recycled on a much larger scale. Biological pest controls (discussed in Appendix 2) will have to replace the use of poisonous controls whenever possible. Water and energy conservation will have to be universally practiced, and rare plant species, with their largely unknown gene potential for future crop plants, will need to be saved from extinction by preservation of their habitats and by other means. The general public will have to be made even more aware of the urgency for wise land management and conservation—which will be especially needed when pressures are exerted by influential forces promoting unwise measures in the name of "progress"—before additional large segments of our natural resources are irreparably damaged or lost forever. Alternatives appear to be nothing less than death from starvation, respiratory diseases, poisoning of our food and drink, and other catastrophic events that could ensure the premature demise of large segments of the world's population.

Scientists and, increasingly, the general public have become alarmed about the effects of human carelessness on our environment. Damage to forests and lakes caused by acid rain, contamination of ground water by nitrates and pesticides, reduction of the ozone shield, major global climatic changes, depletion of aquifers, and loss of biodiversity have gained widespread publicity.

Human and Animal Dependence on Plants

Our dependence on green organisms to produce the oxygen in the air we breathe and to remove the carbon dioxide we give off doesn't stop there. Plants are also the sources of products that are so much a part of human society that we largely take them for granted. We know, of course, that our major crops, wheat, rice, corn, and potatoes, are plants (Fig. 1.4); but all foods, including meat, fish, poultry, eggs, cheese, and milk, to mention just a few, owe their existence to plants. Condiments, such as spices (Fig. 1.5), and luxuries, such as perfumes, are produced by plants, as are some dyes, adhesives, digestible surgical stitching fiber, food stabilizers, beverages (Fig. 1.6), and emulsifiers.

Our houses are constructed with lumber from trees, which also furnish the cellulose for paper, cardboard, and synthetic fibers. Some of our clothing, camping equipment, bedding, curtains, and other textile goods are made from fibers of many different plant families (Fig. 1.7). Coal is fossilized plant material, and oil came from microscopic green organisms or animals

(a)

(b)

Figure 1.4 (a) Rice cakes being manufactured. Unprocessed rice kernels are heated, causing them to expand. The expanded kernels are then compressed into cakes, which are carried by a conveyor belt to the packaging area. (b) A refrigerated produce area in a grocery store. *(a-b) © Kingsley Stern*

Figure 1.5 Some of the spices derived from plants. © *Kingsley Stern*

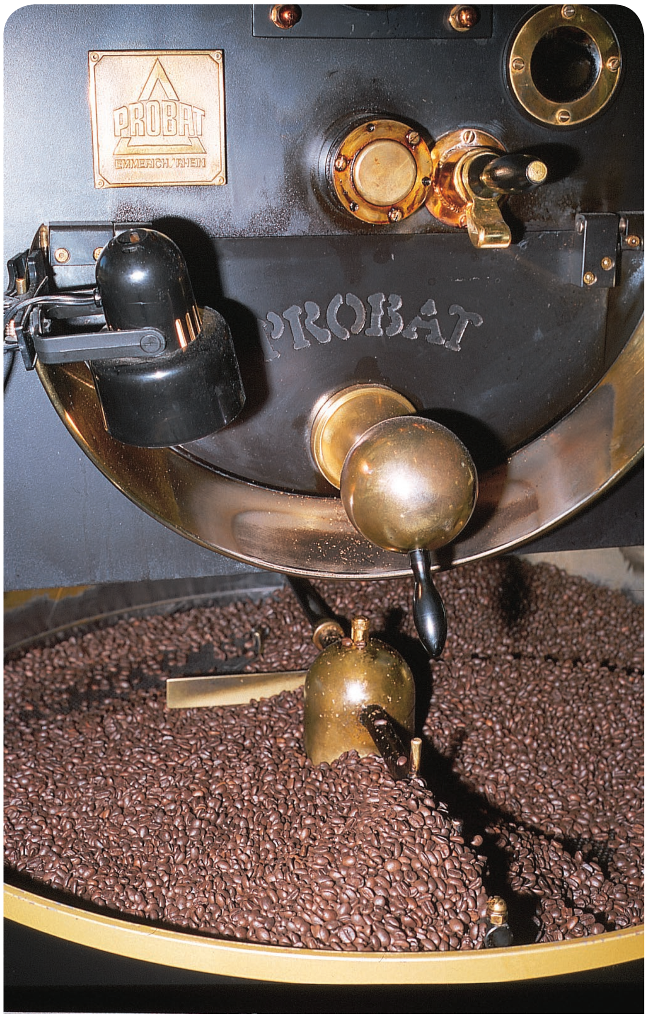
that either directly or indirectly were plant consumers. All medicines and drugs at one time came from plants, fungi, or bacteria, and many important ones, including most of the antibiotics, still do (Fig. 1.8). Microscopic organisms play a vital role in recycling both plant and animal wastes and aid in the building of healthy soils. Others are responsible for human diseases and allergies.

Although shortages of oil and other fossil fuels may sometimes be politically or economically manipulated, there is no question that these fuels are finite and eventually will disappear. Accordingly, the development of alternative energy sources is receiving increased attention. In 2014, 13% of global energy consumption used renewable fuels.

The United States is the largest producer of ethanol in the world. Corn, switchgrass, and other sources of carbohydrates are currently used in the manufacture of ethanol, which is blended with gasoline. Most cars in the United States can run on fuel containing up to 10% ethanol. The Energy Independence and Security Act of 2007 calls for 39 billion gallons of renewable fuel to be used annually in the United States. Currently, ethanol fuel in the United States is mainly produced from corn, but there are concerns about losing food crop land to produce fuel. In addition, the energy and pollution balance of ethanol production is under debate. Cellulosic ethanol, which is derived from inedible plant fiber such as wood chips or switchgrass may overcome some of these concerns.

What about plants and the future? As you read this, the population of the earth already has exceeded 7 billion persons, every one of whom needs food, clothing, and shelter in order to survive. To ensure survival, we may need to learn not only how to cultivate food plants but also how to use plants to remove pollutants from the water, air, and soil (Fig. 1.9), to make land productive again, and to renew urban areas. In addition, we need to minimize the destruction of plant habitats caused primarily by the huge increase in the number of the earth's inhabitants. This subject and related matters are further discussed in Chapter 25.

(a)



(b)

Figure 1.6 Ripening coffee berries. (a) Berries are picked by hand when they are red. The seeds are extracted for roasting after the berries are fermented. (b) Coffee beans cooling after being roasted. *(a-b) © Kingsley Stern*

Figure 1.7 Cotton plants. The white fibers, in which seeds are embedded, are the source of textiles and fabrics. The seeds are the source of vegetable oils used in margarine and shortening. After the oils have been extracted, the remaining "cotton cake" is used for cattle feed. *Courtesy of Derrick Oosterhuis*

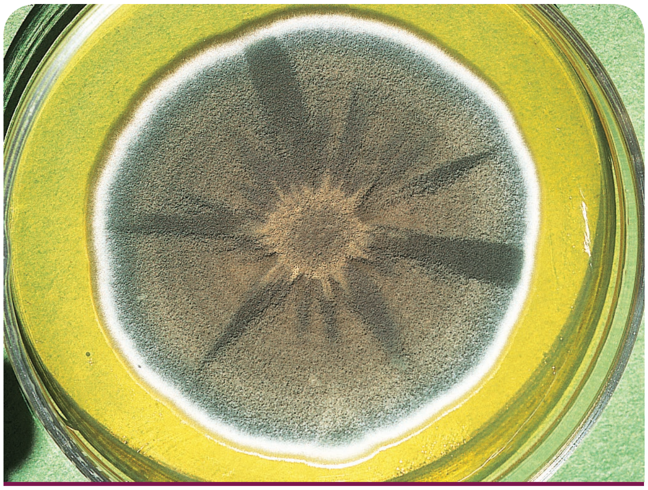


Figure 1.8 A *Penicillium* colony. The tiny beads of fluid on the surface contain penicillin, widely used as an antibiotic. *© Kingsley Stern*

Figure 1.9 A polluted waterway. *Source: U.S. Coast Guard photo by Petty Officer 3rd Class Zac Crawford*

At present the idea that humanity may not be able to save itself may seem radical, but there are a few who have suggested that it might become necessary in the future to emigrate to other planets. Regardless of humanity's future, it is essential that our understanding of plants be used to sustain life on this and maybe even other planets. Experiments with portable oxygen generators have been in progress for many years. Tanks of water teeming with tiny green algae are taken aboard a spacecraft and installed so that they are exposed to light for at least part of the time. The algae not only produce oxygen, which the spacecraft inhabitants can breathe, but also utilize the waste carbon dioxide produced by respiration. As the algae multiply, they can be fed to a special kind of shrimp, which in turn multiply and become food for the space travelers. Other wastes are recycled by different microscopic organisms. When this self-supporting arrangement, called a *closed system,* is perfected, the range of spacecraft should greatly increase because heavy oxygen tanks will not be necessary, and the amount of food reserves will be reduced.

Today, teams of botanists, anthropologists, and medical doctors are interviewing medical practitioners and herbal healers in remote tropical regions and taking notes on various uses of plants by the local inhabitants. These scientists are doing so in the hope of preserving at least some plants with potential for contributions to modern civilization before disruption of their habitats results in their extinction.

Botany as a Science

The study of plants, called **botany**—from three Greek words, *botanikos* (botanical), *botane* (plant or herb), and *boskein* (to feed), and the French word *botanique* (botanical)—appears to have had its origins with Stone Age peoples who tried to modify their surroundings and feed themselves. At first, their interest in plants was mostly practical and centered around how plants might provide food, fibers, fuel, and medicine. Eventually, however, an intellectual interest arose. Individuals became curious about how plants reproduced and how they were put together. This inquisitiveness led to plant study becoming a **science,** which, broadly defined, is simply "a search for knowledge of the natural world." **Botanists** are scientists who study plants.

A science is distinguished from other fields of study by its basis in measurable observations. The scientific method is a series of steps that involves first asking a *question,* then formulating a *hypothesis,* followed by conducting experiments, and finally developing a *theory*.

Hypotheses

A **hypothesis** is simply a tentative, unproven explanation for something that has been observed. It may not be the correct explanation—testing will determine whether it is correct or incorrect. To be accepted by scientists, the results of any experiments designed to test the hypothesis must be repeatable and capable of being duplicated by others.

A scientific experiment is typically carried out with a test group of plants and a control group. The test group receives the experimental treatment, while the control group is treated the same in all ways except that it does not receive the treatment. For example, if you would like to test the effect of light on seed germination, you would divide your seed lot and place some in the light and some in the dark. All other environmental conditions, such as temperature and humidity, would be the same for both sets of seeds. If you observe a germination difference between the two sets of seeds, then it may be due to light.

When a hypothesis is tested, *data* (bits of information) are accumulated and may lead to the formulation of a useful generalization called a *principle.* Several related principles may lend themselves to grouping into a *theory,* which is not simply a guess. A theory is a group of generalizations (principles) that help us understand something. We reject or modify theories only when new principles increase our understanding of a phenomenon. An example of a theory is the concept of natural selection and evolution. This theory describes how the diversity of life on earth came about and provides the foundation for many principles you will encounter in this textbook.

While the testing of hypotheses is a rigorous, well-defined process, the development of hypotheses is not. This aspect of science is creative because it involves finding new ways to look at our natural world. Often, the most successful scientists are those who can think "outside the box," integrating observations across fields or organisms to create a hypothesis that explains a complex phenomenon. While scientific advances are often attributed to luck, there is a growing body of evidence that the methods used by scientists actually harness the unexpected to the benefit of science. When the results of an experiment do not follow predictions, that experiment will be repeated with extra care and from a new perspective. If the unexpected observation is observed again, then the scientist must develop a new hypothesis.

Diversification of Plant Study

Plant anatomy, which is concerned chiefly with the internal structure of plants, was established through the efforts of several scientific pioneers. Early plant anatomists of note included Marcello Malpighi (1628–1694) of Italy, who discovered various tissues in stems and roots, and Nehemiah Grew (1628–1711) of England, who described the structure of wood more precisely than any of his predecessors (Fig. 1.10).

Today, knowledge of plant anatomy is used to help us find clues to the past, as well as for many practical purposes. For example, the related discipline of *dendrochronology* deals with determining past climates by examining the width and other features of tree rings. We can also learn much from

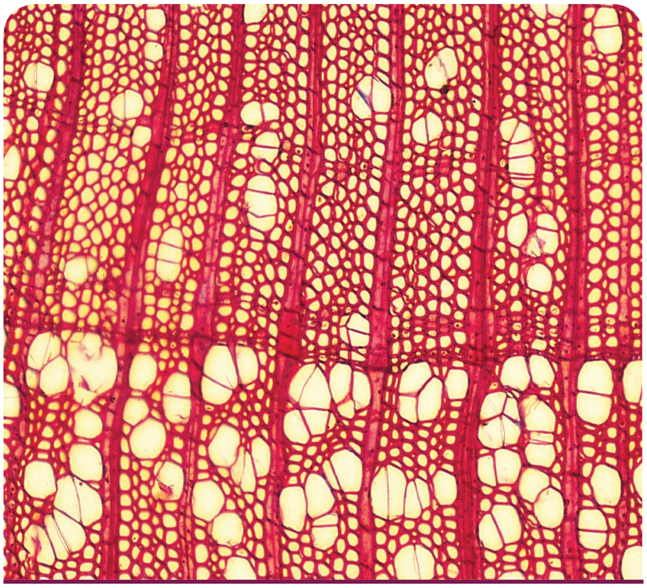


Figure 1.10 A thin section of *Magnolia* wood as seen through a light microscope. ×40. © *Kingsley Stern*

archaeological sites by matching tree rings found in the wood of ancient buildings to the rings of wood of known age. Plant anatomy is also used to solve crimes. Forensic laboratories may use fragments of plant tissues found on clothing or under fingernails to determine where a crime took place or if certain persons could have been present where the crime was committed. The anatomy of leaves, stems, and other plant parts is used to unravel and sort out relationships among plants. A form of plant anatomy, known as *paleobotany,* involves the study of plant fossils.

Plant physiology, which is concerned with plant function, was established by J. B. van Helmont (1577–1644), a Flemish physician and chemist, who was the first to demonstrate that plants do not have the same nutritional needs as animals. In a classic experiment, van Helmont planted a willow branch weighing 5 pounds in an earthenware tub filled with 90.7 kilograms (200 pounds) of dry soil. He covered the soil to prevent dust from settling on it from the air. The willow produced roots and grew, and after 5 years, he reweighed the willow and the soil. He found that the soil weighed only 56.7 grams (2 ounces), less than it had at the beginning of the experiment, but that the willow had gained 76.7 kilograms (169 pounds). He concluded that the tree had added to its bulk and size from the water it had absorbed. We know now that most of the weight came as a result of photosynthetic activity (discussed in Chapter 10), but van Helmont deserves credit for landmark experimentation in plant physiology.

Modern plant physiologists use cloned *genes* (units of heredity that are found mostly within the nuclei of cells) to learn in precise detail much more about plant functions, including how plants conduct materials internally; how temperature, light, and water are involved in growth; why plants flower; and how plant growth regulatory substances are produced, to mention just a few.

During past centuries, Europeans who explored other continents took large numbers of plants back home with them, and it soon became clear to those working with the plants that some sort of formalized system was necessary just to keep the collections straight. Several *plant taxonomists* (botanists who specialize in the identifying, naming, and classifying of plants) proposed ways of accomplishing this, but we owe much of our present system of naming and classifying plants to the Swedish botanist Carolus Linnaeus (1707–1778) (see Fig. 16.2).

Plant taxonomy involves describing, naming, and classifying organisms. **Plant systematics** is a related field but is broader than taxonomy. It is the science of developing methods for grouping organisms. Plant taxonomy is the oldest branch of plant study, begun in antiquity, but Linnaeus did more for the field than any other person in history. Thousands of plant names in use today are those originally recorded in Linnaeus's book *Species Plantarum,* published in 1753. An expanded account of Linnaeus and his system of classification is given in Chapter 16.

There are still thousands of plants, fungi, and other organisms that have not yet been described or even discovered. Although it obviously is already too late to identify species that were not described before they became extinct, plant taxonomists around the world have united to try to identify and describe as many new organisms as possible—many with food, medicinal, and other useful potential—before much more of their natural habitat disappears. Other plant taxonomists, through the use of *cladistics* (analysis of shared features) and molecular techniques, are refining our knowledge of plant relationships. By the year 2000 we had acquired so much new information about natural relationships that some major reclassification took place (see Chapter 16). The molecular knowledge and techniques are also contributing to the improvement of many of our food crops, although some of the changes are controversial.

Many plant taxonomists specialize in certain groups of plants. For example, *pteridologists* specialize in the study of ferns; *bryologists* study mosses and plants with similar life cycles.

The discipline of **plant geography,** the study of how and why plants are distributed where they are, did not develop until the 19th century (Fig. 1.11). The allied field of **plant ecology,** which is the study of the interaction of plants with one another and with their environment, also developed in the 19th century.

After the publication in 1962 of a best-seller entitled *Silent Spring* (authored by Rachel Carson), public awareness of the field of ecology as a whole increased considerably. In this book, based on more than 4 years of literature research, Carson noted that more than 500 new toxic chemicals are put to use annually as pesticides in the United States alone, and she detailed how these chemicals and other pollutants are having a negative impact on all facets of human life and the environment.

The study of the form and structure of plants, **plant morphology,** was developed during the 19th century, and

Figure 1.11 Plant ecologists, plant geographers, and other biologists recognize large communities of plants and animals that occur in areas with distinctive combinations of environmental features. These areas, called *biomes,* are represented here by the tropical rain forest, which, although occupying less than 5% of the earth's surface, is home to more than half of the world's species of organisms. © *Nadezda Zavitaeva/ Shutterstock.com*

during the 20th century much of our basic knowledge about the form and life cycles of plants was incorporated into the plant sciences as we know them today. During this time, the number of scientists engaged in investigating plants also greatly increased.

Genetics, the science of heredity, was founded by the Austrian monk Gregor Mendel (1822–1884), who performed classic experiments with pea plants. Today, various branches of genetics include *plant breeding,* which has greatly improved the yields and quality of crop plants, and *genetic engineering*. Genetic engineering involves the transfer of genes from one organism to another and has already improved the pest, frost, and disease resistance of some crop plants. Genetic engineering is being used to develop better agricultural, medicinal, and other useful plants. It is also being used to control human, animal, and plant diseases. In recent years, the field of **genomics,** which focuses on genes and their function, has burst onto the genetics scene and now impacts nearly all genetics research.

Cell biology (previously called **cytology**), the science of cell structure and function, received a boost from the discovery of how cells multiply and how their various components perform and integrate a variety of functions, including that of sexual reproduction. The mid-20th-century development of *electron microscopes* (see Chapter 3) further spurred cell research and led to vast new insights into cells and new forms of cell research that continues to the present.

Economic botany and **ethnobotany,** which focus on practical uses of plants and plant products, had their origin in antiquity as humans discovered, used, and eventually cultivated plants for food, fiber, medicines, and other purposes. Today there is increased interest in herbal medicines (see Appendix 3) and many other uses of plants by the general public. Research is being conducted in collaboration with indigenous peoples with an eye to discovering new medicines and other useful plant products previously unknown in developed countries.

There is still a vast amount of botanical information to be discovered. Dozens of research journals publish thousands of botanical scientific papers every year. In recent years, open source journals have allowed free online access to research findings for scientists all over the world. While scientists have identified about 2 million species of organisms, the earth likely contains between 5 and 100 million species.