

Edition Eleven

INTRODUCTORY

PLANT BIOLOGY

Kingsley R. Stern

California State University ~ Chico

James E. Bidlack

University of Central Oklahoma

Shelley H. Jansky

University of Wisconsin ~ Madison

INTRODUCTORY PLANT BIOLOGY, ELEVENTH EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020. Copyright © 2008 by The McGraw-Hill Companies, Inc. All rights reserved. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of The McGraw-Hill Companies, Inc., including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

About the Cover

In 1815, a Russian exploratory group sailed its vessel into San Francisco Bay and dropped anchor. The explorers noted the beauty of the surrounding hills, which were covered with thousands of bright golden to orange flowers. These flowers became known as California poppies (*Eschscholzia californica*). The poppies' generic name honors Johann Friedrich Gustav von Eschscholtz, the ship's surgeon. When the scientific name was published formally, the "t" in Eschscholtz was inadvertently omitted.

California poppies grow in well-drained soils in virtually any area with a Mediterranean climate. They are native plants in locations below 6,000 feet, including Baja, California, other western states, and western Texas. More than 90 subspecies, varieties, and forms of poppy exist in the literature; many varieties are developed horticulturally. The California poppy was formally named California's state flower in 1903. It is illegal to pick California poppies (or any other wildflowers in the state) within 25 feet of a highway or road.

Antelope Valley, in northern Los Angeles County, is the site of a 1,745-acre poppy reserve. The entire area is covered with poppies in bloom in the spring. The cover image was photographed near Lancaster, California.



This book is printed on recycled, acid-free paper containing 10% post consumer waste.

1 2 3 4 5 6 7 8 9 0 QPD/QPD 0 9 8 7

ISBN 978-0-07-283067-5
MHID 0-07-283067-0

Publisher: *Thomas D. Timp*
Executive Editor: *Margaret J. Kemp*
Senior Developmental Editor: *Joan M. Weber*
Senior Marketing Manager: *Tami Petsche*
Senior Project Manager: *Kay J. Brimeyer*
Lead Production Supervisor: *Sandy Ludovissy*
Media Producer: *Daniel M. Wallace*
Senior Coordinator of Freelance Design: *Michelle D. Whitaker*
Cover/Interior Designer: *Jamie O'Neal*
(USE) Cover Image: ©*Roy Ooms / Masterfile*
Senior Photo Research Coordinator: *Lori Hancock*
Supplement Producer: *Melissa Leick*
Compositor: *Precision Graphics*
Typeface: *10/12 Times Roman*
Printer: *Quebecor World Dubuque, IA*

Library of Congress Cataloging-in-Publication Data

Stern, Kingsley Rowland.
Introductory plant biology / Kingsley R. Stern, James E. Bidlack, Shelley H. Jansky. —11th ed.
p. cm.
Includes index.
ISBN 978-0-07-283067-5 — ISBN 0-07-283067-0 (hard copy : alk paper)
I. Botany. I. Bidlack, James E. II. Jansky, Shelley, III. Title.
QK47.S836 2008
580—dc22 2006037789

www.mhhe.com

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

About the Authors

In late 1999/early 2000, Kingsley Stern and McGraw-Hill Publishers initiated a search to find outstanding scientists to join the author team for *Introductory Plant Biology*. With nearly three decades of publishing this successful textbook, it was clear to Dr. Stern and the people at McGraw-Hill that new botanists would help to further enrich the content and continue the dedication and hard work needed for future editions. Many professors using the text came to mind but several, in particular, had expressed the desire, knowledge, and enthusiasm to become successful authors. After review of these individuals, Dr. Stern hand-picked two botanists, Dr. Jim Bidlack and Dr. Shelley Jansky, to work with him. Over the years, the team has corresponded directly through personal meetings, dozens of phone calls, and hundreds of e-mails, to improve upon and update content in the book. This eleventh edition reflects their continued teamwork and dedication to the profession of plant biology and related disciplines.

Kingsley R. Stern

Kingsley R. Stern received his undergraduate education at Wheaton College, where he majored in botany. In graduate school, he continued his studies in botany, while minoring in zoology and horticulture. He received his Master's Degree from the University of Michigan at Ann Arbor, and his Ph.D. from the University of Minnesota at Minneapolis. He took additional graduate courses at the University of Illinois in Urbana, and at the Hopkins Marine Station of Stanford University in Pacific Grove, California. While pursuing his studies, Dr. Stern held part-time positions as an instructor in biology at Hamline University and as an instructor in botany at the University of Minnesota, where he received a Conway McMillan Research Fellowship. After accepting a position as Assistant Professor of Botany at California State University in Chico, he was promoted to Associate, and then Full Professor. In 1987, while on leave, he was a Visiting Professor of Botany at the Manoa campus of

the University of Hawaii. During his tenure at California State University, Dr. Stern taught eight different courses, several of which he introduced to the curriculum, and was on the committees of over 50 graduate students. To date, an estimated 15,000 students have enrolled in his classes. He has received several grants from the National Science Foundation in support of bio-systematic investigations in Fumariaceae (Fumitory Family). These investigations, which included studies at the Swedish National Pollen Laboratory in Stockholm, eventually led to the publication of about 20 research papers in professional journals. Dr. Stern's academic awards include being named Outstanding Professor at California State University in 1993, and receiving the school's Distinguished Service Award in 1999 for establishing and developing the University Herbarium, which grew from 2,000 to more than 74,000 specimens. Dr. Stern was most recently honored at the 100th Meeting of the Botanical Society of America, where he accompanied many world-famous botanists in recognition with the Society's Centennial Award.

Editor's Note: Known as a dedicated botanist and teacher, Kingsley passed away a few days after completing final revisions on the eleventh edition.

James E. Bidlack

Jim Bidlack received a B.S. Degree in Agronomy, with a Soil & 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 at Arkansas, Iowa, and Oklahoma focused on soybean physiology, cell wall chemistry, and alternative crops, as well as teaching responsibilities in plant biology. Equipment and student salaries for Jim's research projects have been funded by grants from the National Science Foundation (NSF) and the United States Department of Agriculture (USDA). About a dozen refereed publications, as well as 40 popular articles and abstracts, have resulted from this work. Jim has been active with campus organizations, serving two terms as the local President of the American Association of University Professors (AAUP), and sponsoring Alpha Tau Omega Fraternity, Circle K International Club, and Mortar Board Honor Society. He has been recognized with UCO's Presidential Partner's Excellence in Teaching Award; University Merit Awards in Service, Research, and Teaching; Biology Club Teaching Award; and Pre-Med Teaching Award, as well as AAUP's Distinguished Scholar and Service Awards. Some of Jim's additional responsibilities have included participation on NSF and USDA Review Panels, membership on the National Biology Editorial Board for the Multimedia Educational Resource for Learning and Online Teaching (MERLOT) Project, and Executive Directorship of the Metabolism Foundation. He and his wife, Amy, enjoy hiking and fishing, and spend free time with their daughter, Hanna, at family farms in Oklahoma and Nebraska.

Shelley H. Jansky

Shelley H. Jansky received a Bachelor's Degree in Biology from the University of Wisconsin-Stevens Point in 1982, and M.S. and Ph.D. degrees 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, horticulture, and plant genetics at the University of Wisconsin-Stevens Point from 1990 until 2004. In 2004, she moved to Madison, Wisconsin, where she is a Research Geneticist with the U.S. Department of Agriculture and a professor in the Department of Horticulture at the University of Wisconsin-Madison. Her potato research program focuses on utilization of wild potato relatives for 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 lives near Madison, where she enjoys fishing, gardening, sailing, and swimming with her husband, John, and two children, Mark and Kristin.

Contents in Brief

Preface xi

1	What Is Plant Biology?	1
2	The Nature of Life	13
3	Cells	29
4	Tissues	53
5	Roots and Soils	64
6	Stems	84

7	Leaves	106
8	Flowers, Fruits, and Seeds	126
9	Water in Plants	149
10	Plant Metabolism	165
11	Growth	191
12	Meiosis and Alternation of Generations	215
13	Genetics	224
14	Plant Breeding and Propagation	246
15	Evolution	266
16	Plant Names and Classification	279
17	Domain (Kingdom) Bacteria, Domain (Kingdom) Archaea, and Viruses	292
18	Kingdom Protista	317
19	Kingdom Fungi	346
20	Introduction to the Plant Kingdom: Bryophytes	371
21	The Seedless Vascular Plants: Ferns and Their Relatives	385
22	Introduction to Seed Plants: Gymnosperms	409
23	Seed Plants: Angiosperms	428
24	Flowering Plants and Civilization	448
25	Ecology	474
26	Biomes	498
Appendix 1 Scientific Names of Organisms Mentioned in the Text		510
Appendix 2 Biological Controls		529
Appendix 3 Useful and Poisonous Plants, Fungi, and Algae		537
Appendix 4 House Plants and Home Gardening		562
Appendix 5 Metric Equivalents and Conversion Tables		586
Glossary		588
Index		599

Recently a botanical colleague of mine was contacted by the police to see if she could help them solve a crime. A young woman had disappeared and there was reason to suspect foul play involving a male acquaintance of hers. The police had found tiny bits of plant material in the man's car, and asked if my colleague could identify them. She was able not only to identify two or three different plants, but also knew where that particular association of plants grew. She took the police to the area, and within 20 minutes they found the woman's body. The man was subsequently charged with and convicted of murder.

The field of forensics sometimes uses microscopic bits of plant material to help solve crimes, but in addition to forensics, 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, houseplants, 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 farther 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," "Phylum Psilotophyta," etc. 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, the topics are presented at three different levels. Some instructors will find one or two levels sufficient, whereas others will want to include all three.

I have found that 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.

“I reviewed one of the leading competitor’s textbooks for this course and still feel that Stern is outstanding for the course we teach. The relatively short chapters and the ease of reading make this an excellent book for introductory botany.”

Kathleen Wood, University of Mary Hardin-Baylor

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 and genetics. 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 sixteen 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 the ecological review summaries, in the human and ecological review sections, and in the extensive 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 used more than once are boldfaced and included in a pronunciation glossary. Although scientific names are given in some instances, their use has been minimized throughout the text. However, 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 houseplants, 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 eleventh edition has retained the hallmark style and pedagogy that have made it one of the most enduring and popular introductory plant biology books on the market. At the same time, this edition has undergone important -revisions to: (1) enhance the visual impact of photos by adding new images and replacing others with higher-quality images, (2) update the content, revising concepts and facts as needed, and (3) modernize the art package, producing a more bold and colorful set of illustrations. Some specific improvements for this edition include the following:

- There are several dozen new photos that are more up to date, are in sharper focus, provide a better overall view of anatomical structures, and provide features that complement new information in the chapters.
- Some new artwork designs have either been modified or changed as suggested by reviewers. One example is a new diagram showing the four levels of protein structure in a plant protein (rubisco). This replaces the former illustration based on hemoglobin structure.
- Other artwork has been updated or revised for clarity. For example, in the protein synthesis illustration, an E (exit) site has been added to conform to the current model of the translation machinery. In addition, the DNA replication illustration has been extensively altered to make it easier for students to understand.
- The same emphasis on traditional life cycles has been retained, as this is considered to be one of the most important attributes of the book, distinguishing it from most other plant biology books. The life cycles provide accurate color-coding to distinguish between haploid and diploid structures. In addition, selected life cycles have been enhanced with inset photographs and artistic representations to show how these structures appear in the field, as well as with the aid of a microscope. Several dozen inset micrographs have been added to the life cycles.

“The illustrations in Stern are why I use the book. I refer, in particular, to the chapters that survey the plant kingdom. In choosing a text I want to make sure that the photos and illustrations make the point about the survey and about plant anatomy. Stern does this very well.”

L. Michael Hill, Bridgewater College

- Chapters 25 (Ecology) and 26 (Biomes) have been updated and expanded to be more comprehensive and current in coverage. New material includes information on succession after volcanic eruption, erosion during Hurricane Katrina and the recent tsunami, aquifer depletion, and global warming.
- Overall text modifications and updates, as recommended by reviewers, have been made to nearly every chapter of the book.
- Brighter colors and a more straightforward layout (with no overlapping pictures) have been incorporated as part of the presentation style to make the book more engaging.
- References for suggested readings have been updated in all chapters.

“The descriptions of the individual members of the protists are among the best I have found in an introductory botany text. The author certainly engages the reader with his ability to make botany relevant to the reader. Key strengths include the extensive descriptions of the various algal groups and their methods of sexual and asexual reproduction [Chapter 18]. Making these organisms relevant to the everyday life of the student is a major accomplishment.”

Cherie Wetzel, City College of San Francisco

ACKNOWLEDGMENTS

The valuable contributions of Dr. James Enderby Bidlack and Dr. Shelley H. Jansky, who rewrote and updated Chapters 3, Cells; 10, Plant Metabolism; 13, Genetics; 14, Plant Breeding and Propagation; 25, Ecology; and 26, Biomes, for this edition and previous editions are gratefully acknowledged. Dr. Daniel Scheirer, who contributed most of the “Plant Sciences Inquiry” boxed readings, and Dr. Manuel Molles, who provided highlighted ecological summaries for each chapter, both enhanced the text with what they wrote. The help of these gifted individuals is most appreciated.

Others who read parts of the manuscripts of various editions and made many helpful suggestions include Richard S. Demaree, Jr., Patricia Edelmann, Robert I. Ediger, Larry Hanne, Donald T. Kowalski, Robert B. McNairn, and Robert Schlising. Additional appreciated encouragement and contributions were made by Isabella A. Abbott, Donald E. Brink, Jr., Gerald Carr, William F. Derr, Timothy Devine, Beverly Marcum, Robert McNulty, Paul C. Silva, Lorraine Wiley, the faculty and staff of the Department of Biological Sciences, California State University, Chico, my many inspiring students, the Lyon Arboretum of the University of Hawaii, the editorial, production, and design staffs of McGraw-Hill Publishers, and most of all, my family. Special thanks are due the artists, Denise Robertson Devine, Janet Monelo, and Sharon Stern.

Finally I would like to extend thanks to the following reviewers who provided recent feedback on the text and the illustrations. Their help has been invaluable in shaping the eleventh edition of *Introductory Plant Biology*. Upon reaching this milestone eleventh edition, I would also like to once again extend my 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.

Ligia Arango, *Stone Child College*
Joseph Arditti, *University of California—Irvine*
Mark H. Armitage, *Azusa Pacific University*
Janice Asel, *Mitchell Community College*
Tasneem K. Ashraf, *Cochise College—Sierra Vista*
Ralph A. Backhaus, *Arizona State University*
Nina L. Baghai-Riding, *Delta State University*
Randy G. Balice, *New Mexico Highlands University*
Susan C. Barber, *Oklahoma City University*
Paul W. Barnes, *Southwest Texas State University*
Sharon Bartholomew-Began, *West Chester University*
Robert W. Bauman, Jr., *Amarillo College*
Dorothea Bedigian, *Washington University*
Patricia Bedinger, *Colorado State University*
Maria Begonia, *Jackson State University*
Robert A. Bell, *University of Wisconsin—Stevens Point*

Cynthia A. Bottrell, *Scott Community College*
Richard R. Bounds, *Mount Olive College*
Richard G. Bowmer, *Idaho State University*
Rebecca D. Bray, *Old Dominion University*
James A. Brenneman, *University of Evansville*
George M. Briggs, *State University of New York*
Michelle Briggs, *Lycoming College*
George M. Brooks, *Ohio University*
Suzanne Butler, *Miami-Dade College*
William J. Campbell, *Louisiana Technical University*
Ajoy G. Chakrabarti, *South Carolina State University*
Brad S. Chandler, *Palo Alto College*
Gregory Chandler, *University of North Carolina—Wilmington*
James A. Christian, *Louisiana Technical University*
Richard Churchill, *Southern Maine Technical College*
Jerry A. Clonts, *Anderson College*
John Cruzan, *Geneva College*
Kenneth J. Curry, *University of Southern Mississippi*
David B. Czarnecki, *Loras College*
Stephen S. Daggett, *Avila College*
Raviprakash G. Dani, *Texas Tech University*
Roy Darville, *East Texas Baptist University*
Bill D. Davis, *Rutgers University*
Jerry D. Davis, *University of Wisconsin—LaCrosse*
John W. Davis, *Benedictine College*
Roger del Moral, *University of Washington*
Semma Dhir, *Fort Valley State University*
Rebecca M. DiLiddo, *Mount Ida College*
Susan C. Dixon, *Walla Walla College*
Ben L. Dolbeare, *Lincoln Land Community College*
Patricia M. Dooris, *Saint Leo College*
Tom Dudley, *Angelina College*
Jan Federic Dudt, *Bartlesville Wesleyan College*
Diane Dudzinski, *Washington State Community College*
Kerry B. Dunbar, *Dalton State College*
Carolyn S. Dunn, *University of North Carolina—Wilmington*
Robert Ediger, *California State University—Chico*
H. Herbert Edwards, *Western Illinois University*
William Eisinger, *Santa Clara University*
Inge Eley, *Hudson Valley Community College*
Thomas E. Elthon, *University of Nebraska—Lincoln*
Frederick B. Essig, *University of South Florida*
G. F. Estabrook, *The University of Michigan*
James Ethridge, *Joliet Junior College*
Paul G. Fader, *Freed-Hardeman University*
Bruce Felgenhauer, *University of Louisiana—Lafayette*
Jorge F. S. Ferreira, *Southern Illinois University—Carbondale*
David G. Fisher, *Maharishi University of Management*
Rosemary H. Ford, *Washington College*
Stephen W. Fuller, *Mary Washington College*
Sibdas Ghosh, *University of Wisconsin—Whitewater*
Mike Gipson, *Oklahoma Christian University*
Katherine Glew, *University of Washington*
Richard Glick, *Winston-Salem State University*
Charles Good, *Ohio State University*
David L. Gorchoy, *Miami University of Ohio*
Scott A. Gordon, *University of Southern Illinois*
Steve Greenwald, *Gordon College*
Sharon Gusky, *Northwestern Connecticut Community Technical College*
Timothy C. Hall, *Texas A & M University*

Mark Hammer, *Wayne State College*
Laszlo Hanzely, *Northern Illinois University*
Joyce Phillips Hardy, *Chadron State College*
Nancy E. Harris, *Elon College*
David Hartsell, *Phillips Community College*
Jill F. Haukos, *South Plains College*
David L. Herrin, *University of Texas—Austin*
Peter Heywood, *Brown University*
Jeffrey P. Hill, *Idaho State University*
L. Michael Hill, *Bridgewater College*
H. H. Ho, *State University of New York—New Paltz*
A. Scott Holaday, *Texas Tech University*
Elisabeth A. Hooper, *Truman State University*
Susan Houseman, *Southeastern Community College*
Lauren D. Howard, *Norwich University*
Vernon R. Huebschwerlen, *Reedley Community College*
Patricia L. Ireland, *San Jacinto College, South*
William A. Jensen, *Ohio State University*
Cindy Johnson-Groh, *Gustavus Adolphus College*
Toney Keeney, *Southwest Texas State*
Sekender A. Khan, *Elizabeth City State University*
Joanne M. Kilpatrick, *Auburn University—Montgomery*
Helen G. Kiss, *Miami University*
John Z. Kiss, *Miami University of Ohio*
Kaoru Kitajima, *University of Florida*
Roger C. Klockziem, *Martin Luther College*
Robert L. Koenig, *Southwest Texas Junior College*
David W. Kramer, *Ohio State University—Mansfield*
Robert N. Kruger, *Mayville State University*
Martin LaBar, *Southern Wesleyan University*
Vic Landrum, *Washburn University*
James M. Lang, *Greenville College*
Brenda Price Latham, *Merced College*
Cheryl R. Laursen, *Eastern Illinois University*
Peter J. Lemay, *College of the Holy Cross*
Donald C. Leynaud, *Wabash Valley College*
Barbara E. Liedl, *Central College*
John F. Logue, *University of South Carolina—Sumter*
Elizabeth L. Lucyszyn, *Medaille College*
Karen Lustig, *Harper College*
Erin D. MacKenzie, *Weatherford College*
Paul Mangum, *Midland College*
Steve Manning, *Arkansas State University—Beebe*
Michael H. Marcovitz, *Midland Lutheran College*
Bernard A. Marcus, *Genesee Community College*
David Martin, *Centralia College*
Margaret Massey, *Mississippi University for Women*
William J. Mathena, *Kaskaskia College*
Alicia Mazari-Andersen, *Kwantlen University College*
Joseph H. McCulloch, *Normandale Community College*
Julie A. Medlin, *Northwestern Michigan College*
Larry Mellichamp, *University of North Carolina at Charlotte*
Richard G. Merritt, *Houston Community College*
Andrew S. Methven, *Eastern Illinois University*
Timothy Metz, *Campbell University*
David H. Miller, *Oberlin College*
David W. Miller, *Clark State Community College*
Lillian W. Miller, *Florida Community College—Jacksonville*
Subhash C. Minocha, *University of New Hampshire*
L. Maynard Moe, *California State University—Bakersfield*

Beth Morgan, *University of Illinois, Urbana-Champaign*
Dale M. J. Mueller, *Texas A & M University*
Lytton John Musselman, *Old Dominion University*
Nusrat H. Naqvi, *Southern University*
Joanna H. Norris, *University of Rhode Island*
Chuks A. Ogbonnaya, *Mountain Empire College*
Jeanette C. Oliver, *Flathead Valley Community College*
Sebastine O. Onwuka, *Lesley College*
Clark L. Ovrebo, *University of Central Oklahoma*
A. D. Owings, *Southeastern Louisiana University*
Julie M. Palmer, *University of Texas—Austin*
Richard A. Palmer, *Fresno City College*
Carolyn Peters, *Spoon River College*
Martha M. Phillips, *The College of St. Catherine*
Jerry L. Pickering, *Indiana University of Pennsylvania*
Wayne S. Pierce, *California State University—Stanislaus*
Indiren Pillay, *Southwestern Tennessee Community College*
Mary Ann Polasek, *Cardinal Stritch University*
Dr. Robert J. Porra, *CSIRO*
Kumkum Prabhakar, *Nassau Community College*
Tyre J. Proffer, *Kent State University*
V. Raghaven, *The Ohio State University*
Mohammad A. Rana, *St. Joseph College*
Margene M. Ranieri, *Bob Jones University*
W. T. Rankin, *University of Montevallo*
Dennis T. Ray, *University of Arizona*
Linda Mary Reeves, *San Juan College*
Maralyn A. Renner, *College of the Redwoods*
Penelope ReVelle, *Community College of Baltimore County—Essex*
Tom Reynolds, *University of North Carolina—Charlotte*
Stanley A. Rice, *Southeastern Oklahoma State University*
Dennis F. Ringling, *Pennsylvania College of Technology*
Daryl Ritter, *Okaloosa-Walton Community College*
Suzanne M. D. Rogers, *Salem International University*
Wayne C. Rosing, *Middle Tennessee State University*
Robert G. Ross, *University of Puerto Rico*
Jimmy Rozell, *Tyler Junior College*
Manfred Ruddat, *University of Chicago*
Patricia Rugaber, *Coastal Georgia Community College*
Robert M. Rupp, *Ohio State University, Agricultural Technical Institute*
Thomas H. Russ, *Charles County Community College*
Dennis J. Russell, *University of Alaska Southeast*
Connie Rye, *Bevill State Community College*
C. L. Sagers, *University of Arkansas*
A. Edwards Salgado, *Christian Brothers University*
Thomas Sasek, *Northeast Louisiana University*
Michael A. Savka, *University of West Florida*
Neil W. Sawyer, *University of Wisconsin—Whitewater*
Neil Schanker, *College of the Siskiyous*
Renee M. Schloupt, *Delaware Valley College*
Bruce S. Serlin, *DePauw University*
Wilbur J. Settle, *State University of New York—Oneonta*
Barbara Greene Shipes, *Hampton University*
Richard H. Shippee, *Vincennes University*
Brian R. Shmaefsky, *Kingwood College*
Shaukat M. Siddiqi, *Virginia State University*
Dilbagh Singh, *Blackburn College*
Del William Smith, *Modesto Junior College*
James Smith, *Boise State University*
Joanna M.K. Smith

Steven Smith, *University of Arizona*
Nancy Smith-Huerta, *Miami University*
F. Lee St. John, *Ohio State University—Newark*
Spencer S. Stober, *Alvernia College*
Marshall D. Sundberg, *Emporia State University*
Eric Sundell, *University of Arkansas—Monticello*
Donald D. Sutton, *California State University—Fullerton*
Stan R. Szarek, *Arizona State University*
Mesfin Tadesse, *Ohio State University*
Max R. Terman, *Tabor College*
R. Dale Thomas, *Northeast Louisiana University*
Stephen L. Timme, *Pittsburg State University*
Leslie R. Towill, *Arizona State University*
Richard E. Trout, *Oklahoma City Community College*
Jun Tsuji, *Sienna Heights College*
Claudia Uhde-Stone, *California State University—East Bay*
Gordon E. Uno, *University of Oklahoma*
Rani Vajravelu, *University of Central Florida*
John Vanderploeg, *Ferris State University*
Delmar Vander Zee, *Dordt College*
C. Gerald Van Dyke, *North Carolina State University*
Leon Walker, *University of Findlay*
Betty J. Washington, *Albany State University*
Edgar E. Webber, *Keuka College*
Christopher R. Wenzel, *Eastern Wyoming College*
Cherie Wetzel, *City College of San Francisco*
Ingelia White, *Windward Community College*
Garrison Wilkes, *University of Massachusetts—Boston*
Donald L. Williams, *Sterling College*
Justin K. Williams, *Sam Houston State University*
Marvin Williams, *University of Nebraska—Kearney*
Dwina W. Willis, *Freed-Hardeman University*
James A. Winsor, *The Pennsylvania State University*
Clarence C. Wolfe, *Northern Virginia Community College*
Chris Wolverson, *Ohio Wesleyan University*
Kathleen Wood, *University of Mary Hardin-Baylor*
Richard J. Wright, *Valencia Community College*
Todd Christian Yetter, *Cumberland College*
Brenda Young, *Daemen College*
Rebecca Zamora, *South Plains College*

Teaching and Learning Supplements

McGraw-Hill offers various tools and technology products to support *Introductory Plant Biology*. Students can order supplemental study materials by contacting their local bookstore or by calling 800-262-4729. Instructors can obtain teaching aids by calling the Customer Service Department at 800-338-3987, visiting the McGraw-Hill website at www.mhhe.com, or by contacting their local McGraw-Hill sales representative.

TEACHING SUPPLEMENTS FOR INSTRUCTORS

McGraw-Hill's **Online Learning Center (OLC)** (<http://www.mhhe.com/stern11e>) for *Introductory Plant Biology* is a text-specific website offering an extensive array of teaching tools. In addition to all of the student assets available, this site includes

- Answers to review questions
- Answers to discussion questions
- Botany atlas

- *Instructor's Manual*
- PowerPoint lecture presentations
- eInstruction questions
- List of transparencies
- Lab manual answers

OLC Presentation Center (found at www.mhhe.com/stern11e)

Build instructional materials wherever, whenever, and however you want!

OLC Presentation Center is an online digital library containing assets such as photos, artwork, animations, PowerPoints, and other media types that can be used to create customized lectures, visually enhanced tests and quizzes, compelling course websites, or attractive printed support materials.

Access to your book, access to all books!

The Presentation Center library includes thousands of assets from many McGraw-Hill titles. This ever-growing resource gives instructors the power to utilize assets specific to an adopted textbook as well as content from all other books in the library.

Nothing could be easier!

Accessed from the instructor side of your textbook's website, Presentation Center's dynamic search engine allows you to explore by discipline, course, textbook chapter, asset type, or keyword. Simply browse, select, and download the files you need to build engaging course materials. All assets are copyright McGraw-Hill Higher Education but can be used by instructors for classroom purposes.

Instructors will find the following digital assets for *Introductory Plant Biology* at OLC Presentation Center:

- **Color Art.** Full-color digital files of *all* illustrations in the text can be readily incorporated into lecture -presentations, exams, or custom-made classroom materials. These include all of the art found in this edition, representing some of the most important concepts in botany.
- **Photos.** Digital files of *all* photographs from the text can be reproduced for multiple classroom uses.
- **Additional Photos.** 823 full-color bonus photographs are available in a separate file. These photos are searchable by content and will add interest and contextual support to your lectures.
- **Tables.** Every table that appears in the text is provided in electronic format.
- **Animations.** 147 full-color animations that illustrate many different concepts covered in the study of ecology are available for use in creating classroom lectures, testing materials, or online course communication. The visual impact of motion will enhance classroom presentations and increase comprehension.
- **Active Art.** These 95 special art pieces consist of key botany illustrations converted to a format that allows you to break down the art into core elements and then group the various pieces to create customized images. This is especially helpful with difficult concepts because they can be explained to students step by step.
- **TextEdit Art.** These 214 illustrations have been specially prepared in PowerPoint format to allow labels to be revised, moved, or deleted for use in customized presentations, quizzes, and exams.
- **PowerPoint Lecture Outlines.** Ready-made presentations that combine art and photos and lecture notes are provided for each of the 26 chapters of the text. These outlines can be used as they are or tailored to reflect your preferred lecture topics and sequences.
- **PowerPoint Slides.** For instructors who prefer to create their lectures from scratch, all illustrations, photos, and tables are preinserted by chapter into blank PowerPoint slides for convenience.

McGraw-Hill's Biology Digitized Videos (ISBN: 978-0-07-312155-0; MHID: 0-07-312155-X)

Licensed from some of the highest-quality life science video producers in the world, these brief video clips on DVD range in length from 15 seconds to two minutes and cover all areas of general biology, from cells to ecosystems. Engaging and informative, McGraw-Hill's digitized biology videos will help capture students' interest while illustrating key biological concepts, applications, and processes.

Instructor's Testing Resource CD-ROM

This CD-ROM contains a wealth of cross-platform (Windows and Macintosh) resources for the instructor. Supplements featured on this CD-ROM include a computerized test bank that utilizes EZ Test software to quickly create customized exams. This flexible and user-friendly program allows instructors to search for questions by topic, format, or difficulty level, and edit existing questions or add new ones. Multiple versions of the test can be created, and any test can be exported for use with course management systems such as WebCT, Blackboard, or PageOut. Word files of the test bank are included for those instructors who prefer to work outside of the test-generator software. Other assets on the Instructor's Testing and Resource CD-ROM are grouped within easy-to-use folders.

Transparencies (ISBN-13: 978-0-07-329305-9; MHID: 0-07-329305-9)

A set of over 100 overhead transparencies includes key illustrations and photographs from the text. The images are printed for great visibility and contrast, and labels are large and bold for clear projection.

eInstruction

This classroom performance system (CPS) utilizes wireless technology to bring interactivity into the classroom or lecture hall. Instructors and students receive immediate feedback through wireless response pads that are easy to use and engage students. eInstruction can assist instructors by:

- Taking attendance
- Administering quizzes and tests
- Creating a lecture with intermittent questions
- Using the CPS grade book to manage lectures and student comprehension
- Integrating interactivity into PowerPoint presentations

Contact your local McGraw-Hill sales representative for more information.

Course Delivery Systems

With help from WebCT, Blackboard, and other course management systems, professors can take complete control of their course content. Course cartridges containing website content, online testing, and powerful student tracking features are readily available for use within these platforms.

The Amazing Lives of Plants: The Reproductive Lives of Mosses, Pines, Ferns, Flowers, and Leaves CD-ROM or DVD (CD ISBN: 978-0-07-294047-3; CD MHID: 0-07-294047-6) (DVD ISBN: 978-0-07-294339-9; DVD MHID: 0-07-294339-4)

Available upon adoption, *The Amazing Lives of Plants* includes five independent segments: "Mosses," "Ferns," "Pines," "Flowers," and "Leaves." Their reproductive lives are presented in a vivid, full-color combination of live video footage and sharp animation. Subtitled text makes it easy to cue up for use in lecture, and the pace of the program is suitable for students taking notes.

Introductory Plant Biology Laboratory Manual, Eleventh Edition, by Stern and Bidlack (ISBN: 978-0-07-283068-2; MHID: 0-07-283068-9)

The laboratory manual that accompanies *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.

LEARNING SUPPLEMENTS FOR STUDENTS

Online Learning Center (OLC)
(<http://www.mhhe.com/stern11e>)

This site offers a wide variety of student resources that provide students many opportunities to master the core concepts in botany. Learn more about the exciting features provided for students through the *Introductory Plant Biology* website:

- Practice quizzing
- Botany atlas
- Hyperlinks on chapter topics
- Key term flashcards
- Career information

Contents

Preface xi

1 What Is Plant Biology? 1

Chapter Outline	1
Overview	2
Some Learning Goals	2
The Relationship of Humans to Their Environment	4
Botany as a Science	7
Diversification of Plant Study	8
Plant Sciences Inquiry: Plant Biology and the Web	10
Summary	11
Review Questions	12
Discussion Questions	12
Additional Reading	12

2 The Nature of Life 13

Chapter Outline	13
Overview	14
Some Learning Goals	14
Attributes of Living Organisms	14
Chemical and Physical Bases of Life	15
Summary	27
Review Questions	28
Discussion Questions	28
Additional Reading	28

3 Cells 29

Chapter Outline	29
Overview	30
Some Learning Goals	30
Cells	30
Eukaryotic Versus Prokaryotic Cells	33
Cell Structure and Communication	33
Cellular Components	36
Cellular Reproduction	44
Plant Sciences Inquiry: Microscapes	49
Higher Plant Cells Versus Animal Cells	50
Summary	51
Review Questions	52

Discussion Questions 52
Additional Reading 52

4 Tissues 53

Chapter Outline 53
Overview 54
Some Learning Goals 54
Meristematic Tissues 54
Tissues Produced by Meristems 55
Summary 62
Review Questions 63
Discussion Questions 63
Additional Reading 63

5 Roots and Soils 64

Chapter Outline 64
Overview 65
Some Learning Goals 65
How Roots Develop 65
Root Structure 66
Specialized Roots 70
Mycorrhizae 74
Root Nodules 75
Human Relevance of Roots 75
Soils 77
Plant Sciences Inquiry: Metal-Munching Plants 80
Summary 81
Review Questions 82
Discussion Questions 82
Additional Reading 82

6 Stems 84

Chapter Outline 84
Overview 85
Some Learning Goals 85
External Form of a Woody Twig 85
Origin and Development of Stems 86
Plant Sciences Inquiry: Standing in Fields of Stone 87
Tissue Patterns in Stems 89
Specialized Stems 96
Wood and Its Uses 99
Summary 104
Review Questions 105
Discussion Questions 105
Additional Reading 105

7 Leaves 106

Chapter Outline 106
Overview 107
Some Learning Goals 107
Leaf Arrangements and Types 108

Internal Structure of Leaves 109
Stomata 110
Mesophyll and Veins 111
Specialized Leaves 113
Autumnal Changes in Leaf Color 122
Abscission 122
Human and Ecological Relevance of Leaves 123
Plant Sciences Inquiry: Glass Cuts from Grass? 124
Summary 124
Review Questions 125
Discussion Questions 125
Additional Reading 125

8 Flowers, Fruits, and Seeds 126

Chapter Outline 126
Overview 127
Some Learning Goals 127
Note to the Reader: 127
Differences Between Dicots and Monocots 129
Structure of Flowers 131
Fruits 132
Fruit and Seed Dispersal 139
Seeds 143
Plant Sciences Inquiry: The Seed That Slept for 1,200 Years 146
Summary 147
Review Questions 148
Discussion Questions 148
Additional Reading 148

9 Water in Plants 149

Chapter Outline 149
Overview 150
Some Learning Goals 150
Molecular Movement 151
Water and Its Movement Through the Plant 155
Regulation of Transpiration 157
Transport of Food Substances (Organic Solutes) in Solution 159
Mineral Requirements for Growth 160
Summary 163
Review Questions 163
Discussion Questions 164
Additional Reading 164

10 Plant Metabolism 165

Chapter Outline 165
Overview 166
Some Learning Goals 166
Enzymes and Energy Transfer 166
Photosynthesis 167
Plant Sciences Inquiry: Photosynthesis and Pizza 176
Respiration 180
Additional Metabolic Pathways 185

Assimilation and Digestion 187
Plant Sciences Inquiry: Greenhouse Gases and Plant Growth 187
Summary 188
Review Questions 189
Discussion Questions 190
Additional Reading 190

11 Growth 191

Chapter Outline 191
Overview 192
Some Learning Goals 192
Nutrients, Vitamins,
and Hormones 192
Hormonal Interactions 199
Other Hormonal Interactions 200
Plant Movements 200
Photoperiodism 208
Phytochromes and Cryptochromes 209
A Flowering Hormone? 210
Temperature and Growth 211
Dormancy and Quiescence 211
Summary 212
Review Questions 213
Discussion Questions 213
Additional Reading 214

12 Meiosis and Alternation of Generations 215

Chapter Outline 215
Overview 216
Some Learning Goals 216
The Phases of Meiosis 217
Alternation of Generations 221
Summary 222
Review Questions 222
Discussion Questions 222
Additional Reading 223

13 Genetics 224

Chapter Outline 224
Overview 225
Some Learning Goals 225
Molecular Genetics 226
Plant Sciences Inquiry: The Polymerase Chain Reaction (PCR) 229
Cytogenetics 234
Mendelian Genetics 235
Quantitative Traits 242
Extranuclear DNA 242
Linkage and Mapping 242
The Hardy-Weinberg Law 244
Summary 244
Review Questions 245
Discussion Questions 245

14 Plant Breeding and Propagation 246

Chapter Outline 246
Overview 247
Some Learning Goals 247
Crop Plant Evolution 247
Plant Breeding 249
Plant Propagation 258
Summary 264
Review Questions 264
Discussion Questions 265
Additional Reading 265

15 Evolution 266

Chapter Outline 266
Overview 267
Some Learning Goals 267
A Brief Overview of the Early Development of Evolutionary Concepts 267
Charles Darwin 268
Evidence for Evolution 269
Microevolution—Evolution Within Species 270
Rates of Evolution 272
Macroevolution—How Species Evolve 272
The Role of Hybridization
 in Evolution 274
Discussion 276
Summary 277
Review Questions 277
Discussion Questions 277
Additional Reading 277

16 Plant Names and Classification 279

Chapter Outline 279
Overview 280
Some Learning Goals 280
Development of the Binomial System of Nomenclature 281
Development of the
 Kingdom Concept 283
Classification of Major Groups 283
Cladistics 287
A Key to Major Groups of Organisms (Exclusive of Kingdom Animalia) 288
The Future of Plant Classification 289
Summary 290
Review Questions 291
Discussion Questions 291
Additional Reading 291

17 Domain (Kingdom) Bacteria, Domain (Kingdom) Archaea, and Viruses 292

Chapter Outline 292
Overview 293

Some Learning Goals 293
Features of Kingdoms (Domains) Bacteria and Archaea 294
Domain Bacteria (Kingdom Bacteria) –The True Bacteria 297
Human Relevance of the
Unpigmented, Purple, and Green
Sulfur Bacteria 297
Class Cyanobacteriae –The Cyanobacteria (Blue-Green Bacteria) 303
Class Prochlorobacteriae –The Prochlorobacteria 307
Kingdom Archaea (Domain Archaea) –The Archaeobacteria 307
Viruses 309
Plant Sciences Inquiry: Plant Viruses 311
Viroids and Prions 314
Summary 314
Review Questions 315
Discussion Questions 315
Additional Reading 316

18 Kingdom Protista 317

Chapter Outline 317
Overview 318
Some Learning Goals 318
Features of Kingdom Protista 318
Algae 319
Phylum Chlorophyta –The Green Algae 319
Phylum Chromophyta –The Yellow-Green Algae, Golden•Brown Algae, Diatoms,
and Brown Algae 326
Phylum Rhodophyta –The Red Algae 330
Phylum Euglenophyta –The Euglenoids 333
Phylum Dinophyta –The Dinoflagellates 333
Phylum Cryptophyta –The Cryptomonads 334
Phylum Prymnesiophyta (Haptophyta) –The Haptophytes 335
Phylum Charophyta –The Stoneworts 335
Human and Ecological Relevance of the Algae 336
Other Members of Kingdom Protista 339
Phylum Myxomycota –The Plasmodial Slime Molds 339
Phylum Dictyosteliomycota –The Cellular Slime Molds 341
Phylum Oomycota –The Water Molds 343
Summary 343
Review Questions 344
Discussion Questions 344
Additional Reading 345

19 Kingdom Fungi 346

Chapter Outline 346
Overview 347
Some Learning Goals 347
Distinctions Between Kingdoms Protista and Fungi 347
Kingdom Fungi –The True Fungi 348
Lichens 365
Summary 368
Review Questions 369
Discussion Questions 370
Additional Reading 370

20 Introduction to the Plant Kingdom: Bryophytes 371

Chapter Outline 371
Overview 372
Some Learning Goals 372
Introduction to the Bryophytes 372
Phylum Hepaticophyta – Liverworts 375
Phylum Anthoceroophyta – Hornworts 378
Phylum Bryophyta – Mosses 379
Plant Sciences Inquiry: Hibernating Mosses 382
Human and Ecological Relevance of Bryophytes 383
Summary 383
Review Questions 384
Discussion Questions 384
Additional Reading 384

21 The Seedless Vascular Plants: Ferns and Their Relatives 385

Chapter Outline 385
Overview 386
Some Learning Goals 386
Phylum Psilotophyta – The Whisk Ferns 386
Phylum Lycopphyta – The Ground Pines, Spike Mosses, and Quillworts 388
Phylum Equisetophyta – The Horsetails and Scouring Rushes 394
Phylum Polypodiophyta – The Ferns 398
Fossils 405
Summary 407
Review Questions 407
Discussion Questions 408
Additional Reading 408

22 Introduction to Seed Plants: Gymnosperms 409

Chapter Outline 409
Overview 410
Some Learning Goals 410
Phylum Pinophyta – The Conifers 411
Other Gymnosperms 416
Human Relevance of Gymnosperms 419
Plant Sciences Inquiry: A Living Fossil? 424
Summary 425
Review Questions 426
Discussion Questions 426
Additional Reading 427

23 Seed Plants: Angiosperms 428

Chapter Outline 428
Overview 429
Some Learning Goals 429
Phylum Magnoliophyta – The Flowering Plants 430
Pollination Ecology 436
Herbaria and Plant Preservation 441
Summary 446
Review Questions 446
Discussion Questions 446

24 Flowering Plants and Civilization 448

Chapter Outline 448

Overview 449

Some Learning Goals 449

Origin of Cultivated Plants 449

Selected Families of Flowering Plants 451

Dicots (Now Recognized in Two Groups) 452

Monocots 467

Plant Sciences Inquiry: Coffee and Caffeine 470

Summary 472

Review Questions 472

Discussion Questions 472

Additional Reading 473

25 Ecology 474

Chapter Outline 474

Overview 475

Some Learning Goals 475

Plants and the Environment 475

Life Histories 480

Natural Cycles 480

Succession 483

The Impacts of Humans on Plant Communities 488

Global Warming 488

Erosion 490

Aquifer Depletion 491

Loss of Biodiversity 491

Plant Sciences Inquiry: John Muir, Father of America's National Park System 494

Summary 495

Review Questions 496

Discussion Questions 496

Additional Reading 496

26 Biomes 498

Chapter Outline 498

Overview 499

Learning Goal 499

Major Biomes of North America 499

Plant Science Inquiry: Photosynthesis, Global Warming, and Tropical Rain Forests 508

Summary 508

Review Questions 509

Discussion Questions 509

Additional Reading 509

Appendix 1 Scientific Names of Organisms

Mentioned in the Text 510

Appendix 2 Biological Controls 529

Appendix 3 Useful and Poisonous
Plants, Fungi, and Algae 537

Appendix 4 House Plants and Home
Gardening 562

Appendix 5 Metric Equivalents and Conversion Tables 586

Glossary 588

Index 599