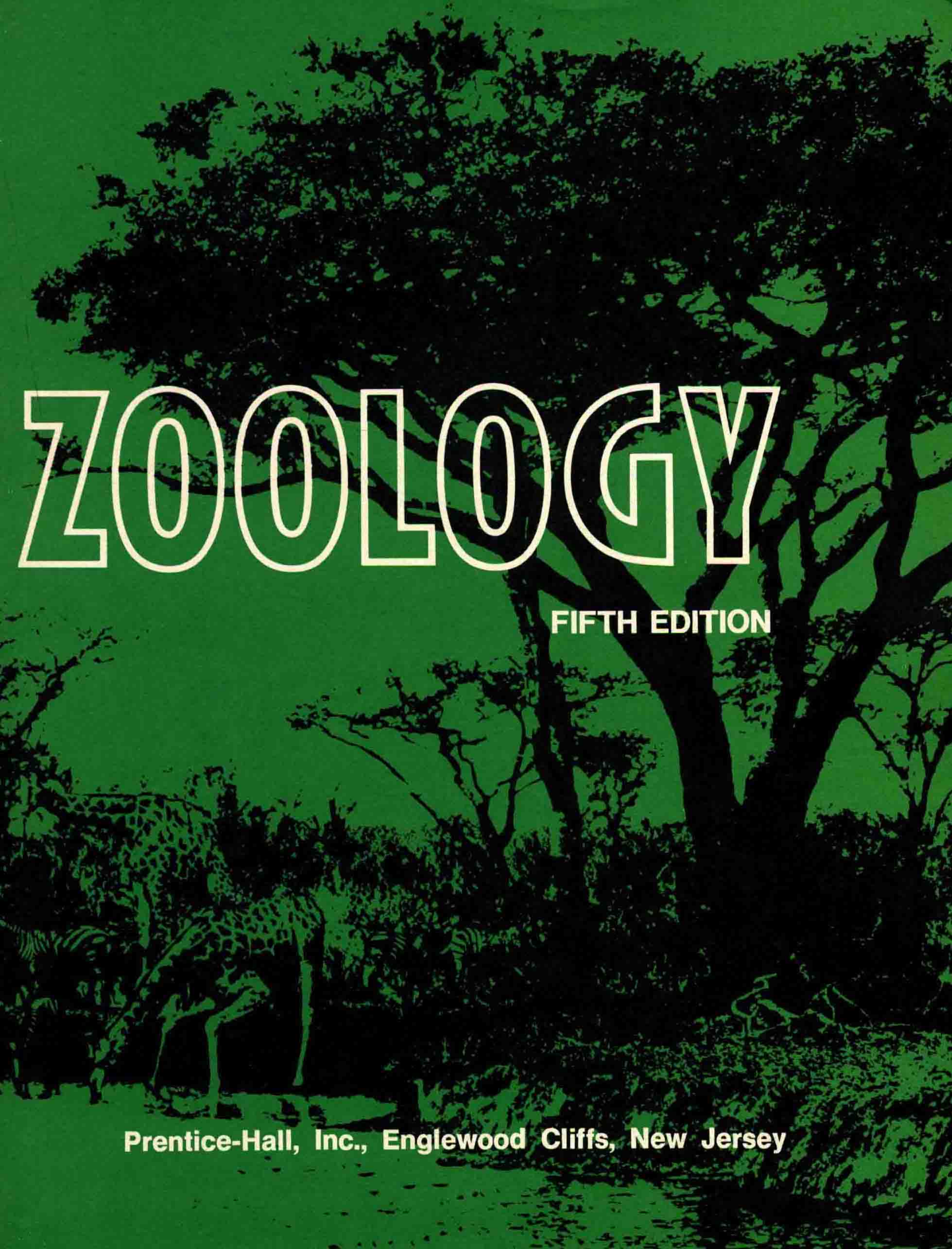

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PREFACE

The study of living things is becoming more exciting each year owing to the advances being made in many areas, particularly at the levels of molecules, cells, and whole animals (behavior). New and improved instruments are advancing our knowledge on many fronts. Physicists and chemists, employing the tools and conceptual methods of their disciplines, are contributing mightily to our understanding of life processes at the molecular level. One of the significant contributions made in this field of research is the regulation of gene activity, which has given us a new approach toward understanding how genes function in development. With the continual improvement of electron microscopes, together with refined techniques of fractionation and purification of cell particulates, the ultrastructure and function of the various parts of cells are rapidly being clarified. The physiologist has at his disposal highly complex recording devices for gaining more information about how animals and their parts function. Remarkable accomplishments are being made in the study of animal behavior using miniaturized electronic equipment, some of which are designed for space travel.

It is our conviction that as much of this new information as possible should be included in a modern textbook of zoology. Students need to be aware of what is going on at the frontiers, but at the same time they must also understand that the newer knowledge is built on a firm foundation established by many brilliant biologists who labored in the past. Consequently, we have tried to integrate the new with the traditional in order that the student may understand that what we are learning today is merely the extension of questions that were asked many years ago.

As we are firmly convinced that organic evolution is the most reasonable approach to the study of zoology, it is the central theme in this edition, as it was in earlier editions. The newer knowledge from laboratory and field studies supplements our understanding of this unifying concept. Molecular biology is adding much to our understanding of evolution at the macromolecular level. It is becoming clearly evident that the way animals behave has evolved as truly as has their morphology and physiological processes. For these reasons, organic evolution is emphasized in every chapter with the hope that there is no question about its importance.

The simplest way to tell the story of organic evolution is, we believe, from the historical approach. Consequently, we have started with the physical laws that were responsible for the formation of our planet and the major events that led eventually to the first forms of life. In order to understand this, a certain amount of elementary chemistry and physics has been included. Much of modern biology requires this background and it seems logical to place it at the beginning.

The subsequent evolution of animals is portrayed, essentially, in the sequence in which it occurred. Throughout these chapters other important principles are included. It is our hope that students will recognize some of the major unsolved problems facing biologists today and the methods used in attacking them. It should become apparent that most of the important problems remain unsolved, and we hope that this information will stimulate students to appreciate, and indeed take part in the solution of, the many mysteries of life that challenge scientists today.

The goal in writing this edition is the same as in earlier editions: to present salient features of animals without overwhelming the student with details. Some of the subject matter is complex, but much effort has gone into writing it as simply as possible. We have tried to present it in such a fashion as to challenge the pre-professional student and to stimulate the general education student. No effort has been made to slant the material toward either group since we feel that all that is included in this book is of equal value to both.

The book is organized the same as in the fourth edition. All chapters have been reevaluated in the light of recent knowledge. Some have been extensively rewritten, others have been supplemented. Some remain essentially unchanged. Considerable new material has been included in the chapters on cell structure and function and genetics. Most of the earlier illustrations have been redrawn and many new ones added. In order to portray the true beauty of animals, a number of colored photographs have been included.

The book consists of eight parts. Following a brief discussion of biology as a science, there follows—in Part I—a description of the scientist, his methods, and the part he plays in society. It is important to recognize that biologists employ the same techniques and disciplines used by all scientists.

The story of evolution begins—in Part II—with a brief discussion of the physical evolution of our planet and the inception of the earliest forms of life. The elementary principles of chemistry and physics are introduced; these must be mastered in order that later discussions of molecular and cellular biology will be meaningful. The cell is also considered in this Part and continued in Part III, where the organization of cells into many-celled organisms is described. The principles of taxonomy are also included in this part. The long evolutionary sequence of animals is covered in Part IV. Representatives of each phylum are treated in some detail, with constant emphasis on how each higher phylum evolved from the next lower group.

The organ systems of man are covered in Part V. Considerable attention should be devoted to this section because of its importance, particularly by those students who take no more courses in zoology.

The continuity of life is discussed in Part VI, beginning with the replication of DNA and protein synthesis and continuing with cell duplication, continuity of the individual, and of the species. Considerable new material has been added to these chapters.

Organic evolution, its meanings, theories, and mechanism are taken up in Part VII. The book is concluded with Part VIII, which considers animal behavior and the relationship of animals to their environment.

Suggested Supplementary Readings are listed at the end of each chapter. They include books and articles primarily from *Scientific American*. Books that are published as paperbacks are so indicated. These titles have been selected for differing reasons. Some contain excellent illustrations; others have presented the chapter contents in a different and more inclusive fashion. A few books are included which treat the topic-in-question in depth. We regard the books and articles as not necessarily the "best," but certainly worthwhile reading. They provide a guide to biological literature which may be very attractive to some students.

Colleagues at the University of Michigan and elsewhere have been most generous in supplying us with illustrative materials and checking the accuracy of chapters devoted to specialized areas of zoology. We should, again, like to express our appreciation to those specialists who read certain chapters in previous editions: Professors L. C. Stuart (Chapters 1–6), H. F. Hogg (Chapters 2–3), J. Hendricks (Parasites), H. vanderSchalie (Mollusks), E. T. Hooper (Mammals), and A. C. Clement (Chordates). The following Professors critically examined specific sections of this revision: E. E. Steiner (Part II—Continuity of Life), B. E. Frye (Chapter 15—Endocrinology), N. E. Kemp (Chapter 22—Embryology), R. D. Alexander (Chapter 27—Animal Behavior), F. F. Hooper (Chapter 28—Ecology). We are grateful to these specialists for their expert opinions. The entire manuscript was read by Professor I. J. Cantrall, whose criticism we greatly appreciate.

As has been mentioned previously, special attention has been given to the illustrations in this revision. The new drawings and those that have been modified or completely redrawn, were done by Jan Powers whose clear lucid style has greatly enhanced the attractiveness of this edition.

In addition to the acknowledgements listed in the back of the book for photographs, we should like to mention our special appreciation to Professors Keith R. Porter, Hugh Huxley, and George Rose for the excellent electron and light micrographs which they so kindly permitted us to use.

We are deeply grateful to the staff of the large elementary zoology course at the University of Michigan for their constant assistance in bringing errors to our attention and for their helpful suggestions regarding the presentations of certain topics. Moreover, we wish to thank the many teachers who have used earlier editions and shared their experiences with us in order to improve this one. We hope that those who read this edition will let us have the benefit of their criticisms.

A.M.E. D.E.O.

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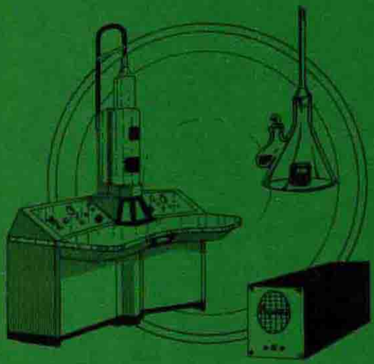

I

ZOOLOGY AS A SCIENCE

1

THE SCIENCE OF ZOOLOGY

We are told by astronomers that it is likely that there are a great many planets in the universe that possess the necessary physical requirements to support living things. Proof of this, one way or another, may come within this century. For the present we must be satisfied with what we can learn about living things as they exist on planet Earth where they are extremely successful in kinds and numbers. The extent of their success is indicated by the fact that if all of the physical world were swept away, the outline of its crust would be maintained in essentially its present form consisting only of the body framework of living organisms.

Possibly the most challenging problems faced by scientists in the past, and even more so today, are those centered around the origin and subsequent history of these living things. The physical world appeared first and life was derived from it at some later time; hence the most obvious classification of objects which make up the world is into nonliving and living. The physical sciences represent the accumulated knowledge of the former, whereas all that we know about the latter comprises **biology**, the science of life. The living world has been arbitrarily divided into **botany**, the study of plants, and **zoology**, the study of animals, the subject of this book.

Physical scientists have made great strides toward understanding many natural laws, impressively so in recent decades when the atom has been torn apart and its components examined. We now know that living things operate within the framework of these same physical laws, but that they have added some remarkable features which help distinguish the living from the nonliving world. Thus, cells and organisms can assemble matter and energy to make additional cells and organisms, developing high levels of order and complexity. Perhaps the most exciting discoveries made today are those at the level where the knowledge of the chemist, physicist, and biologist converge on the problem of the composition of living matter. There is no greater intellectual achievement than the understanding of the laws of nature that initiated and fostered the development of living things on the earth. This becomes more apparent when one considers that these same laws are responsible for the origin of man himself. Few would argue the relative merits of achieving a thorough understanding of the composition and functioning of this one species.

Are the mysteries of the universe being understood? Some of those concerned with our physical world are yielding to our constant probing, and today we are fairly certain of the workings of many natural laws. The atom is gradually yielding its secrets and we are approaching an understanding of the nature of the universe. But what do we know about life? In spite of all of the great accomplishments in chemistry, we have not yet been able to identify the exact chemical composition of a living organism. We do not understand how an animal grows, how a fertilized egg develops into an individual, and how the brain of man works. These and hundreds of other problems are some of the most complex man has so far encountered, but without their solution there can be no understanding of life itself.

In spite of this dearth of knowledge concerning the actual nature of life, there has accumulated a mass of information about animals, particularly about their structure, physiology, and interrelationships and all of it is included in the science of **zoology.** However, as with all scientific knowledge, zoology has become more and more specialized. It has divided into many compartments, such as, among others, **anatomy** (study of gross structure), **physiology** (study of function), **embryology** (study of early development), and **genetics** (study of heredity). In rendering a broad view of the entire field, therefore, it is necessary to select the salient parts of each of these segments and fit them into a unified whole. The purpose of this book is to lay these bits of information before you with the hope that you will grasp the unified picture and as a result gain an understanding of animal life as it has come to be what it is today. More importantly, if you can come to a clearer comprehension of your own origin and the place, you occupy in this world of living things, you may be able to formulate a more satisfying philosophy of life. If you do, the effort you put forth in gaining this knowledge will be well worthwhile and the purpose of this book will have been accomplished.

WHAT SCIENCE IS

Many attempts have been made to define science, and much confusion exists in the minds of most people about just what science is. Science is actually a systematic approach to the solution of problems. It involves observation, the collection of facts, and the drawing of verifiable conclusions based on these facts.

Science has come to mean **organized knowledge** which includes all that man has learned about his world. In volume and scope this has become so tremendous that no one person can even read the titles of research papers that appear each day. Indeed, it requires much reading for a specialist to become familiar with the works of others in his own field. One of the critical problems in modern research that must be solved is some way of condensing the current literature that pours from laboratories all over the world and reducing it to such form that it can be read and understood by those working in the field. Many techniques have been devised, such as microfilming and microcarding, but none have been entirely satisfactory.

Science is more than the mere gathering of facts. A fact in itself has meaning only when it is related to a whole body of information. Counting the number of leaves on a tree or the number of hairs on a dog would result in facts, but such information is relatively useless and anyone doing it might be considered queer. However, even this information could be useful if one was studying the value of certain compounds to increase foliation in trees or fur quality in animals. Indeed, factual information is essential to the solution of many problems. It is meaningless only when out of the context of related information. In other words, gathering of facts is an essential part of all research and should not be ridiculed. The annals of science are replete with instances where certain isolated facts, dug out of the old literature, have been the key to the solution of some new problem.

The highest level of achievement in scientific thought is the formulation of **theories** which explain observed facts. Theories are particularly gratifying if they can be reduced to simple terms such as mathematical formulas. The physical scientists and astronomers have been able to do this to a remarkably advanced degree, but in biology very few processes or principles can be fitted neatly into a formula. The movement of the planets and forces controlling a falling body obey laws which can be stated in mathematical form, but the factors controlling the growth of an embryo cannot be so clearly stated. Biological processes certainly do obey laws, some of which are quite clear today, and a constant struggle is made by biologists to reduce the multitude of complex data that accumulates each day to some sort of working formula.

A good theory is one which explains all of the facts that have been observed but, more important, it makes possible **predictions** of what one might expect in future explorations. In other words, it points the way for future work and takes the "guesswork" out of one's efforts.

In recent years scientists have been in the public eye more than ever before for reasons that are quite obvious. Atomic bombs, intercontinental missiles, space travel, and computerization have commanded the attention of everyone. The people responsible for these achievements are the scientists. What kind of people are they? Scientists are no different from any other group of intelligent, highly motivated people, with one possible exception; they possess a spirit of inquiry which stimulates them to investigate the unknown.

Open-mindedness is another characteristic of a good scientist. Preformed ideas about the ultimate outcome of any investigation are inevitable, but one must be certain that such thoughts do not flavor in any way the facts that are obtained. In biology this tendency is a much greater hazard than in the physical sciences because living things are more complex and thus seemingly less amenable to, for example precise mathematical analysis; oftentimes there is considerable room for interpretation and even speculation, both of which are important in all scientific research. Indeed, perhaps the highest level of achievement in science is in the realm of speculation where sweeping ideas, only partially proven, have spurred further investigation. Out of such mental efforts have come our greatest theories and laws, Newton's Law of Gravity and Darwin's Theory of Natural Selection, to give two examples.

A scientist must be critical of all scientific information, particularly his own. It is only by checking and rechecking one another's work that the ultimate truth can be known. Scientists are their own severest critics, and so they should be. Conclusions must be drawn only after the most rigorous tests have been made, and such conclusions must allow for future discoveries which may alter or extend present knowledge.

COMMUNICATION AMONG SCIENTISTS

In the early days of science, men often worked alone and in secrecy. This was possible because their tools were simple and for the most part could be made by the worker himself. As the problems became more complex and more and more scientists were working on the same or related problems, it became necessary for scientists to depend on one another both for tools, chemicals, and for exchange of ideas. Communication then became a very important aspect of science. Groups of scientists with a common interest formed societies where they could meet at regular intervals to "read" papers, that is, describe their achievements to their peers.

Publication, as understood by scientists, has a meaning somewhat different from that usually assigned to the word. To the scientists, it means putting down on paper the details of his work in such a fashion that anyone properly trained can repeat his observations at any time in the future. **Repeatability** is the very heart of science, and without publication there would be no opportunity to repeat one another's work and scientific progress would be slow indeed.

It has also become traditional that scientific publications be open to the public. One might ask what purpose does open publication serve? When a great many men in all parts of the world are working on a common problem, the knowledge gained by each is available to all if open publication is practiced. This greatly speeds up the solution to problems and is largely responsible for the meteoric advance of science in the past 200 years.

WHAT SCIENCE HAS DONE AND CAN DO

Consider for a moment what science has done for people of the world, what it is doing today, and what it could or might do in the future. One example is the world population. Approximately 275 years ago there was a world population of some 600 millions; that number has increased five-fold to the present time and is now increasing at an unprecedented figure. This means that within this relatively short period there has been a tremendous increase in population compared to the preceding period of approximately 500,000 years which produced the number of people alive in 1700. What has been responsible for this sudden burst of reproductive powers in man? Certainly there has been no physical evolution in man himself in so short a time. It is generally agreed that food is one of the limiting factors in the growth of any population, be it fish or man. Populations always encroach upon the food supply just as closely as they can, often with widespread starvation. This increase in population, then, is due in part to increased food production; increased food production has come about through the application of the scientific method to food production problems. This might be all changed again by a single important discovery, for example, an economical method of producing food from inorganic sources, such as sugar from carbon dioxide and water. A discovery such as this would change the entire food problem of the world overnight. Feeding the half-starved world of today is within the realm of possibility now, although if populations increase at the present rate, it is doubtful that even the best efforts of scientists can keep pace in supplying food.

In colonial days, the average life span of a man was under 40 years; today it is well over 65. It is not that men are any better physically today than they were then. It is due almost entirely to the progress made by science in understanding the cause and prevention of infectious diseases. All of the advancements that have been made in medicine have been accomplished through the agency of science. Before the scientific method was employed in the study of medicine, medical knowledge was largely based on superstition and mysticism. Since the discovery of the germ theory of disease, aseptic surgery, and anesthesia, many of man's ills have been partially or wholly conquered. There is no doubt that many of the infectious as well as organic diseases that plague man today will eventually be eliminated from civilized societies.

It seems clear that the application of the scientific method to the solution of man's physical betterment has been good and bad. It has lifted many burdens from his shoulders by simplifying the work essential for his physical needs; it has extended his average life span also, but, at the same time, has provided him with deadly weapons, such as the atomic and hydrogen bombs. For the first time he has an instrument within his grasp that can annihilate the whole of the civilized world as we know it. Such a situation in an uneasy world certainly is not good when considered from the point of view of survival of a race. Perhaps the application of the scientific method to man's social ills might have some of the success it has had in the alleviation of his physical ills.