Contents

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:

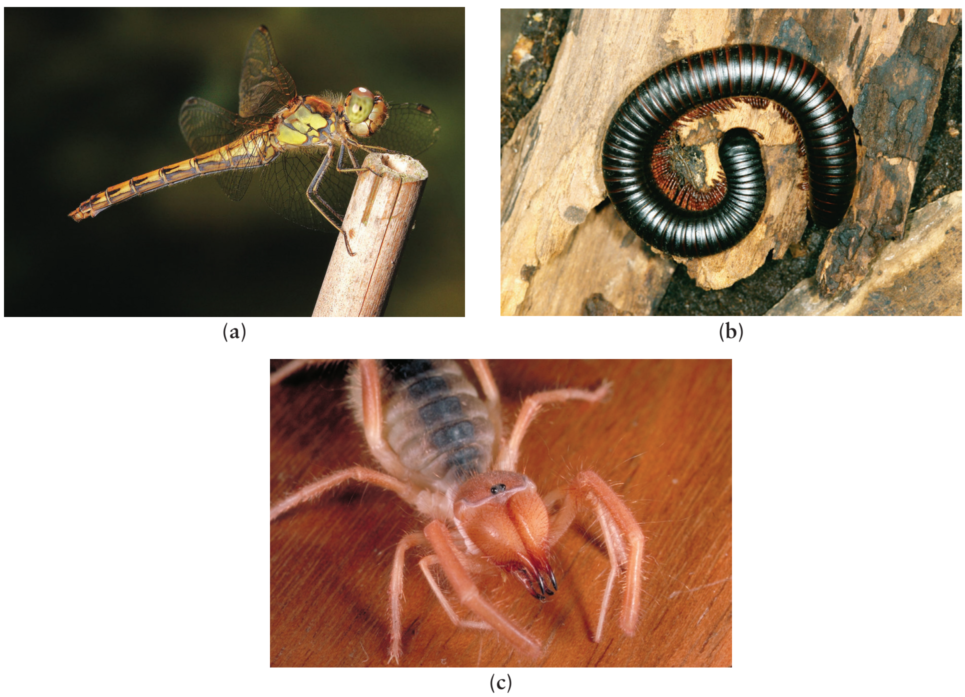


FIGURE 1-1
Three representative arthropods. (a) Dragonfly (insect), (b) julid millipede, and (c) windscorpion (arachnid). All show the basic external features of arthropods including an exoskeleton, segmentation of the body, jointed appendages, and a body design that is bilaterally symmetrical. Photograph 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

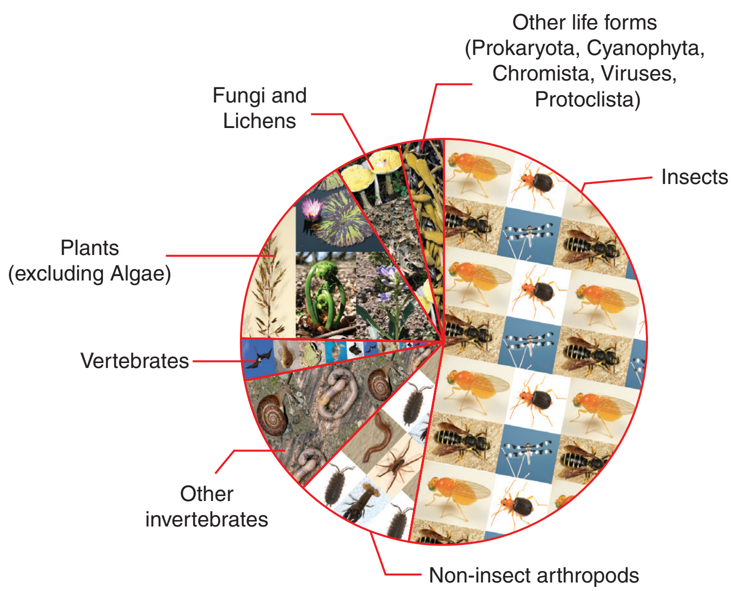


FIGURE 1-2
The relative number of different kinds of life forms known on Earth, based on the number of known species. Of the approximately 1.9 million presently recognized species, just over half are insects. Figures based on *Numbers of Living Species in Australia and the World*, 2nd ed. (2009). Photographs 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

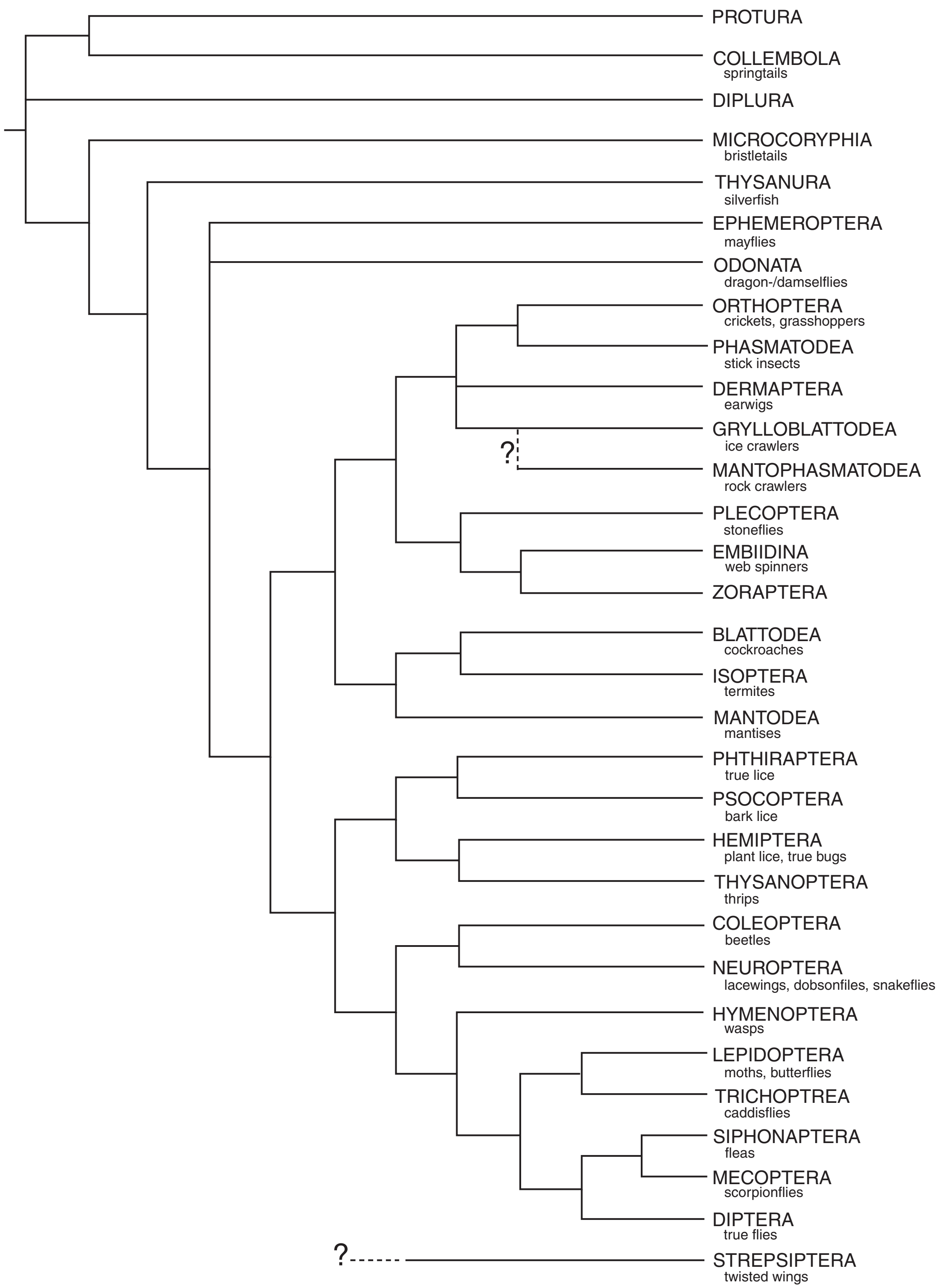


FIGURE 1-9

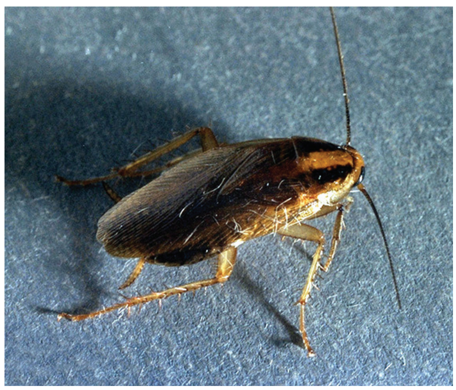
A diagram of a proposed phylogenetic relationship of the insect orders. Phylogenetics is the study of the evolutionary relations between organisms, and in a diagram such as this the orders that are most closely clumped are most closely related. Phylogenetics is a very active field that has been greatly 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 **P**hilip **c**uts **o**pen **f**ive **g**reen **s**nakes.
Kings **p**lay **c**ards **o**n **f**at **g**reen **s**tools.
Kings **p**lay **c**hess **o**n **F**ridays, **g**enerally **s**peaking.
King **P**hilip **c**ried **o**ut—"**f**or **g**oodness **s**ake!"

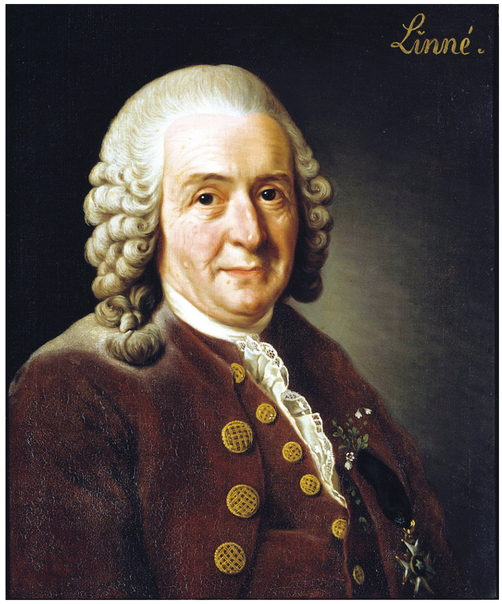


FIGURE 1-13
The principles that guide the classification of living organisms was first formalized in the book *Systema Naturae*, written by Carolus Linnaeus (1707–1778). Painting by Alexander Roslin.

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

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

(*continued*)

TABLE 1-1

HONEY BEE (COMMON NAME)*	SOUTHERN BLACK WIDOW (COMMON NAME)†
Order—Hymenoptera	Order—Araneae
Family—Apidae	Family—Theridiidae
Genus—*Apis*	Genus—*Latrodectus*
Species—*mellifera*	Species—*mactans*
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[†]
    - Order Protura—proturans
    - Order Diplura—diplurans
    - Order Collembola—springtails
  - Subclass Insecta—insects
    - Order Microcoryphia[‡]—jumping bristletails
    - Order Thysanura[‡]—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 Embidiina—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.

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