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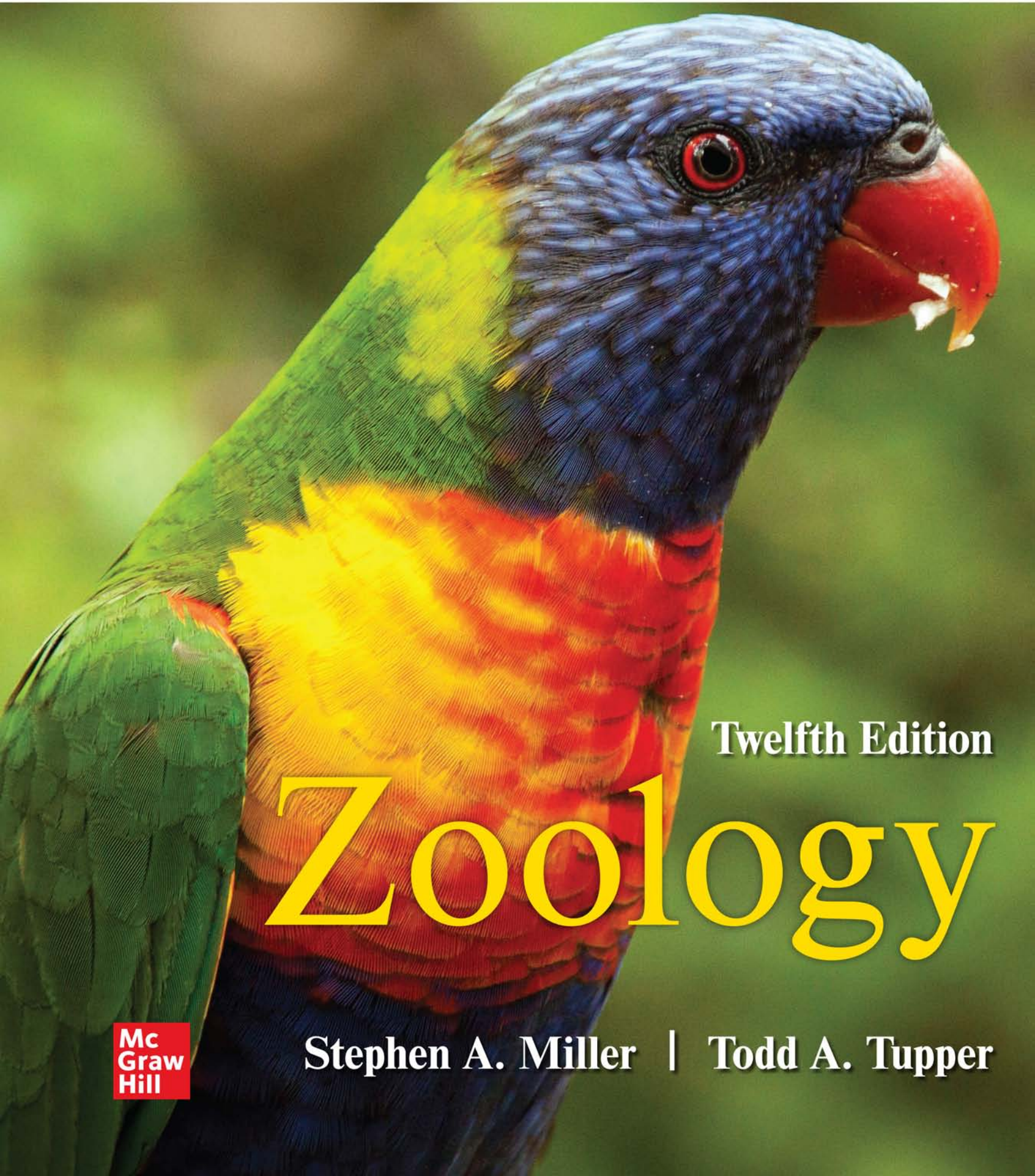

Twelfth Edition

Zoology

Stephen A. Miller | Todd A. Tupper

Mc Graw Hill

Zoology

Twelfth Edition

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ZOOLOGY

This book is printed on acid-free paper.

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ABOUT THE COVER


Kiran Bahra

Species: The Rainbow Lorikeet (*Trichoglossus moluccanus*)

Range: The east coast of Australia from Queensland to South Australia. Introduced to sites in Southwestern Australia.

Rainbow lorikeets are brilliantly colored and charismatic medium-sized parrots; as adults they can reach 31 cm in length and weigh as much as 130 g. They are vociferous birds that can produce loud, high-pitched, and frequent squawk-like calls. Rainbow lorikeets are found in a wide variety of habitats, ranging from pristine rainforests to developed landscapes. They often travel in pairs from roosting sites in search of pollen and nectar that they extract from flowers with their bristly tongues.

Birds have historically been considered members of the vertebrate class Aves (L. *avis*, bird). This class-level designation is in large part due to a remarkable suite of adaptations necessary for the various types of powered flight exhibited by modern birds. Many studies, however, indicate that this class-level designation is not valid and that birds are in fact types of reptiles that have become adapted for flight. Consequently, current classifications are being reevaluated, and the terms “avian reptiles” and “nonavian reptiles” have been adopted to indicate closer relationships than formerly recognized.

Birds are the only surviving group of the clade Dinosauria. Modern birds demonstrate complex behaviors and courtship rituals that were inherited from their extinct ancestors and adapted for life on Earth today. They have acute vision, sensitive hearing, and incredibly diverse life histories. Additionally, birds have evolved remarkable migratory abilities. They use the Earth’s magnetic field, landmarks, and stars to migrate extraordinary distances. In fact, the arctic tern (*Sterna paradisaea*), can migrate some 25,000 miles annually from the Arctic to Antarctic!

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PREFACE

We are pleased to present the twelfth edition of Zoology. This revision process has been slow, and it has been interrupted at times by the turmoil that has gripped our world over the past two years. This slowness, although frustrating for the authors and their families, has probably enhanced the product that you now have in your hands. It has allowed the authors to be in almost daily communication, to contact the individuals who have shared their expertise with us, and to give talented visual artists time to help us secure and enhance the photographs and line art used in this edition. We are so very grateful to these contributors who are acknowledged later in this preface. This extra time has also allowed Dr. Tupper to devote time to combing personal photographs for use in the book.

Throughout the revision process, every chapter was examined by both authors and carefully revised. Our aim has been to continue presenting relevant, up-to-date zoological concepts in the friendly writing style that has characterized the book and that has earned praise from users over the past 30 years. We are convinced that any student completing a general zoology course should come away knowing zoology as a dynamic field of study, appreciate the diversity of the animal kingdom, understand the contemporary threats to this diversity, and be inspired to help search for solutions to our environmental problems. We are honored and humbled by the prospects that this work, along with talented instructors, might inspire the next generation of zoologists.

CONTENT AND ORGANIZATION

The evolutionary and ecological perspectives that characterize this book have been retained. Both are extremely important for preserving the integrity of our discipline and the health of our planet. These perspectives are at the forefront of every chapter. The basic organization of the book is as follows.

Chapters 1 through 6 present cellular, evolutionary, and ecological concepts that unite zoology to biology as a whole. Chapters 7 through 22 cover animal taxonomy and phylogeny (chapter 7), animal origins and phylogenetic highlights (chapter 8), and survey the animal phyla (chapters 9 through 22). Chapters 23 through 29 cover animal structure and function. Revisions throughout the textbook have involved updating written content, revising and replacing line art and photographs, and maintaining a style that captivates students' interest. A detailed explanation of the changes made to each chapter is presented in "New to the Twelfth Edition" later in this preface.

PEDAGOGY

Integrated Learning Outcomes and Critical Thinking

We have retained pedagogical elements useful to science faculty in identifying measurable learning outcomes. **Learning Outcomes** have been retained and enhanced in the twelfth edition for each major section of each chapter. To make each chapter more streamlined, fluid, and cohesive, we have revised and moved the former "Thinking Beyond the Facts" into a new section at the end of each chapter called **Review and Apply**. This new section also includes all of the former Analysis and Application Questions. These questions have been expanded to include new content in the corresponding chapters. Possible answers to these questions are available to instructors in Connect Zoology. These elements allow students to self-test and instructors to document student learning. In addition, instructors and students using Connect Zoology can access auto-gradable and interactive assessment material tied to learning outcomes from the text. These Connect features include the new LearnSmart and SmartBook adaptive learning tools and are described under "Teaching and Learning Resources." We felt that the eleventh edition's Concept Review Questions did not have the rigor necessary for college-level inquiry. These questions, therefore, have been replaced with the aforementioned questions in Review and Apply. Multiple choice assessment options are available to students and instructors in Connect. In addition to being printed in the back of the book, the glossary (which has been revised and expanded) is still available electronically through Connect and in SmartBook.

An Evolutionary and Ecological Focus

Zoology emphasizes ecological and evolutionary concepts and helps students understand the process of science through elements of chapter organization and boxed readings. Each chapter in chapters 9 through 22 begins with a section entitled **Evolutionary Perspective**. This section discusses the relationship of the phylum or phyla covered in the current chapter to the animal kingdom as a whole and to animals discussed in previous chapters. Students are frequently reminded to consult appendices A and B to reorient themselves to phylogenetic relationships and geological time frames of evolutionary events. Similarly, each survey chapter ends with a section entitled **Evolutionary Connections.** This section discusses phylogenetic relationships of groups (subphyla or classes) within the phylum or phyla being studied and is a point of transition between chapters. The discussion in this section is usually supported by a cladogram illustrating important phylogenetic relationships.

Users of previous editions will notice that we have opted to present less information in the form of boxed readings. Information from "Evolutionary Insights" boxes and "How Do We Know" boxes has been updated and rewritten for incorporation into the body of the textbook. The examples and concepts presented in these boxes were central to concepts discussed in the chapter. Our experience suggests that many students tend to view boxed content as supplementary or incidental, and this material is often skipped as students move through a chapter. We hope that moving the material into the body of the text will help emphasize its importance and make assessment of student performance easier for instructors.

The ecological perspective of *Zoology* is stressed throughout chapters 1 to 22. Human population and endangered species statistics have been updated. Ecological problems are discussed in "Earth's Resources and Global Inequality" in chapter 6. The ecological perspective is reinforced by retained boxed readings entitled **Wildlife Alerts**. Wildlife Alerts first appeared in the fourth edition and have been very well received by students and professors. Each boxed reading depicts the plight of selected animal species or broader ecosystem issues relating to preserving animal species. These readings have been revised and updated. Apart from these boxed readings, numerous examples of threatened and endangered species are woven into chapters 4 through 22 that remind students of the delicate status of natural ecosystems of our planet. Students who read and study this book should have an enhanced understanding of ecological principles and how human ignorance and misplaced values have had detrimental effects on our environment in general and on specific animal groups in particular.

Digital Assets and Media Integration

Beginning with the ninth edition of *Zoology,* digital resources were integrated into the book through the Connect Zoology site. Many of the sections within most chapters are linked to animations from McGraw Hill's library of animations. These animations will enhance students' understanding of material within the chapter and are available through Connect.

NEW TO THE TWELFTH EDITION

As with earlier revisions of *Zoology*, the focus for this revision has been on presenting evolutionary and ecological concepts clearly and accurately using examples from current literature as convincingly as possible. The revisions highlighted below should impress students with the excitement experienced in zoology as new information clarifies zoological concepts and informs our understanding of phylogenetic relationships.

- **Chapter 1 (Zoology: An Evolutionary and Ecological Perspective)**
  A new introduction emphasizes the evolutionary and ecological focus of the textbook using the example of the biology, endangerment, and recovery of the least tern (*Sternula antillarum*) in North America. Population, world resources, and threatened and endangered species statistics have been updated with 2020 data.
- **Chapter 2 (The Structure and Function of Animal Cells)**
  Concepts related to energy, enzymes, and reactions have been separated from material covering cellular respiration. Material in these sections has been clarified and condensed. Line art and photographs have been revised throughout this chapter.
- **Chapter 3 (Cell Division and Inheritance)**
  Line art in chapter 3 has been extensively revised, including figures on mitosis and meiosis. The section on DNA replication has been rewritten, and new figures have been prepared. The wildlife alert on preserving animal diversity has been rewritten and features the koala (*Phasocolarctos cinereus*).
- **Chapter 4 (Evolution: History and Evidence)**
  In chapter 4, we have expanded the coverage of concepts related to fitness, mass extinctions (new table 4.1), and homplasy. In addition, two new sections have been added. One of these discusses eipigenetics—the inheritance of environmentally induced variations. The second section, "Interpreting and Applying the Evidence," helps students understand how sources of evidence for evolution work together to provide clear and reliable hypotheses of animal phylogeny.
- **Chapter 5 (Evolution and Gene Frequencies)**
  Chapter 5 has been reorganized, and its contents are, thus, more clearly presented. The section "Natural Selection Reexamined" has been rewritten and expanded. Frequency dependent selection, oscillating selection, and heterozygote advantage are all discussed. Natural selection's action on polygenic traits and sexual selection are also discussed in this section. The section on speciation has been largely rewritten and organized into two subsections: "Reproductive Isolation and Speciation" and "Speciation Models." Finally, the section on rates of evolution has been rewritten.
- **Chapter 6 (Ecology: Preserving the Animal Kingdom)**
  Chapter 6 has substantial updates. We have updated the writing throughout the chapter to explain ecological concepts more thoroughly in language that is accessible to the non-major while retaining the technical rigor necessary for a major's textbook. Additionally, we made changes to the art and photos that more accurately convey the intended message. The largest change to this chapter includes the introduction of new content describing the impact of invasive species, overexploitation of land and water resources, and wicked environmental problems. Lastly, we have updated information on sustainable living.
- **Chapter 7 (Animal Taxonomy, Phylogeny, and Organization)**
  Revisions in chapter 7 are mostly minor clarifications of it important concepts. One of these changes is to present the two major approaches to the study of animal phylogeny—cladistics and evolutionary systematics—as differing interpretations of evidence that ultimately result in stronger hypotheses of evolutionary relationships.
- **Chapter 8 (Animal Origins and Phylogenetic Highlights)**
  In the eleventh edition of *Zoology*, chapter 8 was completely rewritten to discuss Earth's beginning and the evolution of life on Earth. This change has been very well received. In this

new edition, the chapter has been updated with a comparison of hypotheses of life's origin in hydrothermal vents versus volcanic pools. New illustrations accompany this discussion. The phylogeny of higher animal groups is also updated with very recent consensus concepts. Protostomia is described as being comprised of spiralian and ecdysozoan lineages, with Spiralia containing two clades: Lophotrochozoa and Gnathifera. A new figure 8.11 now clearly illustrates developmental characteristics used to define Protostomia and Deuterostomia.

- **Chapters 9 through 17**
  Chapters 9 through 17 survey the animal phyla through the invertebrate chordates. The major revisions in these chapters involve clarifying and updating phylogenetic relationships. "Evolutionary Perspecitive" and "Evolutionary Connections" sections have been carefully revised with the most recent phylogenetic hypotheses. Cladograms have been revised accordingly. The changes include the description of lophotrochozoan and gnathiferan clades within Spiralia, the division of Platyhelminthes into three classes of Neodermata, and the presentation of turbellarians as comprising polyphyletic lineages. Rotifers and acanthocephalans are combined into a single phylum, Syndermata. Phylogenies within Mollusca, Nematoda, and Arthropoda are all revised and updated. Chapters 14 and 15 are reorganized to better reflect arthropod phylogeny. The unsettled phylogenetic status of the arachnids is reflected in these chapters. Descriptions of deuterostome phylogeny in chapters 16 and 17 have been rewritten. In addition to these changes, a new wildlife alert on invasive earthworms has been added to chapter 12, and a new section entitled "Nematodes in Ecosystems and Human Welfare" has been added to chapter 13.
- **Chapter 18 (The Fishes: Vertebrate Success in Water)**
  In chapter 18 we have updated and rewritten the "Reproduction and Development, "Excretion and Osmoregulation," and "Evolutionary Connections" sections. We have also introduced a new boxed reading on the conservation of the Chesapeake logperch. In addition to revising or replacing 13 images, we have expanded information describing the natural history and biology of the fishes throughout the chapter.
- **Chapter 19 (Amphibians: The First Terrestrial Vertebrates)**
  In addition to replacing and revising 11 images and captions in chapter 19, we have made changes throughout the text to provide more thorough accounts of anatomy, physiology, and natural history. The largest of these changes were made in the "Reproduction, Development and Metamorphosis," "Nervous and Sensory Functions," and "Evolutionary Connections" sections. Additionally, data on the conservation status of amphibians has been updated.
- **Chapter 20 (Nonavian Reptiles: Diapsid Amniotes)**
  Chapter 20 has undergone substantial revisions. Twelve images have been replaced and revised. One of the most significant image changes was to figure 20.4. This image now includes photos of actual amniote skulls with markers designating the temporal fenestrae. We also have acquired an image of a recently discovered chameleon species identified as the world's smallest amniote. This image has been incorporated into figure 20.8 and the associated caption has been revised. We have made substantial revisions to "Evolutionary Perspectives," "Early Amniote Evolution and Skull Structure," "External Structure and Locomotion," and the evolution of venom in "Nutrition and the Digestive System." The former boxed reading about snake venom has been updated and moved directly into the main text. As in the other chapters, we have streamlined the writing and provided additional natural history information where appropriate.
- **Chapter 21 (Birds: The Avian Reptiles)**
  In chapter 21, we updated information on avian respiration and provided a new image that more clearly depicts the process. We included new information on avian evolution and included a figure to illustrate the anatomical changes that occurred during the evolution of the avian wing. The boxed reading on the red-cockaded woodpecker was updated, and we updated four additional photos to give a more diverse representation of birds in the chapter (with accompanying natural history information in the caption for the opening photo). Minor text revisions occur throughout the chapter. "Migration and Navigation," however, received substantial revisions.
- **Chapter 22 (Mammals: Synapsid Amniotes)**
  The following sections of chapter 22 have been substantially revised: Support and Movement (formerly the Vertebral Column and Appendicular Skeleton), Nutrition and the Digestive System, Behavior, and Territoriality. The section on circulation, gas exchange and temperature regulation, has been almost completely rewritten and expanded to include more examples of certain physiological processes across different animals. The section on *Homo* has also been entirely rewritten and includes more recent findings. Eight figures have been replaced and updated to give a more accurate representation of the concepts broached in the text. Their respective captions have been updated as well.
- **Chapter 23 (Protection, Support, and Movement)**
  Chapter 23 now has an image illustrating the appendicular and axial skeleton. Five other images have been revised, one of which is the substitution of the former chapter opener with a dragonfly undergoing hemimetabolus transition. This transition better illustrates different processes that involve the integument. The text has been modestly streamlined throughout and contains a larger revision in "Muscular Systems." This section now more clearly describes the differences between the major kinds of vertebrate muscles.
- **Chapter 24 (Communication I: Nervous and Sensory Systems)**
  Chapter 24 has been extensively revised. We have replaced and revised 10 images and now have entirely new and more descriptive images of abdominal phonoreceptors in the pharaoh cicada, and of the chamber housing the crayfish statocyst. We have made various changes throughout the chapter. Information on the action potential has been substantially revised. Additionally, we have completely rewritten information on spinal nerves, the forebrain, hearing and equilibrium, and bitter and sweet chemoreceptors.

- **Chapter 25 (Communication II: The Endocrine System and Chemical Messengers)**
  In chapter 25, we have revised and rewritten the introductory material and the section describing types of chemical messengers. Information on anuran metamorphosis has undergone substantial revision, and we have made smaller revisions throughout the text including edits to homeostasis of blood calcium and mechanisms of hormone action. We have also revised three figures and added an image of a social insect whose caste system is regulated by pheromones: the European hornet.

- **Chapter 26 (Transport and Exchange in Animals)**
  We have revised chapter 26 to include more detail on transport and exchange in invertebrates. In addition, figures have been revised, and many lesser text revisions clarify transport processes in vertebrates.

- **Chapter 27 (Nutrition and Digestion)**
  Chapter 27 has new art that more clearly shows the structures of the human stomach and associated gastric glands. Additionally, we have updated images (and image captions) throughout the chapter to better demonstrate animals and animal feeding as they would be seen in the wild. We have also updated the boxed reading describing bulk feeding in snakes. Due to the importance of microbes in digestion, we have updated the material and moved it into a new chapter section in the main text.

- **Chapter 28 (Temperature and Body Fluid Regulation)**
  Chapter 28 has a new image of an osmoregulatory structure in toads called a seat patch. Three additional images were updated for clarification. Small changes and revisions occur throughout the chapter; the largest of which are revisions to the information describing cooling in nonavian reptiles, and an elasmobranch osmoregulatory strategy called the counteracting osmolyte strategy.

- **Chapter 29 (Reproduction and Development)**
  In chapter 29, we revised and expanded the chapter opener, and replaced the opening image with a placental mammal. We have expanded and revised the introduction portion of section 29.1, amphibian reproduction, clarified the term, "ovoviviparous," and greatly expanded and revised the section on mammal reproduction. The section now contains a more thorough explanation of reproductive strategies in the primates. We have also rewritten and expanded the section on milk production and lactation. Smaller changes exist throughout the chapter where we felt the text needed clarification, additional examples, and streamlining.

- **Appendices**
  The twelfth edition of *Zoology* has retained and expanded the three appendices that were new to the eleventh edition. Appendix A presents one interpretation of animal phylogeny that is developed and used in the textbook. The cladogram has been revised to avoid the awkward break that occurred as a result of being stretched across two pages. A table highlighting major phylogenetic events has been added. Appendix B provides an expanded view of Earth's geological history and some major biological events occurring in each eon, era, and period. Frequent references are made to both of these appendices throughout the textbook. Placing this information in appendices provides students easy access to this important information. We recommend that students bookmark these appendices for quick referral. Appendix C covers the Protozoa. While protists are not animals, they are still very important subjects in many general zoology courses. Appendix C will allow instructors who wish to cover these organisms to do so.

ACKNOWLEDGMENTS

One of our goals for the twelfth edition was to provide students with a better visual representation of animal behavior and ecology *in situ.* Consequently, we have incorporated our own photos from the field into the book, and we have used photos donated by colleagues who are also dedicated to education. We would like to express our sincere gratitude to the following people for generously providing outstanding images to help inspire the next generation of scientists: Robert Aguilar, Basla Andolson, Kiran Bahra, Chris Barnhart, Kelly Boland, Miriam Boucher, Annise Dobson, Mark Faherty, Nicole Freidenfelds, Frank Glaw, Kirk Goolsby, Coline Hay, Michael Huggins, Emily Hunter, Kyran Leeker, Edwin Miller, Berlin Nelson, Valeria Pizarro, Savannah Rose, Jeff Streicher, and Brad Timm. We also would like to thank Amanda Lee for donating hours of time showing us how to edit our photos so that they were suitable for print. She also updated and created images that appear throughout the book.

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SPECIAL THANKS AND DEDICATIONS

The publication of a textbook requires the efforts of many people. We are grateful for the work of our colleagues at McGraw Hill Education who have shown extraordinary patience, skill, and commitment to this textbook. While preparing the twelfth edition, Todd suffered an injury that required surgery and aftercare. He would not have been able to complete the work on schedule if it were not for the efforts of Eva Lorentz, Debbie Shaffer, Beatrice Frey, Troy Morgan, Mary Vander Maten, and Amanda Lee. Todd would like to express a special thanks to Robert Aguilar and Chaundra Schofield for opening their home to him and caring for him for weeks after his surgery. Todd would also like to thank Dr. Aneesh Singla and Dr. Joseph Ferguson for their patience, skill, and dedication to medicine.

We wish to extend special appreciation to our families and loved ones for their patience and encouragement. Janice A. Miller lived through many months of planning and writing of the first edition of *Zoology*. She died suddenly two months before it was released. Steve's wife, Carol A. Miller, has been especially supportive throughout the lengthy revisions of virtually all subsequent editions. Carol, an accomplished musician, spent many hours proofreading *Zoology* for grammatical errors. Over the past 30 years, she has become a much better zoologist than her husband has become a musician—something about practicing got in his way. Todd's long-time friend and mentor, Robert P. Cook, was instrumental in Todd's journey in biology and has been steadfastly committed to wildlife conservation for over 40 years. We thank him for his support and efforts. Lastly, we dedicate this book to our families and send a special memorial dedication to Diane Fitzgerald, Rudolph G. Arndt, and Carl Ernst—may you rest in peace.

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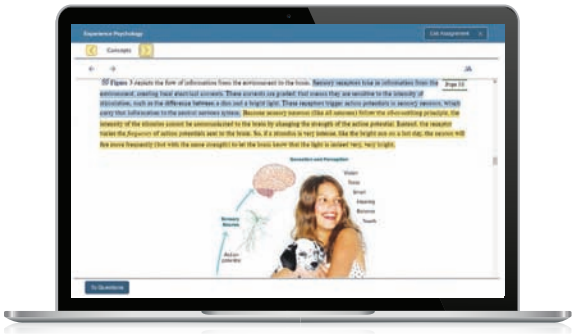

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- Jordan Cunningham,
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Sterna antillarum (the least tern) is an oceanic shoreline and riverine bird distributed in three major populations across North America. Both male and female sexes have a black crown, a white forehead, and dark eye stripes. Their bill is yellow with a black tip. Wings are black dorsally, and the ventral surfaces of their wings and body are white. Legs are orange. Conservation measures have improved the ecological status of formerly threatened or endangered populations of the least tern.
Emily Hunter

1

Zoology: An Evolutionary and Ecological Perspective

Chapter Outline

You are about to begin a journey into the study of animals—a journey that the authors hope informs a deeper appreciation for the diversity of animal life, the evolutionary processes that produced this diversity, and the structural and functional adaptations characteristic of groups of animals. As you read and study, we also hope that you will become more aware of events and practices that threaten animal diversity. You will encounter ecological principles that will help you understand how human behaviors have fostered, or become impediments to, the survival of animals. Welcome to zoology. We hope your journey is one that enhances your life and promotes the welfare of life on our planet.

1.1 INTRODUCTION TO ZOOLOGY

LEARNING OUTCOME

1. Differentiate various approaches to the science of zoology.

Zoology (Gr. *zoon,* animal + *logos,* to study) is the study of animals. It is one of the broadest fields in all of science because of the immense variety of animals and the complexity of the processes occurring within animals. There are more than 1.4 million described species of animals and many more (an estimated 6–7 million) that have yet to be described. There are 400,000 described species of beetles! It is no wonder that zoologists usually specialize in one or more of the subdisciplines of zoology. They may study particular functional, structural, or ecological aspects of one or more animal groups (table 1.1), or they may choose to specialize in a particular group of animals (table 1.2).

Ornithology is the study of birds, and ornithologists work to understand the structure, function, ecology, and evolution of birds. Most field guides of birds estimate that there are between 9,000 and 10,000 species of birds; however, this number may double as ornithologists reconsider how existing bird species are defined and as previously unknown species are described.

Understanding the biology of a single species is a daunting task, yet a task that can be critical to the species' survival. Generations of ornithologists have studied the biology of the least tern (*Sternula antillarum*). This species was originally described in 1847, reclassified in 1942 as a European little tern (*Sternula albifrons*), and—after further studies of vocalizations and behavior—returned to its original species designation in 1976 (*see Chapter Opener Figure*).

Since its original description, ornithologists have learned that *Sternula antillarum* is comprised of three major breeding populations: one resides along the east coast of North America from Massachusetts to Florida and west to the Texas Gulf Coast; a second occupies the Pacific Coast of North America from central California through Baja, California, and into the northern Pacific Coast of Mexico; and a third occupies the Mississippi, Missouri,

TABLE 1.1
EXAMPLES OF SPECIALIZATIONS IN ZOOLOGY

SUBDISCIPLINE	DESCRIPTION
Anatomy	Study of the structure of entire organisms and their parts
Cytology	Study of the structure and function of cells
Comparative Genomics and Bioinformatics	Study of the structure, function, and evolution of the genetic composition of groups of animals using computer-based computational methods
Ecology	Study of the interaction of organisms with their environment
Embryology	Study of the development of an animal from the fertilized egg to birth or hatching
Genetics	Study of the mechanisms of transmission of traits from parents to offspring
Histology	Study of tissues
Molecular biology	Study of subcellular details of structure and function
Parasitology	Study of animals that live in or on other organisms at the expense of the host
Physiology	Study of the function of organisms and their parts
Systematics	Study of the classification of, and the evolutionary interrelationships among, animal groups

TABLE 1.2
EXAMPLES OF SPECIALIZATIONS IN ZOOLOGY BY TAXONOMIC CATEGORIES

SUBDISCIPLINE	DESCRIPTION
Entomology	Study of insects
Herpetology	Study of amphibians and reptiles
Ichthyology	Study of fishes
Mammalogy	Study of mammals
Ornithology	Study of birds
Protozoology	Study of protozoa

and Ohio river drainages of the central United States. In the fall, least terns from all the populations migrate to Caribbean islands and the coasts of Central and South America (figure 1.1).

Least terns are predators of small fish, which they capture after hovering flight and plunging into the water to capture prey in their bills. Eastern and western populations nest in colonies along coastal beaches, and interior populations nest along river shorelines and on riverine sandbars and alluvial islands. Males establish nesting territories spaced 5–7 m apart. Courtship behavior includes an initial flight in which a male flies into the air carrying a fish in its bill. This behavior lures a female to follow in flight. Courtship eventually moves to the ground with the fish-carrying male performing a ritualized circling and feeding of the female (figure 1.2). After courtship and brief copulation, both sexes cooperate in constructing a simple nest by scraping a shallow depression in shoreline sand and gravel—often lining the nest with nearby pebbles or shell fragments. The female lays two or three brownish-yellow, brown-spotted eggs, and both parents share incubation duties (figure 1.3). Eggs hatch into spotted precocial chicks in about three weeks, young fledge (begin flight) 20 days post-hatching, and they remain with the parents two or three months. Early on, parents feed very-small fish and crustaceans to constantly hungry, calling, and begging hatchlings. Fledglings eventually become more adept predators and require less parental care.

Early life is risky for young least terns. Eggs and chicks are well camouflaged against their pebbly substrate, but predators (birds of prey, raccoons, foxes, skunks, and careless beach going humans) still exact a heavy toll from nesting populations. Open nests are relatively unprotected, and hatchlings shelter under clumps of vegetation and debris in the vicinity of the nest. When threatened, chicks carry out an innate flattening and freezing behavior that helps in their concealment. A predator also elicits mobbing behaviors in adult members of a colony. When a predator approaches, the air fills with loudly calling terns. As hatching time nears, adults become more aggressive. They hover, dive in inverted arc paths, strike a predator with their bills, and even defecate on the intruder. A chick that survives its first few months is likely to live 13–15 years.

This account, while unique to *Sternula antillarum*, is not unusual—it is one of many fascinating accounts of animal natural history. Ornithologists around the world gather similar information on all bird species. It is critical to understanding the diversity of bird species, preserving bird species, and understanding how this small branch of the animal kingdom is related to all other animal groups.

1.2 ZOOLOGY: AN EVOLUTIONARY PERSPECTIVE

LEARNING OUTCOMES

1. Appraise the importance of evolution as a unifying concept in zoology.
2. Explain how our taxonomic system is hierarchical.

The least tern (*Sternula antillarum*) has a unique natural history story. Its uniqueness is in the details of its biology, but many elements of the "least tern story" are shared with other shorebirds, like the piping plover (*Charadrius melodus*) with which it often shares nesting habitats. The least tern also shares many characteristics of the larger group of animals commonly called "birds." Birds include 35 orders (*see table 21.1*) of animals that possess evolutionary adaptations that make flight possible (*see chapter 21*). All of these shared characteristics are the result of their common ancestry and the evolutionary forces that influenced their history. Shared characteristics are studied by zoologists in documenting the evolutionary history of any group of animals.

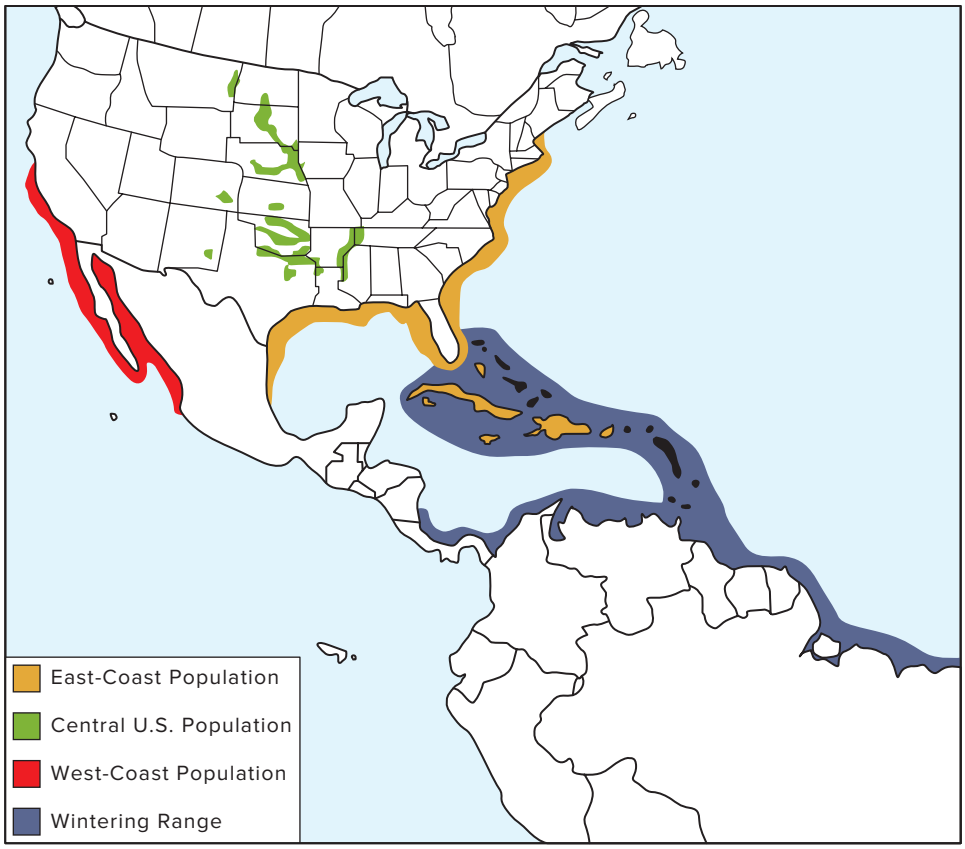


FIGURE 1.1

Distribution of Three Major Populations of *Sternula antillarum*. *Sternula antillarum* is divided into three major breeding North American populations. A west-coast population inhabits Pacific Ocean shorelines from central California into northern Mexico. An interior population is associated with major river drainages of central North America. An east-coast population inhabits Atlantic Ocean shorelines from New England to Florida and westward to the central Gulf Coast. Fall migrations take these birds into the Caribbean islands and the east coast of Central and northern South America.

FIGURE 1.2

The Courtship of *Sternula antillarum*. Courtship behaviors of *Sternula antillarum* involve both aerial and ground behaviors. Males take off in flight over a least tern colony. This behavior, and the fish he carries in his bill, entices a female to follow in pursuit. Depending on the female's response, the male's flight may lead to ground courtship displays that eventually result in the male feeding the fish to the female and to copulation.

Emily Hunter

FIGURE 1.3

Nesting of *Sternula antillarum*. Following mating, a female least tern lays 2–3 eggs in a shallow depression created when the mating pair scrapes sand, gravel, and debris to the margin of the nest. Nests in a colony are spaced about 5 m apart along ocean beach or riverine shorelines. The habit of nesting in open areas makes the brown-spotted eggs and hatchlings vulnerable to predation. Both parents incubate eggs and defend the nest and hatchlings.
Emily Hunter

Organic evolution (L. *evolutus*, unroll) is change in the genetic makeup of populations of organisms over time. Charles Darwin published convincing evidence of evolution in 1859 and proposed a mechanism that could explain evolutionary change. The mechanism proposed by Darwin has been confirmed and now serves as the nucleus of our understanding of why animals, like *Sternula antillarum*, look and behave as they do (*see chapters 4 and 5*). Evolutionary principles also explain the origin of life's diversity and the family relationships among groups of animals (*see chapters 7 and 8*).

Animal Classification and Evolutionary Relationships

Evolutionary principles help us to understand animal relationships. We know that terns, plovers, gulls, and auks are closely related because of genetically based physical characteristics they share and because of molecular studies, which demonstrate that they share more of their genetic material (DNA) with each other than with individuals in other groups. (You are more closely related to your brother or sister than to your cousin for the same reason.) Similar genetic studies help zoologists reevaluate hypotheses regarding relationships between broader animal groups.

Generations of zoologists have considered birds as being united in a major taxonomic class of animals named "Aves." The group "Aves" was considered at the same relationship level as that occupied by bony fishes (Actinopterygii), amphibians (Amphibia), reptiles (Reptilia), and mammals (Mammalia). The "Aves" designation seemed justified by the remarkable flight adaptations present in birds. In recent decades, it has become increasingly apparent that anatomical, physiological, and behavioral characteristics shared by birds and reptiles indicate close evolutionary ties between the two groups (*see chapters 20 and 21*). In addition, hundreds of studies of DNA structure (*see chapters 3, 5, and 7*) have confirmed that birds are reptiles that have become adapted for flight. Birds are the only dinosaurs to survive a mass extinction event that occurred approximately 66 million years ago (*see chapters 4 and 21 and figure 21.3*). The formal class designation, Aves, may be dropped in the future, and birds would then be included within Reptilia. In this textbook, birds are considered reptiles and designated by either of their informal names, birds or avian reptiles.

Like all organisms, animals are named and classified into a hierarchy of relatedness. Although Carl von Linne (1707–1778) is primarily remembered for collecting and classifying plants, his system of naming—**binomial nomenclature**—has also been adopted for animals. A two-part name describes each kind of organism. The first part is the genus name, and the second part is the species epithet. Each kind of organism (a species)—for example, least tern (*Sternula antillarum*)—is recognized throughout the world by its two-part species name. Verbal or written reference to a species refers to an organism identified by this two-part name. The species epithet is generally not used without the accompanying genus name or its abbreviation (*see chapter 7*). Above the genus level, organisms are grouped into families, orders, classes, phyla, kingdoms, and domains, based on a hierarchy of relatedness (figure 1.4). It is not uncommon for levels of taxonomy between these groups to be designated to reflect more precise details of relationships (e.g., subclass or superorder). As seen in the following section, species may also be divided into two or more subspecies when genetic characteristics of two or more groups within a species (populations) are sufficiently distinct. Organisms in the same species are more closely related than organisms in the same genus, and organisms in the same genus are more closely related than organisms in the same family, and so on. When zoologists classify animals into taxonomic groupings they are making hypotheses about the extent to which groups of animals share DNA, even when they study variations in traits like jaw structure, color patterns, and behavior, because these kinds of traits ultimately are based on the genes that they share.

1.3 ZOOLOGY: AN ECOLOGICAL PERSPECTIVE

LEARNING OUTCOMES

1. Use an example to generate an explanation for the importance of ecology as a unifying concept in zoology.
2. Analyze the relationships between human population growth and threats to world resources.

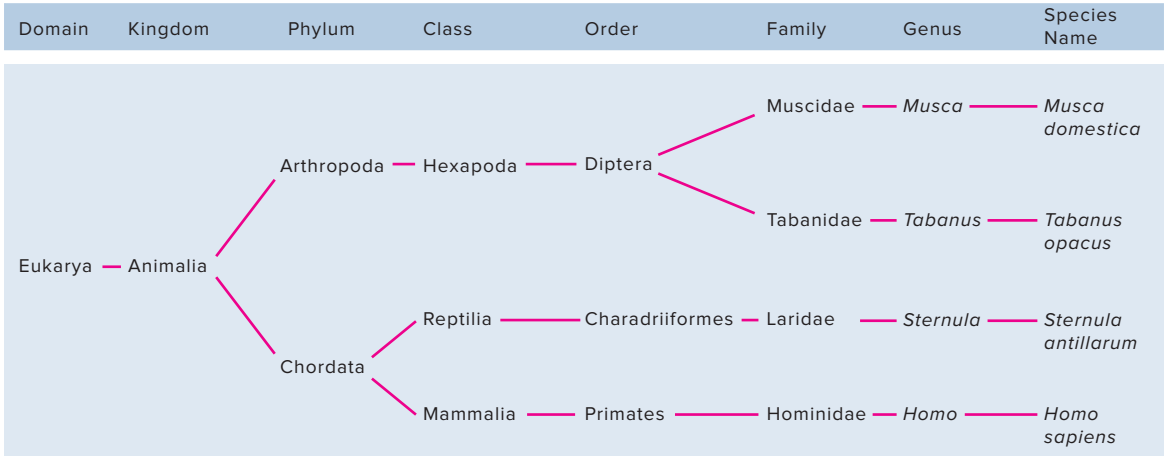


FIGURE 1.4

Hierarchy of Relatedness. The classification of a housefly, horsefly, least tern, and human illustrates how the classification system depicts degrees of relatedness.

Modern zoology requires an ecological perspective. It is a second major unifying theme in zoology. An ecological perspective recognizes that animals can never be understood apart from other organisms and the nonliving components of their environment. **Ecology** (Gr. *okios,* house + *logos,* to study) is the study of the relationships between organisms and their environment (*see chapter 6*). All animal species live within delicate ecological constraints. When the ecological characteristics of a species' habitat remain, or become, favorable the species is likely to survive. Most environmental changes, whether natural or anthropogenic (human-made) in nature, can threaten species survival. A threatened species may (rarely) adapt over many thousands to millions of years or (more commonly) face extinction.

Endangered Animals and World Resources

Populations of *Sternula antillarum* have faced environmental disturbances that threatened their survival. In 1972, the U.S. Fish and Wildlife Service (USFWS) listed the western population of this species as endangered as a result of their vulnerable nests being disturbed by human beachgoers, pollution, and predators (box 1.1). Similar concerns have existed for the eastern populations, and they have been listed as threatened by state and local agencies. The interior population was listed as endangered by the USFWS in 1985. Riverine populations depend upon river shorelines and islands being maintained and kept barren of vegetation for nesting colonies. These nesting habitats are maintained naturally by periodic spring flooding, which scours vegetation along riverbanks and creates islands, sandbars, and shoreline beaches. These habitats have been declining for decades as a result of human development, manipulation of river flow, channelization, and damming. This development has promoted human commerce, but dams and channelization regulate river flow such that little natural erosion and deposition occur. Nest sites established during low-water flow were often flooded by periodic discharges from reservoirs.

This account seems bleak; however, the rest of the least tern story is quite hopeful. After the USFWS lists a species as endangered or threatened conservation measures are enacted to promote the species' recovery. In the case of *Sternula antillarum*, these measures have been quite successful. Restricting human access to beach nest sites has allowed coastal populations to increase in number. Similar protective measures, as well as river-flow management by the U.S. Army Corps of Engineers, vegetation management, and predator control, promoted the creation or restoration of nesting sites of the interior least tern population. In addition to these conservation measures, the least tern has proven to be an adaptable nester. It is a species that can relocate and renest if an existing nest is disturbed, and it uses anthropogenic sites such as gravel roof-tops and sand pits for nesting. Finally, genetic testing of the least tern suggests that there is greater genetic exchange across the three populations than was previously known. Genetic exchange and the increased genetic diversity that results usually promote a species, welfare. (This evidence of genetic exchange has also prompted zoologists to reconsider the original designations of the three populations as three subspecies of *Sternula antillarum*. It is now considered a single species with no subspecies.) Since the original USFWS listings in 1972 and 1985, the populations of *Sternula antillarum* have more than doubled and their ranges have expanded. In 2019, the USFWS removed the least tern from its endangered species list, but the USFWS and state and local agencies continue monitoring the populations.

Conservation efforts directed toward the least tern have had encouraging results. Unfortunately, that is not the case for hundreds of other animal species spread across all animal phyla. "Wildlife Alerts" (*see box 1.1*) that appear within selected chapters of this text remind us of the peril that many species face. The major causes of animal endangerment are anthropogenic. These causes stem from global overpopulation and the exploitation of world resources, which primarily results from overconsumption by developed countries.

BOX 1.1 WILDLIFE ALERT

An Overview of the Problems

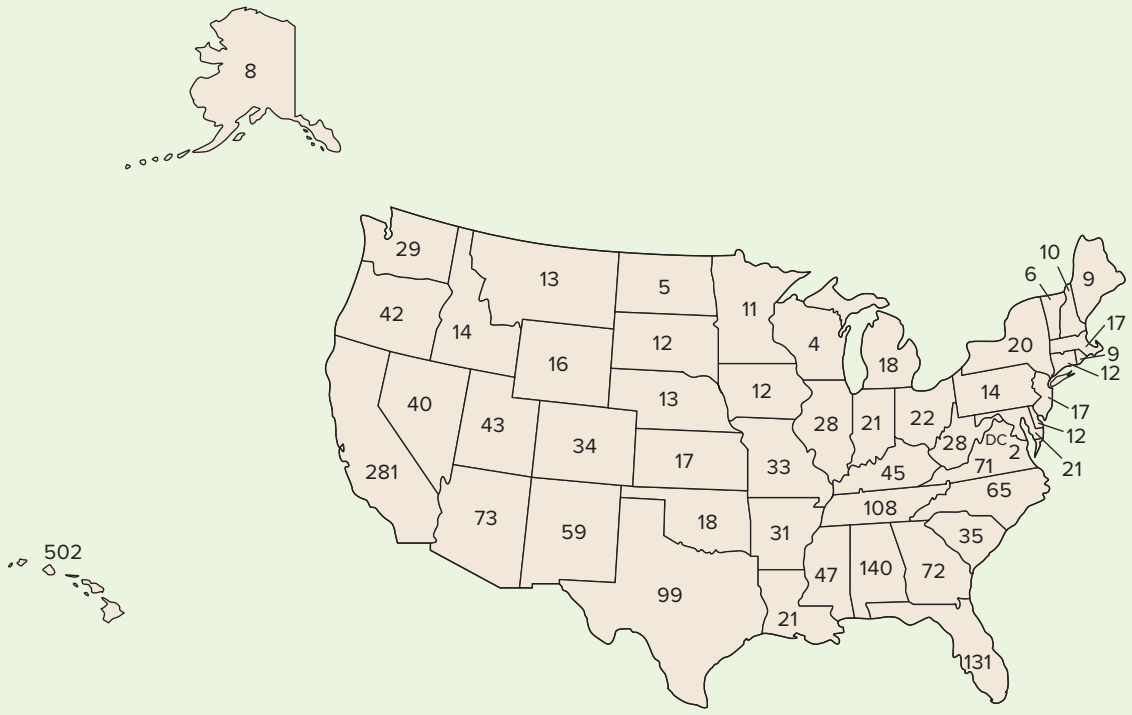
Extinction has been the fate of most plant and animal species. It is a natural process that will continue. In recent years, however, the threat to the welfare of wild plants and animals has increased dramatically—mostly as a result of habitat destruction. Tropical rain forests are one of the most threatened areas on the earth. It is estimated that rain forests once occupied 14% of the earth's land surface. Today this has been reduced to approximately 6%. Each year we lose about 150,000 km^2 of rain forest. This is an area of the size of England and Wales combined. This decrease in habitat has resulted in tens of thousands of extinctions. Accurately estimating the number of extinctions is impossible in areas like rain forests, where taxonomists have not even described most species. We are losing species that we do not know exist, and we are losing resources that could lead to new medicines, foods, and textiles. Other causes of extinction include climate change, pollution, and invasions from foreign species. Habitats other than rain forests—grasslands, marshes, deserts, and coral reefs—are also being seriously threatened.

No one knows how many species living today are close to extinction. As of 2020, the U.S. Fish and Wildlife Service lists 1,665 species in the United States as endangered or threatened. The International Union for Conservation of Nature (IUCN) has assessed over 116,000 species worldwide and of these more than 31,000 species are listed as endangered or threatened. (Recall that it is estimated that there are approximately 5 million species of animals living today.) An **endangered species** is in imminent danger of extinction throughout its range (where it lives). A **threatened species** is likely to become endangered in the near future. Box figure 1.1 shows the number of endangered and threatened species in different regions of the United States. Clearly, much work is needed to improve these alarming statistics.

In the chapters that follow, you will learn that saving species requires more than preserving a few remnant individuals. It requires a large diversity of genes within species groups to promote species survival in changing environments. This genetic diversity requires large populations of plants and animals, living in non-fragmented habitats, which permit gene exchange throughout a population.

Preservation of endangered species depends on a multifaceted conservation plan that includes the following components:

1. A global system of reserves to protect large tracts of land and wildlife corridors that allow movement between natural areas
2. Protected landscapes and multiple-use areas that allow controlled private activity and also retain value as a wildlife habitat
3. Zoos and botanical gardens to save species whose extinction is imminent



BOX FIGURE 1.1 Map Showing Approximate Numbers of Endangered and Threatened Species in the United States. The number for each state includes all endangered or threatened species believed or known to occur in the state. Because the ranges of some organisms overlap two or more states, the sum of all numbers is greater than the sum of all endangered and threatened species. The total number of endangered and threatened species in all listing categories in the United States is 1,658. The total number of listed animals is 770, with fish having the greatest number of listed species.

Population

Global overpopulation and overconsumption by developed countries are at the root of virtually all other environmental problems. The global human population is currently 7.8 billion. Population growth between 2020 and 2050 is expected to be greatest in lower- and middle-income countries where growth rates are expected to increase by 220% and 23%, respectively. This rate of increase is much higher than the projected 3% rate of increase in wealthier countries (table 1.3). By the year 2050, the total population of India (1.64 billion) is expected to surpass that of China (1.41 billion) and the total world population will reach 9.7 billion. The 2020 U.S. population was 331 million. In 2050, it is projected to increase to 379 million. As the human population grows, the disparity between the wealthiest and poorest nations is likely to increase.

World Resources

Human overpopulation is stressing world resources. Although new technologies continue to increase food production, most food is produced in industrialized countries that already have a high per-capita food consumption. Maximum oil production is continuing in this millennium. Deforestation of large areas of the world results from continued demand for forest products, fuel, and agricultural land. This trend contributes to climate change by increasing atmospheric carbon dioxide from burning forests and impairing the ability of the earth to return carbon to organic matter through photosynthesis. Deforestation also causes severe regional water shortages and results in the extinction of many plant and animal species, especially in tropical forests. Forest preservation would result in the identification of new species of plants and animals that could be important human resources: new foods, drugs, building materials, and predators of pests (figure 1.5). Nature also has intrinsic value that is just as important as its provision of resources for humans. Recognition of this intrinsic worth provides important aesthetic and moral impetus for preservation.

The stress being placed on world resources is a worldwide problem—not just one caused by, or occurring in, less developed countries. Major causes of resource problems are directly associated with activities in, and demands created by, industrialized nations. This fact is illustrated by looking at the anthropogenic contribution of greenhouse gases to the atmosphere. The major sources of greenhouse gases are tied to the overuse of fossil fuels, and the greatest contributors to anthropogenic greenhouse gas are China and the United States. Per capita greenhouse gas emissions in lower- and middle-income countries are much lower than in higher-income countries like Canada and the United States (table 1.4). As highly populated lower- and middle-income regions strive to achieve the living standards of wealthier countries, worldwide greenhouse gas emissions could dramatically increase.

Solutions

An understanding of basic ecological principles can help prevent looming ecological disasters. These principles, and more information on ecological problems, are presented in chapter 6. You will learn how matter is cycled and recycled in nature, how populations grow, and how organisms in our lakes and forests use energy. You will also learn that there are no easy solutions to our ecological problems. The loss of natural habitats, climate change, pollution, exploitation of Earth's resources, and the problems associated with invasive species all have ties to over-consumption by developed countries and expanding human populations. We can all individually participate in solving these problems (*see chapter 6*), but it will also require difficult choices involving global cooperation.

TABLE 1.3
WORLD POPULATION PROJECTIONS FOR MAJOR WORLD REGIONS: 2020 AND 2050 (PROJECTED)

WORLD REGION	2020	2050 (PROJECTED)
World	7.8	9.7
Africa	1.3	2.5
Asia	4.6	5.3
Europe	0.75	0.71
Latin America and Caribbean	0.65	0.76
North America	0.37	0.43
Oceania	0.04	0.06

Population sizes are based on figures from the United Nations Department of Economics and Social Affairs (2019) and expressed in billions of people.

TABLE 1.4
MAJOR CONTRIBUTORS OF ANTHROPOGENIC GREENHOUSE GAS EMISSIONS

COUNTRY	$GTCO_2EQ^*$	PER CAPITA TCO_2EQ^*
China	12	8.4
United States	5.8	18
European Union (28 countries)	3.2	6.2
India	3.2	2.4
Russia	2.4	17
Canada	0.78	22

*Greenhouse gas emissions are given in metric ton carbon dioxide equivalents. This number takes into account all greenhouse gases including CO_2, methane, nitrous oxide, and others and is a calculation of their global warming potential. Total yearly emissions for the regions shown here are expressed in metric gigatonnes (1 billion or 1×10^9 metric tonnes). Per capita emissions are metric tonnes per person per year. These 2016 data exclude land-use change and forestry and are from the World Resources Institute.

(a) (b)

FIGURE 1.5

Tropical Rain Forests: A Threatened World Resource. (*a*) A Brazilian tropical rain forest. (*b*) A bulldozer clear-cutting a rain forest in the Solomon Islands. Clear-cutting for agriculture causes rain forest soils to quickly become depleted, and then the land is often abandoned for richer soils. Cutting for roads breaks continuous forest coverage and allows for easy access to remote areas for exploitation. Loss of tropical forests results in the extinction of many valuable forest species.

(a) Morley Read/Getty Images (b) Stockbyte/Getty Images

SUMMARY

1.1 **Introduction to Zoology**

- Zoology is the study of animals. It is a broad field that requires zoologists to specialize in one or more subdisciplines.

1.2 **Zoology: An Evolutionary Perspective**

- Animals share a common evolutionary past and evolutionary forces that influenced their history.
- Evolutionary relationships are the basis for the classification of animals into a hierarchical system. This classification system uses a two-part name for every kind of animal. Higher levels of classification denote more distant evolutionary relationships.

1.3 **Zoology: An Ecological Perspective**

- Animals share common environments, and ecological principles help us understand how animals interact within those environments.
- Human overpopulation is at the root of virtually all other environmental problems. It stresses world resources and results in pollution, climate change, deforestation, and the extinction of many plant and animal species. Overuse of world resources by industrialized nations is a major contribution to environmental degradation.

Review and Apply

1.1 Introduction to Zoology

a. Why is it often necessary for zoologists to specialize in a subdiscipline within zoology?

b. Explain the statement: "The description of the natural history of *Sternula antillarum* in this section is unique, but it is not unusual."

1.2 Zoology: An Evolutionary Perspective

a. Why can zoologists use similarities in DNA, similarities in morphological characteristics, or both when investigating taxonomic (evolutionary) relationships among animals?

b. Use the taxonomic designations class, order, and family to explain how the naming system reflects evolutionary relationships and varying levels of inclusiveness.

c. Explain why it was important for zoologists to reclassify birds from "Aves" into Reptilia. In other words, why does the name matter—isn't a bird by any name still a bird?

1.3 Zoology: An Ecological Perspective

a. How would the knowledge of the natural history, evolution, and ecology of *Sternula antillarum* have contributed to the successful recovery plan enacted by the USFWS?

b. The ecological problems facing our world stem from behaviors of humans from lower-income, middle-income, and higher-income regions of the world. What characteristics of human activity in each of these regions contribute to environmental degradation?