Eleventh Edition

Zoology

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Mc Graw Hill Education

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PREFACE

As the senior author of *Zoology*, I (Stephen Miller) am very pleased to present the eleventh edition of this textbook. I have been associated with this book from its inception. The initial planning, writing, and revision of *Zoology* through preparing this latest edition involved tasks that have spanned more than 30 years of my life. I am honored to have played a small part in the training of zoologists and other biologists, most of whom I will never know personally. Similarly, it has been an honor to feel a connection to the professors who use *Zoology* in their courses and who deserve the credit for mentoring future scientists. The processes of writing and revision have involved many joys, and some headaches, for me personally. I hope these efforts have helped inspire bright young minds to strive to make our planet a better place than Earth would have otherwise been.

I believe the comments of student users and reviewers of this textbook when they say that the strengths of this book lie in presentation of relevant, up-to-date zoological concepts in a friendly writing style. A book that is not read cannot inform and inspire. These strengths are carried on into the eleventh edition. Our goal has been to present zoology as a dynamic field that is critical to understanding and preserving of our planet and to present zoology in a format that is adaptable to a variety of one- or two-semester course formats.

As important as it has been for us to maintain the focus and goals of *Zoology*, change is inevitable. Two important changes faced us in this revision. The first change was the retirement of Dr. John Harley as coauthor. He has been with the book, nearly from the beginning. I wish him the best in his retirement. The second, and very welcome, change was the addition of Dr. Todd Tupper to the book team. Todd teaches general zoology at Northern Virginia Community College. He has earned both teaching and professional achievement awards. Todd involves students in his research and writing, has been a reviewer of the book, has served as an invited contributor to the tenth edition, and has used the book in his classes for many years. I have come to know Todd as someone who lives and breathes zoology and has a hunger for passing his devotion on to students. His expertise is in herpetological conservation, and you will see his ecologically minded fingerprints throughout this edition. Thank you, Todd.

Todd's involvement with zoology began with brief emailed feedback with John and me. His comments were honest and constructive, and they made the book better. We have had similar feedback from other users and students, and we welcome more of the same from you. We take all of your comments very seriously. As always, as soon as we close the cover on one revision, we begin thinking about the next. That planning begins now. Please feel free to contact us at zoology.miller@gmail.com or zoology.tupper@gmail.com.

CONTENT AND ORGANIZATION

Revision for the eleventh edition of *Zoology* has been a bigger than usual undertaking. Every chapter has been carefully scrutinized, and most chapters have had significant changes. 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. A detailed explanation of the changes made to each chapter is presented in "New to the Eleventh Edition" later in this preface. The basic organization of the book is described in the following paragraphs.

Chapters 1 through 6 present cellular, evolutionary, and ecological concepts that unite zoology to biology as a whole. Chapter 2 (The Structure and Function of Animal Cells) has been completely rewritten, and the other chapters are updated with new population statistics, fresh examples, and new illustrations and photographs.

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). For those familiar with previous editions, you will note that chapter 8 is new. We believe that the addition of this chapter makes sense. It should help students move from understanding evolutionary principles (chapters 4 and 5), to knowing how zoologists organize life's diversity (chapter 7), to grasping the "big picture" of animal phylogeny (chapter 8), and to fitting animal phyla into the "big picture" (chapters 9 through 22). The trade-off that was made in presenting animal origins and diversification material in chapter 8 was to condense the coverage of the protists (chapter 8 in earlier editions) by moving it to a newly created appendix C. Instructors who want to cover these important nonanimal eukaryotes can still do so using appendix C. All of the chapters in this group, 7 through 22, include new explanations, photographs, and illustrations.

Chapters 23 through 29 have seen big changes. Although many of the excellent illustrations and photographs from the tenth edition have been retained, the text in these chapters has been largely rewritten, and in some cases reorganized. The goals of this reorganization and rewriting were to create a stronger evolutionary focus, to illustrate important unifying principles of structure and function without presenting excessive detail, and to enhance the readability of these chapters. We believe that we have accomplished these goals.

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 eleventh edition for each major section of each chapter. Each major section ends with a **Thinking Beyond the Facts** question, which requires students to

apply the information presented in the section. Possible answers to these questions are available to instructors using 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."

Each chapter ends with a **Summary** of key concepts organized by section, a set of **Concept Review Questions,** and **Analysis and Application Questions**. These questions have been carefully reviewed and revised as needed. They allow students to test their understanding of chapter concepts and to apply concepts they have learned in each chapter. Suggested answers to these questions are available to instructors through Connect. In addition to being printed in the back of the book, the glossary is 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 **Further Phylogenetic Considerations**. 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.

To further explain and support evolutionary concepts, a set of themed boxed readings entitled **Evolutionary Insights** is present throughout the book. These boxes provide detailed examples of principles covered in a chapter and provide insight into how evolutionary biology works. For example, chapter 4 includes a reading on cat biogeography that illustrates how a variety of sources of evidence are used to paint a picture of the history of one group of animals. Chapter 5 has a reading on speciation of Darwin's finches that illustrates how speciation can occur. Chapter 18 has a reading on the evolution of the vertebrate limb, and chapter 25 has a reading on the evolution of hormone receptors.

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 including a newly written section entitled "Earth's Resources and Global Inequality" in chapter 6. The ecological perspective is reinforced by 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.

The Process of Science

To help students understand that science is a process, not just a body of facts, **How Do We Know** boxed readings are retained in this edition and they highlight research results that provide insight into biological processes. Chapter 9 has a boxed reading entitled "How Do We Know about Sponge Defenses?" This reading describes how zoologists investigated sponge defense mechanisms. Chapter 19 has a boxed reading entitled "How Do We Know about Amphibian Skin Toxins?" This reading describes how scientists are studying antibacterial and anticancer effects of amphibian skin toxins. Students learn that these studies have implications for studying naturally occurring compounds that may aid in the development of novel pharmaceutical drugs.

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 ELEVENTH 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 importance of zoological studies in our modern world. Population, world resources, and threatened and endangered species statistics have been updated with 2018 data. Table 1.4 is new and presents information on the major contributors of anthropogenic greenhouse gas emissions.

- **Chapter 2 (The Structure and Function of Animal Cells)**

  This chapter has been completely rewritten. It begins with the properties and common origin of cells. Coverage of cells is organized by common functions. It begins with cellular membranes and membrane transport, followed by energy processing. Five new figures (2.11–2.13 and 2.15–2.16) and new text art support an introduction to enzymes, ATP, glycolysis, the citric acid cycle, electron transport and chemiosmosis. This coverage provides important background for material that comes later, on energy flow in ecosystems, animal temperature regulation, nutrition, and related topics. The descriptions of the nucleus, ribosomes, and vaults are followed by coverage of functions of the endomembrane system, which are supported by the newly rendered figure 2.19. Peroxisomes, the cytoskeleton, and an introduction to tissues, organs, and organ systems follow. Detailed descriptions of tissue types have been moved to the appropriate system in chapters 23 through 29.

- **Chapter 3 (Cell Division and Inheritance)**

  A new section on cell-cycle control has been added to this chapter.

- **Chapter 4 (Evolution: History and Evidence)**

  The introduction to chapter 4 has been rewritten. In an era in which the validity of science is under attack, students need to be reminded of what a scientific theory is and the work involved with establishing scientific theories. We believe that the beginning of this chapter is the right place to present such a reminder. The revival of the epigenetics movement is briefly addressed. A new section entitled "Geological Time and Mass Extinctions" has been added to this chapter. This content is referenced throughout the book, and it is presented visually in appendix B, where it can be easily accessed. The "Evolutionary Insights" reading on cat phylogeny has been updated and illustrates how data from multiple disciples contribute to our understanding of evolutionary pathways. The cat phylogeny in box figure 4.1 has also been updated.

- **Chapter 5 (Evolution and Gene Frequencies)**

  In chapter 5, we have included an expanded discussion of neutral theory and genetic drift. A new example of founder effect (the brown anole lizard) is presented. The discussion of the effects of limiting gene flow through human influences is expanded with new examples that describe the loss of genetic diversity in bighorn sheep through highway construction and in polar bear populations as a result of sea-ice melting.

- **Chapter 6 (Ecology: Preserving the Animal Kingdom)**

  In chapter 6, the discussions of community stability and ecosystem trophic structure have been revised, including a discussion of biomagnification in the latter. Statistics on human population growth have been updated. We have added a new section entitled "Earth's Resources and Global Inequality," where students are challenged to consider overconsumption in western cultures. The material on biodiversity is revised with additional discussion on its preservation and five reasons it is threatened.

- **Chapter 7 (Animal Taxonomy, Phylogeny, and Organization)**

  Chapter 7 is updated with a newly written section on taxonomic methods. It compares the usefulness of analyses of genomic DNA, mitochondrial DNA, ribosomal RNA, and noncoding DNA sequences in phylogenetic studies. It emphasizes the importance of both molecular and traditional taxonomic data in these studies. There is a new discussion, and supporting figures, illustrating the construction of simple cladograms from phenotypic characters. A new "How Do We Know" boxed reading does the same using data from DNA base sequences.

- **Chapter 8 (Animal Origins and Phylogenetic Highlights)**

  Chapter 8 is new in the eleventh edition of *Zoology*. It begins with a discussion of Earth's beginning and evidence of early life. It continues by presenting what is known of events occurring within the first 3 billion years of Earth's history. It surveys hypotheses regarding life's origin and the evolution of the three domains, including the importance of horizontal gene transfer in early evolutionary events. The role of endosymbiosis in the origin of eukaryons is discussed. This presentation is followed by a discussion of the origins of multicellularity and animal origins within the eukaryotic clade Opisthokonta. The name "Apoikozoa" is introduced to designate the monophyletic choanoflagellate/animal lineage within Opisthokonta. A discussion of the Cambrian explosion follows. Chapter 8 ends with phylogenetic highlights of Animalia, including an introduction to the basal phyla, Protostomia, and Deuterostomia. We believe that this new chapter establishes a firm connection between the discussion of evolutionary theory in chapters 4 and 5, phylogenetics in chapter 7, and the survey of the animal phyla in chapters 9 through 22.

- **Chapters 9 through 17**

  Chapters 9 through 17 survey the animal phyla through the invertebrate chordates. They have been carefully revised and include smaller changes that clarify phylogenetics and natural history. We have included additional examples, often focusing on anthropogenic changes that threaten members of each group of animals. Wildlife Alerts have been rewritten in chapter 11 (freshwater bivalves) and chapter 16 (sea cucumbers). Boxed readings on sponge defenses (chapter 9) and early deuterostome evolution (chapter 17) have also been significantly revised.

- **Chapter 18 (The Fishes: Vertebrate Success in Water)**

  Chapter 18's coverage of early craniate evolution has been rewritten. The evolutionary history of early bony fishes has been revised, including new information on the evolution of paired appendages and jaws within the placoderms.

- **Chapter 19 (Amphibians: The First Terrestrial Vertebrates)**

  Revision of chapter 19 includes updated information on amphibian origins and origins of the Lissamphibia. Descriptions of all the extant amphibian orders have been rewritten with expanded coverage of the natural history of members of each order. The "Evolutionary Pressures" section has been updated and enhanced with expanded coverage and additional examples of amphibian adaptations. The section describing the endangered status of many amphibians has been rewritten and expanded. This section includes both anthropogenic threats like habitat destruction and "enigmatic" threats, including the spread of the chytrid fungus and climate change.

- **Chapter 20 (Nonavian Reptiles: Diapsid Amniotes)**

  Chapter 20 includes a new introduction to the two extant amniote lineages. We have consistently used the designations "nonavian reptiles" to refer to the traditional vertebrate class "Reptilia" and "avian reptiles" to refer to the traditional vertebrate class "Aves." These designations are intended as constant reminders of the accepted makeup of the reptilian lineage. Information on the evolution of Testudines and shell adaptations has been added. There are expanded descriptions of the natural history of the nonavian reptilian orders and squamate suborders. The "Evolutionary Pressures" section has been updated and enhanced with new examples.

- **Chapter 21 (Birds: The Avian Reptiles)**

  In chapter 21, the theropod origin of avian reptiles has been rewritten and expanded, as has the coverage of the evolution of the early birds. The discussion of the appearance of feathers and the evolution of flight has been enhanced. Figures 21.4 and 21.5 on feather structure and development are new, and the "Evolutionary Pressures" section is updated and includes additional examples to illustrate important concepts.

- **Chapter 22 (Mammals: Synapsid Amniotes)**

  Mammalian evolution within the therapsid lineage has been updated, as has mammalian classification. The "Evolutionary Pressures" section has been enhanced, and new information on human evolution has been added.

- **Chapters 23 through 29**

  Chapters 23 through 29 have been largely rewritten. The organization of all subjects in this block of chapters has been carefully examined to streamline their presentations, to ensure that they accurately portray evolutionary changes in animal systems, and to make them as reader friendly as possible. The organ-system histology formerly presented in chapter 2 is now appropriately placed in these chapters. In addition to these organizational revisions, the following content changes are present.

- **Chapter 23 (Protection, Support, and Movement)**

  The discussion of the mechanism of skeletal muscle contraction has been expanded, including new and revised figures. The comparative histology and physiology of fast and slow twitch skeletal muscle fibers, insect flight muscle, cardiac muscle, and vertebrate and invertebrate smooth muscles are explained.

- **Chapter 24 (Communication I: Nervous and Sensory Systems)**

  The presentation of concepts concerning resting membrane potentials, graded potentials, and action potentials has been clarified and enhanced. The presentation of invertebrate nervous systems has been revised to clearly reflect trends toward centralization and cephalization. Similarly, coverage of the evolution of the vertebrate brain has been rewritten with the same goal. A new "Evolutionary Insights" box describes surprising new roles for bitter taste receptors.

- **Chapter 25 (Communication II: The Endocrine System and Chemical Messengers)**

  Chapter 25 has been rewritten to provide clearer descriptions of the evolution and diversity of chemical messengers and the principles of negative and positive feedback control of hormonal functions. Both invertebrate and vertebrate endocrine systems are discussed in a phylogenetically meaningful organization.

- **Chapter 26 (Circulation and Gas Exchange)**

  In addition to clearer and more accurate descriptions of the evolution of vertebrate hearts, chapter 26 has a new discussion of oxygen and carbon dioxide transport, including discussions and illustrations of oxyhemoglobin dissociation curves.

- **Chapter 27 (Nutrition and Digestion)**

  Chapter 27 has a new discussion of the evolution of heterotrophy and a new "Evolutionary Insights" boxed reading on gut microbiomes.

- **Chapter 28 (Temperature and Body Fluid Regulation)**

  Chapter 28 includes a new presentation of temperature regulation, including a new figure 28.3 depicting strategies for animal thermoregulation. The sections on osmoregulation and excretion have been updated. The descriptions of invertebrate nephridia are presented with an evolutionary focus. More detail is provided on the evolution of vertebrate kidneys and the physiology of the metanephric kidney.

- **Chapter 29 (Reproduction and Development)**

  This chapter has been streamlined throughout, and the section on vertebrate reproduction has been enhanced; it now includes a stronger evolutionary focus and a clearer description of hormonal regulation of the human reproductive function.

- **Appendices**

  The eleventh edition of *Zoology* has moved some material into three appendices. Appendix A presents one interpretation of animal phylogeny that is developed and used in the textbook. 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 tab these appendices for quick referral. Appendix C covers the Protozoa. The content of appendix C has been revised and condensed from its appearance in chapter 8 of the tenth edition. 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

We wish to thank reviewers who provided feedback and analysis of the revision plan for the eleventh edition. In the midst of their busy teaching and research schedules, they took time to consider our proposed revisions and offered constructive advice that greatly improved the eleventh edition. We also appreciate the help of individuals who reviewed portions of the eleventh edition manuscript. Dr. Chris Barnhart from Missouri State University provided valuable feedback on the content of the Wildlife Alert on endangered freshwater mussels (chapter 11). His remarkable photographs greatly enhance our understanding of the plight of these animals. Lastly, we'd like to sincerely thank the students and biology faculty at NOVA, Alexandria, for helping to prompt meaningful inquiry and discussion that ultimately led to many of the revisions present in the eleventh edition.

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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. Justin Wyatt and Michael Ivanov served as our Portfolio Mangers during this revision. They have guided *Zoology* through the author transition process, and they have worked very hard as advocates of the extensive revisions present in the eleventh edition. Elizabeth Sievers, Senior Product Developer, coordinated all of the tasks involved with publishing this edition. We learned to expect her emails at all hours of the day, and we are still amazed at her ability to guide reviews, manuscript, figure and table revisions, and new photographs into their proper places in the final version you have in front of you. Thank you for your patience with us on the many occasions that we submitted revised material and then resubmitted the same with additional changes. We know that we must have caused you moments of frustration beyond words. Lisa A. Bruflodt and Amber Bettcher served as Content Project Managers for this edition. We appreciate their efficiency and organization.

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 the eleventh edition. Carol, an accomplished musician, spent many hours proofreading *Zoology* for grammatical errors. Over the past 25 years, she has become a much better zoologist than her husband has become a musician—something about practicing got in his way. Todd's parents, Pamela and Edward Tupper, and his long-time mentor, Dr. Paul Gurn, have been steadfastly supportive and consistently encouraged his commitment to studying and protecting wildlife. We dedicate this book to our families. We send a special memorial dedication to Kasia Wilczak and Dr. Noble S. Proctor—may you rest in peace.

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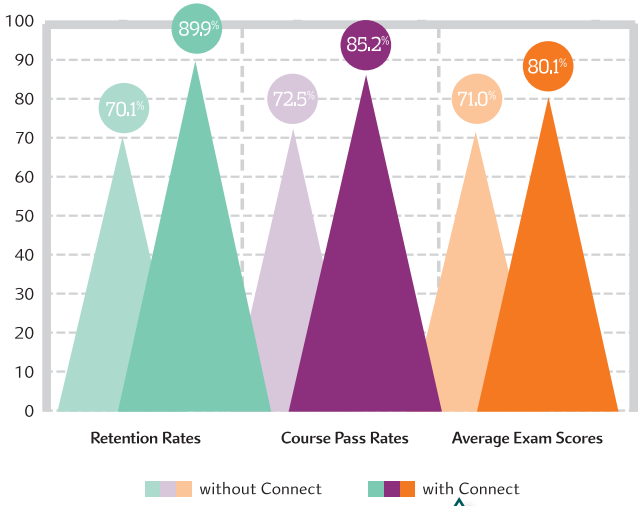

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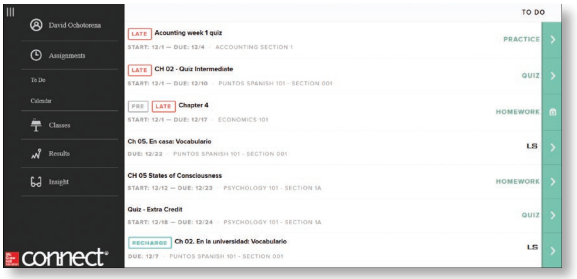

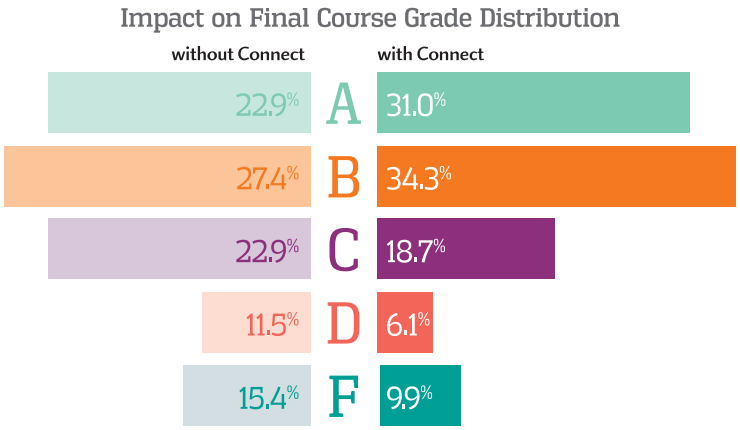

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Generations of Luo fishermen on Lake Victoria, Africa, have caught cichlid fish, including tilapia, as a mainstay of their economy. Recent introductions of the Nile perch (*Lates niloticus*) has changed the Lake Victoria ecosystem and the fishing economy of the lake.

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 and the evolutionary processes that produced this diversity. 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 and zoological principles that help us understand how delicate ecological balances are being challenged and why these challenges impact animals and their environments in specific ways. 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, for example, more than 28,000 described species of bony fishes and more than 400,000 described (and many more undescribed) 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).

Ichthyology, for example, is the study of fishes, and ichthyologists work to understand the structure, function, ecology, and evolution of fishes. These studies have uncovered an amazing diversity of fishes. One large family of bony fish, Cichlidae, contains 2,000 to 3,000 species. Members of this family include the familiar *Tilapia* species that grace our dinner plates and a host fish that hobbyists maintain in freshwater aquaria. Cichlid species range in length from 2.5 cm to 1 m and have an enormous variety of color patterns (figure 1.1), habitats, and body forms. Ichthyologists have described a wide variety of feeding habits in cichlids. These fish include algae scrapers like *Eretmodus* that nip algae with chisel-like teeth; insect pickers like *Tanganicodus;* and scale eaters like *Perissodus*.

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

All cichlids have two pairs of jaws. The mouth jaws are used for scraping or nipping food, and the throat jaws are used for crushing or macerating food before it is swallowed.

Many cichlids mouth brood their young. A female takes eggs into her mouth after the eggs are spawned. She then inhales sperm released by the male, and fertilization and development take place within the female's mouth! Even after the eggs hatch, young are taken back into the mouth of the female if danger threatens (figure 1.2). Hundreds of variations in color pattern, body form, and behavior in this family of fishes illustrate the remarkable diversity present in one relatively small branch of the animal kingdom. Zoologists are working around the world to understand and preserve this enormous diversity.

(a)

(b)

FIGURE 1.1

Cichlids. Cichlids of Africa exist in an amazing variety of color patterns, habitats, and body forms. (*a*) This dogtooth cichlid (*Cynotilapia afra*) is native to Lake Malawi in Africa. The female of the species broods developing eggs in her mouth to protect them from predators. (*b*) The fontosa (*Cyphontilapia fontosa*) is native to Lake Tanganyika in Africa.
(a) ©Blickwinkle/Alamy (b) ©ella1977/Shutterstock

Section 1.1 Thinking Beyond the Facts

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

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.

Animals share a common evolutionary past and evolutionary forces that influenced their history. Evolutionary processes are

FIGURE 1.2

A Scale-Eating Cichlid. Scale-eaters (*Perissodus microlepis*) attack from behind as they feed on scales of prey fish. Two body forms are maintained in the population. In one form, the mouth is asymmetrically curved to the right and attacks the prey's left side. The second form has the mouth curved to the left and attacks the prey's right side. Both right- and left-jawed forms are maintained in the population and prey do not become wary of being attacked from one side. *Perissodus microlepis* is endemic (found only in) to Lake Tanganyika. A male with its brood of young is shown here.
Courtesy of Dr. Kazutaka Ota, University of Kyoto, Laboratory of Animal Ecology, Japan

remarkable for their relative simplicity, yet they have had awesome effects on life-forms. These processes have resulted in an estimated 4 to 10 million species of animals living today. (Over 1.5 million animal species have been described, and about 10,000 new species are added each year.) Many more, about 90%, existed in the past and have become extinct. Zoologists must understand evolutionary processes if they are to understand what an animal is and how it originated.

Evolutionary Processes

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. Since that time, biologists have become convinced that evolution occurs. The mechanism proposed by Darwin has been confirmed and now serves as the nucleus of our broader understanding of evolutionary change (*see chapters 4 and 5*). Our modern understanding of evolution has become one of the two most important unifying concepts within zoology and the most important concept that links zoology to other biological sciences. Evolutionary principles help us understand the origin and evolution of early life-forms (*see chapter 8*) and why animals look and behave as they do.

Understanding how the diversity of animal structure and function arose is one of the many challenges faced by zoologists. For example, the cichlid scale eaters of Africa feed on the scales of other cichlids. They approach a prey cichlid from behind and bite a mouthful of scales from the body. The scales are then stacked and crushed by the second set of jaws and sent to the stomach and intestine for protein digestion. Michio Hori of Kyoto University found that there were two body forms within the species *Perissodus microlepis.* One form had a mouth that was asymmetrically curved to the right, and the other form had a mouth that was asymmetrically curved to the left. The asymmetry results in right-jawed fish approaching and biting scales from the left side of their prey and the left-jawed fish approaching and biting scales from the right side of their prey. Both right- and left-jawed fish have been maintained in the population; otherwise, the prey would eventually become wary of being attacked from one side. The variety of color patterns within the species *Topheus duboisi* has also been explained in an evolutionary context. Different color patterns arose as a result of the isolation of populations among sheltering rock piles separated by expanses of sandy bottom. Breeding is more likely to occur within their isolated populations because fish that venture over the sand are exposed to predators.

Animal Classification and Evolutionary Relationships

Evolutionary principles also help us understand the origin of the diversity of life on our planet, and to organize that diversity in ways that make sense (*see chapters 7 and 8*). This evolutionary perspective helps us understand animal relationships on the grand scale of the animal kingdom, but it also helps us understand relationships on smaller scales—for example, among the 2,000 to 3,000 cichlid species in lakes around the world.

Groups of individuals are more closely related if 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.) Genetic studies suggest that the oldest populations of African cichlids are found in Lakes Tanganyika and Kivu, and from these the fish invaded African rivers and Lakes Malawi, Victoria, and other smaller lakes (figure 1.3). The history of these events is beginning to be understood and represents the most rapid known origin of species of any animal group. For example, the origin of Lake Victoria's cichlid species has been traced to an invasion of ancestral cichlids, probably from Lake Kivu approximately 100,000 years ago. Today, Lake Kivu has only 15 species of cichlids. This invasion continued up to about 40,000 years ago when volcanic eruptions isolated the fauna of Lakes Kivu and Victoria. That time period is long from the perspective of a human lifetime, but it is a blink of the eye from the perspective of evolutionary time. There is firm geological evidence that Lake Victoria nearly dried out and then refilled 14,700 years ago. This event probably did not result in the extinction of all cichlids in the lake because the lake basin may have retained smaller bodies of water, and thus refuges for some cichlid species. After Lake Victoria refilled, these refuge populations provided the stock for recolonizing the lake. More than 500 species of cichlids inhabited Lake Victoria by the beginning of the twentieth century. Many of these species evolved in fewer than 15,000 years. This very rapid evolution is a phenomenon referred to as evolutionary plasticity (*see chapter* 5).

How Do We Know about Genetic Relationships among Animals?

As shown by the example of Lake Victorian cichlids, zoologists often ask questions about genetic relationships among groups of animals. These family relationships are depicted in tree diagrams throughout this book. Early studies of genetic relationships involved the analysis of inherited morphological characteristics like jaw and fin structure that can be readily measured. With the advent of molecular biological techniques, zoologists have added to their repertoire of tools the analysis of variation in a series of enzymes, called allozymes, and DNA structure. These techniques allow zoologists to directly observe genetic relationships because the more DNA that two individuals, or groups of individuals, share, the more closely they are related. Because proteins, like enzymes, are encoded by DNA, variations in the structure of a protein also reflect genetic relationships. The genetic relationships of cichlids described in this chapter were investigated using a combination of morphological characteristics and molecular techniques. These topics are discussed in more detail in chapters 3, 4, and 5.

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, the cichlid scale-eater *Perissodus microlepis*—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). 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.

FIGURE 1.3

Lakes Victoria, Kivu, Tanganyika, and Malawi. These lakes have cichlid populations that have been traced by zoologists to an ancestry that is approximately 200,000 years old. Cichlid populations originated in Lake Kivu and Lake Tanganyika and then spread to the other lakes.

Evolutionary theory has affected zoology like no other single theory. It has impressed scientists with the fundamental unity of all of life. As the cichlids of Africa illustrate, evolutionary concepts hold the key to understanding why animals look and act in their unique ways, live in their particular geographical regions and habitats, and share characteristics with other related animals.

Section 1.2 Thinking Beyond the Facts

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

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.

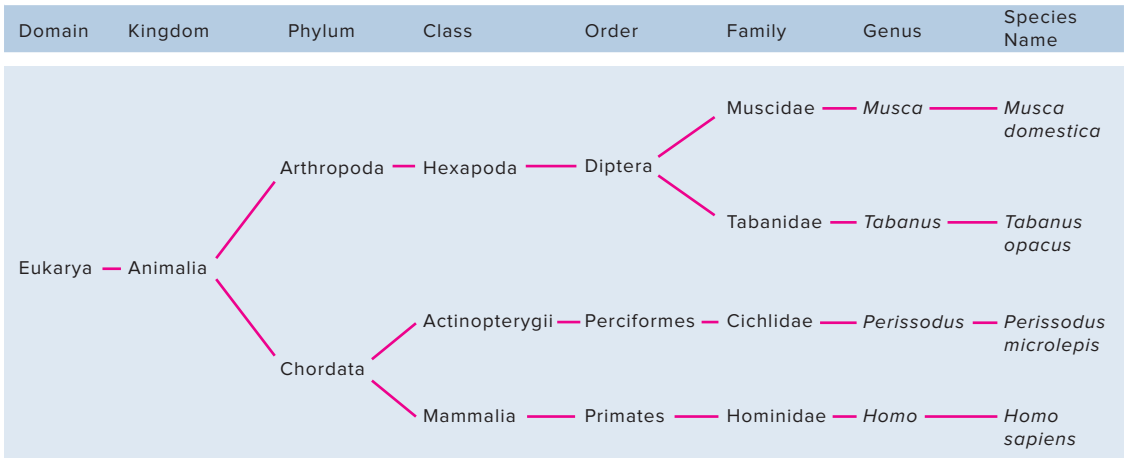


FIGURE 1.4

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

Modern zoology requires an ecological perspective. It is the 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*). Throughout our history, humans have depended on animals, and that dependence too often has led to exploitation. We depend on animals for food, medicines, and clothing. We also depend on animals in other, more subtle ways. This dependence may not be noticed until human activities upset the delicate ecological balances that have evolved over hundreds of thousands of years.

In the 1950s, the giant Nile perch *(Lates niloticus)* was introduced into Lake Victoria in an attempt to increase the lake's fishery (figure 1.5). This voracious predator reduced the cichlid population from 80% to less than 1% of the total fish biomass (total mass of all fish in the lake). Predation by the Nile perch has also resulted in the extinction of 65% of the cichlid species. Because many of the cichlids fed on algae, the algae in the lake grew uncontrolled. When algae died and decayed, much of the lake became depleted of its oxygen. The introduction of nonnative water hyacinth, which has overgrown portions of the lake, has resulted in further habitat loss. To make matters worse, when Nile perch are caught, their excessively oily flesh must be dried. Fishermen cut local forests for the wood needed to smoke the fish. This practice has resulted in severe deforestation around Lake Victoria. The resulting runoff of soil into the lake has caused further degradation. Decreased water quality not only presented problems for the survival of individual cichlids, but also increased turbidity that interfered with critical behavioral functions. Many of these species rely on their bright colors as visual cues during mating. Mouth-brooding species rely on vision to pick up developing eggs. The loss of Lake Victorian cichlids may be the largest extinction event of vertebrate species in modern human history.

There are some hopeful signs in this story. Although many Lake Victorian species have been lost forever, some cichlids are recovering. Heavy fishing pressure on the Nile perch has reduced its population density. (It still comprises more than 50% of catch weight—down from about 90% in the 1980s.) This decline has promoted the recovery of some cichlids that feed on small animals in the upper portions of open-water areas. (The Nile perch is predominately a bottom-dwelling predator.) One cichlid (*Haplochromis pyrrhocephalus*) is faring better than most other cichlid species. Over a 20-year period, scientists have observed rapid evolution of increased gill surface area and associated changes in head morphology, which have allowed this species to survive the lowered oxygen concentrations now present in Lake Victoria.

The Lake Victoria example also illustrates how ecological decisions made for economic reasons can have far-ranging economic and ecological consequences. Nile perch are marketed to Nairobi, the Middle East, and Europe to restaurants and fish markets. The hide is used in belts and purses, and the urinary bladder is used in oriental soup stock and as filter material by European alcohol producers. Catching, processing, and marketing such large fish to diverse foreign markets have resulted in the fishing and processing industries being taken from the hands of local fishermen and processors. These functions are primarily the work of large-boat fishing fleets and large fish-processing corporations. Changes in the local economy to agriculture have resulted in deforestation of the surrounding landscapes, and untreated sewage and agricultural and industrial runoff have further polluted Lake Victoria.

World Resources and Endangered Animals

There is grave concern for the ecology of the entire world, not just Africa's greatest lakes. The problems, however, are most acute in developing countries, which are striving to attain the same wealth as industrialized nations. Two problems, global overpopulation and the exploitation of world resources, are the focus of our ecological concerns.

FIGURE 1.5

Introduction of the Nile perch (*Lates niloticus*) in an attempt to improve Lake Victoria's fishery has resulted in the extinction of many cichlid species and has indirectly contributed to decreased water quality and deforestation. Commercial fishing is the primary means for control of Nile perch, and it is reducing perch populations and aiding in the recovery of native species.

Population

Global overpopulation is at the root of virtually all other environmental problems. Human population growth is expected to continue in the twenty-first century. Virtually all of this growth is in less developed countries, where 6.3 billion out of a total of 7.6 billion humans now live. Since a high proportion of the population is of childbearing age, the growth rate will increase in the twenty-first century. By the year 2050, the total population of India (1.71 billion) is expected to surpass that of China (1.38 billion) and the total world population will reach 9.7 billion. The 2018 U.S. population will reach 329 million. In 2050, it is projected to increase to 389 million. Even though Africa does not have the highest human population, its population is increasing more rapidly than other major regions of the world (table 1.3). As the human population grows, the disparity between the wealthiest and poorest nations is likely to increase.

TABLE 1.3

WORLD POPULATION PROJECTIONS FOR MAJOR WORLD REGIONS: 2018 AND 2050 (PROJECTED)

WORLD REGION	2018	2050 (PROJECTED)
World	7.6	9.7
Africa	1.03	2.39
Asia	4.16	5.16
Europe	0.74	0.71
Latin America and Caribbean	0.60	0.78
North America	0.35	0.45

Population sizes are based on figures from the United Nations Department of Economics and Social Affairs (2015) and expressed in billions of people.

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 expected to continue 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 1.6). 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 (human-made) 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

(a)

(b)

FIGURE 1.6

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.

WILDLIFE ALERT

An Overview of the Problems

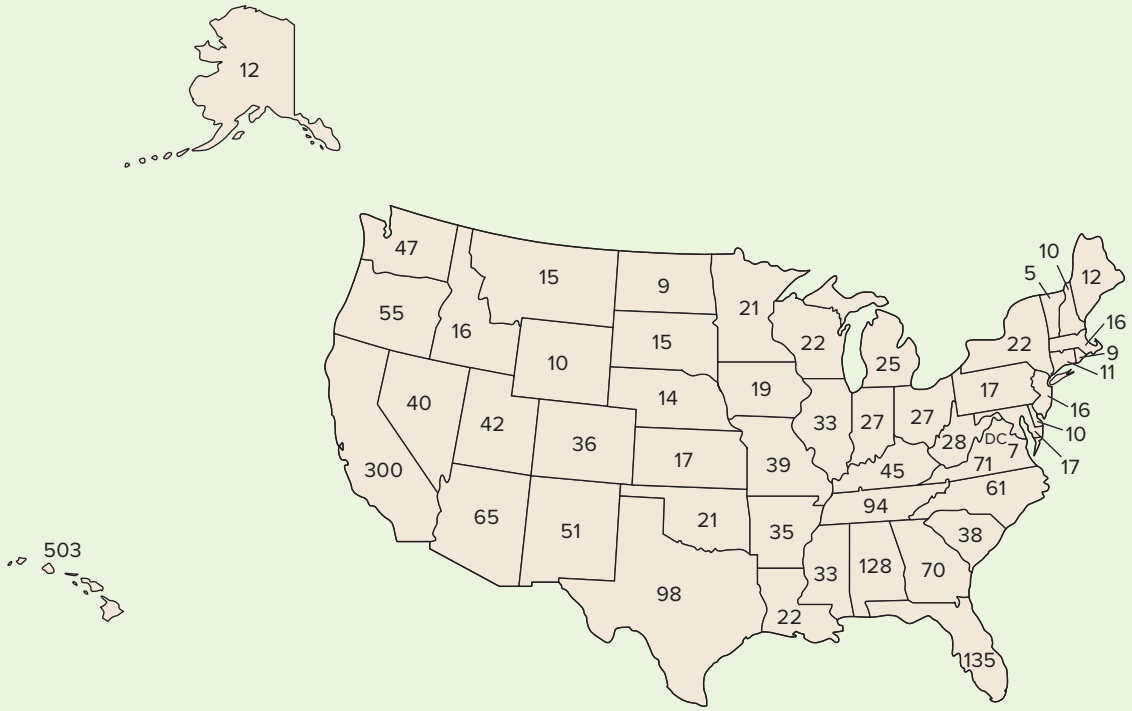
Extinction has been the fate of most plant and animal species. It is a natural process that will continue. In recent years, however, the threat to the welfare of wild plants and animals has increased dramatically—mostly as a result of habitat destruction. Tropical rain forests are one of the most threatened 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 2017, the U.S. Fish and Wildlife Service lists 2,408 species in the United States as endangered or threatened. The IUCN has assessed over 91,000 species worldwide and of these nearly 26,000 species are listed as endangered or threatened. (Recall that it is estimated that there are between 4 and 100 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.

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

1. A global system of national parks 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 2,408. The total number of listed animals is 1,458, with fish having the greatest number of listed species.

TABLE 1.4
MAJOR CONTRIBUTORS OF ANTHROPOGENIC GREENHOUSE GAS EMISSIONS

COUNTRY	$MTCO_2EQ$*	PERCENT OF WORLD TOTAL
China	11,735	26.9
United States	6,280	14.4
European Union (28 countries)	4,225	10.0
India	2,909	6.7
Russia	2,199	5.0
Canada	738	1.7

*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. These 2013 data exclude land-use change and forestry and are from the World Resources Institute.

emissions are China, the United States, and the European Union (table 1.4). These three industrialized regions account for one-half of the greenhouse gas emissions.

Solutions

An understanding of basic ecological principles can help prevent ecological disasters like those we have described. Understanding how matter is cycled and recycled in nature, how populations grow, and how organisms in our lakes and forests use energy is fundamental to preserving the environment. There are no easy solutions to our ecological problems. Unless we deal with the problem of human overpopulation, however, solving the other problems will be impossible. We must work as a world community to prevent the spread of disease, famine, and other forms of suffering that accompany overpopulation. Bold and imaginative steps toward improved social and economic conditions and better resource management are needed.

"Wildlife Alerts" that appear within selected chapters of this text remind us of the peril that an unprecedented number of species face around the world. Endangered or threatened species from a diverse group of animal phyla are highlighted.

Section 1.3 Thinking Beyond the Facts

What is another example of how the careless disregard of ecological relationships has resulted in detrimental environmental consequences? (If you cannot think of an example on your own, see the "Wildlife Alert" boxes in subsequent chapters.)

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.
- Evolution explains how the diversity of animals arose.
- 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.

Concept Review Questions

1. At least three of the following are examples of specialization in zoology. Select the one choice that is not a specialization in zoology or select choice "e."
   a. Ichthyology
   b. Mammalogy
   c. Ornithology
   d. Histology
   e. All of the above are examples of specializations in zoology.
2. A change in the genetic makeup of populations of organisms over time is a definition of
   a. binomial nomenclature.
   b. organic evolution.
   c. evolution.
   d. ecology.
3. Which of the following do zoologists use to study the genetic relationships among animals?
   a. Inherited morphological characteristics
   b. Enzyme structure
   c. DNA structure
   d. All of the above are used by zoologists to study genetic relationships.