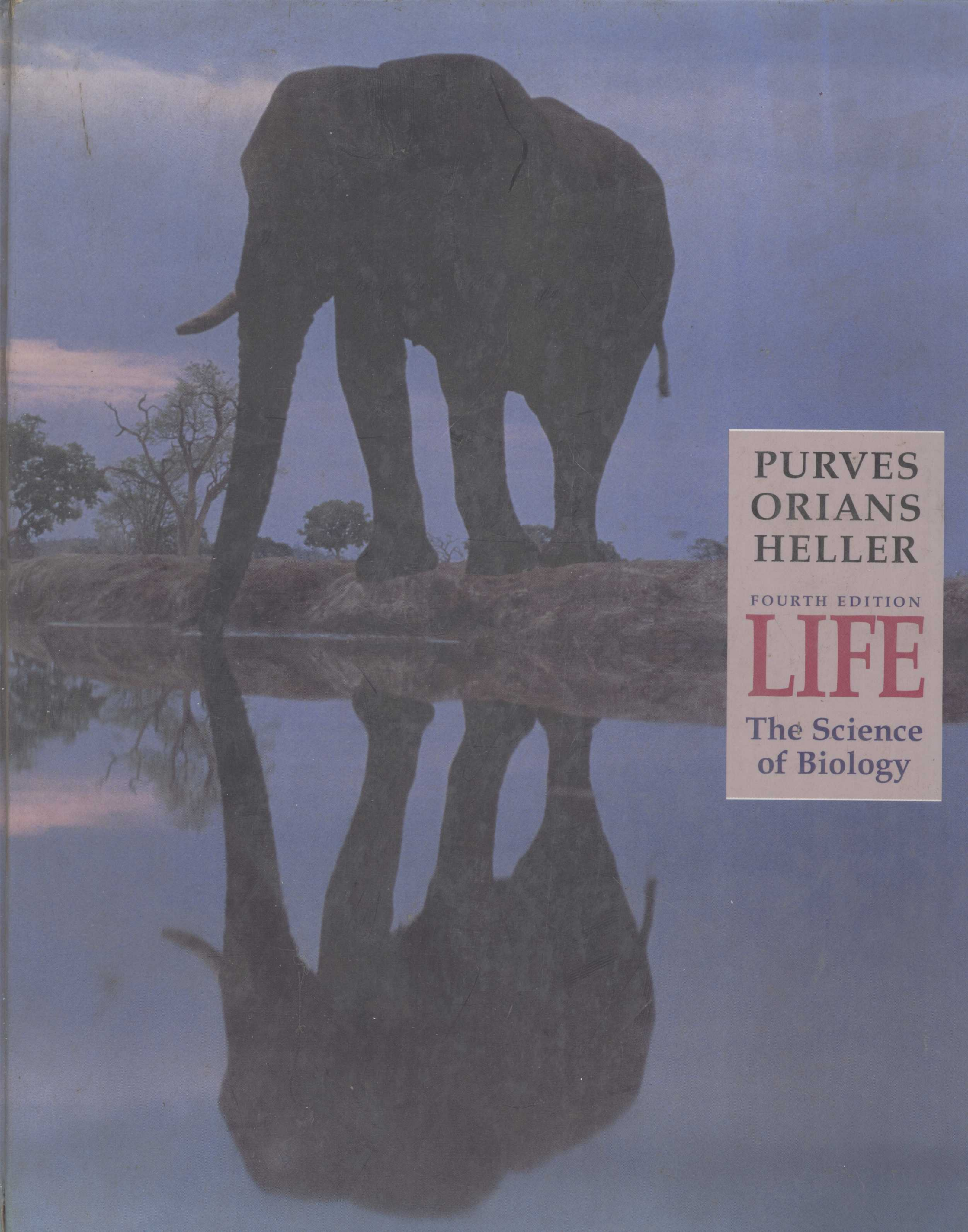

PURVES
ORIANS
HELLER

FOURTH EDITION

LIFE

The Science of Biology

FOURTH EDITION

LIFE

The Science of Biology

William K. Purves
Harvey Mudd College
Claremont, California

Gordon H. Orians
The University of Washington
Seattle, Washington

H. Craig Heller
Stanford University
Stanford, California

SINAUER ASSOCIATES, INC.
W. H. FREEMAN AND COMPANY

THE COVER

Elephants at a water hole in northern Botswana, Africa.
Photograph by Frans Lanting/Minden Pictures.

THE FRONTISPIECE

Scarlet ibis and cattle egrets at Hato el Frio, Venezuela.
Photograph by Art Wolfe.

LIFE: THE SCIENCE OF BIOLOGY, Fourth Edition

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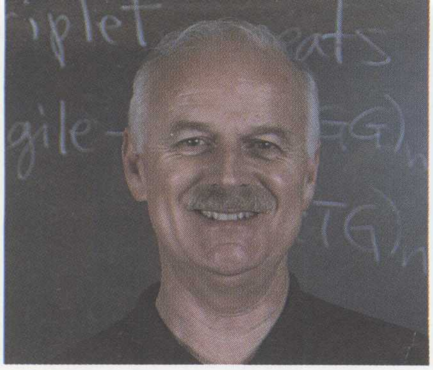
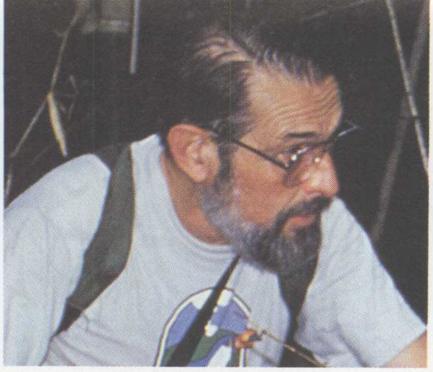
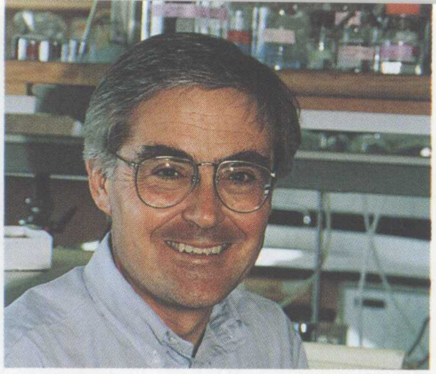
To Jean, Betty, and Renu

ABOUT THE AUTHORS

William K. Purves

Bill Purves is Stuart Mudd Professor of Biology as well as founder and chair of the Department of Biology at Harvey Mudd College in Claremont, California. He received his Ph.D. from Yale University in 1959 under Arthur Galston. A Fellow of the American Association for the Advancement of Science, Professor Purves has served as head of the Life Sciences Group at the University of Connecticut, Storrs, and as chair of the Department of Biological Sciences, University of California, Santa Barbara, where he won the Harold J. Plous Award for teaching excellence. His research interests focus on the chemical and physical regulation of plant growth and flowering.

Professor Purves has taught introductory biology each year for over thirty years and considers teaching the course the most interesting and important of his professional activities. "I can't imagine a year without teaching it," he says. In describing his teaching philosophy, Purves states, "Students learn biological concepts much more rapidly and effectively if they understand where the concepts come from—what the experimental and conceptual background is. 'Facts' by themselves can be boring or incomprehensible, but they become exciting if given a context."

Gordon H. Orians

Gordon Orians is Professor of Zoology at the University of Washington. He received his Ph.D. from the University of California, Berkeley, in 1960 under Frank Pitelka. Professor Orians has been elected to the National Academy of Sciences and the American Academy of Arts and Sciences. He was President of the Organization for Tropical Studies from 1982 to 1994, and is currently President-elect of the Ecological Society of America. He is a recipient of the Brewster Medal from the American Ornithologists' Union, and in 1994 he received the Distinguished Service Award of the American Institute of Biological Sciences.

Professor Orians is a leading authority in ecology and evolution, with research interests in behavioral ecology, plant–herbivore interactions, community structure, and the biology of rare species. Like the other authors, he draws from his research to bring an added dimension to his teaching and writing. "Teachers who understand research because they are engaged in it can more easily communicate the excitement researchers feel as they discover new things," Orians says. "All three authors of *Life* have spent considerable time doing research and we have tried throughout the book to show the sources of our current understanding of biology."

H. Craig Heller

Craig Heller is Lorry Lokey/Business Wire Professor of Biological Sciences and Human Biology and Associate Dean of Research at Stanford University, and is a popular lecturer on animal and human physiology. He received his Ph.D. from Yale University in 1970 and did postdoctoral research at the Scripps Institution of Oceanography on brain regulation of body temperature in mammals. He has continued this research since coming to Stanford in 1972, studying a variety of phenomena ranging from hibernating squirrels to sleeping college students to diving seals to meditating yogis. Professor Heller is a Fellow of the American Association for the Advancement of Science and a recipient of the Walter J. Gores Award for Excellence in Teaching.

"A first course in biology requires the student to learn more new words than a first course in a foreign language," Heller says. "The secret to teaching and learning biology is to focus on central and overarching concepts. Once you grasp the concept of how something works, you have a framework on which the facts and vocabulary fall into place. Conceptual understanding also helps you relate what you learn to the real world."

PREFACE

In revising this book, we have once again examined our goals and our hopes for it. Above all, we want to help students understand biological concepts and see where the concepts originate. For this reason we display biology as an experimental and observational science. Frequently we offer the student a chance to think—to figure out the next step rather than wait passively to learn it from us. For example, we ask the student to interpret experimental data used in elucidating the genetic code, in understanding the role of homeotic genes in flower development, and in working out the Calvin–Benson cycle. In Chapter 21, students are presented with real species with identified character traits and work through how to construct a phylogeny using cladistic methods. We use the cladistic material again in Chapter 27, where we explore human relationships with chimpanzees and gorillas. As yet another example, we lead the student to discover the physiological differences between reptiles and mammals by taking the reader through a series of experiments on the thermal biology of a mouse and a lizard.

Even when we present topics directly, we prefer to explain new material rather than serving it up as a cut-and-dried collection of "facts." Still, the study of biology requires exposure to a stunning number of new facts, and students are easily deterred by a bewildering excess of information. How can we deal with this problem? Our approach is to emphasize fascinating examples wherever possible, using these to engage the student's interest so that she or he wants to learn other related material.

UP-TO-DATE COVERAGE REFLECTS NEW DEVELOPMENTS IN BIOLOGY

The creation of a new edition provides opportunities to rethink how best to present existing material, as well as what from the exploding array of new information to include. Current advances in biomedical sciences present special challenges to the organizers of a course or a textbook. Diseases such as cancer and AIDS are of deep interest in relation to a wide variety of biological topics, including immunology, genetics, evolution, membrane biology, and virology; instructors often want to use the diseases as examples in discussing these topics. Yet students and instructors also want to see a disease and its biology considered in a single place in the book. For this edition, we have adopted an approach that we hope is effective. Recent advances in gene therapy and in the cloning of genes for particular diseases lend themselves to consideration in an all-new Chapter 15, "Genetic Disease and Modern Medicine." We consider some general principles and some widely applicable techniques in this chapter, which also includes much of our coverage of cancer. We build from the close of this chapter to begin the next, "Defenses against Disease," with an overview of AIDS as a worldwide problem. Before the end of Chapter 16, the student knows enough about the immune system to understand AIDS in greater biological detail.

Developmental biology continues to be one of the fastest-moving areas of biology; the newer work is reflected in Chapter 17. We pay particular attention to recent developments in the *Drosophila* larva and *Caenorhabditis elegans* systems. After giving genetic "instructions" for building a fly, we conclude the molecular section of the book with a transition from *Drosophila* larval genetics to evolutionary biology.

In the section on evolution we have expanded the coverage of methods of reconstructing phylogenies. We provide new treatments of cladistic methods and show how phylogenies are used to shed light on a wide variety of evolutionary questions. We use phylogenetic trees a number of times in subsequent chapters in the book to show how traits of organisms evolve under the influence of evolutionary agents.

Our restructuring of the chapters on plant anatomy and physiology resulted in the creation of a new Chapter 31, "Environmental Challenges to Plants," which deals with some of the ways plants cope with harsh environments, predators, and pathogens. We have updated the plant chapters to include material on patch clamping, homeotic mutations, and other important phenomena and techniques.

Three aspects of the animal biology chapters that were significant in the third edition have been strengthened. First, we frequently use a comparative approach to help students understand basic principles and mechanisms as well as their evolutionary variations. Second, we emphasize experimental approaches so that the student learns *how* we know as well as *what* we know. Third, a capstone to the treatment of each physiological system is a discussion of how its contributions to homeostasis are controlled and regulated. Chapter 45, "Animal Behavior," has been revised to focus more strongly on the physiological mechanisms underlying behavior.

Because ecology is an increasingly experimental science, we have added descriptions of well-designed experiments that have been performed to demonstrate the causes of the evolution of traits used in courtship among animals and to assess the importance of predation and competition in structuring ecological communities. To keep pace with the increasing importance of environmental problems, we have expanded our treatment of lake eutrophication and of overexploitation of commercially important species.

PEDAGOGICAL INNOVATIONS ENRICH THE LEARNING PROCESS

Both as textbook authors and as teachers we want to help students in every way possible. In the next section ("To the Student") we offer some helpful advice we'd like students to consider as they begin their study of biology. This advice has helped many of our own students. Following "To the Student" is "*Life* at a Glance," in which we illustrate some of the pedagogic improvements that we discuss in the next few paragraphs.

A major source of the success of the third edition of this textbook was the exciting new art program developed by J/B Woolsey Associates. We have upgraded that already fine art for this edition. We have added many entirely new drawings and graphs, and virtually all the drawings in the book have been improved in one way or another by the development of a new artistic vocabulary for this edition.

Because learning is a visual as well as a verbal process, we have given much attention to creating illustrations that explain biological concepts clearly. To facilitate learning we use color consistently from illustration to illustration; for example, the outside of the cell is always represented by light red and the cytoplasm by pale blue. We have developed a set of icons (see "*Life* at a Glance") to represent biologically important molecules (such as water or ATP), active forms of enzymes, or activation and inhibition of pathways. We have used blocks of color to distinguish major pieces of information from details or to separate an illustration into parts representing discrete ideas; we think of these as "visual paragraphs." Finally, we have flagged via marginal arrowheads (also shown in "*Life* at a Glance") illustrations that are particularly significant. These figures illustrate and synthesize important concepts—protein synthesis, for example, or the life cycle of a flowering plant.

We have developed a new type of chapter-end summary, one that should help students in at least three ways. First, the student can skim the summary for orientation before reading the chapter. Second, after reading the chapter, the student can use the summary to review the material. Finally, each summary identifies the illustrations that give the best overview of the chapter and its most important concepts.

Each chapter starts with a brief introduction intended to catch the reader's interest by discussing a fascinating bit of biology. Each of these new introductions is supported by a striking photograph; an example is shown in "*Life* at a Glance."

Before beginning this edition, we asked 36 biologists, most of whom were using the third edition, to maintain "diaries" and record their ideas for improving the book. These diarists were enormously helpful in getting us started on the right foot for the new edition. Their guidance influenced the decisions to create the two new chapters mentioned earlier and to give priority to simplifying our prose. We are indebted to them.

CAREFULLY REVIEWED WITH STUDENTS' NEEDS AND TEACHERS' CONCERNS IN MIND

As with the first three editions, many of our colleagues reviewed chapters or entire sections of this edition in manuscript. They and the diarists are listed below. The reviewers were helpful, thoughtful, and clearly dedicated to the success of this book, and we thank them all. We particularly thank Bob Cleland, Richard Cyr, Pat DeCoursey, Rob Dorrit, Art Dunham, Margaret Fusari, Harry Green, Ray Huey, Bob Jeffries, Jim Manser, William Milsom, Ron O'Dor, Dianna Padilla, Ronald Patterson, Zoe Roizen, Seri Rudolph, Michael Ryan, Iain Taylor, and David Woodruff. They gave us explicit recommendations for extensive improvements, helped simplify our writing style, and did so in ways that encouraged us to do our very best to live up to their expectations.

THE EFFORTS OF MANY PEOPLE HELPED THE REVISION

The third edition profited greatly from the prodigious efforts of its outstanding developmental editor, Elmarie Hutchinson. We were delighted when Elmarie agreed to take an even stronger role in the development of the fourth edition. Among her innovations are the new type of chapter summary and its suggested use as a chapter preview. Elmarie also helped us respond to diarists' requests for simpler language, better topic sentences, and more restrained use of boldface terms. Her suggestions and guidelines were implemented by our copyeditor, Stephanie Hiebert, whose sharp and prescriptive line editing has helped streamline the book's prose.

In a book like this the illustrations are as important as the prose, and here again Elmarie gave us outstanding input, scrutinizing every figure with an eye for its internal consistency and its agreement with the text. Her suggestions were incorporated by artists John Woolsey and Patrick Lane as they met with the authors to reconceptualize artwork. The task of coordinating and checking the changes made by editors, artists, and authors fell to Carol Wigg, who got the job once again of putting all the pieces together. In addition, previous users of the book will see a significant improvement in the photography program. Jane Potter has tapped important new sources, and we have gone to great lengths to seek out new photographs to illustrate important concepts and enliven the book's appearance.

We wish to thank W. H. Freeman's entire marketing and sales group. Their enthusiasm for *Life* helped bring the book to a wider audience and the efforts of several of the sales representatives put us in touch with a number of our colleagues who had specific questions or criticisms of the book. This contact has been fruitful, and we look forward to more of this "firing line" interaction with the fourth edition.

Finally, the opportunity to work with a publishing company whose president provides frequent personal contacts and feedback that is scientifically useful as well as production-wise, is a great privilege for us. Andy Sinauer is the ideal person for authors to deal with—firm but kind, involved but not overbearing, and friendly—hence, motivating. He also has a superb eye for good associates—the Sinauer team is first-rate!

William K. Purves **Gordon H. Orians** **H. Craig Heller**

September 1994

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TO THE STUDENT

Welcome to the study of life! In our student days—and ever since—we have enjoyed studying the fascinating and fast-changing field of biology, and we hope that you will, too.

There are a few things you can do to help you get the most from this book and from your course. For openers, read the book actively—don't just read passively, but do things that force you to think as you read. If we pose questions, stop and think about them. If a passage reminds you of something that has gone before, think about that, or even check back to refresh your memory. Ask questions of the text as you go. Do you understand what is being said? Does it relate to something you already know? Is it supported by experimental or other evidence? Does that evidence convince you? How does this passage fit into the chapter as a whole? Annotate the book—write down comments in the margins about things you don't understand, or about how one part relates to another, or even when you find an idea particularly interesting. The point of doing these things is that they will help you learn. People remember things they think about much better than they remember things they have read passively. Highlighting is passive; copying is drudge work; questioning and commenting are active and well worthwhile.

For this edition we have developed new ways to help you read the book actively. The chapter-end summaries have been redesigned so that they may be used as both summaries and previews. To find out what a chapter covers, try reading the summary at the end of the chapter before you begin reading the chapter itself. Don't worry about unfamiliar terms in the summary, but notice them as terms you will need to learn. Just read all the statements as an overview and preview without studying the cited illustrations. Then, after reading the chapter, use the summary as a framework for your review. It is essential that you do study the cited illustrations and their captions as you review because important information that is covered in illustrations has been left out of the summary statements. Add concepts and details to the framework by reviewing the text.

Take advantage of our use of color and symbols in the illustrations. We generally use colors to mean the same thing from illustration to illustration, and we have developed a set of symbols (see the section "*Life* at a Glance") to represent biologically important molecules and phenomena. In many of the illustrations you will see blocks of color used to help you separate the illustration into parts representing discrete ideas. Also, some figures are identified by an arrow in the margin. These figures are particular significant; they illustrate and synthesize important concepts and retell visually the story you read in the text. Studying them will help you learn important biological concepts and systems. Going back to review them will help you to remember these concepts.

The chapter summaries will help you quickly review the high points of what you have read. A summary identifies particular illustrations that you should study to help organize the material in your mind. A way to review the material in slightly more detail after reading the chapter is to go back and look at the boldfaced terms. You can use the boldfaced terms to pose questions—and see if you can answer those questions. The boldfacing will probably be more useful on a second reading than on the first.

Use the self-quizzes and study questions at the end of each chapter. The self-quizzes are meant to help you remember some of the more detailed material and to help you sort out the information we have laid before you. Answers to all self-quizzes are in the Appendix. The study questions, on the other hand, are often fairly open-ended and are intended to cause you to reflect on the material.

Two parts of a textbook that are, unfortunately, often underused or even ignored are the glossary and the index. Both can help you a great deal. When you are uncertain of the meaning of a term, check the glossary first—there are more than 1,500 definitions in it. If you don't find a term in the glossary, or if you want a more thorough discussion of the term, use the index to find where it's discussed.

What if you'd like to pursue some of the topics in greater detail? At the end of each chapter there is a short, annotated list of supplemental readings. We have tried to choose readings from books and magazines, especially *Scientific American*, that should be available in your college library.

Most students occasionally have difficulty in courses, including biology courses. If you find that you are slipping behind in the course, or if a particular topic is giving you an unreasonable amount of trouble, here are some useful steps you might take. First, the basics: attend class, take careful lecture notes, and read the textbook assignments. Second, note that one of the most important roles of studying is to discover what you don't know, so that you can do something about it. Use the index, the glossary, the chapter summaries, and the text itself to try to answer any questions you have and to help you organize the material. Make a habit of looking over your lecture notes within 24 hours of when you take them—find out right away what points are unclear, and get them straightened out in your mind. We also call your attention to the Study Guide that accompanies *Life*. It is by Jon Glase at Cornell and Jerry Waldvogel at Clemson. It parallels this textbook and each chapter contains learning objectives, key concepts, activities, and questions with full answers and explanations.

If none of these self-help remedies does the trick, get help! Other students are often a good source of help, because they are dealing with the material at the same level as you are. Study groups can be very useful, as long as the participants are all committed to learning the material. Tutors are almost always helpful and useful, as are faculty members. The main thing is to get help when you need it. It is not a good idea to be strong and silent and drift into a low grade.

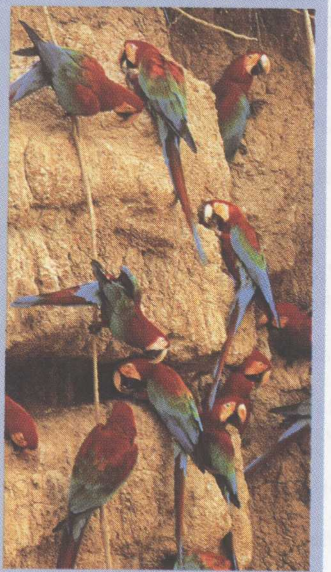
But don't make the grade the point of this or any other course. You are in college to learn, to pursue interesting subjects, and to enjoy the subjects you are pursuing. We hope you'll enjoy the pursuit of biology.

Bill Purves **Gordon Orians** **Craig Heller**

LIFE

Intriguing chapter openers combine arresting photos and text to spark interest at the outset, setting the stage for the material that follows.

They Are Not All the Same
When observed closely, the individuals in a population of red and green macaws vary a great deal.



19

The Mechanisms of Evolution

We are aware that no two people (unless they are identifical twins) look exactly alike. We also recognize our pets as distinct individuals. But we have great difficulty in seeing differences among individuals of most other species of organisms. The brilliant red and green macaws feeding on a clay cliff in the Peruvian jungle may all appear identical to the untrained eye; scientists who study them closely, however, realize that each is unique. The colored feathers display many slight variations in pattern, and the black-and-white feathers that surround the birds' eyes form patterns that, like human fingerprints, are unique to the individual. Members of many groups, particularly among behaviorally sophisticated animals such as vertebrates, readily recognize one another and adjust their behavior accordingly.

Differences among individuals in local populations, even if they are subtle, are the raw material upon which evolutionary mechanisms act to produce the striking variability revealed by the multitude of organisms living on Earth today. A good fossil record can reveal much about when and how the forms of organisms changed. Fossils may also provide clues about the reasons for those changes, but they provide only indirect evidence of the causes of evolutionary change. To obtain direct evidence we must study evolutionary changes happening today. The study of variability is at the heart of investigations into the mechanisms of evolution.

In this chapter we discuss the agents of evolution and the short-term studies designed to investigate them. By testing hypotheses observationally and experimentally we can answer key questions about the processes guiding evolutionary changes. In later chapters we consider how we use this information to explain longer-term features of the evolutionary record.

Although ideas about evolution have been put forth for centuries, until the last one hundred years none of the h
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WHAT IS EVOL

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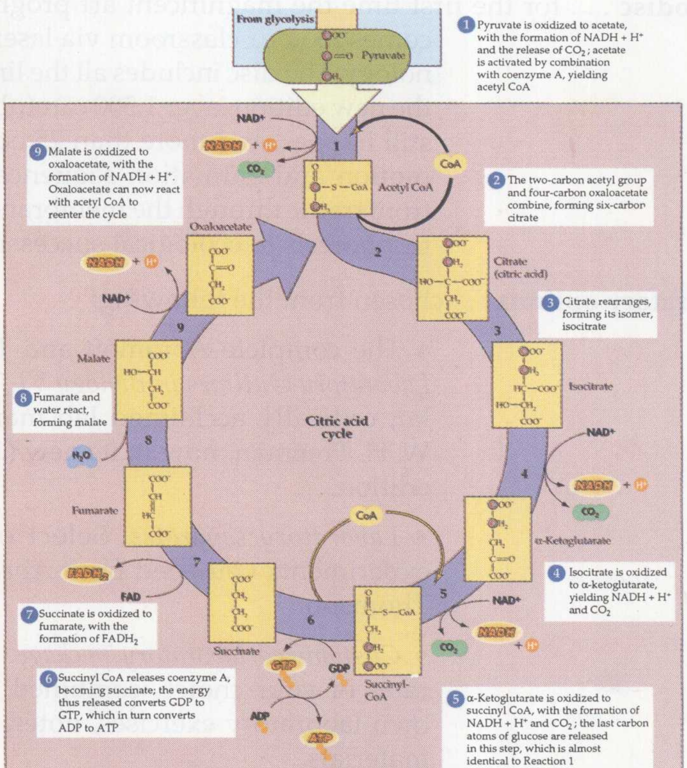

7.13 The Citric Acid Cycle
The first reaction produces the two-carbon acetyl CoA. Notice that the two carbons from acetyl CoA are traced with color through reaction 5, after which they may be at either end of the molecule (note the symmetry of succinate and fumarate). Reactions 1, 4, 5, 7, and 9 accomplish the major overall effect of the cycle—the storing of energy—by passing electrons to the carrier molecule NAD. Reaction 6 also stores energy.

Consistent icons and color-coding clarify illustrations. Icons are used to represent biologically important molecules, active forms of enzymes, and the activation and inhibition of pathways. Color is used consistently throughout the text.

SUPPLEMENTS

Life, Fourth Edition, is accompanied by a comprehensive set of supplements:

Study Guide . . . reviewed by students and extensively revised by Jon Glase of Cornell University and Jerry Waldvogel of Clemson University to help students master the textbook material.

Instructor's Manual . . . by Roberta Meehan of the University of Northern Colorado, featuring chapter objectives, chapter outlines, teaching hints and strategies, references, resources, and key terms.

Overhead transparencies and **slides** . . . a package of 300 full-color images from the book.

Transparency masters . . . of all text art figures not included in the overhead transparency / slide set.

Test bank . . . revised and updated, with at least 10 new questions per chapter and over 4,000 questions in total. Available in printed form, and in IBM and Macintosh formats.

Videodisc . . . for the first time the magnificent art program in *Life* comes to your classroom via laserdisc technology. The disc includes all the line art from the new edition, over 1,500 carefully selected still images, and more than 25 outstanding motion and animation sequences ranging from traffic through the membrane and electrophoresis to ecological succession.

Laboratory options . . . chosen from the following:

- The complete Abramoff and Thomson's *Laboratory Outlines in Biology VI*. The popular, critically acclaimed lab manual from W. H. Freeman, now in its new (1995) sixth edition.
- *Laboratory separates*. Select only those experiments you need from Abramoff and Thomson.
- *Customized laboratory package*. The separates of your choice, combined with your own laboratory exercises, notes, and other materials.

For information regarding policy on the educational use of these supplements, please contact your local W. H. Freeman representative.

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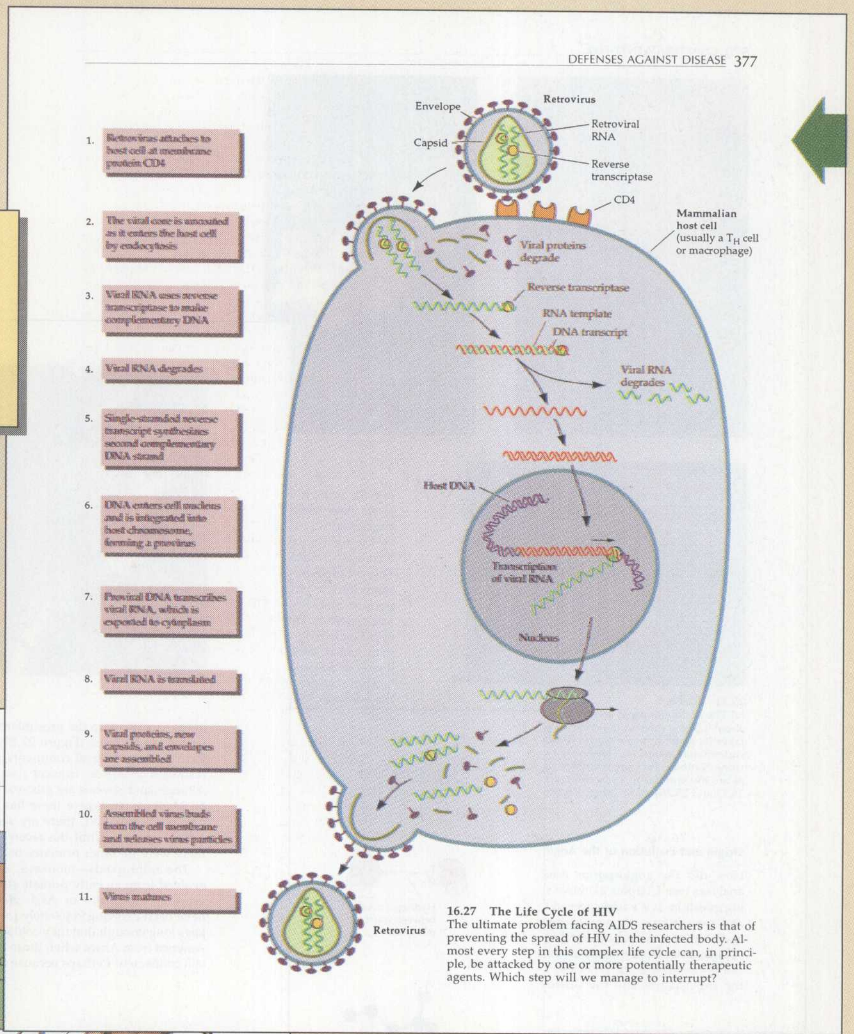
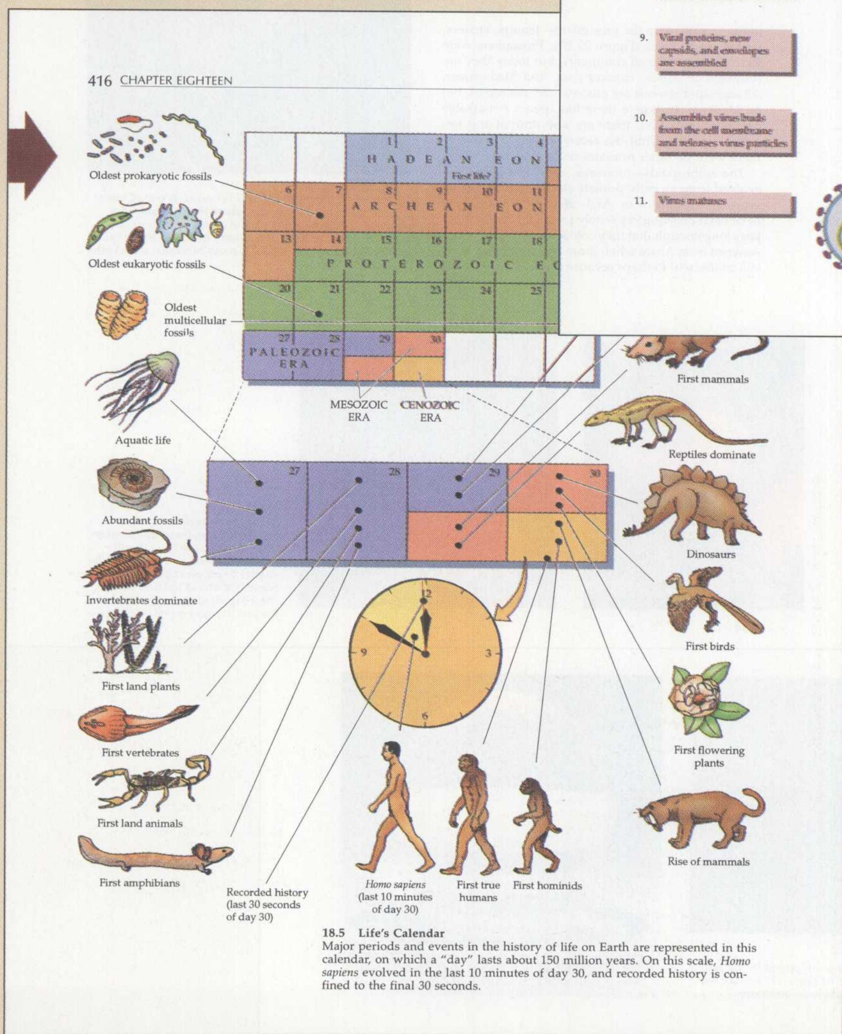
In addition, Tad Day, William Eickmeier, and Paul Ramp conducted student reviews of the videodisc, and Jon Glase had his students review the Study Guide. We greatly appreciate their efforts.

AT A GLANCE

Dynamic visual paragraphs dramatize important concepts in a way that the text alone cannot. These are flagged with marginal arrows so the student is able to refer to them readily.



16.27 The Life Cycle of HIV
The ultimate problem facing AIDS researchers is that of preventing the spread of HIV in the infected body. Almost every step in this complex life cycle can, in principle, be attacked by one or more potentially therapeutic agents. Which step will we manage to interrupt?



18.5 Life's Calendar
Major periods and events in the history of life on Earth are represented in this calendar, on which a "day" lasts about 150 million years. On this scale, *Homo sapiens* evolved in the last 10 minutes of day 30, and recorded history is confined to the final 30 seconds.

Stunning photos capture the excitement of *Life*, illustrating important concepts and enlivening the book's appearance.


570 CHAPTER TWENTY-FIVE

(a) (b) (c)

25.31 Dicots
(a) The cactus family is a large grou
about 1,500 species in the Americas.
takes its name from its scarlet flowe
Anterrhinum majus. (c) These wood
stone National Park are members o
as are the familiar roses from your
25.25 and 25.26*a* show other dicots.

pected, primarily
phyta have vess
angiosperms. In
by the light-micr
tilization in *Ephe*
The cycadeoids,
same time as di
portant characte
angiosperms. Th
cycadeoids, altho
with naked seed
flower of *Magnol*
The next grea
the question, Wh

Origin and Evolution of the Angio

How did the angiosperms aris
analyses (see Chapter 21) have s
ing question. It is widely agreed t
and two groups of gymnosper
and the long-extinct cycadeoids
cycads, arose from a single ances
rise to no other groups. A close
the angiosperms and the Gneto

32 CHAPTER TWO

(a)

Hydrogen bond between water molecules

(c)

Hydrog
in a pro

2.18 Surface Tension
(a) A water strider "skates" along, supported by the surface tension of the water that is its home. (b) Surface tension demonstrated by a soap bubble on a teacup.

(a) (b) (c)

lineage gave rise to the prosimians—lemurs, tarsiers, pottos, and lorises (Figure 27.29). Prosimians were formerly found on all continents, but today they are restricted to Africa, tropical Asia, and Madagascar. All mainland species are arboreal and nocturnal, but on Madagascar, where there has been a remarkable prosimian radiation, there are also diurnal and terrestrial species. Until the recent arrival of humans, there were no other primates on Madagascar.

The anthropoids—monkeys, apes, and humans—evolved from an early primate stock about 55 million years ago in Africa or Asia. New World monkeys have been evolving separately from Old World monkeys long enough that they could have reached South America from Africa when those two continents were still connected. Perhaps because tropical America has

27.29 Prosimians
(a) The sifaka lemur, *Propithecus verreauxi*, is one of many lemur species of Madagascar, where they are part of a unique assemblage of plants and animals. (b) *Loris tardigradis*, the slender loris, of southern India. (b) In the rainforests of Borneo, this tarsier (*Tarsius bancanus*) seems otherworldly to our eyes.

(a) (b)

27.30 Monkeys
(a) Golden lion tamarins (*Leontopithecus rosalia*) are New World monkeys, living in the trees of the coastal Brazilian rainforest. (b) Some Old World species, such as these Japanese macaques (*Macaca fuscata*) live and travel in groups.

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Boxes describe fascinating biological phenomena, highlighting special interest topics and expanding the discussion of many issues.

BOX 27.A

The Four-Minute Mile

Many mammals can run much faster, yet we humans are proud to have achieved a four-minute mile. Terrestrial vertebrates did not achieve such speeds easily. Amphibians and reptiles fill and empty their lungs using some of the same muscles they use for walking. In addition, because the limbs protrude laterally, their movement generates a strong lateral force that bends the body from side to side. Recent studies have shown that these animals cannot breathe while they walk or run. Therefore, they can operate aerobically only briefly. Because they depend upon anaerobic glycolysis while running, they tire rapidly.

In the lineage leading to dinosaurs and birds and in the lineage leading to mammals, the legs assumed more vertical positions, which reduced the lateral forces on the body during locomotion. Special ventilatory muscles that can operate independently of locomotory muscles also evolved. These muscles are visible in living birds and mammals. We can infer their existence in dinosaurs from the structure of the vertebral column and the capability of many dinosaurs for bounding, bipedal (using two legs) locomotion. The ability to breathe and run simultaneously, a capability we take for granted, was a major innovation in the evolution of terrestrial vertebrates.

A future four-minute miler?

Figure 28.12). The ability to move actively on land was not achieved easily. The first terrestrial vertebrates probably moved only very slowly, much more slowly than their aquatic relatives. The reason is that they apparently could not walk and breathe at the same time. Not until evolution of the lineages leading to the mammals, dinosaurs, and birds did special muscles evolve enabling the lungs to be filled and emptied while the limbs moved (Box 27.A). This ability enabled its bearers to maintain steady, high levels of activity, which generated enough heat to result in

subclass Aves)
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(Figure 27.22),
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pteryx was cov-
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much reduced
nay have been

vs features re-
he modern

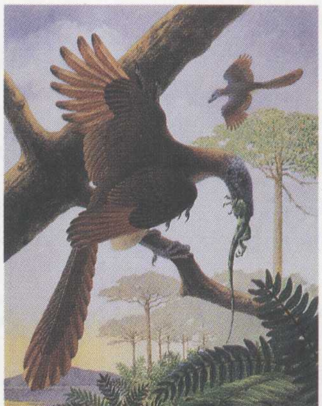

TABLE 49.4
Areas, Biomass of Plants, and Net Primary Production of Earth's Major Vegetation Zones

	AREA		MASS OF PLANTS		NET PRIMARY PRODUCTION	
VEGETATION ZONE	10^6 Km^2	PERCENT	10^9 TONS	PERCENT	10^9 TONS	PERCENT
Polar	8.05	1.6	13.77	0.6	1.33	0.6
Conifer forest	23.20	4.5	439.06	18.3	15.17	6.5
Temperate	22.53	4.5	278.67	11.5	17.97	7.7
Subtropical	24.26	4.8	323.90	13.5	34.55	14.8
Tropical	55.85	10.8	1,347.10	56.1	102.53	44.2
Total land	133.89	26.2	2,402.5	100	171.55	73.8
Glaciers	13.9	2.7	0	0	0	0
Lakes and rivers	2.0	0.4	0.04	<0.01	1.0	0.4
All continents	149.79	29.3	2402.54	100	172.55	74.2
Ocean	361.0	70.7	0.17	<0.001	60.0	25.8
Earth total	510.79	100	2,402.71	100	232.55	100

from the vents. Most of the other organisms of these ecosystems live directly or indirectly on the sulfur-oxidizing bacteria (see Figure 22.2).

This overview of the global pattern of biological production on Earth is sufficient to identify which processes limit primary production and nutrient cycling in different climatic zones and how they operate, but it does not give you a picture of what these ecosystems look like and how they function. Describing ecosystems is one of the goals of the next chapter.

SUMMARY of Main Ideas about Ecosystems

Ecosystems are powered by solar energy that first enters living organisms via photosynthesis at rates controlled by temperature and precipitation.
Review Figure 49.1

Food webs summarize who eats whom in ecological communities.
Review Figures 49.2 and 49.3

Because much of the energy taken in by an organism is used for maintenance and is eventually dissipated as heat, the efficiency of energy transfer to higher trophic levels is usually very low.
Review Figures 49.4 and 49.5

The main elements of living organisms—carbon, nitrogen, phosphorus, sulfur, hydrogen, and oxygen—cycle between organisms and other compartments of the global ecosystem.
Review Figures 49.10, 49.11, 49.12, 49.13, and Table 49.3

Human activity greatly modifies cycles of basic minerals on local, regional, and global scales.
Review Figures 49.14, 49.15, and 49.16

Earth's climate is determined primarily by the pattern of solar energy input at different latitudes and by Earth's rotation on its axis.

The directions of prevailing winds differ over the surface of Earth.
Review Figure 49.19

Surface winds drive global oceanic circulation.
Review Figure 49.20

The distribution of primary production on Earth is determined primarily by Earth's climate.
Review Figure 49.21

New chapter summaries synthesize information in the text and the art. Important concepts are encapsulated in clearly written summary sentences, with references back to key illustrations.

CONTENTS