

# ● Contents

**PREFACE** *ix*

**ACKNOWLEDGMENTS** *xi*

- 1** Introduction to the Arthropods 1
- 2** What One Sees on the Outside—External Features of Insects 14
- 3** The Internal Organization 39
- 4** Growth and Metamorphosis 58
- 5** The Arachnids—Spiders, Scorpions, Mites, and Other Eight-Legged Wonders 75
- 6** The “Other” Arthropods 119
- 7** Oldies but Goodies 136
- 8** Insects Fly! 144
- 9** Jumpers and Strollers—Grasshoppers, Crickets, and Walkingsticks 155
- 10** Variety Is the Spice of Life—Some Minor, but Interesting, Insect Orders 171
- 11** Roach Cities and Assassin Cousins 182
- 12** Lousy Nitpickers 202
- 13** Life on an All-Fluid Diet 212
- 14** Insect Bruisers and Their Lacewinged Cousins 252
- 15** City Builders That Rule 296
- 16** Scale-Winged Beauties and Custom Homebuilders 339

17 “Gift” Bearers of Plague—or a Plump Insect Wedding Present 377

18 Marvels of the Air—Two-Winged Wonders 387

APPENDIX I: STATE INSECTS 425

APPENDIX II: LARGEST ARTHROPODS 431

APPENDIX III: SUMMARY OF FEATURES OF THE HEXAPOD ORDERS 435

GLOSSARY 459

INDEX 475

# 1

## ● Introduction to the Arthropods

### What Is an Arthropod?

The subjects of this book are the arthropods that live among us, primarily the insects but also some of their relatives, such as arachnids, millipedes, centipedes, and a few crustaceans. When formally classified, these animals are placed in the phylum Arthropoda, which comprises a huge number of species with a tremendous diversity of forms and habits. Nonetheless, all arthropods share certain features that together define them as a distinct form of life:



(a)



(b)



(c)

#### FIGURE 1-1

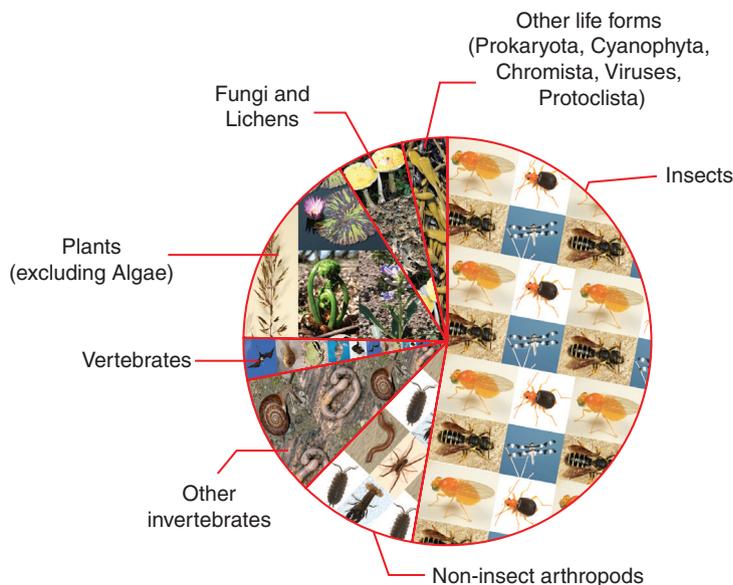
Three representative arthropods. (a) Dragonfly (insect), (b) julid millipede, and (c) windscorpion (arachnid). All show the basic external features of arthropods including an exoskeleton, segmentation of the body, jointed appendages, and a body design that is bilaterally symmetrical. Photograph of the dragonfly courtesy of Brian Valentine; photograph of the millipede courtesy of Jim Kalisch/University of Nebraska; photograph of the windscorpion by Jack Kelly Clark and provided courtesy of the University of California IPM Program.

- All arthropods have a body supported by a hardened external skeleton (**exoskeleton**), a reverse type of engineering compared to our internal skeleton. To allow growth, this exoskeleton must be periodically shed, and a new one rebuilt.
- The body of an arthropod is divided into segments, a feature shared by some other animal groups, such as earthworms (phylum Annelida) and velvet worms (phylum Onychophora).
- The appendages of arthropods—their legs, antennae, and mouthparts—are jointed. This is the feature that defines the phylum. (In Greek, arthropod means “jointed foot.”)
- Internally, the nerve cord runs along the lower (ventral) part of the body and is not enclosed in a protective spinal column. These features contrast with those found in phylum Chordata to which we belong.
- Blood is moved by the aid of a tube-like heart, located along the back (dorsal) part of the body.
- The overall body arrangement is **bilaterally symmetrical**, so that, if the body were cut through the center from head to tail, the two halves would be a mirror image of one another.

## The Diversity and Abundance of Arthropods

The arthropods are, by far, the most diverse life form on the planet. Insects alone, with approximately 970,000 known species, comprise over one-half of all kinds of life known to occur on the planet. Yet despite the impressive numbers, these reflect only “known species,” ones that have been suitably described in the scientific literature and accepted as distinct species. This number represents only a small fraction of the number of species estimated to be present on the planet today. This number is also a tiny fraction of all the insects that ever were on the planet. It has been suggested that perhaps 95% of all insects that have ever existed, since their first appearance some 400 million years ago (mya), are now extinct.

Today, the number of insect species thought to occur is often estimated at about four to five million species. The great majority of these, at least 80%, remain unknown to science so far. Progress is being made to close this gap, with over 7,000 new insect



**FIGURE 1-2**

The relative number of different kinds of life forms known on Earth, based on the number of known species. Of the approximately 1.9 million presently recognized species, just over half are insects. Figures based on *Numbers of Living Species in Australia and the World*, 2nd ed. (2009). Photographs courtesy of Tom Murray.

species being described annually, over 20 per day on average. At this rate of new discovery, impressive as it is, perhaps we can expect a full catalog of the five million insects to be ready in about 550 years or so.

A much more difficult question to answer is “How abundant are insects and other arthropods in terms of total population numbers?” One of the problems is that the overwhelming number of arthropods are minute and live in soil. For example, one of the first attempts at counting all of the arthropods in a sample of soil was done in an English

pasture during November 1943. About 2.5 billion arthropods were estimated per hectare, with mites comprising some 62% and springtails 23% of the total number. On the basis of surveys such as this it has been estimated that the insects, springtails, mites, and other land-dwelling arthropods outnumber humans by as much as 250 million to 1. Furthermore, these arthropods collectively comprise over 80% of the total biomass of the terrestrial animals, far outweighing all the other land dwellers such as earthworms, reptiles, birds, and mammals.



(a)



(b)

**FIGURE 1-3**

(a and b) Springtails and soil-dwelling mites are the most abundant kinds of animal life on the planet. A billion or more may typically be found in a hectare of fields, pasture, or lawn. Photographs courtesy of Brian Valentine.

## The Many Roles of Arthropods

If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos. (E. O. Wilson, *The Diversity of Life*)

Although small in size, arthropods, in their tremendous numbers, collectively account for the most biomass of all land animals. In the Amazon rain forest, the weight of just one family of insects, the ants, is estimated to be four times more than all the mammals, birds, fish, reptiles, and amphibians

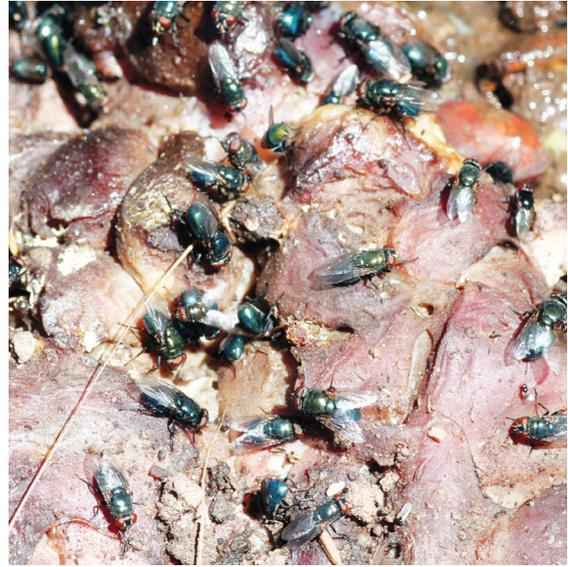
combined. Furthermore, the roles of arthropods in ecosystems are myriad, but central to the functioning of planet Earth:

**Pollination of flowering plants.** Insects are essential to the pollination of most flowering plants, and many of the flowering plants are the result of **coevolution** with their insect pollinators. The tremendous variety of flower types reflect different ways that plants have evolved to more efficiently attract pollinators. In response, new species of insects have arisen to better exploit these sources of nectar and pollen. In addition to native plants, essentially all fruits, vegetables, and many of the forage crops (e.g., clover, alfalfa) are dependent on insects to produce seed.



**FIGURE 1-4**

A leafcutter bee pollinating sweet pea. Many plants are dependent on insects for their pollination. Photograph by Whitney Cranshaw/Colorado State University.



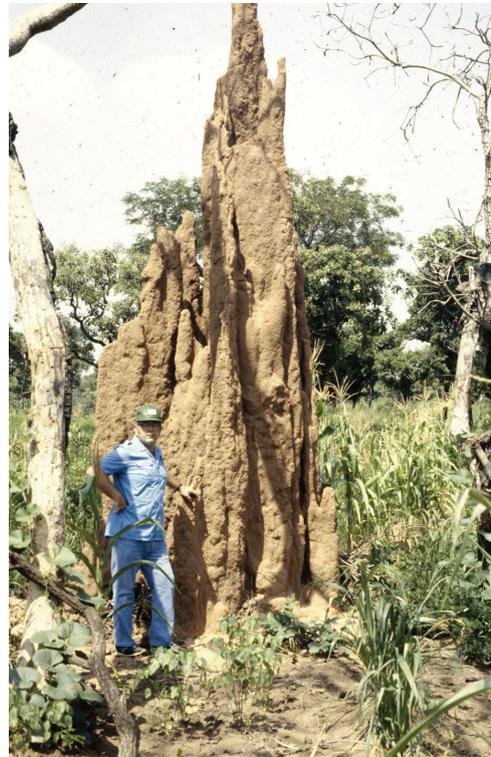
**FIGURE 1-5**

Blow flies colonizing fresh carrion. Insects help in the decomposition of dead plant and animal matter and have central roles in the cycling of nutrients in natural systems. Photograph by Whitney Cranshaw/Colorado State University.

**Recycling plant and animal matter.** Many insects develop by feeding on dead plant matter, dead animal matter, or animal dung. In this role, they function as **macrodecomposers** that are in the first-line “clean-up crew” essential to the recovery and recycling of nutrients. Through insect feeding, these substances are broken down into much smaller particles and partially digested, which greatly accelerates the process of decay that frees the nutrients to nourish later generations of plants. In the absence of insects, nutrient-recycling systems break down and organic matter accumulates.

**Soil formation and mixing.** The great majority of terrestrial arthropods live within the soil. These animals help to turn the soil and incorporate organic matter and nutrients. The impacts of these activities can be very dramatic, with some of the social insects (e.g., the ants and termites) moving and mixing tremendous amounts of soil as they tunnel. These processes are critical to soil formation and the maintenance of soil fertility. Without these insects, plant growth would be reduced and restricted.

**Centrality to animal food chains.** Through their feeding activities, plant-feeding insects (about 25% of the species on the planet) convert plant biomass to animal biomass. In turn, these creatures serve as the primary source of food for other insects (another 25% of the planet’s species) and for many birds, fish, and mammals



**FIGURE 1-6**

Mound-building termites are central to soil formation and mixing in large areas of Africa. Photograph courtesy of USDA APHIS PPQ Archives/Bugwood.org.

that are, in turn, food for yet still more animals. Thus, plant-eating insects are the critical link between plants and much of the rest of animal life on Earth (including humans).



**FIGURE 1-7** Many types of wildlife utilize insects as an important part of their diet. Photograph courtesy of David Leatherman.

**Maintenance of plant communities.** Although the effects of large plant-feeding mammals are conspicuous, it is the activities of insects that most often determine what plant life is present. Insects do this in many ways, including feeding on plants (**phytophagy**), feeding on seeds, pollination, and dispersing seeds.



**FIGURE 1-8** Through their foraging activities, leafcutting ants can have dramatic effects on the kinds of plant life that occur. Photograph courtesy of Ronald F. Billings/Texas Forest Service/Bugwood.org.

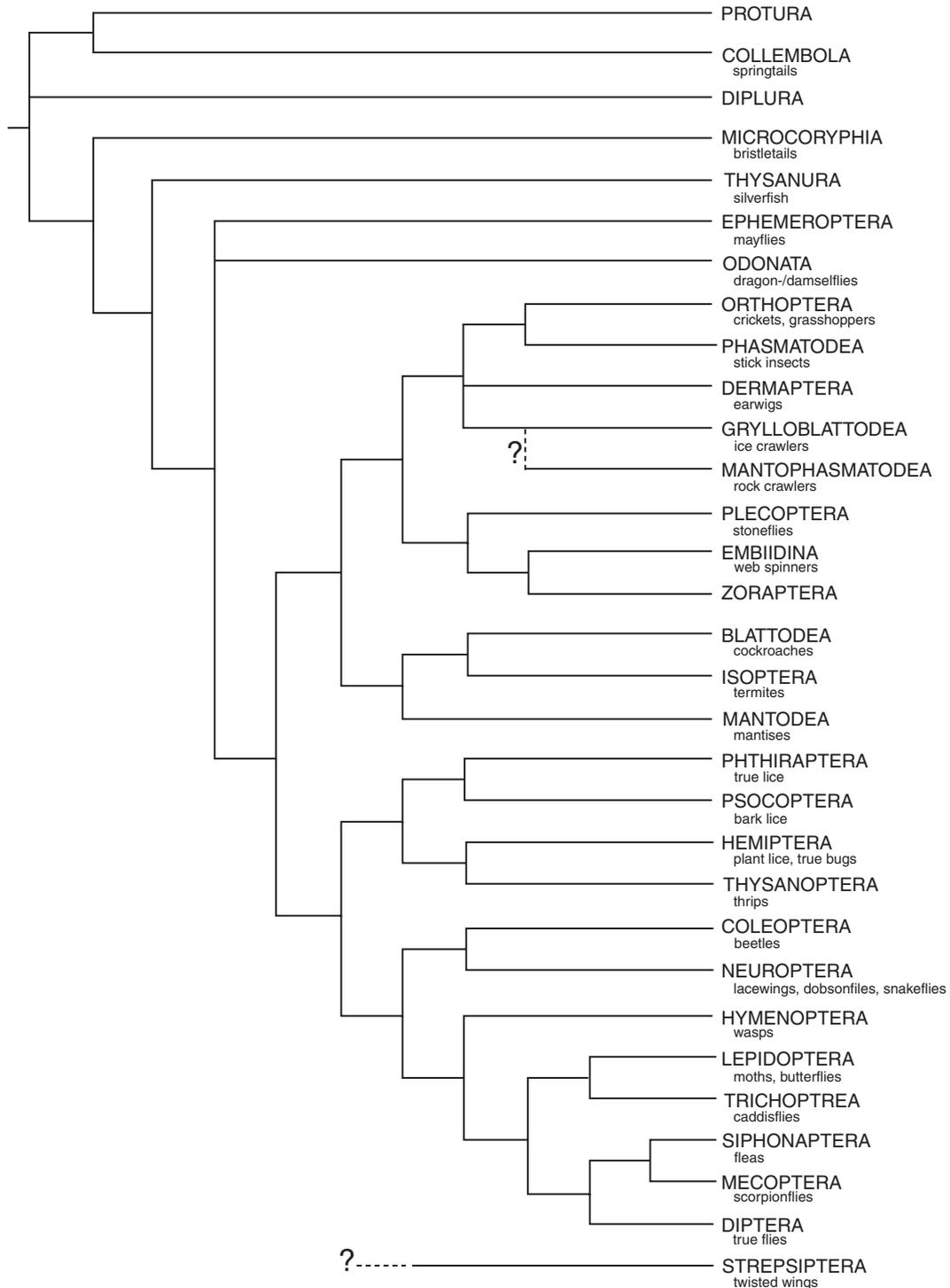
Unfortunately, most people recognize only those arthropods that are directly and immediately affecting human activities. These species are often considered negatively, as competitors, because of their ability to cause several types of harm—destruction of crops, damage to stored products or structures, transmission of plant and animal pathogens, and stings or bites—or merely some degree of annoyance. Those that do affect us in these ways are judged to be “pests,” a subjective and very flexible term that is defined by how much impact they are personally perceived to have. It is important to keep in mind that only a tiny fraction of all arthropods are ever elevated to this infamous status. A listing of all insects worldwide that are considered pests for one reason or another would include fewer than 10,000 species, approximately 1% of the total number of *known* insect species. A list of species that are directly beneficial to humans may be larger by an order of magnitude.

All too often people try to separate the insect world into “good bugs” and “bad bugs.” Alternatively, one often hears the question “What good is this insect/scorpion/spider?” These types of categorizations fail to recognize the tremendous importance of the arthropods to the functioning of this planet, usually in ways we little understand. It is perhaps important to keep in mind the words of pioneer conservationist/naturalist John Muir: “When we try to pick out anything by itself, we find it hitched to everything else in the Universe.”

Insects are neither good nor bad. They are, along with all other extant life forms, a representation of the latest expression of what has evolved on Earth.

## Classification of the Arthropods

In the classification of biological organisms, all life forms are grouped according to how related they are, usually based on physical features. Within this organization, all life forms are arranged in a series of subgroupings that become increasingly specialized. This science of classification is known as **taxonomy** and is conducted by specialists known as taxonomists. Closely associated with taxonomy, and often guiding the classification arrangements, is the science of **systematics** that seeks to determine the relatedness of different life forms. Systematists make extensive use of the fossil records of extinct species along with all



**FIGURE 1-9**

A diagram of a proposed phylogenetic relationship of the insect orders. Phylogenetics is the study of the evolutionary relations between organisms, and in a diagram such as this the orders that are most closely clumped are most closely related. Phylogenetics is a very active field that has been greatly aided by genetics. With new information, evolutionary relationships and taxonomic groupings are constantly being reevaluated, and changes in taxonomic arrangement are frequent. (Modified from Grimaldi and Engel, 2005.)

manner of biological features of present (**extant**) species. Increasingly, genetics also guides systematics. The powerful new tools that allow sequencing of genes are producing a revolution in the systematics of insects (and many other organisms) during which we are seeing many taxonomic arrangements being modified and many new species being recognized.

Using this system, all animals are classed together within the broadest type of grouping, a **kingdom**—specifically the kingdom Animalia. The kingdom containing all animals is next subdivided into various **phyla** (singular, **phylum**), one of which is Arthropoda—the arthropods that are the focus of this book. (Examples of some other animal phyla include Annelida, the segmented worms; Nematoda, the round worms; Mollusca, the mollusks; and Chordata, the animals with a hollow, ventral nerve cord, which includes humans.) In turn, a phylum is subdivided into sections, each known as a **class**. Four classes of arthropods (millipedes, centipedes, arachnids, hexapods/insects) are the primary focus of this

book. Also discussed, in part, are a group of arthropod classes collectively known as crustaceans (subphylum Crustacea).

The classes are subdivided into **orders**. For example, once you have identified something as an insect (from the class Hexapoda), the next grouping is the order of insects where it has been placed. Butterflies and moths, insects that have characteristic scale-covered wings, are placed by taxonomists in the order Lepidoptera. Beetles that have a hardened front pair of wings are in the order Coleoptera, while the flies, with their unique single pair of wings, are classified in the order Diptera. Because of differences in how scientists classify the insects, you may see some differences in the number of and names for the orders among the many books describing insect life and in their names. The classification system used for this book follows that of the 7th edition of *Borror and DeLong's Introduction to the Study of Insects* (2005), which lists in the class Hexapoda 28 orders of insects and 3 orders of entognathous hexapods.



(a)



(b)



(c)

**FIGURE 1-10**

(a–c) Representatives of three insect orders: sulfur butterfly (Lepidoptera), blatellid cockroach (Blattodea), and ground beetle (Coleoptera). Photographs courtesy of David Cappaert/Michigan State University/Bugwood.org, Ken Gray/Oregon State University, and Jim Kalisch/University of Nebraska, respectively.

Orders are subdivided into **families**, scientific names usually ending in “idae.” For example, the beetles (order Coleoptera) are divided into scores of families, including lady beetles (Coccinellidae),

weevils and bark beetles (Curculionidae), and leaf beetles (Chrysomelidae). Each family is divided into **genera** (singular **genus**), and each genus into various **species**.



(a)



(b)



(c)

**FIGURE 1-11**

(a–c) Representatives of three families within the order Coleoptera (beetles): lady beetle (Coccinellidae), weevil (Curculionidae), and darkling beetle (Tenebrionidae). Photographs courtesy of Whitney Cranshaw/Colorado State University, Brian Valentine, and Jim Kalisch/University of Nebraska, respectively.

Each species of insect, as well as all other life forms, has its own **scientific name**. This name is constructed by combining the genus name and what is known as the **specific epithet**. The genus name is capitalized, the specific epithet is not, and both are written in italics. For example, the scientific name of the house fly is *Musca domestica* and that of the tomato hornworm is *Manduca quinquemaculata*. The idea of

giving each species a scientific name that is universally recognized was formalized by Carolus Linnaeus (sometimes Anglicized as Carl Linnaeus), a Swedish physician and biologist (1707–1778). The outline he developed, published in the book *Systema Naturae* (1st edition 1735), was revolutionary and remains the fundamental framework whereby all living organisms are classified, based on shared features.



(a)



(b)



(c)

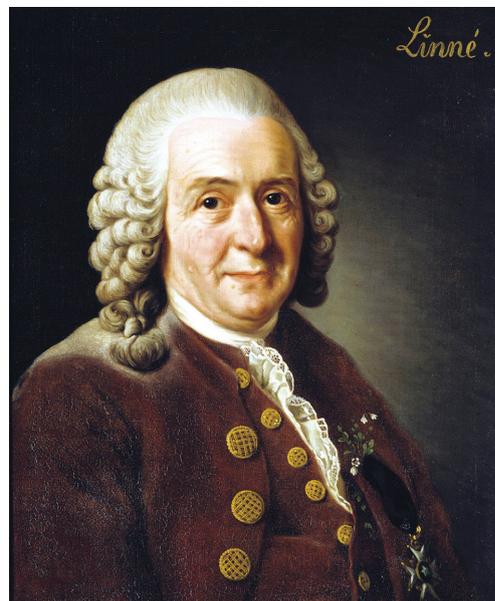
**FIGURE 1-12**

(a–c) Representatives of three different species within the beetle family Coccinellidae (lady beetles): *Hippodamia parenthesis*, *Harmonia axyridis*, *Coleomegilla maculata*. Photographs by Whitney Cranshaw/Colorado State University.

Since each scientific name has two parts, it is described as **binomial nomenclature**. This has become the universally recognized standard for discussing the identity of different organisms in a world that shares few other common languages. In the formal naming of an organism, the person who originally described it is also placed at the end of the name. Therefore in the scientific literature the house fly would be *Musca domestica* Linnaeus and the tomato hornworm *Manduca quinquemaculata* (Haworth), recognizing that these two insects were originally described by Linnaeus and Haworth, respectively. In this book, the descriptor names are left out for simplification, not to diminish in any way the contributions of those who took it upon themselves to first identify the insect as being a unique species.

Several mnemonic phrases have been developed to help reinforce learning of the basic taxonomic groups—kingdom, phylum, class, order, family, genus, species—including the following:

- King Philip cuts open five green snakes.
- Kings play cards on fat green stools.
- Kings play chess on Fridays, generally speaking.
- King Philip cried out—“for goodness sake!”



**FIGURE 1-13**  
The principles that guide the classification of living organisms was first formalized in the book *Systema Naturae*, written by Carolus Linnaeus (1707–1778). Painting by Alexander Roslin.

**TABLE 1-1** Taxonomic position of the honey bee, *Apis mellifera* Linnaeus, and the southern black widow, *Latrodectus mactans* (Fabricius).<sup>‡</sup>

HONEY BEE (COMMON NAME)*	SOUTHERN BLACK WIDOW (COMMON NAME) <sup>†</sup>
	
<p><b>FIGURE 1-14</b> The honey bee, <i>Apis mellifera</i> Linnaeus. Photograph courtesy of Joseph Berger/Bugwood.org.</p>	<p><b>FIGURE 1-15</b> The southern black widow, <i>Latrodectus mactans</i> (Fabricius). Photograph courtesy of Clemson University/Bugwood.org.</p>
<p>Phylum—Arthropoda</p>	<p>Phylum—Arthropoda</p>
<p>Class—Hexapoda</p>	<p>Class—Arachnida</p>

(continued)

**TABLE 1-1**

HONEY BEE (COMMON NAME)*	SOUTHERN BLACK WIDOW (COMMON NAME)†
Order—Hymenoptera	Order—Araneae
Family—Apidae	Family—Theridiidae
Genus— <i>Apis</i>	Genus— <i>Latrodectus</i>
Species— <i>mellifera</i>	Species— <i>mactans</i>
Original descriptor—Linnaeus	Original descriptor—Fabricius‡

\*Common name accepted by the Entomological Society of America.

†Common name accepted by the American Arachnological Society.

‡The original 1775 description by Fabricius used the genus name *Aranea*. In later revisions, the southern black widow was placed in a different genus (*Latrodectus*). This change from the original is indicated by the parentheses surrounding the name of the original descriptor.

It must be recognized that whatever type of classification is used, it is a human construct and thus subject to change. Orders, families, and even classes of organisms may be rearranged following revisions made by taxonomists as new information becomes available through discoveries of new species, better fossil records, and the use of modern molecular genetic techniques.

As our understanding of how different organisms are related has increased, additional groupings have been required. These are most often created by the prefix “sub” or “super.” For example, a subclass is a division of a class but will still contain within it one or more orders of the class. A superfamily will contain one or more families within the same order. The taxonomic arrangement used for this book is presented in table 1-2.

**TABLE 1-2** Primary taxonomic divisions of the phylum Arthropoda. Orders have been included for the terrestrial or freshwater arthropods that are the focus of this book (classes Arachnida and Hexapoda; subphylum Crustacea in brief).

- Subphylum Trilobita—trilobites (fossils only)
- Subphylum Chelicerata
  - Class Merostomata—eurypterids (fossils only) and horseshoe crabs
  - Class Arachnida—arachnids
    - Order Scorpiones—scorpions
    - Order Palpigradi—micro whipscorpions
    - Order Thelyphonida (Uropygi)—whipscorpions
    - Order Schizomida—shorttailed whipscorpions
    - Order Amblypygi—tailless whipscorpions, whipspiders
    - Order Araneae—spiders
    - Order Ricinulei—hooded tickspiders
    - Order Opiliones—harvestmen, daddy longlegs
    - Order Acari—mites and ticks
    - Order Pseudoscorpiones—pseudoscorpions
    - Order Solifugae—windscorpions, sunspiders
  - Class Pycnogonida—sea spiders
- Subphylum Crustacea—crustaceans
  - Class Cephalocarida

(continued)

**TABLE 1-2**

- Class Branchiopoda
  - Order Anostraca—fairy shrimp
  - Order Notostraca—tadpole shrimp
  - Order Conchostraca—clam shrimp
  - Order Cladocera—water fleas
- Class Ostracoda
- Class Copepoda
- Class Mystacocarida
- Class Remipedia
- Class Tantulocarida
- Class Branchiura
- Class Cirripedia
- Class Malacostraca
  - Order Amphipoda—amphipods
  - Order Isopoda—iso­pods
  - Order Stomatopoda—mantis shrimp
  - Order Decapoda—lobsters, crayfish, crabs, shrimp
- Subphylum Atelocerata
  - Class Diplopoda\*—millipedes
  - Class Chilopoda\*—centipedes
  - Class Pauropoda\*—pauropods
  - Class Symphyla\*—symphylans
  - Class Hexapoda—hexapods (includes insects)
    - Subclass Entognatha<sup>†</sup>
      - Order Protura—proturans
      - Order Diplura—diplurans
      - Order Collembola—springtails
    - Subclass Insecta—insects
      - Order Microcoryphia<sup>‡</sup>—jumping bristletails
      - Order Thysanura<sup>‡</sup>—silverfish
      - Order Ephemeroptera—mayflies
      - Order Odonata—dragonflies and damselflies
      - Order Orthoptera—grasshoppers, crickets, katydids
      - Order Phasmatodea—walkingsticks and leaf insects
      - Order Grylloblattodea—rock crawlers
      - Order Mantophasmatodea—heelwalkers or gladiators
      - Order Dermaptera—earwigs
      - Order Plecoptera—stoneflies
      - Order Embiida—webspinners
      - Order Zoraptera—zorapterans, angel insects
      - Order Isoptera—termites
      - Order Mantodea—mantids
      - Order Blattodea—cockroaches
      - Order Hemiptera—true bugs, cicadas, hoppers, psyllids, whiteflies, aphids, and scale insects
      - Order Thysanoptera—thrips
      - Order Psocoptera—psocids
      - Order Phthiraptera—lice

*(continued)*

TABLE 1-2

Order Coleoptera—beetles
Order Neuroptera—alderflies, dobsonflies, fishflies, snakeflies, lacewings, antlions, and owlflies
Order Hymenoptera—sawflies, parasitic wasps, ants, wasps, and bees
Order Trichoptera—caddisflies
Order Lepidoptera—butterflies and moths
Order Siphonaptera—fleas
Order Mecoptera—scorpionflies
Order Strepsiptera—twisted-wing parasites
Order Diptera—flies

\*Arthropods that are often referred to as Myriapoda, the myriapods.

†The classification of the various entognathous hexapods is subject to debate, although each of the three groups is considered distinct. Some classification schemes consider them as separate subclasses or even classes.

‡The orders Microcoryphia and Thysanura (alternately named as Archaeognatha and Zygentoma) consist of insects with primitive features that originated before the development of wings. As such they are sometimes considered together as the Apterygota, in contrast with the other insect orders (Pterygota) that have physical features associated with wings. This arrangement is subject to debate, as many other features of the Thysanura indicate that they are more closely related to the insects that developed wings than to the Microcoryphia.

## Common Name or Scientific Name?

Some insect orders and families, and many individual species of insects, have a **common name**. This is the familiar insect name in English, in contrast to the more formal **scientific name**. For example “beetles” is the common name for the order Coleoptera, “swallowtails” is the common name for the butterflies within the family Papilionidae, and “house fly” is the common name for the insect *Musca domestica*.

Scientific names are universal; they are the same in every country. That is their utility and appeal—although names of genera and even families are sometimes rearranged when new information (now usually genetics) leads to taxonomic revisions. However, most people find it easier to learn and use the common names when discussing local insects. Unfortunately, such common names may be used for very different insects in different locations, thus leading to some confusion. For example, an insect formally known as the armyworm (*Mythimna unipuncta*) is a common pest caterpillar of grain crops in much of the central

United States. However, when outbreaks of the forest tent caterpillar (*Malacosoma disstria*) occur in forests of northern Minnesota and Wisconsin and the caterpillars are seen marching across roads, this very different insect is called an “armyworm” and elsewhere other caterpillars seen in bands are often referred as “armyworms.” Similarly, an odd group of insects known as Jerusalem crickets are known locally by a wide variety of names such as “children of the earth,” “old baldheaded man,” and “potato bugs.” (In turn, a great number of other generally round-bodied arthropods are known as “potato bugs,” including pillbugs and the Colorado potato beetle.) Therefore the use of formally accepted common names provides a means to discuss and write about insects in a manner that allows the identification of the species to be consistently recognized.

The Entomological Society of America attempts to standardize the common names of insects used in the United States in the publication *Common Names of Insects and Related Organisms*. Common names of arachnids are similarly codified by the American Arachnological Society. Around the world, similar publications have been developed by various professional organizations committed to the study of arthropods.



(a)



(b)

**FIGURE 1-16**

(a) The armyworm, *Mythima unipuncta*, and (b) the forest tent caterpillar, *Malacosoma disstria*, each have formalized common names through the Entomological Society of America. The armyworm is a pest of grain crops, and the forest tent caterpillar feeds on various deciduous trees. During outbreaks, forest tent caterpillars are sometimes referred to as “armyworms,” which can cause confusion as to the species in question. Photographs by Frank Peairs and Whitney Cranshaw/Colorado State University.



(a)



(b)



(c)

**FIGURE 1-17**

Jerusalem crickets (a), *Stenopelmatus* spp., may locally be called by many different names including “children of the earth,” “old baldheaded man,” and “potato bug.” Among the other arthropods that are sometimes called “potato bugs” are (b) pillbugs, *Armadillidium vulgare*, and (c) the Colorado potato beetle, *Leptinotarsa decemlineata*. Photographs by Ken Gray/Oregon State University, Whitney Cranshaw/Colorado State University, and David Cappaert/Michigan State University/Bugwood.org, respectively.

# Index

- Abdomen 22, 36–38, 76  
Acari (mites and ticks) 10, 99–115  
Accessory glands 49  
Aedeagus 37, 48  
*Aedes aegypti* 393, 394, 395–397  
*Aedes* species 393–397  
African rock crawlers  
    (Mantophasmatodea)  
    11, 180–181, 441  
Africanized honey bees 319–320  
Agave worm 373–374  
Agramonte, Aristides Louis 395  
Alderflies 291, 450  
Alexander, C.P. 389  
Amblypygi (tailless whipscorpions) 10, 76,  
    82–83  
Ambush bugs 32, 221  
American dog tick (*Dermacentor  
    americanum*) 99, 102, 104  
Amphipoda (amphipods) 11, 127–128  
Angel insects (Zoraptera) 11, 176–177, 443  
*Anopheles* species 393, 394  
Anostraca 11, 128–129  
Antennae 29  
Antlions (Myrmeleontidae) 293–294, 450  
Ants (Formicidae) 236–237, 297,  
    328–338, 451  
    Aphid associations 236–237,  
    330–331, 334–335  
Aphids (Aphididae) 29, 202, 233–237,  
    331, 447  
    Ant associations 236–237, 330–331,  
    334–335  
Apiculture (beekeeping) 308, 314–320  
Apodeme 14, 15  
Apoysis 59  
Aposematic coloration 18, 346  
Apple maggot (*Rhagoletis pomonella*) 421  
Apterygota 141  
Arachne 75  
Arachnida (arachnids) 10, 75–118  
    Daddy longlegs (Opiliones) 10, 76,  
    97–99  
    Hooded tickspiders (Ricinulei)  
    10, 96–97  
    Micro whipscorpions (Palpigradi) 10, 80  
    Mites and Ticks (Acari) 10, 99–115  
    Pseudoscorpions  
    (Pseudoscorpiones) 10, 115–116  
    Scorpions (Scorpiones) 10, 78–80, 431  
    Shorttailed whipscorpions  
    (Schizomida) 10, 82  
    Spiders (Araneae) 10, 75, 76, 77,  
    83–96  
    Tailless whipscorpions (Amblypygi)  
    10, 76, 82–83  
    Whipscorpions (Thelyphonida) 10,  
    81–82  
    Windscorpions, sun spiders (Solifugae)  
    1, 10, 75, 76, 116–118  
*Arachnocampa* 48  
Arachnophobia 77, 341  
Araneae (spiders) 10, 75, 76, 77, 83–96  
Arbovirus 395, 397  
Archaeognatha 12, 141  
Argentine ant (*Linepithema  
    humile*) 334–335  
Arizona bark scorpion (*Centruroides  
    sculpturatus*) 79–80  
Armored scales (Diaspididae) 243–244  
Army ants 335–337  
Army cutworm (“miller moth”) 351, 354  
Armyworms 12, 351–352  
Arthropod classification 5–11  
Arthropod diversity and abundance 2  
Arthropod ecological roles 3–4  
Arthropod physical features 1, 2  
Arthropod size 16–17, 42–43, 431–432  
Asian citrus psyllid (*Diaphorina citri*) 240  
Assassin bugs (Reduviidae) 221–223  
Aster leafhopper (*Macrosteles  
    quadrilineatus*) 231  
Aster yellows 231  
Auchennoryncha 212, 225, 447  
Autocidal controls 414–415  
  
*Bacillus thuringiensis* 403–405  
Backswimmers (Notonectidae) 214–215  
Baldfaced hornet (*Dolichovespula  
    maculata*) 298, 326–327  
Ballooning 86, 90, 91  
“Banana spiders” (*Phoneutria*) 92  
Bark beetles (Scolytinae) 288–291  
Barklice 210, 211, 445–446  
Base temperature 71  
Batesian mimicry 347, 349  
Beatles, naming of 253–254  
Bed bugs (Cimicidae) 46, 223–225  
Bees 9–10, 28, 298, 306–320, 324, 451  
Beet curly top virus 231  
Beet leafhopper (*Circulifer tenellus*) 231  
Beetles (Coleoptera) 11, 252–291,  
    416, 425–428, 431–433,  
    448–449  
Berlese funnel 140  
Binomial nomenclature 9  
Biological control 199, 260, 273,  
    274–275, 285, 335, 362–363  
Bioluminescence 266, 267, 268–269  
Black Death 381, 382, 384  
Black flies (Simuliidae) 402–403  
Black widow (see Widow spiders)  
Blacklegged tick (*Ixodes scapularis*) 99, 104,  
    105–107  
Blattodea (cockroaches) 11, 32, 59,  
    182–188, 443–444  
Blister beetles (Meloidae) 278–279  
Blood 43–44, 84, 173, 175, 257, 272, 278  
Blow flies (Calliphoridae) 4, 27,  
    412–416, 455  
Body louse 206, 208, 209  
Bogong moth 354  
Boll weevil (*Anthonomus grandis*) 286–288  
Bombardier beetles 254–255  
Book lungs 77, 84  
Booklice 210–211, 445–446  
Bot flies (Oestridae) 419–420  
Brachycera 389  
Brain 51  
Brine shrimp (fairly shrimp) 11, 128–129  
Brown marmorated stink bug  
    (*Halyomorpha halys*) 17  
Brown recluse spider 92–94  
Brown spiders (*Loxosceles*) 92–94  
Brushfooted butterflies  
    (Nymphalidae) 345–348  
Bullet ant 324  
Bumble, bees (*Bombus*) 28, 306, 320–321  
Butterflies 21, 27, 34, 42, 341–350,  
    425–430, 433, 452  
  
Caddisflies (Trichoptera) 11, 173–175,  
    339, 374–376, 453  
Camel crickets (Rhopidophoridae)  
    31, 167  
Camel spiders 117–118  
Cantharidin 278–279  
Carmine 246  
Carpenter ants (*Camponotus*) 329–330  
Carrion beetles (Silphidae) 256–257  
Carroll, James 395  
Cat flea 279, 380  
Cattle grub 420  
Cattle tick fever 104–105  
Cattle ticks 101, 104–105  
Centipedes (Chilopoda) 11, 130–132, 431  
*Centruroides sculpturatus* (Arizona bark  
    scorpion) 79–80  
Cephalothorax 22, 76  
Cerci 37  
Chagas disease 222–223  
Chelae 78

- Chelicerae 75, 76, 78, 81, 82, 83, 98, 101, 115, 117  
Chelicerata 10, 75  
Chemoreceptors 54  
Chiggers 114–115  
Chigoe flea (*Tunga penetrans*) 379  
Chilopoda (centipedes) 11, 130–132, 431  
Chinch bugs (*Blissus*) 58  
Chironomid midges (Chironomidae) 175, 390–391, 455  
Chrysalis 67, 343  
Cibarial pump 225  
Cicadas (Cicadidae) 14, 124, 225–229, 447  
Circulatory system 43–44  
Citrus greening disease (Huanglongbing) 240  
Click beetles (Elateridae) 265  
Clothes moths 359–360  
Cluster flies (*Pollenia*) 413–414  
Cochineal dye 246  
Cochineal scales (Dactylopidae) 243, 245–246  
Cockroaches (Blattodea) 11, 32, 59, 182–188, 443–444  
Cocoon 253, 298, 340, 343, 366, 368, 448, 452–454  
Codling moth (*Cydia pomonella*) 56–57, 363  
Coleoptera (beetles) 11, 252–291, 416, 425–428, 431–433, 448–449  
Collembola (springtails) 2, 11, 42, 136–139, 435  
Color production 18–21, 285–286  
Colorado potato beetle (*Leptinotarsa decemlineata*) 282–283  
Colorado tick fever 104, 105–107  
Common name 12–13  
Compound eyes 29, 52–53  
Conenose bugs 221–223  
Convergent lady beetle (*Hippodamia convergens*) 273–274  
Coprophagy 46  
Corn root aphid (*Aphis middletoni*) 237  
Cornfield ants (*Lasius*) 237  
Cottony cushion scale 274–275  
Crab louse 207  
Crabs 122, 123, 124, 431  
Crane flies (Tipulidae) 174, 389–390  
Crayfish 123–124  
Crickets (Gryllidae) 156, 165–166  
Crimson dye 246  
Crochets 340, 341  
Crustaceans 10–11, 119–129  
    Amphipoda (amphipods) 11, 127–128  
    Anostraca 11, 128–129  
    Decapoda (decapods) 11, 122–127  
    Isopoda (isopods) 11, 120–122  
    Merostomata (horseshoe crabs) 10, 75  
    Notostraca 11, 128  
    Pycnogonida (sea spiders) 10, 75  
Cryptic coloration 21–22  
Cryptic species 163  
*Culex* species 393, 394–395, 397–398  
Curtice, Cooper 105  
Cutworms (Noctuidae) 351–355  
Daddy longlegs (Opiliones) 10, 76, 97–99  
Damsel flies (Odonata) 18, 147–154, 438  
Darkling beetles (Tenebrionidae) 18, 276–277  
Decapoda (decapods) 11, 122–127  
Deer flies (Tabanidae) 408–409  
“Deer tick” (*Ixodes scapularis*) 99, 104, 105–107  
Degree day 71  
Dengue 394, 397  
Dermaptera (earwigs) 11, 37, 177–179, 441–442  
Dermestid beetles (Dermestidae) 269–271, 416  
Diapause 71–73, 74, 273  
Dictyoptera 171, 182  
Digestive system 44–46  
Diplopoda (millipedes) 1, 11, 43, 133–135, 431  
Diplura, (diplurans) 11, 136, 140–141, 436  
Diptera (True flies) 4, 12, 26, 27, 34, 174, 175, 387–422, 455  
Dobsonflies (Corydalidae) 291–292, 450  
Dolbear’s Law 165  
Dorsal vessel 44  
Dragonflies (Odonata) 1, 35, 147–154, 438  
Driver ants (*Dorylus*) 335–337  
*Drosophila melanogaster* 422  
Drywood termites (Kalotermitidae) 196–197  
Dung feeders 258, 259–261  
Dung rollers 258, 261  
Dust mites 115  
Dutch elm disease 264, 289–291  
Dyes from insects 245–246  
Earwigs (Dermaptera) 11, 37, 177–179, 441–442  
Ecdysis 59  
Ecdysone 59, 69, 70  
Egyptian gods and scarabs 258  
Elephant beetles 259, 432  
Elytra 33, 253, 448  
Embiidina (webspinners) 11, 175–176, 443  
Emerald ash borer (*Agrilus planipennis*) 263, 264  
Endocuticle 15, 59, 60  
Entognathous hexapods, (Entognatha) 11, 136–141  
    Collembola (springtails) 2, 11, 42, 136–139, 435  
    Diplura (diplurans) 11, 136, 140–141, 436  
    Protura (proturans) 11, 136–137, 435  
Entomophagy 124–126  
Ephemeroptera (mayflies) 62, 144–147, 173–175, 437  
Epicuticle 15, 59  
Epidermal cells 59, 60  
Epidermis 15, 59  
Epipharynx 24  
Eriophyid mites 110–111  
European corn borer (*Ostrinia nubilalis*) 361–362  
Excretory system 47–48  
Exocuticle 15, 59, 60  
Exoskeleton 2, 14–23, 59–61, 68, 69–70  
Eyespot markings 19  
Face fly (*Musca autumnalis*) 417–418  
Fairy shrimp (brine shrimp) 11, 128–129  
Fat body 44  
Fattailed scorpions (*Androctonus*) 79  
Field ants (*Formica*) 331–332  
Fire ants (*Solenopsis*) 333–334  
Firebrat (*Thermobia domestica*) 143  
Fireflies (Lampyridae) 265–268  
Fishflies 291  
Flea beetles (Alticinae) 283–284, 362  
Fleas (see also Siphonaptera) 31, 377–384, 386, 454–455  
Flower flies (Syrphidae) 41, 411–412  
Follicle mites 111–112  
Forensic entomology 72, 415–416  
Fruit flies (Tephritidae) 419–421  
“Gadfly” 419, 420  
Gall midges (Cecidomyiidae) 406–407  
Gall wasps (Cynipidae) 304–305  
Galls 110–111, 236, 239, 250–251, 304–305, 406–407  
Gas exchange 37, 39–43  
Giant silk moths (Saturniidae) 368–370  
Giant water bugs (Belostomatidae) 215–216  
Gills 37  
Gladiator insects 441  
Glassy-winged sharpshooter (*Homalodisca vitripennis*) 232

- Glowworms 48, 266, 268–269  
Goliath beetles 259, 261, 432–433  
Gorgas, William 395  
Gossamer 91  
Grain moths 360–361  
Grape phylloxera (*Daktulosphaira vitifoliae*) 237–238  
Grasshoppers (Acrididae) 20, 24, 32, 63, 156–162, 439  
Greenhouse whitefly (*Trialeurodes vaporariorum*) 240–241  
Griffinflies 43, 148, 431  
Ground beetles (Carabidae) 31, 254–256  
Grylloblattodea (rock crawlers) 179–180, 441  
Gypsy moth (*Lymantria dispar*) 355–357
- Haldane, J.B.S. 253  
Halteres 34, 387, 455  
Hamuli 296, 451  
Hard ticks (Ixodidae) 101–107  
Harvester ants (*Pogonomyrmex*) 324, 330, 332–333  
Hawk moths (Sphingidae) 371–373  
Head 23–29  
Head louse 204–206  
Heelwalkers (Mantophasmatodea) 11, 180–181, 441  
Hellgrammite 291–292  
Hemelytra 33, 212–213  
Hemiptera 29, 212–247, 447  
Hemocyanin 84  
Hemoglobin 43, 84, 175  
Hemolymph 43–44  
Hercules beetles 261  
Hessian fly (*Mayetiola destructor*) 406  
Heteroptera (true bugs) 213–224, 447  
Hexapoda (hexapods) 11–12, 136, 435–456  
Hilltopping 329  
“Hobo” spider (*Tegenaria agrestis*) 94  
Homoptera 212  
Honey bee (*Apis mellifera*) 9–10, 16, 28, 298, 306, 308–320, 324  
    Castes 310–311  
    Diseases, pests 315–318  
    Honey 308, 313–315  
    Swarming 311, 319–320  
    Wax production 309, 311,  
Honeydew 126, 233, 236, 237, 239, 240, 330–331, 334  
Hooded tickspiders (see Ricinulei)  
Hormones 43, 58, 59, 68, 70, 357  
Horn fly (*Haematobia irritans*) 418  
Hornet (*Vespa*) 327  
Horntails 297, 300–301  
Hornworms (Sphingidae) 371–373  
Horse flies (Tabanidae) 408–409, 455
- Horseshoe crabs (Merostomata) 10, 75  
House fly (*Musca domestica*) 12, 27, 34, 417–418  
Human bot fly (*Dermatobia hominis*) 419–420  
Human flea 380  
“Hummingbird moths” 372  
Hunting wasps (Sphecidae) 322–323  
Hymenoptera 296–338, 451  
Hypopharynx 25, 26, 27
- Indianmeal moth (*Plodia interpunctella*) 360–361  
Insect growth regulators 69–70, 357  
Insect orders  
    Archaeognatha 12, 141  
    Blattodea (cockroaches) 11, 32, 59, 182–188, 443–444  
    Coleoptera (beetles) 11, 252–291, 416, 425–428, 431–433, 448–449  
    Dermaptera (earwigs) 11, 37, 177–179, 441–442  
    Embiidina (webspinners) 11, 175–176, 443  
    Ephemeroptera (mayflies) 62, 144–147, 173–175, 437  
    Grylloblattodea (rock crawlers) 179–180, 441  
    Hemiptera (true bugs, aphids, scale insects, cicadas, etc.) 29, 212–247, 447  
    Homoptera 212  
    Hymenoptera (bees, wasps, ants, sawflies) 296–338, 451  
    Isoptera (termites) 4, 45, 46, 188–198, 444  
    Lepidoptera (moths, butterflies) 12, 16, 21, 339–373, 425–430, 433–434, 452  
    Mantodea (mantids) 11, 32, 50, 198–201, 445  
    Mantophasmatodea (heelwalkers) 11, 180–181, 441  
    Mecoptera (scorpionflies) 11, 37, 377, 384–386, 454  
    Megaloptera 291–292  
    Microcoryphia (jumping bristletails) 11, 141–142, 436  
    Neuroptera (lacewings, dobsonflies, snakeflies, owlflies, etc.) 11, 291–295, 450  
    Notoptera 179  
    Odonata (damselflies and dragonflies) 1, 11, 18, 35, 43, 65, 147–154, 438  
    Orthoptera (grasshoppers, crickets, katydids) 11, 20, 24, 31, 32, 48, 125–126, 155–168, 439
- Phasmatodea (walkingsticks and leaf insects) 11, 43, 168–170, 431, 440  
Phthiraptera (lice) 202–209, 446  
Plecoptera (stoneflies) 11, 63, 171–174, 442  
Psocoptera (booklice, barklice) 202, 210–211, 445–446  
Siphonaptera (fleas) 31, 377–384, 386, 454–455  
Strepsiptera (twisted-wing parasites) 423–424, 456  
Thysanoptera (thrips) 247–251, 448  
Thysanura (silverfish) 11, 61, 142–143, 437  
Trichoptera (caddisflies) 11, 173–175, 339, 374–376, 453  
Zoraptera (Angel insects) 11, 176–177, 443  
Zygentoma 12, 142  
Insecticide resistance 109, 240, 241, 242–243  
Instar 58  
Iron-gall ink 304–305  
Isopoda (isopods) 11, 120–122  
Isoptera (termites) 4, 45, 46, 188–198, 444
- Japanese beetle (*Popillia japonica*) 262  
Jerusalem crickets (Stenopalmatidae) 12, 162–163, 439  
Jumping bristletails (Microcoryphia) 11, 141–142, 436  
Jumping spiders (Salticidae) 77, 89  
Juvenile hormone 68, 69, 70, 357
- Katydids (Tettigoniidae) 23, 48, 163–165, 439–440  
Khepri 258  
Kilbourne, F.L. 105  
“Killer bees” 319–320  
“Kissing bugs” 221–223
- Labium 24–28, 212, 248  
Labru 24, 26–28, 212, 248  
Lac scale (Kerridae) 246–247  
Lacewings (Chrysopidae, Hemerobiidae) 293, 445–446  
Lady beetles (Coccinellidae) 60, 271–276, 425–426  
Langstroth, Lorenzo 314–415  
Lazear, Jesse 395  
Leaf beetles (Chrysomelidae) 282–286  
Leaf insects 168, 169, 440  
Leafcutter bees (*Megachile*) 4, 306–307  
Leafcutting ants (*Atta*) 5, 337–338  
Leaffooted bugs (Coreidae) 218–220  
Leafhoppers (Cicadellidae) 213, 230–232  
Leafrollers (Tortricidae) 363–365

- “Leatherjackets” 390  
Legionary ants (*Eciton*) 335–337  
Legs 30–31, 435–456  
Lepidoptera 12, 16, 21, 339–373, 425–430, 433–434, 452  
Lerps 239  
Lice (Phthiraptera) 202–209, 446  
Light attraction 353  
Light perception 52–53  
Linnaeus, Carolus 8, 9  
Little Miss Muffet 78  
Lobster 119, 431  
Locusts 159–162, 228  
Lone star tick (*Amblyomma americanum*) 99, 102, 103, 104  
Longhorned beetles (Cerambycidae) 279–282, 431  
“Lovebug” 405–406  
Lyme disease 104, 105–107  
  
Maggot therapy 413  
Makech 277  
Malaria 394, 396–400  
Malpighian tubules 45, 47–48, 253, 293  
Mandible 24–28, 212, 248  
Mandibulata 76  
Mantidflies (Mantispidae) 294  
Mantids (Mantodea) 11, 32, 50, 198–201, 445  
Mantodea (mantids) 11, 32, 50, 198–201, 445  
Mantophasmatodea (heelwalkers) 11, 180–181, 441  
March flies (Bibionidae) 405–406  
Mason bees (*Osmia*) 307  
Maxillae 24–28, 212, 248  
May/June beetles 261–262  
Mayflies (see also Ephemeroptera) 62, 144–147, 173–175, 437  
Mealybugs (Pseudococcidae) 243, 245  
Mechanoreceptors 54  
Mecoptera (scorpionflies) 11, 37, 377, 384–386, 454  
Mediterranean fruit fly (*Ceratitis capitata*) 415, 421  
Megaloptera 291–292  
Merostomata 10, 75  
Metallic wood borers (Buprestidae) 262–264  
Metamorphosis 58, 61–69  
    Ametabolous development 61  
    Anamorphic development 68, 132, 134  
    Complete metamorphosis 64, 65–68  
    Hemimetabolous development 61–62, 64, 65  
    Holometabolous development 64, 65–68  
    Simple metamorphosis 61–62, 64, 65  
Mexican jumping bean 365  
Mezcal worm 373–374  
Micro whipscorpions (Palpigradi) 10, 80  
Microcoryphia (jumping bristletails) 11, 141–142, 436  
Millipedes (Diplopoda) 1, 11, 43, 133–135, 431  
Mimicry 346–347, 349–350, 411  
Mole crickets (Gryllopteralidae) 32, 168  
Molting 15, 18, 59–61, 68, 69–70  
Monarch butterfly (*Danaus plexippus*) 345–348, 425–428  
Mormon cricket (*Anabrus simplex*) 125, 164–165  
Morpho butterfly 21  
“Mosquito hawk” 389  
Mosquito repellents 401–402  
Mosquitoes (Culicidae) 24, 34, 391–402  
Moths 16, 227, 34, 341–343, 351–374, 433–434, 452  
Mottephobia 341  
Mouffet, Thomas 78  
Mound-building termites (Termitidae) 197–198  
Mouthparts 24–28, 212–214, 247–248, 339, 340–341, 388–389, 448  
Mullerian mimicry 346  
Multicolored Asian lady beetle (*Harmonia axyridis*) 273–274  
Muscid flies (Muscidae) 417–418  
Mycetomes 46  
Myriapoda 129  
  
Nagana 409–411  
Nematocera 389  
Nervous system 50–53  
Neuroendocrine system 58  
Neuroptera 11, 291–295, 450  
Neurosecretory cells 51  
Neurotransmitter 50, 52  
Notoptera 179  
Notostraca 11, 128  
  
Ocelli 29–30  
*Ochlerotatus* species 392, 393  
Odonata (damselflies and dragonflies) 1, 11, 18, 35, 43, 65, 147–154, 438  
Onchocerciasis (river blindness) 403  
Opiliones (daddy longlegs) 10, 76, 97–99  
Opisthosoma 76  
Orbweaver spiders (Araneidae) 84, 85, 86, 87, 89  
Oriental fruit fly (*Bactrocera dorsalis*) 415, 421  
Oriental rat flea 380, 381  
Orthoptera 11, 20, 24, 31, 32, 48, 125–126, 155–168, 439  
Ovaries 49  
Ovipositor 37, 38  
Owlflies (Ascalaphidae) 294–295, 450  
Oxygen transport by blood 43, 84, 175  
  
Pain perception 50  
Painted lady (*Vanessa cardui*) 345  
“Palmetto bug” 182  
Palpigradi (micro whipscorpions) 10, 80  
Paper wasps (*Polistes*) 324, 327–328  
Parasitic Hymenoptera 38, 297, 301–303  
Paupoda (paupods) 11, 132  
Pectines 78  
Pedipalps 76, 78, 80, 81, 82, 115, 117  
Peppered moth (*Biston betularia*) 21–22  
Periodical cicadas (*Magicicada*) 226–228  
Peritrophic membrane 45  
Pesticide resistance 109, 240, 241, 242–243  
Phase polymorphism 159, 164  
Phasmatodea (walkingsticks and leaf insects) 11, 43, 168–170, 431, 440  
Pheromones 54–56, 357  
Phoresy 116, 420  
Phthiraptera (lice) 202–209, 446  
Phylogenetics 6  
Phytoseiid mites (Phytoseiidae) 109  
Pierce’s disease of grape 231–232  
Pillbug 12, 120–122  
Plague 380–384  
Plannipenia 291, 293–295  
Plant bugs (Miridae) 219–220  
*Plasmodium* 398–400  
Plecoptera (stoneflies) 11, 63, 171–174, 442  
Pollination 3–4, 307, 309, 317, 321  
Polydnaviruses 303  
“Potato bug” 12  
Potato/tomato psyllid (*Bactericera cockerelli*) 239–240  
“Praying mantid” 199  
Proboscis 212  
Procuticle 15, 59, 60  
Prolegs 300, 340–341, 451, 452  
Propolis 309  
Prosoma 76  
Protura (proturans) 11, 136–137, 435  
Pseudoscorpions (Pseudoscorpiones) 10, 115–116  
Pseudoscorpiones (pseudoscorpions) 10, 115–116  
Psocoptera (booklice, barklice) 202, 210–211, 445–446  
Psyllids (Psyllidae, Trioziidae) 239–240  
Pupa 63, 66, 241, 248–249, 253, 298, 340, 343, 378, 389, 448, 452–455  
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- Puparia 389  
Pycnogonida (sea spiders) 10, 75
- Rattailed maggot 41, 411  
Reed, Walter 395  
Reflex bleeding 173, 272  
Resilin 15  
Reproductive system 48–49  
Rhaphidioptera 291, 292–293  
Ricinulei (hooded tickspiders) 10, 96–97  
“River blindness” 403  
Robber flies (Asilidae) 409  
Rock crawlers (see Grylloblattodea) 441  
Rocky Mountain locust (*Melanoplus spretus*) 161–162  
Rocky Mountain spotted fever 104  
Rocky Mountain wood tick 102, 103, 104  
“Roly-poly” 12, 120–122  
Rove beetles (Staphylinidae) 257–258
- Sawflies 297, 298, 299–300, 340, 451  
Scabies mites (Sarcoptidae) 112–113  
Scale insects (Coccoidea) 243–247, 274–275, 447  
Scarab beetles (Scarabaeidae) 258–262, 432–433  
Scarlet 246  
Schizomida (shorttailed whipscorpions) 10, 82  
Scientific name 8, 12  
Sclerite 14, 32  
Sclerotization 59, 60  
Scorpiones (scorpions) 10, 78–80, 431  
Scorpionflies (see also Mecoptera) 454  
Scorpions (Scorpiones) 10, 78–80, 431  
Screwworm (*Cochliomyia hominivorax*) 413–415  
Sea scorpion 431  
Sea spiders (Pycnogonida) 10, 75  
Setae 16, 340  
Seventeen-year cicadas (*Magicicada*) 226–228  
Shellac 246–247  
Shorttailed whipscorpions (Schizomida) 10, 82  
Shrimp 124, 125, 127, 128–129  
Silk 84–88, 90, 91, 253, 293, 298, 309, 329, 339, 340, 366–370  
Silkworm (*Bombyx mori*) 366–367  
Silverfish 61, 62, 142–143, 437  
Siphonaptera (fleas) 31, 377–384, 386, 454–455  
Skippers (Hesperiidae) 339, 341–343  
Slave-making ants 332  
Sleep 74  
Sleeping sickness 409–411
- Small fruit (vinegar) flies (Drosophilidae) 17, 422  
Smith, Theobald 104  
Snakeflies 292–293  
“Snow fleas” 139  
Social insects 186, 188, 251, 298–299, 303–308, 315–316, 320–321, 324–325, 326, 328  
Sod webworms 361  
Soft ticks (Argasidae) 104, 107–109  
Soft scales (Coccidae) 126, 243, 244  
Solifugae (windscorpions, sun spiders) 1, 10, 75, 76, 116–118  
Sound perception 54, 156, 163  
Sound production 156, 162, 163, 165–166, 168, 173  
Sowbug 120–122  
“Spanish fly” 279  
Spermatheca 49  
Spermatophore 48, 78, 435–437  
Sphinx moths (Sphingidae) 371–373  
Spittlebugs (Cercopidae) 229–230  
Spider mites (Tetranychidae) 109–110  
Spider wasps (Pompilidae) 322–323  
Spiders (Araneae) 10, 75, 76, 77, 83–96  
Spiracles 37, 40, 42  
Springtails (Collembola) 2, 11, 42, 136–139, 435  
Stable fly (*Stomoxys calcitrans*) 26, 418  
Stemmata 30  
Sterile insect technique (SIT) 414–415  
Sternorrhyncha 212, 232, 447  
Sticktight flea 378–379  
Stinging hairs 370–371  
Stinging insects 298, 323–324, 325–327, 331, 333–334  
Stink bugs (Pentatomidae) 213, 217–218  
Stoneflies (Plecoptera) 11, 63, 171–174, 442  
Strepsiptera (twisted-wing parasites) 423–424, 456  
Stylet bundle 212  
Subterranean termites (Rhinotermitidae) 193–196  
Sun spiders (Solifugae) 1, 10, 75, 76, 116–118  
Swallowtails (Papilionidae) 346–348, 425–429, 433  
Swarming 311, 319–320, 328, 330, 333  
Sweat bees 306, 324  
Sweetpotato whitefly (*Bemisia tabaci*) 241  
Sydney funnelweb spider 92  
Symbionts 45, 46, 193, 198  
Symphyla (symphylans) 132–133  
Systematics 5–6
- Tadpole shrimp 128  
Tagmata 22–23
- Tailless whipscorpions (Amblypygi) 10, 76, 82–83  
Tarantism 95–96  
Tarantula hawk 19, 323, 324  
Tarantulas 86, 94–96, 431  
Taxonomy 5–12  
Tegmina 33, 155, 183, 199, 439, 440, 443, 447  
Telson 78  
Temperature  
Adaptation to cold 180  
Color and 19–20  
Cricket chirp rate and 165  
Development rate and 71–72  
Tent caterpillars (Lasiocampidae) 12, 358  
Termites (Isoptera) 4, 45, 46, 188–198, 444  
Testes 48  
Thatcher ants (*Formica*) 331–332  
Thelyphonida (whipscorpions) 10, 81–82  
Thigmotactic 178  
Thorax 30–36  
Thrips (see Thysanoptera)  
Thysanoptera (thrips) 247–251, 448  
Thysanura 11, 61, 142–143, 437  
Tick paralysis 104  
Tick removal 103  
Tick-borne relapsing fever 104, 109  
Tiger beetles (Cicindellinae) 24, 255–256  
Tiger moths 354–355, 358–359  
Tortoise beetles 285–286  
Tracheal system 39–42  
Traumatic insemination 224  
Tree crickets 165, 166  
Trichoptera (caddisflies) 11, 173–175, 339, 374–376, 453  
Trilobites 10, 128  
Triungulin 278, 294, 424, 456  
Trochophyllaxis 193, 444  
True flies 387–422, 455  
*Trypanosoma cruzi* 222–223  
Tsetse flies (*Glossina*) 26, 409–411  
Tussock moths (Lymantriidae) 355–357  
Twisted-wing parasites 456  
Tympanal organs 54, 156, 163  
Typhus 207, 208–209
- Uropygi (see Thelyphonida)  
Urticating hairs 370–371
- Varroa mites 317–320  
Vectors of animal pathogens  
Black fly vectored pathogens 403  
Flea vectored pathogens 380–384  
Kissing bug vectored pathogens 222  
Louse vectored pathogens 207, 208–209  
Mite vectored pathogens 115

- Vectors of animal pathogens (*continued*)  
  Mosquito vectored pathogens 394–400  
  Tick vectored pathogens 103–107  
  Tsetse fly vectored pathogens 409–411
- Vectors of plant pathogens  
  Aphid vectored pathogens 236  
  Bark beetle vectored pathogens 289–291  
  Horntail vectored pathogens 301  
  Leafhopper vectored pathogens 231–232  
  Longhorned beetle vectored pathogens 281  
  Psyllid vectored pathogens 239–240  
  Thrips vectored pathogens 249–250  
  Whitefly vectored pathogens 241
- Vectors of polydnaviruses 303
- Vedalia beetle 274–275
- Viceroy (*Limenitis archippus*) 346–347
- Vinegar flies (Drosophilidae) 17, 422
- Vinegaroons (Thelyphonida) 10, 81–82
- Von Frisch, Karl 312
- Walkingsticks 43, 168–170, 431, 440
- Wasps 38, 297, 298, 301–305, 322–328, 451
- Water boatmen (Corixidae) 31, 214–215
- Water quality and insects 171, 173–175
- Water striders (Gerridae) 17, 214
- Wax production 309, 311, 320
- Weaver ants (*Oecophylla*) 335
- Webspinners (Embiidina) 11, 175–176, 443
- Weevils (Curculionidae) 286–291
- West Nile Virus 394, 397–398
- Wetas (Anostostomatidae) 167–168, 432
- Whipscorpions (Thelyphonida) 10, 81–82
- Whipspiders (Amblypygi) 10, 76, 82–83
- White admiral (*Limenitis arthemis*) 430
- Whiteflies (Aleyrodidae) 240–241, 447
- Whitetailed spiders (*Lampona*) 94
- Widow spiders (*Latrodectus*) 9–10, 87, 88, 91–92, 95
- Windscorpions (Solifugae) 1, 10, 75, 76, 116–118
- Wings 32–36, 62, 148, 153, 213, 247, 252–253, 296, 339, 340, 387–388, 435–456
- Wolf spiders (Lycosidae) 89, 90, 95, 135
- Woollybears 358–359
- Yellow fever 393, 395–397
- Yellowjackets (*Vespula*) 29, 324–326
- Yellowlegged sac spiders 94
- Yucca moths 373
- Zoraptera (Angel insects) 11, 176–177, 443
- Zygentoma 12, 142