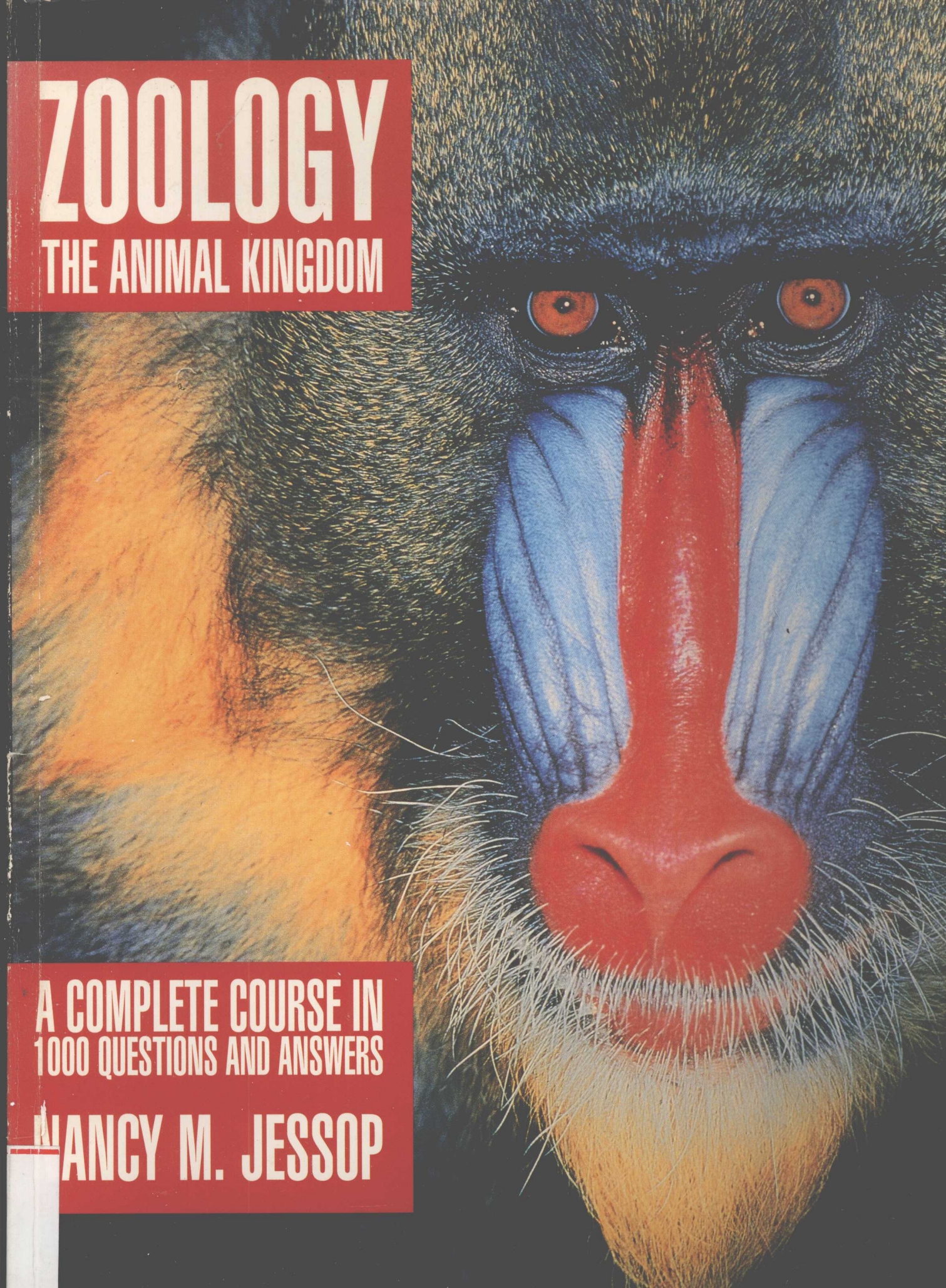# ZOOLOGY
## THE ANIMAL KINGDOM

## A COMPLETE COURSE IN
### 1000 QUESTIONS AND ANSWERS

## NANCY M. JESSOP

# ZOOLOGY:

## THE ANIMAL KINGDOM

A Complete Course In 1000 Questions and Answers

**NANCY M. JESSOP, Ph.D.**

*Associate Professor of Life Sciences*
*Palomar College*
*San Marcos, California*

## McGRAW-HILL, INC.

*New York St. Louis San Francisco Auckland Bogotá Caracas London*
*Madrid Mexico City Milan Montreal New Delhi Lisbon*
*San Juan Singapore Sydney Tokyo Toronto*

*To my daughters, Christina and Laurel*

**NANCY M. JESSOP,** Associate Professor of Life Sciences at Palomar College, received an M.A. in Biology from the University of Oregon and a Ph.D. in Zoology from the University of California at Berkeley. She has undertaken research in the fields of experimental zoology, mammalian genetics, and animal behavior, and finds particular pleasure in observing and recording the activities of animals in the wild. Dr. Jessop is also the author of *Biosphere: A Study of Life.* She has served as secretary and education committee chairperson of the Animal Behavior Society and as a consultant to the National Science Foundation and the Commission on Undergraduate Education in the Biological Sciences.

This book is printed on recycled paper containing 10% postconsumer waste.

# Preface

In these days of rising costs of education (and everything else) it seemed a worthwhile undertaking when McGraw-Hill invited me to write a general zoology textbook that would be extremely affordable yet substantive and up to date. Forgoing colored illustrations constituted a major savings. In my opinion, detailed, uncolored scientific line drawings are often to be preferred when color does not represent reality but is used only for effect and contrast. The ways of animals are colorful enough, and so I set out to capture the innate brightness and spriteliness of the animal world as best I could through the medium of language. I had fun writing this book, and I hope that others will have fun reading it. Animals are fascinating, often delightful, frequently perplexing. Getting to know animals in their native habitats has given me unbounded pleasure right from the time I was a juvenile backyard naturalist with more curiosity than sense. I still have the curiosity, and probably very little more sense.

Creating a very economical textbook also demanded great economy with words: stringent requirements of brevity and conciseness required unflagging exercise of personal judgment as to which vital areas of zoological lore should be woefully abridged or omitted. In making these difficult decisions, I have been guided by the conviction that a textbook designed for one-term zoology courses should place its greatest emphasis on *animals* themselves, with their prismatic display of adaptations and patterns of bodily organization. Accordingly, 16 chapters out of 25 have been devoted to reasonably thorough considerations of the particular characteristics and biotic contributions of the major animal groups or phyla: each of these chapters includes the organismal biology and ecological considerations germane to the animal group under scrutiny. The remaining nine chapters (1, 2, 3, 4, 5, 8, 23, 24, and 25) present concise introductions to scientific methodology, structural organization of cells and organisms, basic chemistry, paleontology, genetic and evolutionary mechanisms, embryonic development, nutritional processes in cells and organisms, integrative mechanisms and behavior, and ecological principles.

In keeping with the scientific spirit of inquiry, this book takes the form of a series of questions and answers. As an aid to self-study, many of these text questions can be looked upon as sample examination questions, and their answers as representative short-essay examination responses. The answers given are based upon scientific methods of description or experimentation, but they should not be considered definitive, since all "answers" formulated by scientists must be held subject to revision in the light of new discoveries. Furthermore, when there is a practical need to formulate concise answers to complex questions, those answers cannot help being somewhat oversimplified and incomplete.

Despite the impressive volume of zoological data amassed to date, we should keep in mind that zoology, like other sciences, is a discipline in motion, constantly subject to revision and reinterpretation, and that zoologists, like other people, often find themselves in lively disagreement. As a case in point, the taxonomic grouping of animals on the basis of relatedness has long been an area of spirited contention, so that both students and authors come to feel frustrated by the plethora of contradictory schemes of classification found throughout the zoological literature. In due time, this confusion will subside as biochemical analysis of each species' genetic material provides quantitative means of

exact definition. Until then, both students and practitioners of zoology do well to cultivate a flexible outlook by which differing systematic constructs are seen as mere milestones along the tortuous route toward fuller understanding of the history and interrelationships of the animal world as we see it today. The taxonomic usages favored herein are not necessarily more correct than those favored by other authors; all may be subject to eventual modification on the basis of DNA analyses. The important thing is to perceive and understand animals themselves, and not to dwell unduly upon the labels which humans bestow upon them, useful as these may be.

A lifelong fascination with animals has enriched my own cognitive life, and I hope to have successfully conveyed this interest to my readers, whose lives can also be enriched by a knowledge and appreciation of our fellow creatures. Yet today this appreciation must be laced with anxiety for the fate of an appalling number of species threatened with imminent extinction by the expansion of human populations to an unprecedented 5 billion hungry bipeds. In many ways, humans need and benefit by the great diversity of animal life: now, animals need us too, for without the efforts of concerned individuals and groups throughout the world, future human generations will irrevocably be robbed of the wildlife which we ourselves have enjoyed. If this book not only informs its readers but promotes concern for the preservation of animal life, it will have achieved one of my most cherished aims.

I wish to express especial thanks to McGraw-Hill editors Jeanne Flagg and Elizabeth Zayatz for their encouragement and expert assistance, and to McGraw-Hill, Inc. for permission to reproduce a number of line drawings from that classic text, *General Zoology*, Sixth Edition, by T.I. Storer, R.C. Stebbins, R.L. Usinger, and J.W. Nybakken. I thank colleagues whom I have consulted regarding zoological particulars, but wish to state that I alone am responsible for errors of subject matter, which I hope will prove few.

Finally, I acknowledge my indebtedness to those who have been my students during the more than 30 years I have been privileged and delighted to teach young adults (of all ages) about the marvels of the animal kingdom. I sincerely hope that their minds are fuller and their vision keener for their experiences with me in classroom and field, since they have provided my inspiration for the writing of this book.

*Nancy M. Jessop*

# Contents

# Chapter 1

# Introduction to Zoology

Zoology is fun. It can enrich your life by helping you understand the fascinating diversity of creatures that share this planet with us. It can also save your life.

## 1.1. What is zoology?

*Zoology* is the scientific study of animal life.

## 1.2. What is "scientific study"?

The basic commitment of science is to collect objective *data* (facts that are observable and measurable) and then reach conclusions and formulate generalizations by analyzing such data. A generalization that represents a cohesive statement of principle is known in scientific parlance as a *theory*. (Since in nonscientific usage "theory" may connote fanciful imaginings, this unfortunate semantic difference can lead to considerable misunderstanding between scientists and other people.) No matter how firm the data base upon which a scientific theory rests, the theory must always remain subject to revision in the light of additional data.

> **Example 1:** The "theory of evolution" is actually a well-established biological principle based on an extensive array of data that indicate that living things change through successive generations: the *fact* of such change is well established, but new data continue to elucidate its *mechanisms*.

## 1.3. How do scientists go about collecting data?

Scientific methods include (*a*) collecting data by observation and (*b*) collecting data by controlled experimentation.

(*a*) When *collecting data by observation*, without experimental intervention, scientists must ensure that the data are as free as possible of subjective bias (a real pitfall since scientists are only people), recorded and analyzed instrumentally when possible, and extensive enough so that such factors as range of variability can be defined, preferably statistically.

> **Example 2:** The song of a chipping sparrow is easy to recognize by ear, but it can be recorded more objectively and accurately by a sound spectrograph, which provides a visual record of frequency, duration, and pattern to augment acoustic recordings. Enough recordings must be made to determine how much or how little variability occurs in (1) the songs of each individual bird, (2) the songs of different individuals living in close proximity, (3) the songs of chipping sparrows from different geographic regions.

(*b*) When *collecting data by controlled experimentation*, scientists begin by asking questions, which they then try to answer. A testable question is called a *hypothesis*. Hypotheses are often tested by means of a *controlled experiment*, in which one or more *experimental* groups are compared with one or more *control* (often tantamount to "normal") groups, under conditions that are held standard except for one factor, the *variable*. The number of organisms used is important: an experiment based on only a few test organisms is apt to be nonpredictive and unreliable.

> **Example 3:** *Hypothesis:* Does calcium deficiency have detrimental effects on animal growth, health, and longevity?
>
> *Experiment:* The subject organisms (preferably siblings of inbred strains to accentuate genetic likeness), selected for similarity in age and original weight, are maintained under identical conditions *except* that the controls are given a diet with normal (but precisely measured) amounts of calcium, whereas the experimental groups are fed diets in which the calcium content is reduced by some known amount.
>
> *Conclusion:* Measurable and reproducible differences appearing between the control and experimental groups indicate effects of calcium deficiency upon the latter.

A verified conclusion becomes a *datum* (fact) that, summated with enough other compatible data, may contribute to the formulation of a theory (cohesive statement of principle). *Theory:* Calcium is widely required in the animal world for skeletal growth and the normal functioning of nerves and muscles.

**Example 4:**   Venomous American coral snakes are conspicuously banded in red, yellow, and black; they appear to be avoided by most predators. Why?

Two hypotheses suggest themselves: (*a*) the avoidance may be a learned response based on the predators' having recovered from a nonlethal bite; (*b*) the avoidance may be instinctive and shown by animals that never have been bitten. For testing these hypotheses, the major aspects of "control" are that predators of known life history must be used as subjects, and these must be offered sample objects of several patterns.

*Experiment:* Motmots (a tropical American bird species known to eat snakes in the wild) were raised in captivity so that they would have no experience with any snakes. Offered a selection of differently painted rods (as an artificial version of snakes), the naive motmots readily pecked at rods that were longitudinally striped in yellow and red or ringed in green and blue, but consistently avoided rods ringed end to end in red and yellow. (Note that the striped model served as a *control* to see if the birds would respond to red and yellow, regardless of pattern, as "warning colors," whereas the green-and-blue model served as control to determine whether the birds would avoid a ringed model even if it were not red and yellow.)

*Conclusion:* Naive motmots innately avoid rod-shaped models painted with alternating red and yellow rings.

This leads to the *tentative* conclusion that inexperienced motmots would also avoid attacking live coral snakes; if you don't mind risking your tame motmots, the next step would be to go collect some coral snakes.

**Example 5:**   Sometimes the control and experimental aspects of an experiment must be carried out sequentially, rather than being conducted simultaneously on two different groups. An example of this is Niko Tinbergen's classic field experiments on the homing behavior of digger wasps.

The female wasp digs burrows in which she lays her eggs, after which this diligent mama works ceaselessly to bring fresh insects to feed her young. Upon leaving a burrow, the wasp makes a localized reconnoitering flight, which looks as if she were fixing in her tiny brain landmarks that would enable her to find the burrow again. Such a conclusion cannot be assumed; it must be tested.

The investigator first recorded the wasp's behavior free of interference (the control); then, after the wasp had left the scene, he modified the setting to see if this impaired her ability to find the burrow when she returned with food (the experiment). For instance, while the mother wasp was within the burrow, the investigator would simply place a ring of pinecones around the burrow, and after she had flown away to gather more prey, he would shift the circle of cones a short distance to one side. On her return the mother would home on the ring of pinecones, losing track of the burrow because the landmarks had been moved. Since this behavior was verified in a number of these wasps, it could be concluded that, yes, such wasps really do acquire a "photographic memory" of landmarks during the brief circling flight they engage in after exiting the burrow.

Did these examples raise new questions in your mind? If so, you are coming to understand how science progresses; every question answered seems to lead to more, so that scientific investigation may have all the excitement of detective work.

## 1.4.   What constitutes "life"?

Life is defined by its properties; all animals *and* plants share certain fundamental characteristics of life, which are listed in Table 1.1.

**Example 6:**   Bodily changes between rest and exercise exemplify *adaptability* of the individual: the heart beats more rapidly and forcibly, the lungs take in deeper and more frequent breaths, the circulatory system shunts blood away from digestive organs to the muscles and skin, extra red blood corpuscles enter the bloodstream from the spleen, and so forth. These changes are temporary, but with continued training, growth of muscle fibers, a slower, stronger heartbeat, and other more lasting benefits accrue. Such adaptive changes are *not* genetically transmissible to the offspring.

**Table 1.1   Characteristics of Living Organisms**

| | |
|---|---|
| Reproduction | The process of producing new generations of genetically similar organisms; may be *asexual* (single parent) or *sexual* (recombination of genes from two interacting parents). |
| Adaptation | The process of changing to promote survival; includes (*a*) *adaptability* of individual organism in direct response to some specific challenge (Example 6) and (*b*) *mutability* (alteration) of genes and chromosomes, which occurs at random and not in response to specific need, producing a range of variability in offspring (Examples 7 and 8). |
| Irritability | Ability to sense and respond adaptively to external and internal stimuli. |
| Endogenous (self-generated) motility | Not all organisms are capable of locomotion (mobility) during all stages of their lives, but no matter how stationary an organism itself may be, *self-generated* movement of body parts does occur (e.g., plants' foliage turns toward light and roots turn toward gravity). |
| Nutrition | The process of obtaining and using substances (nutrients) for growth, maintenance, and reproduction. |
| Ingestion | Taking in nutrients. |
| Digestion | Mechanical and chemical breakdown of nutrients. |
| Absorption | Uptake into tissues of products of digestion. |
| Internal transport | Distribution of foods, wastes, etc., through the body, often by means of a circulatory system. |
| Metabolism | Chemical conversion of nutrients within the cells; includes (*a*) *catabolism*, which is the breakdown of large molecules into smaller ones, with liberation of energy, and (*b*) *anabolism*, which is the synthesis of larger molecules from smaller ones, with the use of some of this energy. |
| Respiration | Exchange of gases involving, for animals, net uptake of oxygen ($O_2$, used in making water as a catabolic end product) and net removal of carbon dioxide ($CO_2$, another product of catabolism). |
| Excretion* | Removal of metabolic wastes, such as ammonia and urea, or any substance present to excess, as needed to maintain the body's state of dynamic chemical equilibrium (*homeostasis*). |
| Nucleic acids | DNA (deoxyribonucleic acid) and RNA (ribonucleic acid), which are macromolecules synthesized by all living organisms and on which all biological reproduction depends. |
| Proteins | Macromolecules of nearly infinite variety that perform many functions: structural components (collagen in connective tissue), hormones, oxygen-binding molecules (hemoglobin), enzymes that catalyze (facilitate) chemical reactions (e.g., pepsin, a protein-digesting enzyme). |

*Excretion should not be confused with *egestion*, which is removal from the body of undigested residues that have never actually been absorbed into the cells.

**Example 7:**   *Mutations* are changes that occur in the hereditary material, especially when genes and chromosomes are reproducing themselves. They occur spontaneously and can also be induced by *mutagenic agents* such as certain chemicals and forms of radiation. These changes *are* transmissible to offspring, provided they take place in reproductive cells. If this is the case, then all body cells of the new individual will carry the mutation; many mutations are *recessive* and neither help nor harm that individual, although the next generation may be affected (e.g., albinism).

**Example 8:**   Environmental circumstances may define the survival value of a mutant trait. The very restricted habitat of the white gypsum sand dunes of White Sands National Monument, New Mexico, is successfully inhabited by whitish varieties of both mammals and reptiles, whose darker relatives inhabit the surrounding desert but lack protective coloration for the dunes. In this case a minor genetic change affecting coloration has opened up an entire new habitat for exploitation by the mutant organisms.

### 1.5.  What is an animal?

The word itself, from the Latin *anima* ("breath," "soul"), implies a being that is animated (lively), mobile, and sentient, a bit much to ask of a sponge! Yet sponges are animals. So, more conservatively, let us say that an *animal* is an *organism* (living thing) that as a rule ingests organic materials (proteins, fats, carbohydrates, etc.) and digests them internally.

### 1.6.  How does animal life differ from plant life?

The major differences between most plants and animals are outlined briefly in Table 1.2.

Although the basic unit of structure and function of both plants and animals is the *eukaryotic cell* (i.e., nucleated cell; see Chapter 2) and plant and animal cells are so much alike as to strongly suggest a common ancestor, there are two salient points of difference: (*a*) animal cells lack *chloroplasts*, which are plants' photosynthetic factories, and (*b*) animal cells are not enclosed in the nonliving *cell walls*, composed mainly of *cellulose*, which furnish structural rigidity to plants.

**Table 1.2   Some Major Differences between Plants and Animals**

|  | Plants | Animals |
|---|---|---|
| Mode of nourishment | Autotrophic (carry out photosynthesis; contain chloroplasts) | Heterotrophic (do not photosynthesize; lack chloroplasts) |
| Extent of growth | Indeterminate | Determinate |
| Cell wall | Cellulose (long glucose chain); rigid, inert | Absent |
| Nervous system | Absent | Present in most |
| Mobility | Mostly immobile | Mostly mobile |
| Primary food reserve | Starch (unbranched glucose chain); unsaturated oils | Glycogen (multiply branched glucose chain); saturated fats |
| Waste products | $O_2$ from photosynthesis, $CO_2$ from metabolism; kidneys not needed since nitrogenous wastes not generated | $CO_2$ and nitrogenous wastes; kidneys needed in most animals |

Owing to the presence of chloroplasts, most plants carry on *autotrophic* (self-nourished) *nutrition* through the process of photosynthesis; by converting radiant energy into chemical bonding energy, autotrophs build simple sugars out of carbon dioxide and water, giving off oxygen as a waste product. Although this process will not be dwelt upon in a book about animals, we should pay it due homage, because in the absence of autotrophic plants, animal life could not exist, for want of both food to eat and atmospheric oxygen to breathe. Animals exhibit *heterotrophic nutrition:* they cannot construct organic molecules out of inorganic substrates. This lamentable deficiency has had prodigious consequences, for it is fundamental to the evolutionary divergence of animals and plants. A lineage of organisms that has had to search out, apprehend, and often subdue dinners that may have their own means of resisting such fate is bound to come up with descendants remarkably different from those of autotrophic ancestry that need simply bask in the sun and absorb minerals, carbon dioxide, and water.

As a rule, plants grow throughout life (*indeterminate growth*), whereas most animals attain a certain adult size and cease to grow (*determinate growth*), compact body form being more compatible with the mobility prompted by the quest for food; all but the simplest plants are immobile.

Most animals have nervous systems and sense organs; nothing of this nature is demonstrable in plants, but some plant cells, especially at growing tips, are sensitive to certain stimuli.

Plants store much of their food reserves as *starch*, a long unbranched chain of glucose (simple sugar) molecules; the main carbohydrate food reserve of animals is *glycogen*, a highly branched chain of glucose, which yields free sugar molecules much more readily than starch does.

Animals' metabolic rates are so high that proteins are formed and broken down rapidly enough that toxic nitrogenous wastes (ammonia, urea, etc.) are produced and must be excreted as components of *urine;* plants do not produce urine and require no kidneys.

## 1.7.  Why study animals?

Animals are involved in many aspects of human existence, both contemporary and historical, and concern with animals is by no means limited to the scientific world. Directly and indirectly, more than we may realize, we rely on animals to maintain the complex, interdependent web of life that is our planetary ecosystem. The unprecedented expansion of human populations and the resultant pollution, transformation, and degradation of habitats are threatening the survival of nonhuman species as never before in historical times, making it imperative for our own long-term survival that we investigate and understand the interdependencies of species, even when these do not appear to be of direct or immediate benefit to humanity.

## 1.8.  How do animals contribute positively to human existence?

The many ways in which humans rely on animals is summarized in Table 1.3.

### Table 1.3   Human Reliance on Animals

| Benefits to Humans | Examples |
|---|---|
| Food sources | Livestock, game, fish, shellfish; animal products such as honey, eggs, and dairy products; exotic fare such as insects, grubs, and highly relished palolo worms. |
| Nonedible economic products | Leather, down, fur, silk, wool, ivory, biogenic limestone, chalk, and marble |
| Transport and labor | Horses, donkeys, llamas, camels, dogs, oxen, Asiatic buffalo, and elephants |
| Biomedical uses | |
| Products, extracts | Venoms, insulin, pig heart valves (chemically treated to destroy living pig cells and used to replace diseased human heart valves when judged superior to artificial devices), antibodies for protective inoculations (e.g., against tetanus) |
| Research | Subjects used to create animal models of human diseases and their treatment |
| Ecological value | Essential links in food chains (Example 9); essential for the pollination of most flowering plants (Example 10); agents of *biocontrol* (the maintenance of natural population balances that hold potentially detrimental plant and animal species in check) (Examples 11 and 12) |
| Psychological benefits | |
| Esthetic value | Subjects and inspiration for works of art, from cave paintings to present-day creations; some cultures revere totem animals and cultivate in themselves the positive attributes they perceive in animals. |
| Affectional bonds | Pets and residents in wildlife parks, fulfilling various noneconomic human needs; used by some psychotherapists in their work with patients (Example 13) |

**Example 9:**  Microscopic plants known as diatoms are the major photosynthesizers of the open sea, but they are so minute that only extremely tiny animals can feed upon them. These wee creatures, such as copepods, are themselves mostly too small to be collected for human consumption, but they in turn are food for infant fish and other small zooplankton. Thus, through several levels of consumption, the energy and mass trapped by diatoms eventually benefits us in the form of millions of tons of tuna, cod, and other marketable fish. Should anthropogenic pollutants (i.e., those of human origin) decimate key species of zooplankton small enough to feed directly on diatoms, the higher levels of oceanic food chains would collapse even if diatoms themselves remained abundant.

**Example 10:**  Animals are essential for the *pollination* of most flowering plants. Unwise use of pesticides can result in widespread crop failures, leaving us little to eat but grains (which are wind-pollinated). But far beyond this, if pollinator species (most of which are insects) die off globally, visualize a world depleted of most types of higher vegetation, and therefore a world in which we ourselves might be unable to survive.

**Example 11:** To avoid possible chemical insecticide injury to its valuable animal collection, the San Diego Zoo is said to rely entirely on biocontrol to protect its equally valuable plant collection, for instance, by release of laboratory-raised insectivorous (insect-eating) insects such as ladybird beetles.

**Example 12:** Hippopotamuses in Africa and manatees in Florida are important agents in clearing waterways of obstructing vegetation such as the water hyacinth.

**Example 13:** The tremendous popularity of pets and wildlife parks and the annual roster of injuries sustained when people get chummy with park bears give us a clue that animals not only are interesting to many persons but also provide some positive psychological reinforcement that may be of incalculable significance to the mental health of humanity as a whole. In fact, it has been shown that suicide rates are lower among pet owners. Empathy for nonhuman species may wear thin in regions where human nutrition is so marginal that nearly anything living is eyed with a view to edibility, but even in extreme circumstances of deprivation, people of some cultures and religions consider animals sacred and endowed with an inherent right to share the earth with humans.

Should human population levels soon stabilize and living standards rise globally, more than ever we may experience a psychological need to relate to nonhuman species. Even today the burgeoning of animal-oriented tourism attests to the importance to many people of affectional bonds with animals, even undomesticable sorts. Such psychological considerations rather than purely scientific ones often undergird the sometimes heroic measures taken to salvage species on the brink of extinction, even while human pressures on the environment are increasingly at the root of their predicament.

## 1.9.  Do animals pose any dangers to human life?

Although few animals consider humans a regular dietary item, many people still suffer death or injury from animal attacks, some predatory (e.g., by tigers, crocodiles), but most defensive (e.g., bites of venomous snakes and spiders, scorpion and insect stings). A number of animal species are dangerous human parasites that either inflict illness and death in their own right (e.g., the malaria parasite) or endanger their hosts by transmitting other disease agents (e.g., anopheline mosquitoes that carry malaria). Relatively few animal species are economically destructive, but these few (mainly insects) cause millions of dollars in damage to food crops, trees and lumber, and livestock.

## 1.10.  How can we *best* control "pest" species and guard ourselves against potentially detrimental animals?

Solutions have often been sought through ill-advised means that create more problems in the end, such as promiscuous use of chemical insecticides to which most insect pests by now have developed immunity, while the nonbiodegradable chemicals travel through food chains to harm many other life-forms. The better option seems to be to study each potentially harmful species and find out how to control it or protect ourselves through our knowledge of that species' behavior and needs.

**Example 14:** In the late nineteenth century, a parasitic insect, cottony cushion scale, was accidentally introduced into California's San Joaquin Valley, where it happily fell upon the citrus crops, with severe economic consequences. Introduction of ladybird beetles reduced the scale population to a level well below economic significance and held it there for decades. After World War II, local farmers embraced the "wonder" pesticide DDT, one immediate effect of which was the first resurgence of cottony cushion scale to economically significant levels.

By now this is an old, familiar story: broad-spectrum pesticides may unleash the very pests they seek to control by killing off the agents of biocontrol, including insectivorous insects, birds, amphibians, reptiles, and mammals. In this case, the DDT also killed the ladybird beetles that had been keeping the cottony cushion scale under control; the pest species apparently recuperated more successfully from the insecticide than the predator could, resulting in a resurgence of the pest to significant levels.

**Example 15:** Female insects of certain species are monogamous and mate only once in their lives. If they have the bad fortune to accept semen from an infertile male, they lay only unfertilized eggs. Discovery of this aspect of animal behavior is contributing to successful control of such pest species as the screwworm fly, whose larvae form hideous lesions in the hides of livestock. Screwworm flies are propagated in the laboratory, so that large numbers of males sterilized by X-radiation can be set

**Table 1.4  Major Subdivisions of Zoology**

| | Subdivision | Area of Study |
|---|---|---|
| **TAXONOMIC** | Invertebrate zoology | Animals without backbones |
| | Protozoology | Animals that are basically unicellular |
| | Helminthology | Worms (mainly parasitic) |
| | Malacology | Mollusks (snails, clams, oysters, squid, octopus) |
| | Entomology | Insects |
| | Vertebrate zoology | Animals with backbones |
| | Ichthyology | Fishes |
| | Herpetology | Amphibians and reptiles |
| | Ornithology | Birds |
| | Mammalogy | Mammals |
| **NONTAXONOMIC** | Morphological zoology | Animal structure |
| | Gross anatomy | Nonmicroscopic anatomy |
| | Paleontology | Fossils |
| | Histology | Organs and tissues at the microscopic level |
| | Cytology | Cell structure, often at electron microscopy level |
| | Physiological zoology | Animal function |
| | Organismal physiology | Body functions of the entire organism; may be studied under standard laboratory conditions or in the field |
| | Organ and cell physiology | Vital activities of organs and cells; may be monitored *in vivo* (within the living body) or *in vitro* (maintained outside the body, such as cells propagated in nutrient media as "tissue cultures") |
| | Zoological genetics | Hereditary traits and their transmission; is the basis of selective breeding; contributes significantly to the knowledge of human genetics |
| | Evolutionary zoology and systematics | Evolutionary relationships among animals; attempts to develop improved models of animal classification |
| | Zoological ecology | The relationship between animals and their *biotic* (living) and *abiotic* (physicochemical) environments; is essential to successful management of animals in the wild; includes *population dynamics*, the analysis of population structure and trends (e.g., to regulate fisheries and hunting) |
| | Animal behavior | Important to the management of wild, captive, and domestic animals and to the training of animals |
| | Ethology | Species-typical (often instinctive) behaviors exhibited in the wild (or at least under quasi-natural conditions) |
| | Animal psychology | Animal learning, particularly under controlled laboratory conditions |
| | Animal pathology and epidemiology | The causes and effects of disease processes in animals; includes the practice of veterinary medicine in zoos and even in the wild |

free wherever a screwworm outbreak is reported, swamping the wild population so that the females have a greater probability of breeding with sterile than with fertile males.

**Example 16:** The life cycle of the human liver fluke, mainly endemic in the orient, includes a period of mandatory encystment (dormancy) in the flesh of certain freshwater fishes. People get infected with this parasite only by eating raw or pickled fish. Armed with this knowledge, self-protection is

simple: cook the fish. *Knowledge*, therefore, is the key to understanding, appreciating, conserving, and controlling animal life, and much knowledge comes from scientific inquiry.

### 1.11. What are some of the things zoologists do?

The major subdivisions of zoology are listed in Table 1.4. Some zoologists devote their time to studying animals belonging to one particular taxonomic category (i.e., one of a hierarchy of levels along which animals are classified); others study one or more aspects of animal structure, function, or behavior, often using a comparative approach.

# Chapter 2

# Animal Architecture

Animal life presents a dazzling array of creatures exhibiting many body forms and ranging in size from 30-meter (m) blue whales to unicellular protozoans only a few micrometers (μm) in length (Fig. 2.1). Confronted with such diversity, we need first to recognize that biotic organization is fundamentally the same in all. The differences that distinguish various kinds of animals largely disappear at cellular levels, and pervasive similarities abound. At the molecular level, we find that for all their remarkable complexity, living things are composed of the same basic elements that make up the nonliving world, transiently organized into molecules with unique properties, by virtue of the energy of light. Stolid and massive as an elephant may be, in the last analysis it is more space than mass, a latticework of atoms briefly bound together by fettered sunlight.
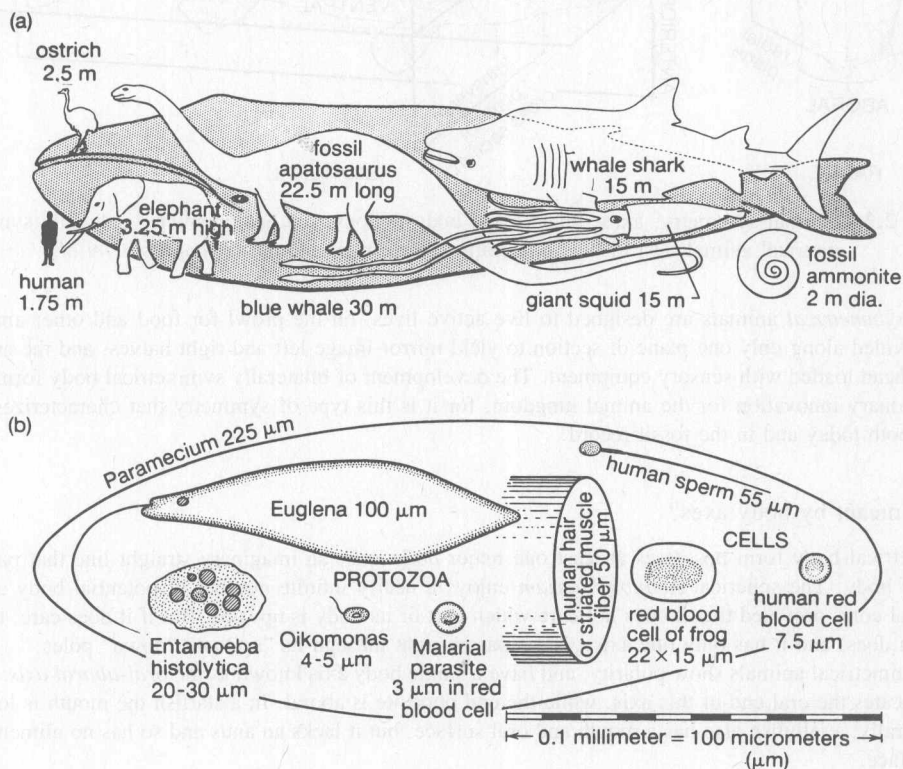
**Fig. 2.1** Size in the animal world. (*a*) Some of the largest animals compared with the human body. (*b*) One-celled animals and animal cells, shown within the outline of a *Paramecium*. (*From Storer et al.*)

## 2.1. What basic factors determine body form?

Animal bodies are made up of from one to trillions of cells, all of which are fundamentally similar, but which must interact developmentally to produce a single, coordinated living body, the *organism*, exhibiting harmonious integration of form and function, together with adaptation to some particular mode of life. The basic features of organismal form include symmetry, axial polarities, and proportionalities.

9

## 2.2. What is meant by "symmetry"?

The animal body is usually *symmetrical*, which means that it can be cut into mirror-imaged halves along one or more planes of section (Fig. 2.2). Three basic types of animal symmetry, related to three different modes of life are spherical, radial, and bilateral. *Spherically symmetrical* animals are globular, with *appendages* (extensions or limbs) radiating in all directions (e.g., the unicellular *Actinosphaerium* and *Heleosphaera* (see Fig. 6.5a); they are usually buoyant drifters. *Radially symmetrical* animals display the symmetry of a wheel or umbrella with body parts radiating from a single central axis (e.g., jellyfish and sea anemones); these unambitious creatures may remain stationary or slowly creep or drift, contacting the environment equally on all sides.
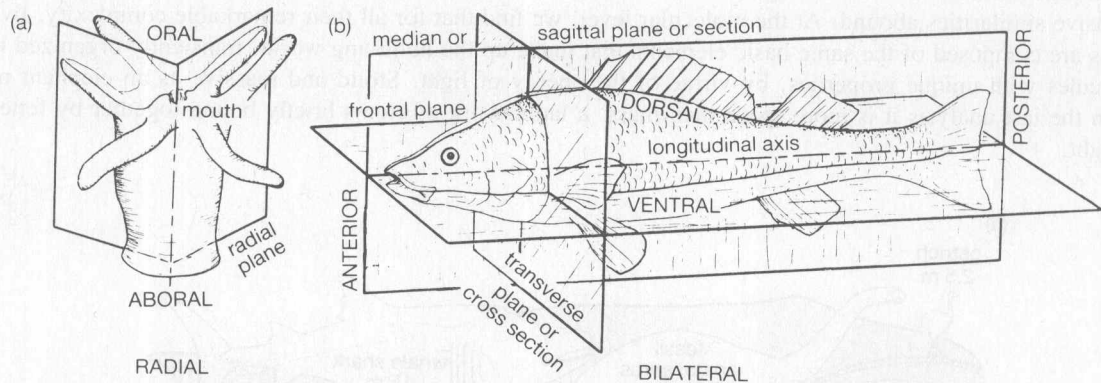


**Fig. 2.2** Animal symmetry, axes, planes, and body regions. (*a*) Sea anemone, a radially symmetrical animal. (*b*) Fish, a bilaterally symmetrical animal. (*From Storer et al.*)

*Bilaterally symmetrical* animals are designed to live active lives, on the prowl for food and other amenities; their bodies can be divided along only one plane of section to yield mirror-image left and right halves, and the anterior end is specialized as a head loaded with sensory equipment. The development of bilaterally symmetrical body forms constituted a mighty evolutionary innovation for the animal kingdom, for it is this type of symmetry that characterizes most major animal groups, both today and in the fossil record.

## 2.3. What is meant by body axes?

Any symmetrical body form possesses at least one major *body axis*, an imaginary straight line that passes through the center of the body. The spherical *Actinosphaerium* enjoys a nearly infinite number of potential body axes, passing through its central core, provided that it does not care which part of its body is upward. But if it does care, then it shows *polarity* (as earth does) and it has only one axis, which passes right through its "up" and "down" poles.

Radially symmetrical animals show polarity, and have a single body axis known as the *oral-aboral axis*: the centrally located mouth locates the oral end of this axis, while the end opposite is aboral. In a starfish the mouth is located orally, and the anus aborally; a jellyfish also has a mouth and oral surface, but it lacks an anus and so has no alimentary opening on its aboral surface.

Bilaterally symmetrical animals have two major body axes: a *longitudinal*, or *anteroposterior*, axis that passes from head to tail and a *dorsoventral* axis that passes from top to bottom. The animal's dorsal surface, or "back," is usually uppermost, and its *ventral* surface, or "belly," is usually oriented downward, but the same terms apply to inverted animals such as tree sloths, which spend their lives suspended dorsum down, venter up.

## 2.4. What are the major anatomical planes of section?

An anatomical *plane of section* divides a body along a plane that intersects or parallels some body axis (see Fig. 2.2): (*a*) a *transverse* section bisects the body crosswise at right angles to the anteroposterior axis; (*b*) a *sagittal* section divides the body into left and right halves along the anteroposterior axis; (*c*) a *frontal* section is at right angles to the dorsoventral axis and divides the body into dorsal and ventral portions.