AN INTRODUCTION TO THE STUDY OF INSECTS

FOURTH EDITION

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fourth edition

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Holt, Rinehart and Winston
New York, Chicago, San Francisco, Atlanta, Dallas, Montreal, Toronto, London, Sydney

Library of Congress Cataloging in Publication Data

Borror, Donald Joyce, 1907–
An introduction to the study of insects.

Includes bibliographies and index.
1. Entomology. 2. Insects—United States.
I. De Long, Dwight Moore, 1892– joint author.
II. Triplehorn, Charles A., joint author.
III. Title.
QL463.B69 1971b 595.7 75-26620
ISBN 0-03-088406-3

Printed in the United States of America
9 8 7 6 032 1 2 3 4 5 6 7 8 9

Art Supervisor: Renee Davis Art Studio: Vantage Art Designer: Scott Chelius

PREFACE

The importance of the role played by insects in the world of living things is becoming more appreciated each year, not only because of the attention given to the species which act as pests, but because of the increasing realization that many species are extremely valuable to man. The study of insects is an important part of the training of every agriculturalist, biology teacher, and student of nature.

Many books are already available to the student or teacher interested in insects; some give special emphasis to the biological or economic aspects, and others emphasize the taxonomic phase of entomology, but few combine emphasis on both insect study—working with insects—and identification. This book is intended to serve as a text for a beginning course in college entomology, and as a guide for teachers and others interested in the study of insects; it might also serve as a text for an advanced course in systematic entomology, as it contains keys for the identitication of all the families of insects occurring in North America north of Mexico, and keys to some subfamilies.

The discussions of morphology and physiology in this book may not be as complete as in some other books; our aim has been to present enough material on these phases of entomology to enable the student to use the keys and to understand something of the general biology of the insects he encounters. An attempt has been made to make the keys as workable as possible by illustrating most of the key characters. No attempt has been made to present keys to immature forms.

Insects should be observed and studied in the field as well as in the classroom and laboratory, and this book is designed to serve as a text for entomology courses which involve both field and laboratory work. We realize that field work is difficult or impossible in some courses, due to the season in which the course is given, the location of the school, or other factors, but many insects can be maintained indoors in cages or aquaria, and the study of such living material can be substituted for field observations.

We have drawn on many sources of information in the preparation of this book, some of which are listed in the bibliographies at the end of each chapter. These bibliographies are far from complete; rather than striving for completeness, we have tried to list references which can serve as a starting point for the student interested in going further. In our treatment of the various orders we have generally followed the most recent or accepted classification; in some cases we have used a somewhat simplified classification because it seemed more suitable in a book of this type. Concepts of insect relationships and classification change as our knowledge of insects increases, and no arrangement of orders and families is likely to be permanent.

There have been several major changes in the fourth edition. A new chapter has been added on insect behavior. The two separate chapters on the phylum Arthropóda have been combined into one chapter. The chapters on collecting and preserving insects and activities and projects in insect study have also been combined into a new chapter. Many of the keys have been revised, new illustrations have been added and some old ones deleted, and the reference lists have been updated. The classification in a few orders has been updated, with the addition of a few new families to the list for North America. General revisions have been made throughout the book, in some cases by minor changes in rewording, in other cases by completely rewriting a section or adding new material. We have added a third coauthor for this edition, Dr. Charles A. Triplehorn, whose contributions have included the revision of Chapters 25 and 34.

Many people have made valuable suggestions or criticisms regarding particular parts of this book, or have helped with taxonomic problems or in other ways, but we are particularly indebted to the following people for assistance in preparing this edition: Dwight Bennett, Glen Berkey, N. Wilson Britt, Harley P. Brown, Leland R. Brown, Horace R. Burke, Donald S. Chandler, Frank W. Fisk, Donald F. J. Hilton, Roger Hoopingarner, C. Dennis Hynes, Albin T. Khouw, Alice B. Kolbe, Robert J. Lavigne, John F. Lawrence, Kingston L. H. Leong, William F. Lyon, Carl R. Mappes, Frank W. Mead, Arnold Menke, Carl Mohr, Ian Moore, Martin H. Muma, Milledge Murphy, Joseph C. Schaffner, Charles L. Selman, Robbin W. Thorp, J. R. Vockeroth, Tsing Cheng Wang, and Richard E. White.

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November, 1975 C. A. T.

ACKNOWLEDGMENTS

Throughout previous editions a great many people have made valuable suggestions and criticisms regarding specific portions of this book, or have helped solve problems of taxonomy in various orders. We would like to acknowledge their help in the past.

FIRST EDITION

J. Gordon Edwards, T. H. Hubbell, Maurice T. James, Clarence H. Kennedy, Josef N. Knull, Karl V. Krombein, John E. Lane, A. W. Lindsey, Harlow B. Mills, C. F. W. Muesebeck, Alvah Peterson, E. S. Ross, H. H. Ross, Marion R. Smith, Kathryn M. Sommerman, Louis J. Stannard, Edward S. Thomas, and E. M. Walker.

The majority of the original drawings in this book was made by or under the direction of the senior author. The following persons have assisted in the preparation of these drawings: Richard D. Alexander, Calvin E. Beckelheimer, Arthur C. Borror, G. Mallory Boush, William C. Costello, Edward W. Huffman, John E. Lane, Paul D. Ludwig, George W. Murphy, Robert F. Ruppel, and Celeste W. Taft. The original photographs were made principally by the junior author, assisted by Oscar Metze.

Many entomologists and a few editors have assisted with the loan of illustrations or permission to use certain illustrations previously printed in their publications. In each case where a borrowed illustration is used its source is indicated. Special credit, we believe, should be given the following persons: James S. Ayars, Stanley F. Bailey, Richard M. Bohart, Hazel E. Branch, A. W. A. Brown, H. E. Burke, Barnard D. Burks, R. W. Burrell, C. P. Clausen, Ralph H. Davidson, Donald DeLeon, Lafe R. Edmunds, Richard C. Froeschner, B. B. Fulton, Robert Glenn, Ashley B. Gurney, David G. Hall, Philip H. Harden, M. J. Hayell, William R. Horsfall, H. B. Hungerford, Maurice T. James, B. J. Kaston, George F. Knowlton, J. N. Knull, J. W. Leonard, Philip Luginbill, E. A. McGregor, Luis F. Martorell, John Moser, Claud R. Neiswander, Harry L. Parker, Alvah Peterson, Edward S. Ross, Herbert H. Ross, John G. Shaw, Herbert H. Smith, Kathryn M. Sommerman, R. W. Strandtmann, George R. Struble, Edwin Way Teale, C. A. Triplehorn, G. Stuart Walley, E. M. Walker, and Mrs. Blanche P. Young. To all organizations and individuals who have loaned illustrations, we wish to express our sincere thanks for permission to use their material.

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THIRD EDITION

Richard D. Alexander, Donald M. Anderson, Ross H. Arnett, Jr. (particularly for the loan of a number of illustrations of beetles), N. Wilson Britt, Barnard D. Burks, George W. Byers, Donald R. Davis, W. Donald Duckworth, J. Gordon Edwards, Frank W. Fisk, Oliver S. Flint, Richard H. Foote, Raymond J. Gagné, Robert C. Graves, Ashley B. Gurney, Robert W. Hamilton, Ronald W. Hodges, F. P. Ide, Donald E. Johnston, Josef N. Knull, L. V. Knutson, Karl V. Krombein, John D. Lattin, Paul M. Marsh, Frank W. Mead, Frank J. Moore, Thomas E. Moore, C. F. W. Muesebeck, Lois B. O'Brien, Kellie O'Neill, Vincent D. Roth, Louise M. Russell, Curtis W. Sabrosky, Howard A. Schneiderman, F. Elizabeth Sims, David R. Smith, Thomas E. Snyder, Paul J. Spangler, Ted J. Spilman, George C. Steyskal, Alan Stone, William H. Telfer, Charles A. Triplehorn, Barry D. Valentine, Luella M. Walkley, Richard E. White, Willis W. Wirth, J. Porter Woodring, and David A. Young.

MEASUREMENT TABLES

ENGLISH TO METRIC

LENGTH

1 in = 2.54001 cm = 25.4001 mm
1 yd = 0.9144 m
1 mi = 1.60935 km

AREA

1 in^2 = 6.452 cm^2
1 yd^2 = 0.8361 m^2
1 acre = 0.40469 hectares

VOLUME

1 in^3 = 16.387 cm^3
1 yd^3 = 0.765 m^3
1 qt = 0.9463 liter

WEIGHT

1 oz = 28.3495 g
1 lb = 453.5924 g = 0.45359 kg

METRIC TO ENGLISH

LENGTH

1 mm = 0.03937 in
1 m = 39.37 in = 1.0936 yd
1 km = 0.62137 mi

AREA

1 mm^2 = 0.00155 in^2
1 m^2 = 10.76387 ft^2 = 1.195986 yd^2
1 hectare = 2.471 acres

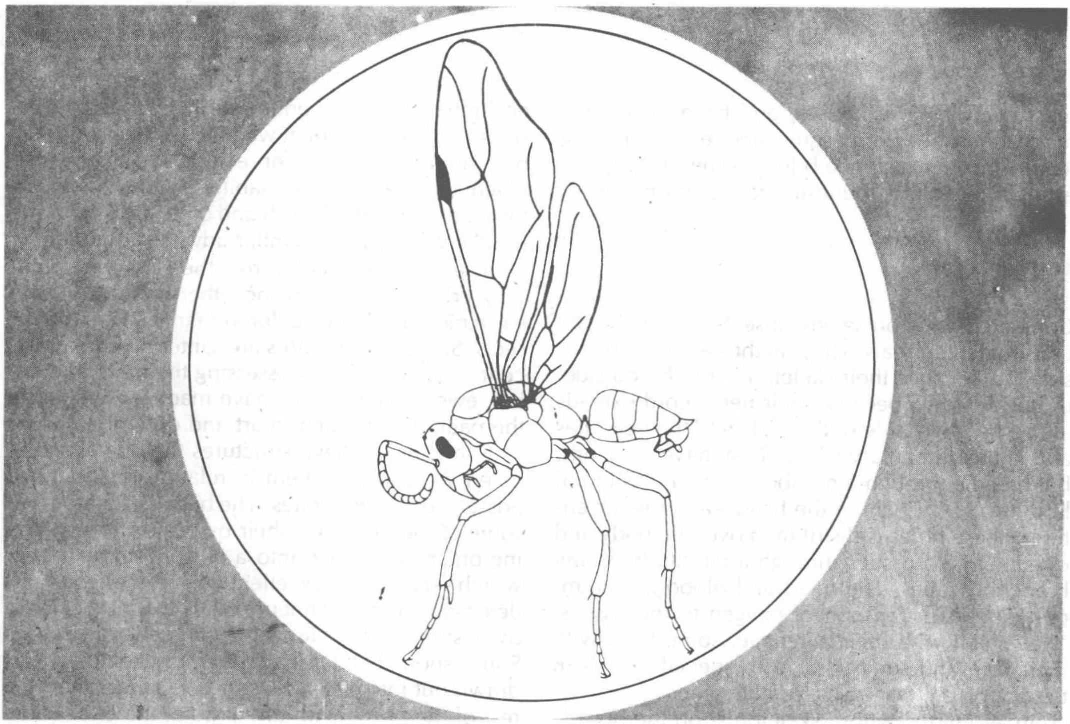
VOLUME

1 cm^3 = 0.0610 in^3
1 m^3 = 35.315 ft^3 = 1.3080 yd^3
1 liter = 1.05671 qt

WEIGHT

1 g = 0.03527 oz
1 kg = 2.2046 lb

CONTENTS



1: INSECTS AND THEIR WAYS

Insects are the dominant group of animals on the earth today. They far surpass all other terrestrial animals in numbers, and they occur practically everywhere. Several hundred thousand different kinds have been described – three times as many as there are in the rest of the animal kingdom – and there are probably as many more that are still undescribed. Over a thousand kinds may occur in a fair-sized backyard, and their populations often number many millions to the acre.

A great many insects are extremely valuable to man, and human society could not exist in its present form without them. By their pollinating activities they make possible the production of many agricultural crops, including many orchard fruits, clovers, vegetables, cotton, and tobacco; they provide us with honey, beeswax, silk, and other products of commercial value; they serve as the food of many birds, fish, and other useful animals; they perform valuable services as scavengers; they help to keep harmful animals and plants in check; they have been useful in medicine and in scientific research; and they are looked upon as interesting animals by people in all walks of life. A few insects are harmful and cause enormous losses each year in agricultural crops, stored products, and the health of man and animals.

Insects have lived on the earth for about 350 million years – compared with less than 2 million for man – and during this time they have evolved in many directions to become adapted to life in almost every type of habitat, and have developed many unusual, picturesque, and even amazing features. Let us examine briefly some of the interesting things to be found in the world of insects.

STRUCTURE

Compared with ourselves, insects are peculiarly constructed animals. They might be said to be inside out because their skeleton is on the outside, or upside down because their nerve cord extends along the lower side of the body and the heart lies above the alimentary canal. They have no lungs, but breathe through a number of tiny holes in the body wall—all behind the head—and the air entering these holes is distributed over the body and directly to the tissues through a multitude of tiny branching tubes. The heart and blood are unimportant in the transport of oxygen to the tissues. They smell with their antennae, some taste with their feet, and some hear with special organs in the abdomen, front legs, or antennae.

In an animal whose skeleton is on the outside of the body, the mechanics of support and growth are such that the animal is limited to a relatively small size. Most insects *are* relatively small; probably three fourths or more are less than ¼ inch (6 mm) in length. Their small size enables them to live in places that would not be available to larger animals. This fact, plus the fact that there are a great many different kinds of places where they can live, is in part responsible for the large number of different kinds of insects.

Insects range in size from about 1/100 to 13 inches (0.25 to 330 mm) in length, and from about 1/50 inch to nearly a foot (0.5 to 300 mm) in wingspread; one fossil dragonfly had a wingspread of over 2½ feet (760 mm)! Some of the largest insects are very slender (the 13-inch (330 mm) insect is a walking stick occurring in Borneo), but some beetles have a body nearly as large as one's fist. The largest insects in North America are some of the moths, with a wingspread of about 6 inches (150 mm), and the walking sticks, with a body length of about 6 inches (150 mm).

The insects are the only invertebrates with wings, and these wings have had an evolutionary history different from that of the wings of vertebrates. The wings of flying vertebrates (birds, bats, and others) are modifications of one of the pairs of paired limbs; those of insects are structures *in addition to* the paired "limbs," and might be likened to the wings of the mythical Pegasus (flying horse). The wings of insects are certainly one of the features responsible for the dominant position insects hold on the earth. With wings, insects can leave a habitat when it becomes unsuitable; aquatic insects, for example, have wings when adult, and if their habitat dries up they can fly to another habitat. Fish and other aquatic forms usually perish under similar adverse conditions.

Insects range in color from the very drab to the very brilliant; there are no other animals on the earth more brilliantly colored than some of the insects. Some insect colors are glittering and iridescent, and the insects possessing them are like living jewels. Their colors have made many insects the patterns for much in art and design.

Some insects have structures that are amazing when we consider them in relation to structures possessed by vertebrates. The bees and wasps and some of the ants have their ovipositor or egg-laying organ developed into a poison dagger (sting) which serves as an excellent means of offense and defense. Some ichneumons have a hairlike ovipositor 4 inches long that can penetrate wood. Some snout beetles have the front of the head drawn out into a slender structure longer than the rest of the body, with tiny jaws at the end. Some stalk-eyed flies have their eyes situated at the ends of long slender stalks, which in one South American species are as long as the wings. Some of the stag beetles have jaws half as long as the body, and branched like the antlers of a stag. Certain individuals in some of the honey ants become so engorged with food that their abdomens become greatly distended, and they serve as living storehouses of food which they regurgitate "on demand" to other ants in the colony.

PHYSIOLOGY

A feature of insect physiology that enables these animals to survive adverse climatic conditions is their cold-bloodedness; their body temperature follows very closely the temperature to which they are exposed. When the environmental temperature drops, their body temperature also drops, and their physiological processes slow down. Many insects can withstand short periods of freezing temperatures, and some can withstand long periods of freezing or subfreezing temperatures. During the winter they are quiescent and their metabolic rate is extremely low; during these adverse conditions when food is not available, they can survive without it.

Insect sense organs are often peculiar compared with those of man and other vertebrates. Some insects have two kinds of eyes—two or three simple eyes located on the upper part of the face, and a pair of compound eyes on the sides of the head; the compound eyes are often very large, occupying most of the head, and may consist of thousands of individual eye units. Some insects hear by means of eardrums, while others hear by means of very sensitive hairs on the antennae or elsewhere on their bodies; an insect possessing eardrums may have them on the sides of the body at the base of the abdomen (short-horned grasshoppers), or on the front legs below the "knee" (long-horned grasshoppers and crickets).

The reproductive powers of insects are often tremendous; most people do not realize just how great they are. The capacity of any animal to build up its numbers through reproduction depends on three characteristics of that animal—the number of eggs laid by each female (which in insects may vary from one to many thousands), the length of a generation (which may vary from a few days to several years), and the proportion of each generation that are females and will produce the next generation (in some insects there are no males).

An example that might be cited to illustrate insects' reproductive powers is *Drosóphila*, the pomace flies, that have been studied so much by geneticists. These flies develop rapidly, and under ideal conditions may produce 25 generations in a year. Each female lays up to 100 eggs, of which about half will hatch into males and half into females. Now, suppose we started with a pair of these flies and allowed them to reproduce under ideal conditions, with no checks on increase, for a year—with the original and each succeeding female laying 100 eggs before she dies, and each egg hatching and growing to maturity and reproducing again. The number of flies that would be produced in the twenty-fifth generation is staggering, about 10^{41}. If this many flies were packed tightly together, 1000 to a cubic inch, they would form a ball of flies 96 *million miles* in diameter, or a ball extending nearly from the earth to the sun!

Throughout the animal kingdom an egg usually develops into a single individual. In man and some other animals an egg occasionally develops into two individuals (for example, identical twins in man), or on rare occasions three or four. Some insects carry this phenomenon of polyembryony (more than one young from a single egg) much further; some platygasterid wasps have as many as 18, some dryinid wasps as many as 60, and some encyrtid wasps have *over a thousand* young developing from a single egg. A few insects have another unusual method of reproduction—paedogenesis (reproduction by larvae); this occurs in the gall gnat genus *Miástor* and in the beetle genera *Micromálthus, Phengòdes,* and *Thylódrias.*

DEVELOPMENT

In the nature of their development and life cycle, insects run the gamut from the very simple to the complex and even amazing. Many insects undergo very little change as they develop, with the young and adults having similar habits, and differing principally in size. Most insects, on the other hand, undergo in their development rather remarkable changes, both in appearance and in habits. Most people are familiar with the metamorphosis of insects and possibly think of it as commonplace—which, as a matter of fact, it is—but in comparison with the development of a vertebrate it is indeed fantastic. Consider the development of a butterfly: an egg hatches into a wormlike caterpillar; this caterpillar eats ravenously and every week or two sheds its skin; after a time it becomes a pupa, hung from a leaf or branch like a ham in a meat shop; and finally a beautiful winged butterfly emerges from this "ham." If this sort of thing happened in a bird, it would be like an eagle developing from a snake—an event that would indeed be fantastic.

The majority of the insects have a life cycle like that of a butterfly; the eggs hatch into wormlike larvae, which grow by periodically shedding their outer skin (together with the linings of the foregut, hindgut, and breathing tubes), finally transforming into an inactive pupal stage from which the winged adult emerges. A fly grows from a maggot; a beetle grows from a grub; and a bee, wasp, or ant grows from a maggotlike larval stage. When these insects become adult they stop growing; a little fly (in the winged stage) does not grow into a bigger one.

An insect with this sort of development (complete metamorphosis) may live as a larva in a very different sort of place from that in which it lives as an adult. One fly that is a common household pest spends its larval life in garbage or some other filth; another very similar fly may have spent its larval life eating the insides out of a grub or caterpillar. The junebug that beats against the screens at night spent its larval life in the ground; and a long-horned beetle one may see on a flower spent its larval life in the wood of a tree or log.

BEHAVIOR

Many insects have unusual features of structure, physiology, or life cycle, but probably the most interesting things about insects are what they do. One may find many instances where the behavior of an insect seems to surpass in intelligence the behavior of man. Some insects seem to show an amazing foresight, especially as regards laying eggs with a view to the future needs of the young. Insects have very varied food habits, they have some interesting means of defense, many have what (compared with vertebrates) might be considered fantastic strength, and many have "invented" things which we may think of as strictly human accomplishments. Complex and fascinating social behavior has been developed in some groups of insects.

Insects feed on an almost endless variety of foods, and they feed in many different ways. Thousands of species feed on plants, and practically every kind of plant (on land, or in fresh water) is fed upon by some kind of insect. The plant feeders may feed on almost any part of the plant; caterpillars, leaf beetles, and leafhoppers feed on the leaves, aphids may feed on the stems, white grubs feed on the roots, certain weevil and moth larvae feed on the fruits, and so on. These insects may feed on the outside of the plant, or they may burrow into it. Thousands of insects are carnivorous, feeding on other animals; some are predators, and some are parasites. Many insects that feed on vertebrates are blood-sucking; some of these, such as mosquitoes, lice, fleas, and certain bugs, are not only annoying pests because of their bites, but may serve as disease vectors. Some insects feed on dead wood; others feed on stored foods of all types; some feed on various fabrics; and many feed on decaying materials. Drugstore beetles are capable of feeding on almost everything from face powder to mustard plasters.

The digger wasps have an interesting method of preserving food collected and stored for their young. These wasps dig burrows in the ground, provision them with a certain type of prey (usually other insects or spiders), and then lay their eggs (usually on the body of a prey animal). If the prey animals were killed before being put into the burrows, they would dry up and be of little value as food by the time the wasp eggs hatched. These prey animals are not killed; they are stung and paralyzed, and thus "preserved" in good condition for the young wasps when they hatch.

Insects often have interesting and effective means of defense against intruders and enemies. Many insects "play dead," either by dropping to the ground and remaining motionless, or "freezing" in a characteristic position. Many insects are masters of the art of camouflage, being so colored that they blend with the background and are very inconspicuous; some very closely resemble objects in their environment—dead leaves, twigs, thorns, or even bird droppings. Some insects become concealed by covering themselves with debris. Some insects that do not have any special means of defense very closely resemble another that does, and presumably are afforded some protection because of this resemblance. Many moths have the hind wings (which at rest are generally concealed beneath the front wings) brightly or strikingly colored—sometimes with spots resembling the eyes of a larger animal (for example, giant silkworm moths; see Figure 426)—and when disturbed display these hind wings; the effect may sometimes be enough to scare off a potential intruder. Some of the sound-producing insects (for example, cicadas, some beetles, and others) will produce a characteristic sound when attacked, and this sound often scares off the attacker.

Many insects utilize a "chemical warfare" type of defense. Some insects secrete foul-smelling substances when disturbed; stink bugs, broad-headed bugs, lacewings, and some beetles might well be called the skunks of the insect world, as they have a very unpleasant odor. A few of the insects utilizing such defensive mechanisms are able to eject the substance as a spray, in some cases even aiming it at an intruder. Some insects, such as the milkweed butterflies, ladybird beetles, and net-winged beetles, apparently have distasteful or mildly toxic body fluids, and are avoided by predators.

Many insects will inflict a painful bite when handled; the bite may be simply a severe pinch by powerful jaws, or it may be what amounts to a hypodermic injection by needlelike mouth parts. The bites of mosquitoes, fleas, black flies, assassin bugs, and many others are much like hypodermic injections, and the irritation caused is due to the saliva injected at the time of the bite.

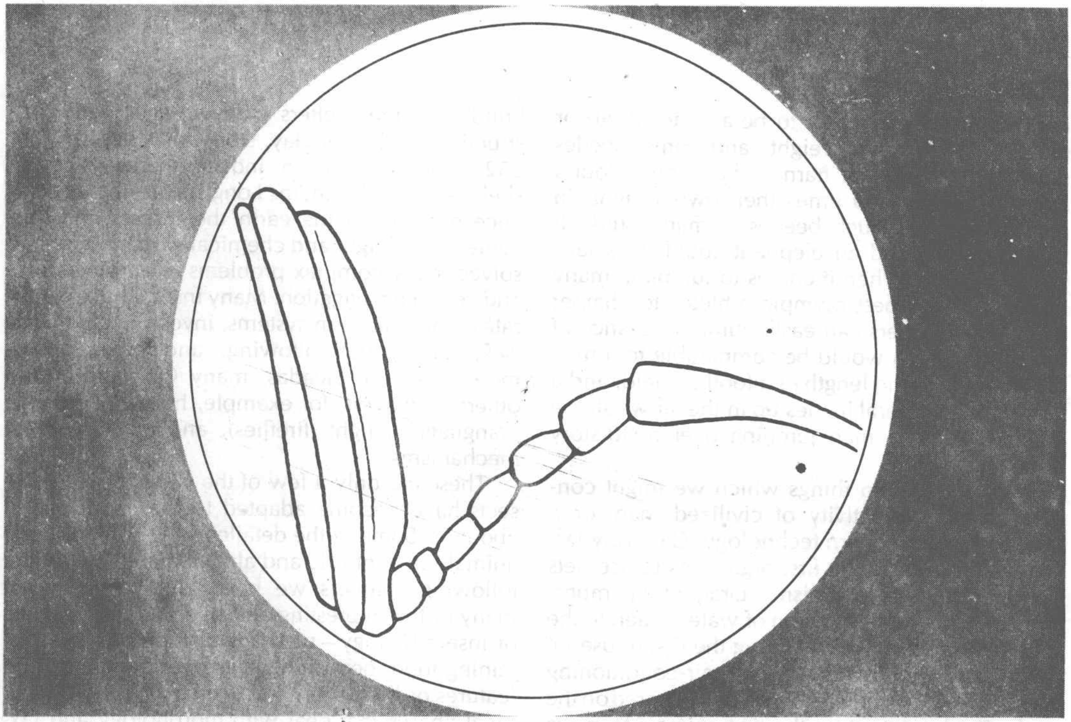
Other means of defense include the stinging hairs possessed by some caterpillars (for example, the saddleback caterpillar and the larva of the io moth), body fluids that are irritating (for example, blister beetles, death feigning (many beetles, and some insects in other orders), and warning displays, often including eye spots on the wings (many moths and mantids) or other bizarre or grotesque structures or patterns.

One of the most effective means of defense possessed by insects is a sting, which is developed in the wasps, bees, and some ants. The sting is a modified egg-laying organ, hence only females sting. It is located at the posterior end of the body, so the "business" end of a stinging insect is the rear.

Insects often perform what—compared with man—are near impossible feats of strength. It is not unusual for an insect to be able to lift 50 or more times its own weight, and some beetles rigged with a special harness have been found able to lift over 800 times their own weight; in comparison with such beetles, a man could lift some 60 tons, and an elephant could lift a fair-sized building! When it comes to jumping, many insects put our best olympic athletes to shame; many grasshoppers can easily jump a distance of three feet, which would be comparable to a man broad-jumping the length of a football field, and a flea jumping several inches up in the air would be comparable to a man jumping over a 30-story building!

Many insects do things which we might consider strictly an activity of civilized man, or a product of our modern technology. Caddisfly larvae were probably the first organisms to use nets to capture aquatic organisms. Dragonfly nymphs, in their intake and expulsion of water to aerate the gills in the rectum, were among the first to use jet propulsion. Honey bees were air-conditioning their "hives" long before man even appeared on the earth. The hornets were the first animals to make paper from wood pulp. Long before man began building crude shelters many insects were constructing shelters of clay, stone, or "logs" (Figure 352), and some even induce plants to make shelters (galls) for them. Long before the appearance of man on the earth the insects had "invented" cold light and chemical warfare, and had solved many complex problems of aerodynamics and celestial navigation. Many insects have elaborate communication systems, involving chemicals (sex, alarm, trail-following, and other pheromones), sound (cicadas, many Orthoptera, and others), behavior (for example, honey bee dance "language"), light (fireflies), and possibly other mechanisms.

These are only a few of the ways in which insects have become adapted to life in the world about us. Some of the detailed stories about these animals are fantastic and almost incredible. In the following chapters we have tried to point out many of the interesting and often unique features of insect biology—methods of reproduction, obtaining food, depositing eggs, rearing young, and features of life history—as well as the more technical phases that deal with morphology and taxonomy.



2: THE ANATOMY OF INSECTS

A knowledge of the anatomy of insects is essential to an understanding of how insects live and how they can be distinguished from one another and from other animals.

THE GENERAL STRUCTURE OF AN INSECT

Insects are generally more or less elongate and cylindrical in form and are bilaterally symmetrical, that is, the right and left sides of the body are essentially alike. The body is segmented, and the segments are grouped into three distinct regions—head, thorax, and abdomen (Figure 1). The head bears the eyes, antennae, and mouth parts; the thorax bears the legs and wings (when these are present); the abdomen usually bears no locomotor appendages, but often has some appendages at its apex. Most of the appendages of an insect are segmented.

THE BODY WALL

In man and other vertebrates the skeleton or supporting framework is on the inside of the body and is spoken of as an endoskeleton; in insects and other arthropods the skeleton is, for the most part, on the outside and is called an exoskeleton. The insect's body wall thus serves not only as the outer