GENERAL ZOOLOGY

fourth edition

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PREFACE

This text is a general introduction to zoology at the college and university level. The subject matter is arranged to facilitate readings with either lectures or laboratory work and for reference use. Part I deals with general principles of animal biology. After a brief introduction and some history of zoology, the frog is discussed as a typical animal, to establish basic ideas of structure and function. Following this are chapters dealing with the finer structures of the body and their organization into special systems for carrying on essential life processes. Succeeding chapters consider the more general phases of animal existence—reproduction, heredity, distribution, and evolution.

In Part II, following an introduction to the classifying and naming of animals, each chapter describes the structure and physiology of typical animals belonging to each major group —from the one-celled protozoans to man. The accounts of natural history and reproduction show how structure and function serve in the life histories of these and related animals. Some interrelations between animals and their environments are discussed, and there is frequent mention of the importance of animals to mankind. The broader relationships among animals are dealt with further in the general chapters on distribution and evolution.

The synopses of classification, a special feature of the book, have been extracted from recent sources and organized on a uniform pattern. They show the extent, diversity, and relationships of animals comprising each of the larger groups and something of their mode of occurrence. These synopses facilitate identification of specimens to the order and, in some cases, to the family. Common or notable representatives are mentioned by scientific and common names, using North American examples principally. The geological ranges of groups and various fossil representatives (marked †) are mentioned.

The references at the ends of chapters direct the reader to further information. Some "classical" references—by Mendel, Darwin, and others—are cited so that the reader may become acquainted with a few of the major contributions to biological thought. Comprehensive works in foreign languages are included. The lists include significant new books and other important recent literature.

Technical words in the text are distinguished by different type faces, as follows: anatomical and other terms, ***humerus, monohybrid;*** scientific names of genera or species, *Rana pipiens, Mus;* names of families and higher systematic groups, CULICIDAE, PROTOZOA, etc. Throughout the summaries of classification the pattern is: Phylum **ARTHROPODA,** Class *INSECTA,* Order **Diptera,** Family TABANIDAE.

The fourth edition incorporates new material reflecting advances in many fields of research. A new chapter expands discussion on the physical and chemical aspects of life—particularly the organic compounds, enzymes, nucleic acids, DNA and RNA, and cellular metabolism. Description of cellular structure includes results from work with the electron microscope. Accounts or organ systems are extended in materials on comparative physiology. Sections have been added on the role of DNA in heredity, population genetics, medical genetics, and energy flow in ecosystems; in addition, new illustrations have been provided in the discussion on evolution and speciation. In Part II most synopses of classification have been revised, some being completely redrafted to agree with the latest authoritative publications on the subject. In keeping with current thought, the hemichordates have been separated from the chordates. Illustrated accounts of *Neopilina* and the pogonophores have been added. The section on human prehistory has been rewritten because of the increase of knowledege on the subject.

Most of the illustrations are original. Anatomical figures, wherever possible, were made from special dissections and those of bilateral animals are shown from the left side to facilitate comparisons. In series showing embryological or larval development, the individual figures are brought into comparable positions so that changes during growth or metamorphosis can be traced or compared directly with drawings of the adult animals.

The illustrations have undergone substantial revision for this edition; many have been modified, others replaced by better figures, and a considerable number of new ones added. Mrs. Emily P. (Thompson) Reid continues to be our artist-collaborator. She has a sympathetic interest in the new illustrative materials, having provided many original ideas in planning drawings besides her skill in execution. For previous editions she provided most of the figures of invertebrates, some of vertebrates, and many in the general chapters. Others in the latter two groups were made by Norman C. Bilderback and W. Schwartz. Some photographs were furnished by the National Zoological Park, the San Diego Zoological Society, and others. The sources of these, and other illustrations are credited in the legends.

Besides the many persons acknowledged as helping in the three previous editions, we have been aided by the following for this edition: Thomas H. Jukes (Chapter 4 and Table 6-1), Rudolph L. Pipa (Chapters 9 and 10), Richard M. Eakin (Chapter 11), William Balamuth (advice on protozoan classification), Clarence J. Weinmann (Chapters 19 and 20), Henning Lemche (*Neopilina*), Howell V. Daly, Jr. (Chapter 26), Reeve M. Bailey and George S. Myers (advice on Chapter 31), Charles L. Camp (classification of amphibians and reptiles). Our colleagues in the biological sciences at Davis and Berkeley have provided assistance with many problems. Mrs. Alyce W. Jewett helped with the index. Readers and users of the book, since it first appeared in 1943, have provided a continuing generous flow of suggestions and minor corrections. To all who have helped this enterprise we extend our grateful appreciation.

TRACY I. STORER

ROBERT L. USINGER

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Part I

GENERAL ANIMAL BIOLOGY

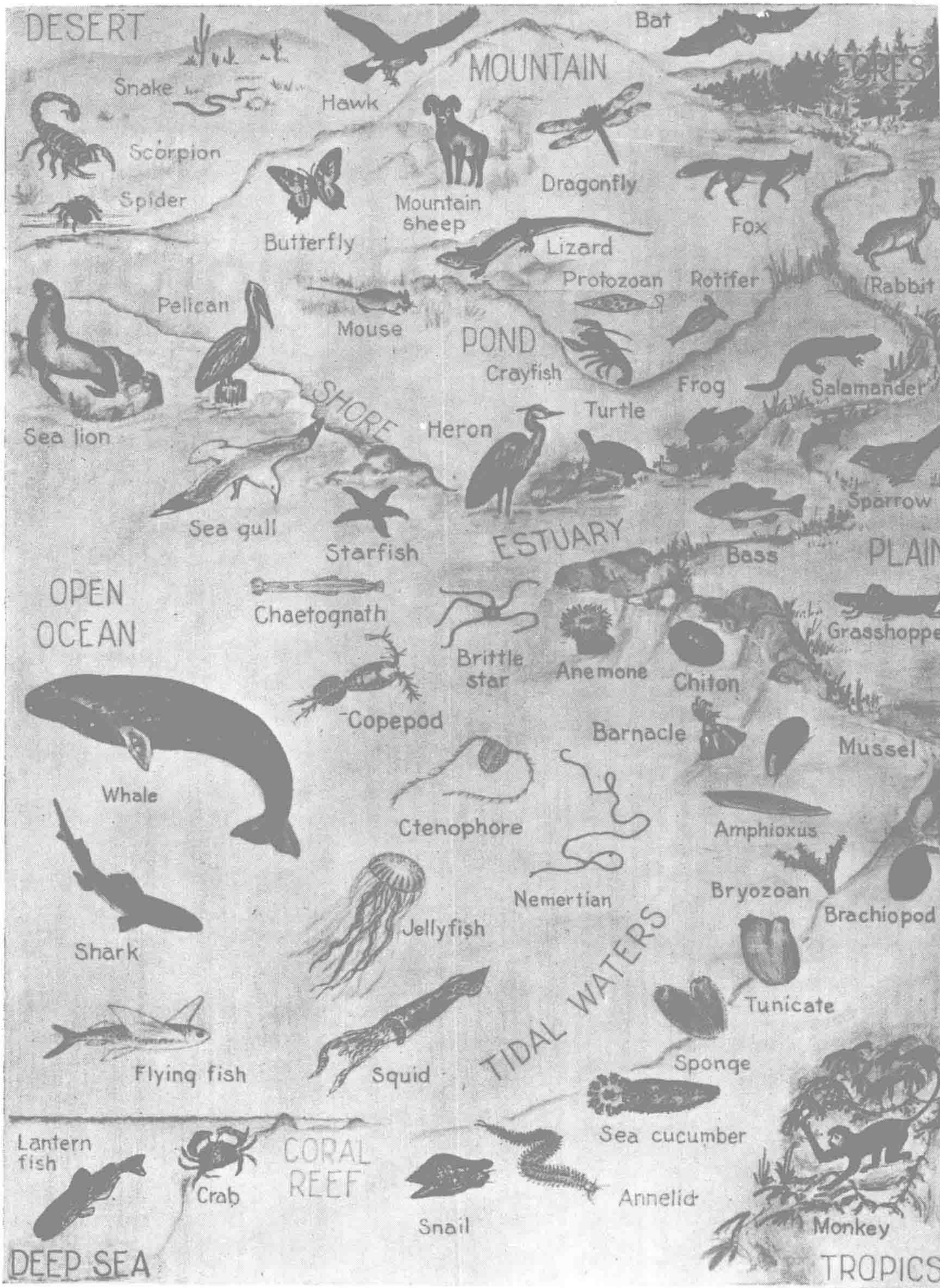

Fig. 1-1. Some common representative animals and the environments in which they live.

1 INTRODUCTION

The world in which we live contains an enormous variety of animals, on the land, in the waters, and even in the air. Many other kinds have existed during past geological time. Native animals can be found in almost any outdoor environment—forest, grassland, lake, streamside, or seashore (Fig. 1-1). Public aquaria and zoological gardens display living representatives, including many that are rarely seen or that are native to distant parts of the world. Museums exhibit mounted specimens of these and other kinds, often in settings that show the environments occupied by the animals in nature. Elementary biology and natural history are taught in the lower schools, and a variety of courses dealing with animals are offered in colleges and universities.

Animals differ from one another in size, structure, manner of life, and other features. Mankind has acquired enough detailed knowledge about animals to fill a large library, but much more needs to be learned and there are many questions.

What is life? In what ways are the various kinds of animals alike or unlike in structure, internal processes, and modes of life? How do animals carry on their activities? How are the many kinds related to one another? In what ways does man resemble and differ from other living things? How is he affected by animals, and how have his activities influenced those about him? The answers to many of these questions are provided by the ***science of zoology*** (Greek *zoön,* animal + *logos,* discourse) that deals with animal life.

BIOLOGY

1-1. Science (Latin *scientia,* knowledge) is exact knowledge or tested and verified human experience. It is modern man's way of carefully exploring his environment, the material universe. The raw materials of science are ***facts,*** the real state of things. Science seeks facts to demonstrate the natural orderly relationships among phenomena; it is self-testing, and it avoids myth, legend, or bias (prejudice). Simple facts—that fire is hot, water is wet, etc.—may be determined by direct observation, but even these gain precision by the use of scientific instruments and permit observations by one person to be compared with those of others. In many fields of science progress is dependent upon the instruments that are available, and the development of a new tool such as the electron microscope or the cyclotron opens up new subjects and methods not even suspected earlier.

The records of science are accumulated facts or ***data*** (sing., *datum*). Qualitative data deal with different kinds of things, and quantitative data with dimensions, weights, or other facts that can be expressed in numerical terms.

A ***scientist*** is a person of inquiring mind, curious about natural phenomena. He asks questions and he seeks answers supported by dependable evidence. Absolute honesty in thought and action are basic to the ***scientific method***, which is the making of careful observations and experiments, then using the data obtained to formulate general principles. The scientific method begins with some observations that arouse speculations as to their meaning. For example, it is commonly noted that moths are attracted to a light. To the scientist this suggests that a principle is involved in the relation between cause (light) and effect (attraction). He sets up a temporary working explanation or ***hypothesis***—that moths react positively to light. Then he plans experiments to test the hypothesis. Various kinds of moths are exposed to lights of different intensity and wavelength. If the experiments support the hypothesis, the scientist can formulate a more definite ***theory*** to explain the observed facts. In this case the theory might state that certain kinds of moths are attracted to light in the blue portion of the spectrum but are repelled by longer wavelengths that appear to us as yellow or red. Such a theory then becomes the basis for extensive trials over a period of years. As a result of such scientific study and deduction, electrical manufacturers have produced yellow lights that are considered to be "insectproof," not attractive to insects. Moths destructive to agricultural crops can be sampled and even lured to their death by "light traps" with white or blue lamps. Finally, through repeated proof as to cause and effect, a theory may be restated as a general ***principle*** or ***law***—but even this is never beyond criticism. New facts may be discovered that require the principle to be restated or discarded. Thus the scientific method accepts no knowledge as completely fixed or infallible but constantly seeks added evidence to test and to formulate basic principles of nature. Useful observations in zoology can be made by anyone who uses the scientific method. The thrill of discovering new facts is a rewarding experience.

1-2. Specialized fields of science. The average person has more or less ***common knowledge*** about animals. A child learns that dogs bark and are covered with hair, that birds fly and are covered with feathers, and many similar facts. Much detailed information of this sort is known to primitive peoples who live in the wild and to farmers whose livelihood depends on an understanding of nature. Other people may develop a special interest in ***natural history*** and study the habits of birds or other common animals. The science of zoology includes these kinds of information together with all other knowledge about animals, both popular and technical. With ***botany***, the science of plants, it forms ***biology*** (Gr. *bios*, life), the science of living things. Biology in turn is one of the natural sciences that have to do with the phenomena of nature. Some other natural sciences are geology—earth structure; mineralogy—substances in the earth's crust; physiography—surface features of the earth; and meteorology—weather and climate. The natural sciences may be contrasted with the ***physical sciences***—physics dealing with the properties of matter and chemistry with its constitu-

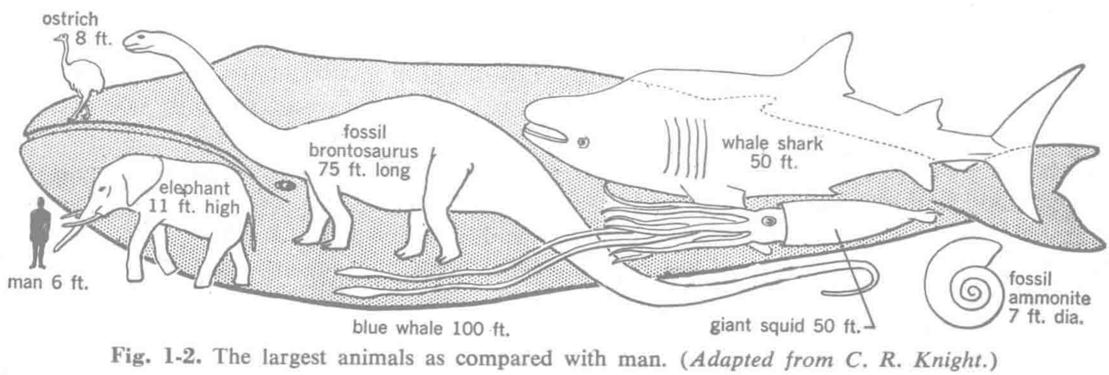

Fig. 1-2. The largest animals as compared with man. (*Adapted from C. R. Knight.*)

tion. Applied science is directed at the solution of practical problems such as many of those in agriculture or engineering, whereas "pure" or basic science has no such immediate objective. Yet many economic problems have been resolved by using the findings of basic scientific studies.

In ancient times one man such as Aristotle (Greek, 384–322 B.C.) might master the entire field of science, and only a century ago Louis Agassiz (1807–1873) and some others knew and could teach all the natural sciences. With the subsequent great increase in knowledge this is no longer possible and scientific fields have of necessity been divided and redivided. A scientist now must specialize in one field or related parts of a few. Although unfortunate in some respects, specialization has made for much more rapid advance in both science and industry. A scientist has, therefore, the problem of working in a particular branch of knowledge yet endeavoring to develop a broad vision of the world about him.

Scientific publications are the means of communication between scientists throughout the world. They have grown progressively until about a half million separate articles now are published each year. Any one scientist finds difficulty in keeping abreast of current publications and to do so must rely in part on special abstracting journals, reviews, and digests.

Some principal subdivisions of zoology and the chapters where they are discussed are:

MORPHOLOGY (Gr. *morphe,* form), structure as a whole (Chaps. 2, 5–10, 16–36)
HISTOLOGY (Gr. *histos,* tissue), microstructure of tissues (Chap. 3)
CYTOLOGY (Gr. *kytos,* hollow), structures and functions within cells (Chap. 3)
PHYSIOLOGY (Gr. *physis,* nature), living processes or functions within animals (Chaps. 2–10, 16–36)
NUTRITION (L. *nutrio,* feed), use and conversion of food substances (Chap. 6)
EMBRYOLOGY (Gr. *en,* in + *bryo,* swell), growth and development of the new individual within the egg (Chap. 11)
GENETICS (Gr. *genesis,* origin), heredity and variation (Chaps. 12, 14)
PARASITOLOGY (Gr. *para,* beside + *sitos,* food), study of animals that live and subsist on or in other animals (Chaps. 13, 16–27)
NATURAL HISTORY, life and behavior of animals in their natural surroundings (Chaps. 2, 13, 16–36)
ECOLOGY (Gr. *oikos,* house), relations of animals to their environments (Chaps. 2, 13, 16–36)
ZOOGEOGRAPHY (Gr. *zoön,* animal + geography), distribution of animals in space (Chap. 13)
PALEONTOLOGY (Gr. *palaios,* ancient + *ont,* being), fossil animals and their distribution in time (Chaps. 13, 14, 16–36)
EVOLUTION (L. *e,* out + *volvo,* roll), origin and differentiation of animal life (Chap. 14)
TAXONOMY (Gr. *taxis,* arrangement + *nomos,* law), classification of animals and principles thereof (Chaps. 15, 16–36)

Zoology is also divided for the study of particular animal groups such as:

PROTOZOOLOGY, study of the one-celled animals, or protozoans (Chap. 16)
ENTOMOLOGY, study of insects; further subdivided into insect taxonomy, economic entomology, etc. (Chap. 26)
MAMMALOGY, study of mammals (Chap. 35)

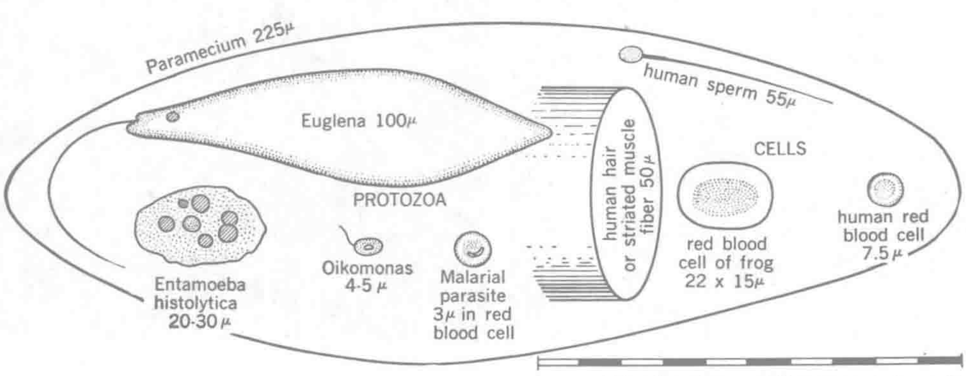

Fig. 1-3. Some of the smallest animals and some animal cells, all included within the outline of a *Paramecium.* Magnified about 500 times.

1-3. Living vs. nonliving matter. Most living things or ***organisms*** can be distinguished readily from nonliving materials by their form and size, chemical composition, organization, and other features discussed below. Dormant seeds of plants and the eggs of most animals appear inert, but when placed under proper conditions each will reveal its living nature.

Some nonliving things show one or more attributes of the living. A crystal of an inorganic chemical like table salt has such definite organization that it can be identified by its physical features; it can grow by additions on the exterior. The flame of a candle has distinctive form, size, and color; in the presence of oxygen the wax is burned to yield carbon dioxide and heat, somewhat like the "burning" of food within an animal's body. The crystal and flame, however, lack other basic attributes of living matter such as irritability and reproduction. Perhaps on the border between living and nonliving matter are the viruses (par. 14-2); they can reproduce, but some also can be crystallized (Fig. 1-4).

The main differences between living and nonliving things are:

FORM AND SIZE. Each kind of living organism usually has a characteristiic form and size (Figs. 1-2, 1-3), within certain limits; most of them are also arranged as definite individuals. A whale, a flea, or any common plant is so recognized. Nonliving materials vary widely in such respects, as from a sand grain to a mountain or a drop of water to an ocean.

CHEMICAL COMPOSITION. Living organisms are composed chiefly of carbon, hydrogen, oxygen, and nitrogen in various but definite proportions, together with small amounts of other chemical elements (Chap. 4). These materials are organized into complex organic molecules, often of great molecular weight, and collectively form the living substance or protoplasm (Chap. 3). The same and other chemical elements occur as compounds in nonliving minerals, but the molecular weights are small (below 2,000).

ORGANIZATION. The parts of each living organism are composed of complex micro-

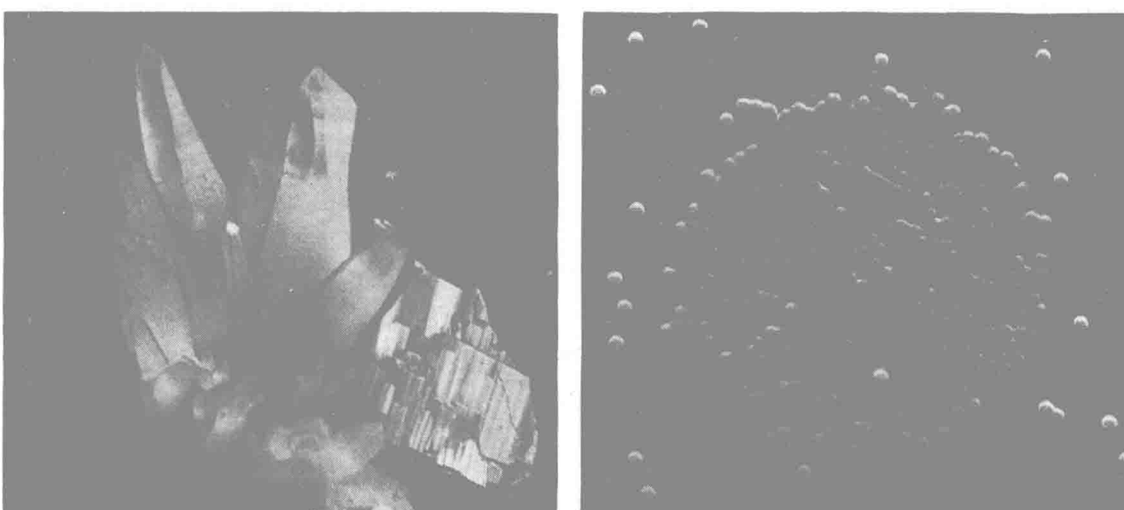

Fig. 1-4. Nonliving vs. living things. *Left.* Crystals of quartz (long, white) and of iron pyrites. About natural size. *Right.* Crystallized form of the poliomyelitis virus which, when in cells of animals or man, "lives" and multiplies. × 110,000. (*Electron miscroscope photo from W. M. Stanley.*)

scopic cells, and these are assembled into interrelated systems for performing the life processes. The living plant or animal rearranges and recombines the chemical elements for its needs. Rocks and minerals cannot recombine materials like a living system; any of their structural features such as crystal pattern depend on the chemicals present and mode of formation.

METABOLISM. Various vital processes, collectively known as ***metabolism***, are constantly taking place within living organisms. These include the physical and chemical changes by which materials derived from food are transformed and used for growth, maintenance, and repair, and to yield energy. Nonliving things have no metabolic changes.

IRRITABILITY. The living organism and its parts react to changes in the environment. These act as stimuli that produce responses by the organism. Stimuli may be external, such as heat, light, moisture, pressure, or contact, or else internal. The degree of response is often disproportionate to that of the stimulus, and the organism is often not permanently altered by the stimulus. When inanimate materials react, there is a definite quantitative relation between the intensity of the environmental change and the reaction produced, as in the expansion of a metal by heat.

REPRODUCTION. Each kind of living organism has the ability to duplicate itself in kind—pine seeds produce pine trees and not oaks, and chicken eggs yield little chicks and not ducklings or puppies. Organisms reproduce by using materials within their bodies (Chap. 11). Nonliving things cannot reproduce.

GROWTH AND LIFE CYCLE. Living organisms grow by development of new parts between or within older ones and may replace parts during life. Each individual has a definite life cycle—birth, growth, maturity, life span, and death. If nonliving things increase, they do so by external addition, as with crystals, and there is no orderly cycle of change.

1-4. Animals vs. plants. Children learn to distinguish between ordinary animals and plants, but some living organisms are not easy to place. In general, animals can move about or move parts of the body, but so can a few plants such as the Venus' fly-trap that closes its leafy "jaws" to catch insects. Many animals become fixed early in life: sponges, sea anemones, oysters, barnacles, etc. Others are both fixed and of plant-like form, such as hydroids and bryozoans (Fig. 1-5). A few lower organisms seem truly intermediate between the ANIMAL KINGDOM and PLANT KINGDOM: the one-celled microscopic *Euglena* moves and takes food like an animal but contains chlorophyll like a plant, hence is claimed by both zoologists and botanists.

The principal differences between animals and plants are:

FORM AND STRUCTURE. In animals the body form is rather constant, the organs are mostly internal, the constituent cells are within delicate membranes, and the tissues are bathed in a solution containing sodium chloride (NaCl). Growth is usually differential, producing changes in proportions of body parts with age. The plant body is often variable, organs are added externally, the cells are usually within thick rigid walls of cellulose, and sodium chlo-

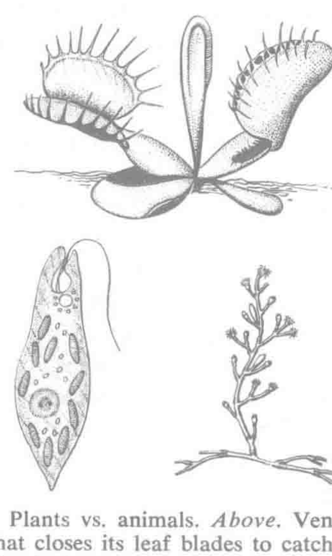

Fig. 1-5. Plants vs. animals. *Above.* Venus' fly-trap, a plant that closes its leaf blades to catch insects for food. *Left.* Euglena, a one-celled organism "claimed" by both botanists and zoologists (par. 16-10). *Right.* Colonial hydroid, a marine animal of plant-like form (par. 18-13).

ride is usually toxic. Growth is usually terminal, at the ends of organs, and often continues throughout life.

METABOLISM. Animals require complex organic materials as food, obtained only by eating plants or other animals. Food is broken down (digested) and rearranged chemically within the body. Oxygen (O_2) is needed for respiration. The end products of metabolism are chiefly carbon dioxide (CO_2), water (H_2O), and urea, $(NH_2)_2CO$. Most plants utilize carbon dioxide from the air together with water and inorganic chemicals obtained in solution from the soil. By photosynthesis—the action of sunlight on the green pigment, chlorophyll—these simple materials are formed into various organic compounds, and oxygen is released as a by-product (Fig. 13-1).

IRRITABILITY. Most animals have a nervous system and can respond quickly to stimuli. Plants have no such system, and their responses are slower.

The world of life is a huge complex system in which various "levels or organization" can be recognized, small to large—atoms, molecules, compounds, cells, tissues, organs, organ systems, entire animals and plants, populations of each kind, and plant-animal communities. Different aspects can be studied to advantage at each level as shown in later chapters. An entire organism is an assemblage of parts and systems, integrated structurally and functionally, to perform the many processes essential for life.

1-5. Animal life of the world. About one million kinds or species of living animals are known, and new sorts are constantly being discovered. Some are enormously abundant, others are present in moderate numbers, and still others are rare. For convenience in study and to indicate relationships between the different kinds, the Animal Kingdom is divided into various groups, large and small (Chap. 15).

Every kind of animal has special requirements for life, determined by its structure and its needs as to food, shelter, and reproduction. Different parts of the earth are covered with salt or fresh waters or with soil or rocks of many types. Tropical regions receive more solar heat than those near the poles, and the amount of moisture in the atmosphere or precipitated as rain or snow varies locally. Therefore the physical environment on different parts of the earth is diverse. This influences the kinds of plants that grow on the land, and the plant cover in turn influences the types of animals that can live in any one place. In consequence, the numbers and kinds vary widely on different parts of the earth (Chap. 13).

Each animal species is influenced by the physical environment and by the other plants and animals that make up its biological environment. Most animals are affected by enemies, diseases, and competitors. The total of all these interactions comprises the "web of life" or the "balance of nature," a dynamic complex of physical and biological forces that acts on every living organism, including man.

1-6. Relations of animals to man. Primitive races "live off the land" by gathering wild seeds, fruits, and animals for food (Chap. 36). Large human populations in civilized countries must produce their own food: cultivated grains (wheat, corn, rice) and domesticated animals (cattle, sheep, swine, and poultry). Both primitive and civilized peoples levy on animals in fresh and salt waters—fishes, oysters, crabs, and others—for additional supplies of animal protein; the aquatic harvest declines where overexploited.

The wool of sheep and pelts of fur-bearing mammals provide clothing, bird feathers are used in pillows and quilts, hides supply leather and glue, hair is made into felt, and the glands and other internal organs yield many medicinal preparations. Honey, beeswax, and natural sponges are other useful animal products. The livestock and meat-packing industries, commercial fisheries, fur trade, and beekeeping are animal industries that provide profitable employment for thousands of persons.

Of harmful animals, large predatory mammals are no longer dangerous to man in civilized countries, but they kill some domestic livestock and useful wild animals. The insects and rodents that feed upon crop plants, grasses, herbs, or trees take a heavy toll that necessitates large expenditures for control. Other insects and the "house" rats and mice damage stored foods and property. Some insects, spiders, scorpions, and snakes are dangerously poisonous. The many kinds of parasites—protozoans, worms, insects, and ticks—bring illness and death to man, his domestic livestock, and useful wild species. Disease organisms carried by animals have exercised a dominant role in the history of mankind; examples are the protozoan parasites of malaria and the virus of yellow fever, both carried by mosquitoes, the bacteria of plague transmitted by fleas, and the typhus spread by lice and fleas.

HISTORY OF ZOOLOGY

1-7. Early zoology. Prehistoric man had a practical interest in animals that provided food, clothing, and other essentials and in the wild beasts that menaced him. Later, animals came to have a part in his religion, medicine, and art. The Cro-Magnon peoples made paintings of animals (Fig. 1-6) and some animal statues in caves of southwestern Europe. Much later the ancient civilizations about the eastern Mediterranean produced pottery, sculpture, and tapestries that portrayed animals. The languages of all primitive races include many words pertaining to animals; these differ from tribe to tribe, indicating that knowledge of animals is as old as the languages.

Fig. 1-6. Paintings of wild horse, cattle, and reindeer (originals in color) by prehistoric Cro-Magnon men in cave at Lascaux, Dordogne, France.

The Egyptians had some knowledge of animals, and before 1500 B.C. they used the parts and excretions of animals for medical treatments. Many animals are shown in decorations of Egyptian tombs. The domestication of animals by early civilizations (Chap. 36) yielded practical information on breeding, growth, and nutrition.

THE GREEKS. The early eastern Greeks, however, made the first real contributions to biology, and they were the first to speculate on the origin of the universe and of the earth and its animal inhabitants. Anaximander (611–547 B.C.) believed that living things arose from a primordial mud, with a sequence from lower life up to man who had arisen from a fish form. Xenophanes (sixth century B.C.) recognized fossils as animal remains and inferred that the presence of marine forms up on mountains indicated the latter had once been beneath the sea. Empedocles (fifth century B.C.) is said to have rid a town of malaria by draining the nearby swamps.

The oldest zoölogical document is a Greek medical work of the fifth century B.C., with a simple classification of edible animals, chiefly fishes. Best known of early Greek physicians was Hippocrates (?460–370 B.C.); his writings show a high level of scientific thought and a "modern" approach to medicine. Students of today subscribe to the oath of Hippocrates when admitted to the practice of medicine.

Aristotle (384–322 B.C.) was the first zoologist of record and one of the greatest. He studied under Plato, taught Alexander the Great, lectured to pupils at the Lyceum in Athens, and wrote extensively on philosophy, politics, and other topics besides zoology. His *Historia animalium* of nine "books" (about 500 pages in a modern printed translation) includes a miscellany on the structure and habits of animals native to Greece, Macedonia, and Asia Minor. The parts based on personal observations (and dissections?) are accurate, but some from other sources are erroneous. He showed how animals

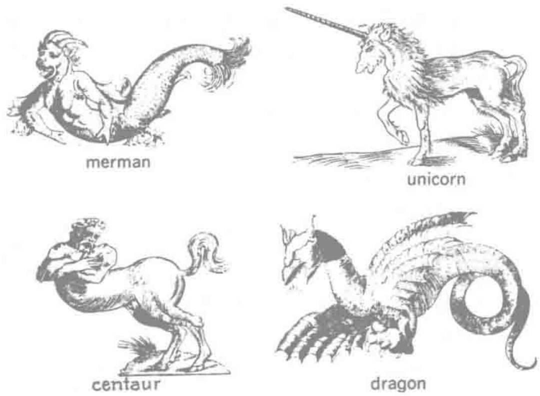

Fig. 1-7. Mythical animals. Creatures of the imagination figured in early books and on sculptures, mosaics, vases, and tapestries. A unicorn supports the arms of England, and St. George's dragon is stamped on British coins. (*After Ashton, Curious creatures in zoology, Cassell & Co., Ltd., London.*)

could be grouped according to structure, habitat, and habits, but offered no system of classification (par. 15-6). Portions of other writings by Aristotle, *On the Parts of Animals* and *On the Reproduction of Animals,* also survive. He followed the development of the chick embryo, knew that drone bees develop by parthenogenesis, and that the young of some sharks develop within the mother. Aristotle insisted on the importance of observation, recognized the regularity and law inherent in biological phenomena, and used the inductive method of forming conclusions from observed facts. The human body served him as a reference in comparative discussions. He conceived an evolutionary development from lower to higher forms, which he ascribed to a supreme "guiding intelligencc."

THE ROMANS. Pliny the Elder (A.D. 23–79) compiled an encyclopedic *Natural History* of 37 books, covering all natural phenomena and their applications, wild and domestic animals, animal husbandry, medicine, and other topics. Although there was little new material and much of fancy and fable among the 20,000 items culled mainly from other writings or tales, the work served for over 1,500 years as a major source of natural-history information. A few other Roman writers on biology were Lucretius (96–55 B.C.), M. T. Varro (116–27? B.C.), Virgil (70–19 B.C.), and Celsus (A.D. 30?).

Galen (A.D. 130–200?), a Greek physician who later lived in Rome, was the last great biologist of antiquity. He was influential in developing a coherent system of physiology. Since dissection of human bodies was rarely possible, he used other animals, especially the Barbary ape. He described various internal organs and the blood vessels, showing that the arteries and left side of the heart contained blood and not air as believed by earlier writers; he also inferred that arteries and veins must be connected. He gave good accounts of the brain and nerves, and by experiment differentiated sensory and motor nerves. Food, he assumed, was "transformed" in the stomach, passed to the liver, and there converted into blood. Galen localized various qualities of the soul in different body parts and believed that all organs had been created in the most perfect form. In consequence, his long and detailed writings were acceptable in the ages of Christianity that followed. They were considered infallible and served as almost the only text on medical anatomy in western Europe.

DARK AGES. A downward trend in scientific inquiry began before Greek civilization ended; it continued throughout the years of the Roman Empire and the centuries when Europe was overrun by barbarians. After Galen a thousand years elapsed with no biologist who made critical observations. The church held the people to narrow and dogmatic beliefs and discouraged original inquiry. Older writings were copied repeatedly with commentaries (and errors), but no copyist himself ever looked at the animals to verify that which he copied. Pliny, Galen, and Aristotle were the chief sources of biological information. Aristotle's writings were acceptable to the church because he believed that the earth was the center of the universe and that a supreme intelligence directed all natural phenomena.

Meanwhile, in the Near East, men continued to read the old Greek writings. They did some original work in mathematics, astronomy, and chemistry, but little in biology. Later, the