BEETLES

of Eastern North America

Arthur V. Evans

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DEDICATION

This book is dedicated to CHARLES "CHUCK" LAWRENCE BELLAMY (1951–2013) and RICHARD LAWRENCE HOFFMAN (1928–2012) in recognition of their years of friendship, good cheer, support, and shared passion for all things beetle. I miss them both very much.

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Back cover photographs, left to right: *Typocerus velutinus* (1) and *Strangalia luteicornis* (3); *Chrysochus auratus*; *Alaus oculatus*; all by Arthur V. Evans
Title-page photograph: Flat-headed Redbud Borer *Ptosima gibbicollis*, by Arthur V. Evans

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PREFACE

When I moved from California to Virginia some 14 years ago, I found myself surrounded by a beetle fauna that was at once familiar, yet exotic. Familiar because, as a scarab beetle specialist, I had more than a working familiarity with the scarab fauna of eastern North America and its literature. Exotic because most of the beetles in other families were entirely new to me. I took the opportunity to extend my focus beyond scarabs to include all families of beetles that occurred in my newly adopted state. Through fieldwork, macro photography, literature searches, and the examination of museum collections, I soon discovered that Virginia's coastal, sandhill, piedmont, and montane plant communities served as habitats for a tremendous diversity of beetles that included those with decidedly boreal or austral distributions. In other words, studying the beetles of Virginia was like taking a crash course in the fauna of all of eastern North America.

Several books became my primary entrée to the beetles of the region, including *An Illustrated Descriptive Catalogue of the Coleoptera or Beetles (exclusive of the Rhynchophora) Known to Occur in Indiana* (Blatchley 1910) and *Rhynchophora or Weevils of North Eastern America* (Blatchley and Leng 1916). *A Manual of Common Beetles of Eastern North America* (Dillon and Dillon 1972) was also very helpful. *The Beetles of Northeastern North America* (Downie and Arnett 1996) provided numerous keys for identifying species. The two-volume *American Beetles* (Arnett and Thomas 2000, Arnett et al. 2002) provided a badly needed taxonomic update for the North American beetle fauna supported with well-illustrated keys and extremely useful bibliographies. Much of the published taxonomic, biological, ecological, and distributional information for the species that inhabit eastern North America is tucked away, however, among thousands of notes, articles, and monographs published in hundreds of departmental circulars, newsletters, peer-reviewed journals, regional guides, and various online resources.

Beetles likely make up nearly one-fifth of all plant and animal species found in eastern North America. Although beetles are frequently eye-catching because of their color, form, or habit, no one photographic guide covering species in all 115 families known in the region has been attempted until now. Most of the 1,409 species that appear in this work are quite conspicuous and found throughout the region, while a few are decidedly boreal or Floridian in distribution; however, it must be remembered that the species presented within these pages represent fewer than 10% of the entire eastern beetle fauna. As such, readers should not expect to find every species they encounter described among these pages; for example, typically rare forms excluded from this book may become locally common under extraordinary conditions. Still, readers using this book are likely to identify the majority of conspicuous beetles that cross their paths to the species level and should be able to reliably assign others to their appropriate genus or family.

The primary goal of this book is to present the beetles of eastern North America in an engaging format that is accessible to the amateur naturalist interested in beetles, yet authoritatively written to serve the needs of the professional biologist. I hope this richly illustrated book will increase the enjoyment of all interested in the natural world, serve as an introduction for students desiring to know more about beetles, and stimulate those who have already embraced the world's largest and most diverse group of animals as their life's work.

ACKNOWLEDGMENTS

First and foremost, I thank Robert Kirk, executive editor at Princeton University Press, for the opportunity to write this book. His support, guidance, and, most importantly, patience, were instrumental in the creation of this work. I also appreciate the dedication and expertise of Mark Bellis and Lorraine Doneker at Princeton University Press, copyeditor Lucinda Treadwell, and typesetter David Price-Goodfellow for their encouragement, advice, creativity, and expert copyediting.

A book of this size, depth, and quality would have been impossible to achieve were it not for the excellent images supplied by a talented and dedicated cadre of photographers. Their persistence in seeking out and capturing images of all kinds of beetles served as an inspiration to me as I compiled this work. I am particularly grateful for the efforts of Chris Wirth and Tom Murray, whose stunning work represents a significant portion of the images that appear on these pages. The contributions of the following photographers provided this book with the taxonomic breadth and depth required to establish its utility, and enhance its aesthetic appeal: Ken Allen, Dave Almquist, Jerry Armstrong, Lyn Atherton, Troy Bartlett, Christy Beal, Paul Bedell, Christoph Benisch, Thomas Bentley, Ashley Bradford, Donna Brunet, Val Bugh, Bob Carlson, Chris Carlton, Carmen Champagne, Jan Ciegler, Patrick Coin, Alan Cressler, Stephen Cresswell, Rob Curtis, Denis Doucet, Josef Dvořák, Charley Eiseman, Mardon Erbland, John Frisch, David Funk, Nicolas Gompel, Henri Goulet, Bob Gress, Joyce Gross, Guy Hanley, Randy Hardy, Phil Harpootlian, Jeff Hollenbeck, Scott Justis, James Kalisch, WonGun Kim, Thor Kristiansen, Jessica Lawrence, René Limoge, Ilona Loser, Stephen Luk, Ted MacRae, Crystal Maier, Daniel Marlos, Steve Marshall, Ole Martin, Charles Matson, John Maxwell, Sean McCann, Richard Migneault, Graham Montgomery, Roy Morris, Tim Moyer, Steve Nanz, Scott Nelson, Mark O'Brien, Jenn Orth, Johnny Ott, Nikola Rahme, Jon Rapp, Jennifer Read, David Reed, Lary Reeves, Charles Robertson, Matt Roth, Kurt Schaefer, Lynnette Schimming, Kyle Schnepp, Jimmy Sherwood, Tom Schultz, Roy Sewall, Ken Schneider, Marvin Smith, Gayle (deceased) and Jeanell Strickland, Tracy Sunvold, Mike Thomas, Alexey Tishechkin, Ed Trammel, Donna Watkins, Alex Wild, Jane Wyche, Dan Young, and Robert Lord Zimlich. I am forever grateful to all these superb photographers for their generosity and enthusiasm for this project.

Jennifer Read expertly prepared all 1,500+ images used in this work. She converted jpegs into tifs when needed and, when absolutely necessary, cropped, sharpened, adjusted exposures, repaired or replaced the occasional missing or damaged appendage, and removed dust and stray hairs so that each and every image in this book would look its absolute best. Jen also rendered the illustrations accompanying the key to families. Many thanks to Graham Wilson and Megan Rollins for their assistance in the initial phase of developing these illustrations.

I thank the following friends and colleagues for their assistance with specimen identifications, sorting out taxonomic issues, providing pertinent literature, collecting live specimens to photograph, supplying unpublished biological and geographic data, and reviewing portions of the manuscript: Albert Allen, Bob Anderson, Bob Androw, Chuck Bellamy (deceased), Vassili Belov, Larry Bezark, Yves Bousquet, Michael Brattain, Carlyle Brewster, Adam Brunke, Chris Carlton, Mike Caterino, Don Chandler, Anne Chazal, Jan Ciegler, Andy Cline, Maureen Dougherty, Hume Douglas, Terry Erwin, David Funk, François Genier, James Gibbs, Bruce Gill, Phil Harpootlian, Chris Hobson, Richard Hoffman (deceased), W.M. Hood, Mike Ivie, Paul Johnson, Kerry Katovich, Sergey Kazantsev, John Kingsolver, Nadine Kriska, John Lawrence, John Leavengood, Rich Leschen, Stephané Le Tirant, Steve Lingafelter, Darren Loomis, Chris Ludwig, Ted MacRae, Chris Majka, Blaine Matheson, Adriean Mayor, Chuck McClung, Will Merrit, Alfred Newton, Rolf Obeprieler, Charlie O'Brien, M.J. Paulsen, Stewart Peck, Keith Philips, Keith Pike, John Pinto, Darren Pollock, Jens Prena, Jennifer Read, Steve Roble, Bill Shepard, Floyd Shockley, Derek Sikes, Paul Skelley, Charlie Staines, Warren Steiner Jr., Margaret Thayer, Mike Thomas, Alexey Tishechkin, Natalia Vandenberg, Robert Vigneault, Graham Wilson, Rebecca Wilson, Norm Woodley, and Dan Young.

Finally, I thank my wife, Paula, whose love and support have made all my entomological pursuits in this century possible. Without her I would never have been able to undertake or complete this book.

I share the success of *Beetles of Eastern North America* with all the aforementioned individuals, but the responsibility for any and all of its shortcomings, misrepresentations, inaccuracies, and omissions is entirely my own.

HOW TO USE THIS BOOK

To get the most out of this book, read its introductory sections before venturing out into the field. Once you have become familiar with the bodies and lives of beetles, when to find them, where they live, and how to collect them, move on to the family diagnoses that punctuate the species accounts. Begin learning the physical features that characterize each family and distinguish them from similar families. Then peruse the individual accounts to get an idea of where and when to look for specific species. With this information at your disposal, you will be much better prepared to find and observe beetles and recognize the specific characteristics that will aid in their identification.

CLASSIFICATION

Numerous and substantial changes have been made in the classification of the Coleoptera since the appearance of the *American Beetles* volumes, and this process is ongoing. The families and species covered in this book mostly follow the order presented in *Family Group Names in Coleoptera (Insecta)* (Bouchard et al. 2011). In this book, the Cybocephalidae, treated elsewhere as a subfamily of the Nitidulidae, is treated as a family. The Ischaliidae, also recognized in this book, has been considered either its own family or a subfamily of the Anthicidae by previous authors. See the appendix, Classification of the Beetles of Eastern North America (p.501), for further details.

KEY TO FAMILIES

To assist with the correct placement of the most commonly encountered beetles in their proper family, a dichotomous key is presented (pp.53–7). This key consists of a series of "either–or" choices based on the quality of physical features possessed by a specimen. As with a road map, the reader is directed to a series of junctions called *couplets* that, through a process of elimination, will lead to a smaller and more manageable subset of the most commonly encountered families with which the beetle in question can be compared, checked against similar families, and, it is hoped, matched to a species photo and account.

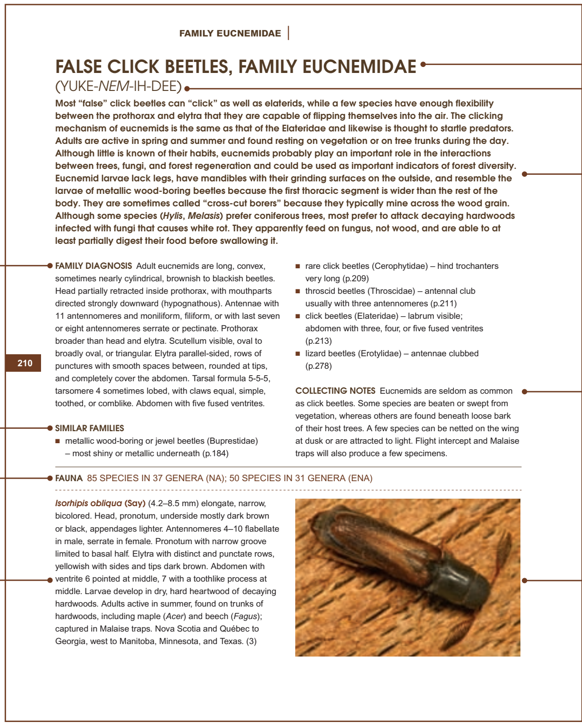
FAMILY DIAGNOSES

Each family diagnosis provides information on the accepted common family name, pronunciation of the scientific family name, a brief overview of the natural history of the species in the family, and family diagnosis based on morphological features, including length in millimeters, shape, color, and features of the head, thorax, abdomen, and appendages. This information is augmented by descriptions of select features of other families of beetles containing species superficially similar in appearance or habit. Finally, the numbers of species and genera of each family (if known) found in the Nearctic and eastern North America are presented to give readers an idea of the beetle diversity in the region and how it compares with the combined fauna of Canada and the United States. Some of these numbers are only estimates since many taxa are inadequately known.

SPECIES ACCOUNTS

The species accounts provide the accepted common name (if any), scientific name, length in millimeters, overall form, and color of living beetles. The bright colors (pink, red, orange, yellow, green) of some living beetles frequently fade after death, while metallic colors and iridescence are usually permanent, except in some tortoise beetles (Chrysomelidae). Read the species accounts carefully to discern species-specific features that may not be evident in the photo. As good as the photographs are in this book, they sometimes do not adequately highlight the subtle characters necessary for accurate species identification. Snap judgments based solely on overall appearance and color often result in misidentifications. Information on distinguishing males and females is presented for many species in which the sexes markedly differ from one another externally. Brief notes on seasonality, habitat, food preferences (for adults and occasionally larvae), and distribution are also provided. The origin of species not native to North America, either purposely or accidentally introduced, is indicated when appropriate. Every effort has been made to ferret out published distributional records and augment them with unpublished data gleaned from local lists, records provided by avocational coleopterists, and specimens in select museums. Still, the actual distributions

A representative page showing the main elements of the family diagnoses and species accounts (see p.9).



FAMILY EUCNEMIDAE |

FALSE CLICK BEETLES, FAMILY EUCNEMIDAE

(YUKE-*NEM*-IH-DEE)

Most "false" click beetles can "click" as well as elaterids, while a few species have enough flexibility between the prothorax and elytra that they are capable of flipping themselves into the air. The clicking mechanism of eucnemids is the same as that of the Elateridae and likewise is thought to startle predators. Adults are active in spring and summer and found resting on vegetation or on tree trunks during the day. Although little is known of their habits, eucnemids probably play an important role in the interactions between trees, fungi, and forest regeneration and could be used as important indicators of forest diversity. Eucnemid larvae lack legs, have mandibles with their grinding surfaces on the outside, and resemble the larvae of metallic wood-boring beetles because the first thoracic segment is wider than the rest of the body. They are sometimes called "cross-cut borers" because they typically mine across the wood grain. Although some species (*Hylis*, *Melasis*) prefer coniferous trees, most prefer to attack decaying hardwoods infected with fungi that causes white rot. They apparently feed on fungus, not wood, and are able to at least partially digest their food before swallowing it.

FAMILY DIAGNOSIS Adult eucnemids are long, convex, sometimes nearly cylindrical, brownish to blackish beetles. Head partially retracted inside prothorax, with mouthparts directed strongly downward (hypognathous). Antennae with 11 antennomeres and moniliform, filiform, or with last seven or eight antennomeres serrate or pectinate. Prothorax broader than head and elytra. Scutellum visible, oval to broadly oval, or triangular. Elytra parallel-sided, rows of punctures with smooth spaces between, rounded at tips, and completely cover the abdomen. Tarsal formula 5-5-5, tarsomere 4 sometimes lobed, with claws equal, simple, toothed, or comblike. Abdomen with five fused ventrites.

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SIMILAR FAMILIES

- metallic wood-boring or jewel beetles (Buprestidae) – most shiny or metallic underneath (p.184)
- rare click beetles (Cerophytidae) – hind trochanters very long (p.209)
- throscid beetles (Throscidae) – antennal club usually with three antennomeres (p.211)
- click beetles (Elateridae) – labrum visible; abdomen with three, four, or five fused ventrites (p.213)
- lizard beetles (Erotylidae) – antennae clubbed (p.278)

COLLECTING NOTES Eucnemids are seldom as common as click beetles. Some species are beaten or swept from vegetation, whereas others are found beneath loose bark of their host trees. A few species can be netted on the wing at dusk or are attracted to light. Flight intercept and Malaise traps will also produce a few specimens.

FAUNA 85 SPECIES IN 37 GENERA (NA); 50 SPECIES IN 31 GENERA (ENA)

Isorhipis obliqua **(Say)** (4.2–8.5 mm) elongate, narrow, bicolored. Head, pronotum, underside mostly dark brown or black, appendages lighter. Antennomeres 4–10 flabellate in male, serrate in female. Pronotum with narrow groove limited to basal half. Elytra with distinct and punctate rows, yellowish with sides and tips dark brown. Abdomen with ventrite 6 pointed at middle, 7 with a toothlike process at middle. Larvae develop in dry, hard heartwood of decaying hardwoods. Adults active in summer, found on trunks of hardwoods, including maple (*Acer*) and beech (*Fagus*); captured in Malaise traps. Nova Scotia and Québec to Georgia, west to Manitoba, Minnesota, and Texas. (3)

of many species described in this guide are very likely broader than indicated in this book. At the end of most accounts is the total number of species in the genus known east of the Mississippi river.

SPECIES IDENTIFICATION

The identification of beetles can be challenging. Many conspicuous species are easily identified by direct comparison with a photograph, but most beetles are small and the characters necessary for species identification simply are not going to be available for examination without the specimen in hand. This is why it is best to capture and properly prepare a short series of specimens and have them available for detailed microscopic examination. Although 10× or 20× hand lenses are very useful for this purpose, a stereoscopic dissecting microscope with good lighting is ideal. Using a hand lens or microscope to examine specimens takes a bit of practice at first, but once you have mastered these indispensible tools, you will never again waste time by straining your unaided eyes to count tarsomeres and antennomeres or examine genitalia.

Many beetles can be positively identified to species only through examination of the male reproductive organs and comparison with detailed illustrations, photos, or previously identified specimens that were determined by experts. Although providing detailed drawings of thousands of beetle genitalia is well beyond the scope of this book, it is useful to get into the habit of extracting the male genitalia while the specimen is still fresh and pliable so they can be easily examined by a specialist or compared to literature that depicts the genital structures of closely related species. You can extract the genitalia from the posterior opening of the abdomen by gently pulling them out with fine-tipped forceps or with the aid of a fish-hooked insect pin. Extracting genitalia from dried specimens requires that the specimens first be softened in a relaxing chamber, or placed in boiling water with a few drops of dish soap added as a wetting agent. Once the genitalia are extracted, you can leave them attached to the tip of the abdomen by their own tissue, where they will dry in place, or remove them entirely and glue to an insect mounting point, and pin the point just below the pinned specimen for later examination. Some beetles, especially very small species, require specialized techniques for extracting and preserving their genitalia. Consult the pertinent literature or a specialist before undertaking the dissection of these specimens.

Readers requiring accurate species identification, especially for control of horticultural, agricultural, and forest pests, are encouraged to consult coleopterists affiliated with cooperative extension offices or the entomology department of a museum or university for verification.

INTRODUCTION TO BEETLES

BEETLE ANATOMY

Although colors and patterns are sometimes useful, beetles are classified and more reliably identified on the basis of their anatomical features. Therefore, a basic understanding of beetle anatomy (Fig. 1) is essential for better understanding of not only their evolutionary relationships, but also the terminology used in the family diagnoses and species accounts that appear in this book.

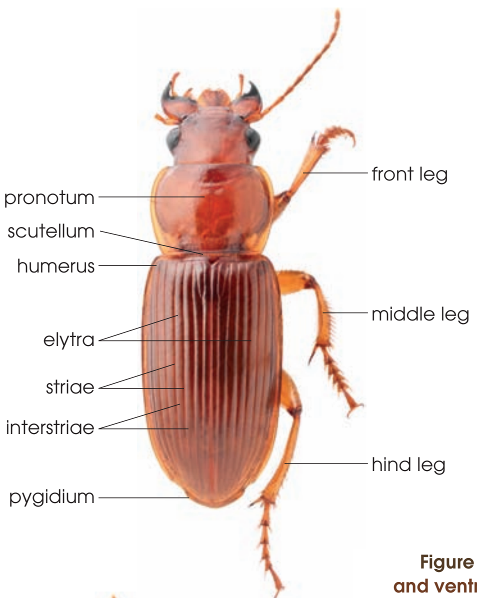
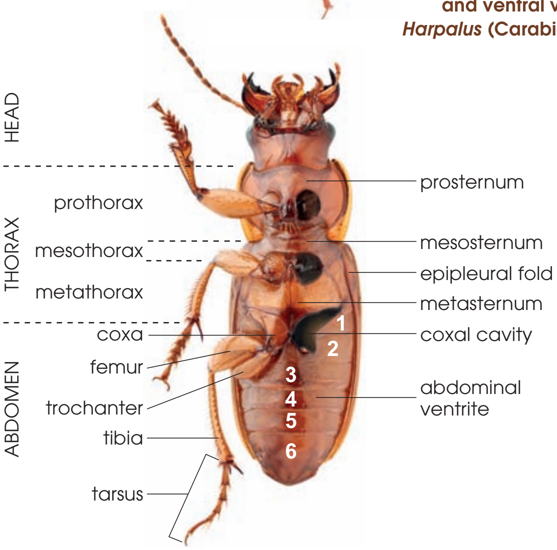


Figure 1. Dorsal and ventral views, *Harpalus* (Carabidae).



EXOSKELETON

Adult beetles are covered and protected by a highly modified *exoskeleton* that functions as both skeleton and skin. Internally, the exoskeleton serves as a foundation for powerful muscles and organ systems, while externally providing a platform for important sensory structures connecting them to their surrounding environment. The exoskeleton is light yet durable and composed of a multilayered structure comprising the polysaccharide *chitin* and the protein *sclerotin*.

The exoskeleton is subdivided into *segments*, some of which are composed of smaller plates, or *sclerites*. The segments are joined into functional units that form appendages (mouthparts, antennae, legs) and three body regions (head, thorax, abdomen). Segments are joined together by membranes of pure chitin or separated by narrow furrows called *sutures*. The division of the exoskeleton into body regions and sclerites affords flexibility to beetle bodies, much the way the joints and plates of armor allowed knights to maneuver in battle.

BODY SHAPE

The basic body shape (Figs. 2a–n) of a beetle when viewed from above is sometimes variously described as elongate, oval, triangular, or antlike, among others. Parallel-sided refers to the straight and parallel sides of the elytra, the wing covers of a beetle. Terms like *convex*, *hemispherical*, flat, and flattened are useful too for describing the upper or *dorsal* surface, a description best determined when viewed from the side. Lady beetles (Coccinellidae) and some leaf beetles (Chrysomelidae) are sometimes referred to as “hemispherical” because their dorsal surface is very convex while the *ventral* surface or underside is relatively flat. *Cylindrical* is usually applied to elongate, parallel-sided species with convex dorsal and ventral surfaces and suggests that they would appear almost circular in cross section.

SURFACE SCULPTURING

The nature of the body surface on beetles, or surface sculpturing, is very useful in species identification. Surfaces can be shiny like patent leather or dulled (*aluteceous*)

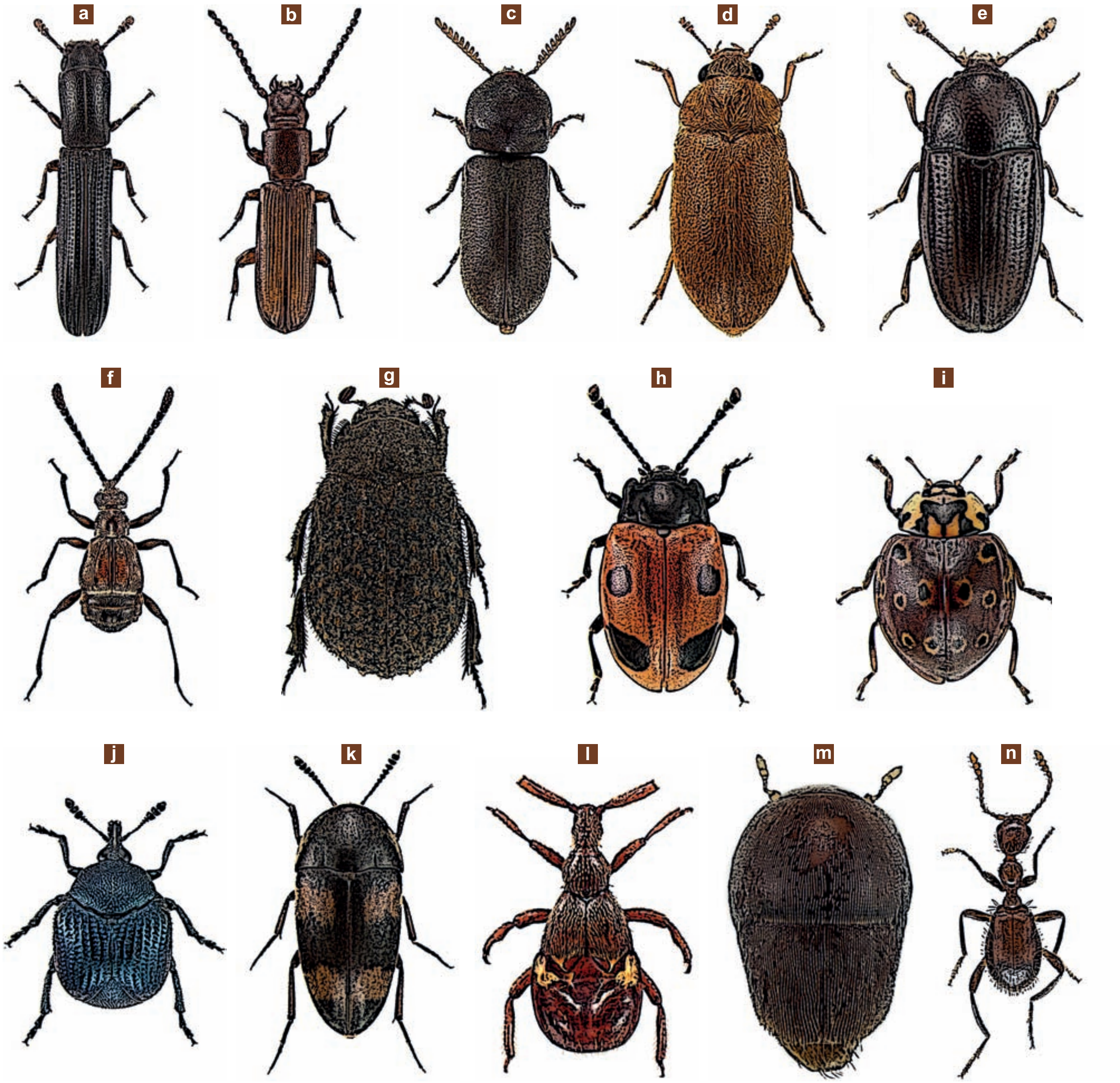


Figure 2. Body shapes.
a. elongate, *Colydium* (Zopheridae); b. elongate, *Catogenus* (Passandridae); c. elliptical, *Ptilinus* (Ptinidae); d. elongate-oval, *Byturus* (Byturidae); e. elongate-oval, *Philothermus* (Cerylonidae); f. elongate-oval, *Ctenisodes* (Staphylinidae); g. oval, *Trox* (Trogidae); h. oval, *Endomychus* (Endomychidae); i. broadly oval, *Anatis* (Coccinellidae); j. broadly oval, *Pterocolus* (Attelabidae); k. obovate, *Holostrophus* (Tetratomidae); l. triangular, *Adranes* (Staphylinidae); m. limuloid, *Sepdophilus* (Staphylinidae); n. antlike, *Acanthinus* (Anthicidae).

by a minute network of fine cracks resembling those of human skin. The surfaces of the head and legs, especially in burrowing species, are sometimes dulled by normal abrasion as the beetle burrows through soil or wood. Sometimes the surface is *glaucous*, or coated with a grayish or bluish coating of waterproof wax secreted by epidermal glands underlying the exoskeleton. This coating is easily rubbed off or dissolved in chemical preservatives and is usually evident only in freshly emerged individuals.

Shiny or not, many beetle bodies are typically covered to varying degrees with small pits called *punctures*. Punctures range from very small (*finely punctate*) to large (*coarsely punctate*) and may be shallow or deep. The density or distance of punctures from one another is often reported in terms of the degree of separation in relation to the puncture's diameter. Contiguous or nearly contiguous punctures are those with rims that touch one another, or nearly so. In *rugopunctate* surfaces, the punctures are so tightly spaced, the surface appears rough. Punctures sometimes bear a single hairlike *seta* (pl. *setae*). Setae are fine or bristly, stand straight up (*erect*), or lie nearly flat on the surface (*recumbent*). Flattened setae, or *scales*, range in outline from nearly round, to *oval* (egg-shaped), *obovate* (pear-shaped), *lanceolate* (spear-shaped) to linear (long and slender). Densely setose or scaled surfaces may be partially or completely obscured from view, while the complete absence of setae or scales altogether is referred to as *glabrous*.

An *impunctate* surface lacks punctures altogether, while *rugose* (rough) surfaces have raised areas that are formed by small wrinkles, distinct ridges, bumps, or fingerprint-like whorls. *Granulate* surfaces consist of many small, distinct, and rounded bumps, like the pebbled surface of a basketball.

HEAD AND ITS APPENDAGES

The capsule-shaped *head* (Fig. 3) is attached to the thorax by a flexible, membranous neck that is sometimes visible from above (e.g., Meloidae) but usually hidden, along with part of the head, within the first thoracic segment, or *prothorax*. In the fireflies (Lampyridae), some hooded beetles (Corylophidae), and other beetle families, the head is completely hidden from above by a hoodlike extension of the dorsal sclerite of the prothorax, or *pronotum*.

The compound eyes are usually conspicuous and composed of dozens or hundreds of individual facets or lenses. Awash in light, the lenses of day-active (*diurnal*) beetles are relatively small and flat, while nocturnal species have more convex lenses that gather all available light. Flightless, cave-dwelling, and subterranean species often have small compound eyes with only a few lenses or may lack eyes altogether. Compound eyes are typically round, or oval to kidney-shaped in outline. The front margins of kidney-shaped eyes are weakly to strongly notched, or *emarginate*; the antennae of some species may originate within or near the emargination. The eyes are sometimes partially divided in front by a narrow ridge of cuticle called the *canthus*. In whirligigs (Gyrinidae) and some throscids (Throscidae) and longhorns (Cerambycidae), the canthus completely divides the eye. Some skin beetles (Dermestidae) and omaline rove beetles (Staphylinidae) also possess a simple eye, or *ocellus*, comprising a single lens located on the front of the head between the compound eyes.

The males of several eastern species (e.g., Geotrupidae, Scarabaeidae, and Tenebrionidae) have horns on their heads modified into spikes, scooped blades, or paired knobs that are used in mostly "bloodless" battles with other males of the same species over resources that will attract females. The variation of horn size in males of the same species is of particular interest to scientists who study mate selection. Environmental factors, especially larval nutrition, often play a more important role in horn development than genetic factors. Although outgunned in battle, lesser endowed males are still fully capable of mating with females and fertilizing their eggs when the opportunity arises.

The mouthparts of all beetles follow the same basic plan: an upper lip (*labrum*), two pairs of chewing appendages (*mandibles*, *maxillae*), and a lower lip (*labium*). Although the mandibles of beetles are variously modified to cut and tear flesh (e.g., Carabidae), grind leaves (e.g., Chrysomelidae), or strain fluids (some Scarabaeidae), they also serve other purposes. The outsized mandibles of some male stag beetles (Lucanidae) are not used for feeding at all, but rather for battling other males over females. The tile-horned prionus, *Prionus imbricornis* (Cerambycidae) uses its imposing mandibles to tunnel out of wood as well as for weapons of defense. Male tiger beetles (Carabidae) use their mandibles to firmly grasp the female during copulation. Attached to the maxilla and labium are delicate, flexible, fingerlike structures, or *palps*, that assist beetles in the manipulation of food. The long and conspicuous maxillary palps of water scavengers (Hydrophilidae) are easily mistaken for antennae. Each palp is divided into articles or

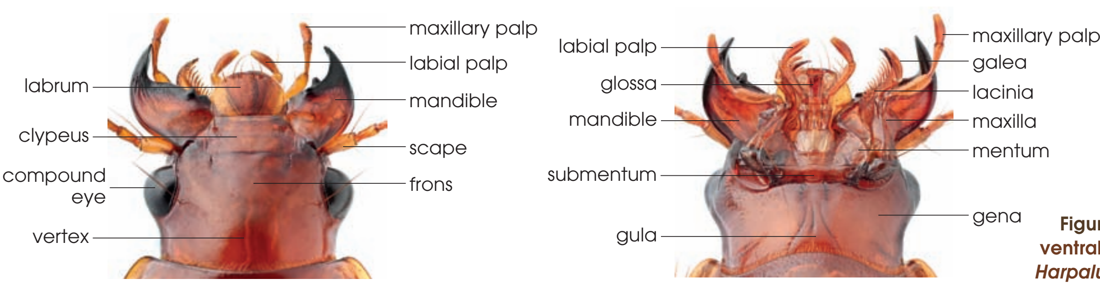


Figure 3. Dorsal and ventral views of head, *Harpalus* (Carabidae).

sections called *palpomeres*. Protecting the mouthparts from above in most beetles is a broad plate of cuticle formed by the leading edge of the head, or *clypeus*. Below the head at the base of the labium in most beetles are two sclerites: *mentum* and *gula*.

The mouthparts of predatory and some wood-boring beetles are typically *prognathous* (Fig. 4), directed forward and parallel to the long axis of the body. *Hypognathous* mouthparts (Fig. 5) are directed downward and typical of most plant-feeding beetles, including chafers (Scarabaeidae), some longhorn beetles (Cerambycidae), leaf beetles (Chrysomelidae), and weevils (Curculionidae). The hypognathous mouthparts of some net-winged beetles (Lycidae) and narrow-waisted beetles (Salpingidae), and many weevils and their relatives (Curculionidae, Nemonychidae, Brentidae, Anthribidae) are drawn out into a short, broad beak, or an elongate *rostrum* (Fig. 6).

Figure 4. Prognathous mouthparts, *Hesperandra* (Cerambycidae).

Figure 5. Hypognathous mouthparts, *Chrysochus* (Chrysomelidae).

Figure 6. Rostrum, *Curculio* (Curculionidae).

The *antennae* are beetles' primary organs of smell and touch and usually attached to the sides of the head, often between the eyes and the bases of the mandibles. Although the antennae exhibit an incredible diversity of sizes and shapes, they all consist of three basic parts: *scape*, *pedicel*, and *flagellum* (Fig. 7). The usual number of antennal articles is 11, but 10 or fewer are common in some groups, while 12 or more occur only rarely. Insect morphologists note that only the scape and pedicel have their own internal musculature and are the only true antennal segments, while the remaining articles of the flagellum lack intrinsic musculature and are called *flagellomeres*. Distinguishing segments and flagellomeres to communicate information about the number of antennal articles and the like is unwieldy at best. For the sake of morphological correctness and clarity, all visible antennal articles are referred to as *antennomeres*. The scape is antennomere 1 and the pedicel is antennomere 2. Antennomeres 3–11 refer to the articles of the flagellum.

The antennae are generally shorter than the body and somewhat similar in both sexes; however, male pine sawyers in the genus *Monochamus* (Cerambycidae) have long, threadlike antennae up to three times the length of the body, while those of the female are only slightly longer than the body. In other species, the ornate antennal modifications possessed by male *Polyphylla* (Scarabaeidae), *Phengodes* (Phengodidae), *Sandalus* (Rhipiceridae), and wedge-shaped beetles (Ripiphoridae) are packed with sensory pits capable of tracking pheromones released by distant or secretive females.

The principal forms of beetle antennae (Figs. 8a–l) include the following:

- *filiform*, or threadlike, with antennomeres uniformly cylindrical, or nearly so
- *moniliform*, or beadlike, with round antennomeres of uniform size
- *serrate*, or saw-toothed, with flattened, triangular antennomeres
- *pectinate*, or comblike, with short antennomeres each bearing a prolonged extension
- *bipectinate*, or comblike, with short antennomeres each bearing two prolonged extensions

- *flabellate*, or fanlike, with antennomeres bearing long extensions that fit together like a fan
- *plumose*, or featherlike, with antennomeres bearing long, slender, flexible extensions
- *clavate*, with outermost antennomeres gradually enlarged to form a distinct symmetrical club
- *capitate*, with outermost antennomeres abruptly enlarged to form a round or oval symmetrical club
- *lamellate*, with outermost antennomeres flat, forming a distinct, lopsided club
- *geniculate*, or elbowed, with a long, slender scape with pedicel and flagellomeres attached at a distinct angle; pedicel and capitate or lamellate flagellomeres are collectively referred to as the funicle

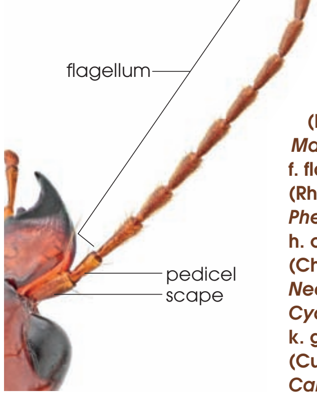


Figure 7. Parts of the antenna, *Harpalus* (Carabidae).

BELOW: Figure 8. Antennal types: a. filiform *Stenocorus* (Cermabycidae); b. moniliform, *Omoglymmius* (Carabidae); c. serrate, *Tytthonyx* (Cantharidae); d. pectinate, *Leptoceletes* (Lycidae); e. bipectinate, *Macrosiagon* (Ripiphoridae); f. flabellate, *Sandalus* (Rhipiceridae); g. plumose, *Phengodes* (Phengodidae); h. clavate, *Bruchus* (Chrysomelidae); i. clavate, *Necrobia* (Cleridae); j. lamellate, *Cyclocephala* (Scarabaeidae); k. geniculate, *Otiorhynchus* (Curculionidae); l. capitate, *Carpophilus* (Nitidulidae).

THORAX AND ITS APPENDAGES

Like that of all insects, the beetle thorax is divided into three segments, the *prothorax*, *mesothorax*, and *metathorax*, each bearing a pair of legs. The underside of the thorax is sometimes modified with impressions or distinct grooves that accommodate the antennae or legs.

The prothorax is always exposed and forms the distinctive "midsection" of the beetle body, while the remaining wing-bearing mesothorax and metathorax, or *pterothorax*, are hidden beneath the wing covers, or *elytra*. The prothorax is either firmly or loosely attached to the pterothorax. The dorsal sclerite of the prothorax, or *pronotum*, is sometimes hoodlike and extends forward to partially (e.g., Corylophidae) or completely (e.g., Lampyridae) cover the head when viewed from above. In some males, the pronotal surface is modified with horns, pits, bumps, or ridges that are useful in species identification. The sides, or lateral margins of the prothorax may be partly or completely sharply ridged or keeled (e.g., Carabidae, Gyrinidae, Dytiscidae), or distinctly rounded (e.g., Meloidae, some Cerambycidae). Underneath, the central portion of the prothorax is called the *prosternum* and is sometimes attenuated into a spinelike structure directed toward the head or backward. The prosternum is flanked on either side by the *propleuron*. Sometimes the propleuron is divided into two sclerites by the *pleural suture*; the sclerite in front is called the *proepisternum*, while the sclerite behind is the *proepimeron*. A distinct line delimits the outer portion of propleuron or suture that separates it from the pronotum called the *notopleural suture* in the Carabidae, Gyrinidae, Haliplidae, Noteridae, and Dytiscidae. The front legs are inserted into prothoracic cavities called *procoxal cavities*. Although sometimes very difficult to see, the nature of these cavities is important in the identification of families, subfamilies, and tribes of beetles. If the cavities are enclosed behind by the *proepimeron*, or a junction of the proepimeron and the prosternum, they are said to be "closed behind" (Fig. 9a). If these cavities open directly to the mesothorax, they are said to be "open behind" (Fig. 9b).

The segments of the pterothorax are broadly united with one another. The mesothorax bears the middle legs below and is largely covered by the elytra above. In many beetles, the mesothorax is evident dorsally by the presence of a small triangular or shield-shaped sclerite called the *scutellum*. The scutellum, if visible, is always located directly behind the pronotum, at the base and between the elytra. The hind thoracic segment, or metathorax, bears the hind legs and, if present, flight wings folded beneath the elytra. The hind coxae are usually wide, or *transverse*. In the Carabidae, Gyrinidae, Haliplidae, Noteridae, and Dytiscidae, the hind coxae are immovably fused to the *metasternum* and extend backward past or "completely divide" the first abdominal segment. In the crawling water beetles (Haliplidae), the hind coxae form broad plates that conceal nearly the entire abdomen. In all other families, the hind coxae are "free," or not fused to the metasternum and do not extend past or "divide" the first abdominal segment. The segments of the pterothorax are usually shortened in wingless (*apterous*) or reduced-wing (*brachypterous*) species.

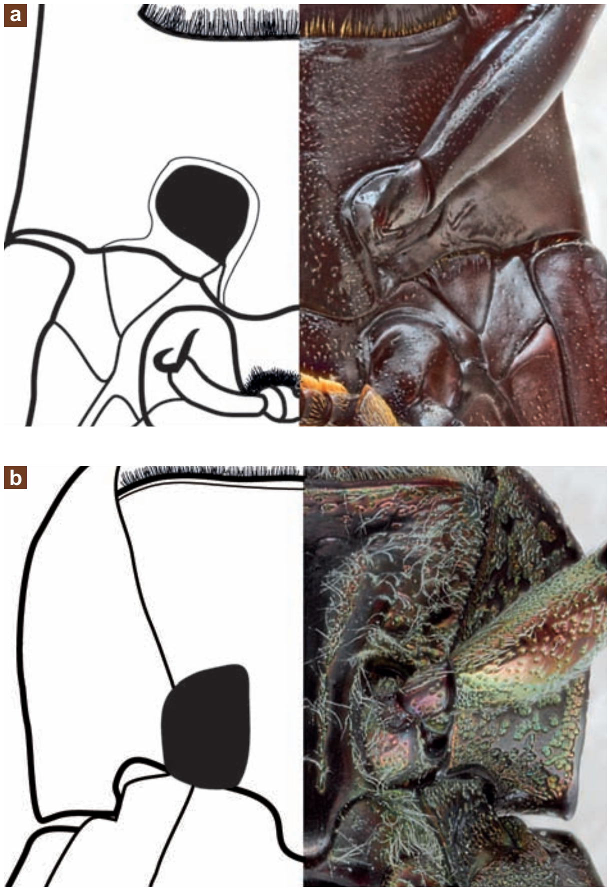


Figure 9. Procoxal cavities. a. closed; b. open.

The most conspicuous and unique feature of nearly all adult beetles is their possession of elytra (sing. *elytron*) that partially or completely cover the abdomen. The elytra are opaque, soft, and leathery (e.g., Lycidae, Phengodidae, Lampyridae, Cantharidae), or hard and shell-like. At rest, the elytra usually meet over the middle of the back along a distinct and straight line called the *elytral suture*. The tips, or apices, of the elytra usually meet at the elytral suture, too, although they are often slightly separated; distinctly diverging elytral tips, such as those seen in *Lichnanthe* (Glaphyridae) are referred to as *dehiscent*. The outer basal angle of each elytron, or "shoulder," is called the *humerus* (pl. *humeri*). Punctures irregularly scattered over the elytral surface are referred to as *confused*. Elytra with punctures arranged in rows that may or may not be connected by impressed lines or that occur within narrow grooves (*striae*) running lengthwise are called *punctostriate*. The spaces between striae are called *intervals*. The portion of side margins of each elytron that is folded down is called the *epipleural fold*. Bordering the epipleural fold is a narrow inner edge, or *epipleuron* (pl. *epipleura*) that is of variable width and may or may not extend to the tip of the elytron.

The elytra are typically short in the rove (Staphylinidae), clown (Histeridae), and sap beetles (Nitidulidae). The elytra of male glowworms (Phengodidae) are oarlike, while those of some ripiphorids (Ripiphoridae) resemble flaplike scales. In most species, the elytra are lifted and separated when airborne, but in the fruit chafer genera *Cremastocheilus*, *Cotinis*, and *Euphoria* (Scarabaeidae), and in the metallic wood-boring beetles *Acmaeodera* (Buprestidae), the elytra are partially or totally fused along the elytral suture. When taking to the air, these fast-flying beetles lift their elytra slightly as the membranous flight wings unfold and expand through broad notches along the lateral margins near the bases.

The membranous flight wings are supported by a network of hemolyph-filled veins that help them to expand or fold. Some of these veins are hinged so that the wings can be carefully tucked and folded under the elytra. Flight wings are seldom used to identify genera or species, but their venation patterns do offer important clues to the relationships of families. The flight wings of some species (e.g., some female Scarabaeidae, Tenebrionidae, some female Cerambycidae, Curculionidae) are reduced in size or absent altogether. Adult females of all phengodids (Phengodidae) and some glowworms (Lampyridae) are *larviform* and lack both flight wings and elytra altogether.

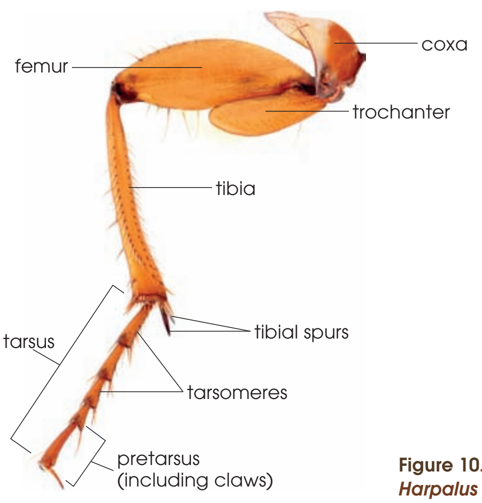


Figure 10. Hind leg, *Harpalus* (Carabidae).

Beetle legs are subdivided into six segments (Fig. 10). The *coxa* (pl. *coxae*) is generally short and stout, and it firmly anchors the leg into the coxal cavity of the thorax while allowing for the horizontal to-and-fro movement of the legs. The *trochanter* is usually small, freely movable in relation to the coxa, but fixed to the femur. The *femur* (pl. *femora*) is the largest and most powerful leg segment and greatly enlarged in species that jump (e.g., Scirtidae, Chrysomelidae). The *tibia* (pl. *tibiae*) is usually long and slender but often modified into a rakelike structure on the forelegs of burrowing species. The *tarsus* (pl. *tarsi*), if present, is typically divided into multiple articles called *tarsomeres* that lack their own internal musculature, and a claw-bearing segment called the *pretarsus*.

The tarsi are of particular value in beetle identification. Each tarsus consists of up to four tarsomeres, plus the pretarsus. The three-digit tarsal formulas used in this book, such as 5-5-5, 5-5-4, or 4-4-4, indicate the number of articles (tarsomeres + pretarsus) on the front, middle, and hind legs, respectively. Some articles, especially the *penultimate*, or next to last, tarsomere, are difficult to see without careful examination under high magnification and are typically denoted as "appears 4-4-4, but actually 5-5-5." The front tarsi of some male predaceous diving beetles (e.g., *Cybister*, *Dytiscus*) are highly modified into adhesive pads that enable them to grasp the female's smooth and slippery elytra while mating, or absent altogether in some dung beetles (Scarabaeidae). The feet of some longhorn (Cerambycidae) and leaf beetles (Chrysomelidae) are equipped with broad, brushy pads that are tightly packed with setae that help them to walk on smooth vertical surfaces or cling to uncooperative mates, while those of some click beetles and other species have tarsomeres with membranous flaps that project outward.

The claws of beetles are frequently modified (Figs. 11a–f). *Cleft* or *incised* claws are finely notched near the tip. *Toothed* claws have one or more distinct teeth underneath. *Appendiculate* claws have a broad flange at the base. *Serrate* claws have finely notched undersides resembling the teeth of a saw. *Pectinate* claws have comblike teeth underneath. *Simple* claws, which are typical of many beetles, lack any such modifications.

ABDOMEN

Beetles typically have nine abdominal segments, but only five or six segments are usually visible. These segments are ringlike and consist of four sclerites: a dorsal *tergum*

Figure 11. Claws. a. cleft, *Macrodactylus* (Scarabaeidae); b. toothed, *Polyphylla* (Scarabaeidae); c. appendiculate, *Oberea* (Cerambycidae); d. pectinate, *Melanotus* (Elateridae); e. serrate, *Synuchus* (Carabidae); f. simple, *Alaus* (Elateridae).

(pl. *terga*) or *tergite*, the ventral *sternum* (pl. *sterna*), and two lateral *pleura* (sing. *pleuron*); some segments may be only partially ringlike. The terga are thin and flexible in beetles with abdomens completely covered by the elytra, but are thicker and more rigid in species with short elytra. The penultimate and ultimate terga are called the *propygidium* and *pygidium*, respectively. The pleura are usually small, more or less hidden from view. Each pleuron has a single breathing pore, or *spiracle*, on the surface.

The visible abdominal sternites are called *ventrites*, and each is numbered beginning from the base of the abdomen regardless of the true morphological segment it represents. For example, ventrite 1 is usually abdominal sternite 2. The ventrites are of varying lengths in relation to one another and are either distinctly or barely separated by deep to shallow sutures or narrow membranes, especially, down the middle. Ventrites that are fused together, as evidenced by shallow or obsolete sutures, are said to be fused or *connate*, while “free” ventrites are those that are separated by distinct membranes. In some families, some or all of the ventrites are connate.

The remaining segments are internal and variously modified for reproductive activities: egg laying in females and copulation in males. Long *ovipositors* are characteristic of beetles that deposit their eggs deep in sand or plant tissues, while short and stout ovipositors are indicative of species that deposit their eggs directly on the surface of various substrates. The often elaborate male reproductive organs are of considerable value in species identification and sometimes the only method of separating closely related species.

BEHAVIOR AND NATURAL HISTORY

The mating behaviors, developmental strategies, and life cycles of most of the beetles in eastern North America assure their reproductive success by maximizing their efforts to locate mates, eliminating competition for food and space between larvae and adults, and adapting them to cope with dramatic seasonal shifts in temperatures that are typical of a temperate climate. With their compact and armored bodies, chewing mouthparts, and specialized limbs, beetles are equipped to occupy and thrive in a staggering array of habitats. They chew, dig, mine, and swim their way through a myriad of habitats in sandy coastal beaches and dunes, arid sandhills, backyards, urban parks, agricultural fields, lush woodlands, wetlands, and rocky mountain outcrops. Their ability to fly increases their chances of finding food and mates, and affords them opportunities to seek out and colonize new habitats.

MATING BEHAVIOR

With relatively short lives that last only weeks or months, most beetles have little time to waste in finding mates. They have developed various channels of communication that enhance their efforts at finding a mate, including scent, sight, or sound. These strategies are often remarkably effective, luring in numerous eager mates from considerable distances. Sex-attractant *pheromones* are used by many species to attract and locate mates over long distances. Males of these species often have longer or more elaborate antennal structures (e.g., Scarabaeidae, Ptilodactylidae, Rhipiceridae, Phengodidae, some Elateridae, Ripiphoridae, Cerambycidae) that provide more surface area for incredibly sensitive sensory pits capable of detecting just a few molecules of the female's pheromone wafting about in the air. These males typically track and locate females by flying in a zigzag pattern until they cross through the female's "odor plume" of pheromone. Once the plume is located, the male follows the increasing concentration of pheromone molecules directly to its source. Compounds other than pheromones are used for intersexual communication. For example, male *Neopyrochroa flabellata* (Pyrochroidae, p.375) secrete cantharidin into a large cranial pit located between their eyes not only to attract females, but also to inform them of their fitness as a mate.

The best-known example of visual communication in beetles is that of *bioluminescence*. Bioluminescence is a characteristic of many eastern fireflies (Lampyridae) and larval and adult female glowworms (Phengodidae) (Figs. 12a–b), as well as some click beetles (Elateridae). The whitish, greenish-yellow, or reddish light emanating from these insects is produced by special abdominal (e.g., Lampyridae, Phengodidae) or pronotal (e.g., Elateridae) organs with tissues that are supplied oxygen by numerous tracheae. The brightness and duration of these lights are controlled by the nervous system, which regulates the amount of oxygen reaching these tissues and reacting with the pigment luciferin, a chemical reaction sped up by the presence of the enzyme luciferase; color of the

Figure 12. ***Phenogodes*** **(Phengodidae) larva.**

light may vary depending on temperature and humidity. Bioluminescence in fireflies is virtually 100% efficient, with almost all the energy that goes into the system given off as light. In fact, the light produced by just one firefly produces 1/80,000th of the heat produced by a candle flame of the same brightness. By comparison, notoriously inefficient incandescent lightbulbs lose up to 90% of their electrical energy as heat.

Some male death-watch beetles (Ptinidae) bang their heads against the walls of their wooden galleries to lure females into their tunnels, but most beetles produce sound by rubbing two ridged or roughened surfaces together in a process known as *stridulation*. Stridulation generally occurs during courtship, confrontations with other beetles, or in response to other stressful situations, such as attack by a predator. Longhorn (Cerambycidae), June (Scarabaeidae), and bark beetles (Curculionidae) stridulate by rubbing their elytra with their legs or abdomen to create a chirping or squeaking sound when handled or attacked, possibly to startle predators; some aquatic species stridulate by rubbing their elytra and abdomen together.

Adult bess beetles (Passalidae) stridulate to communicate with their larvae. Using a pair of rasplike, oval patches located on the fifth abdominal segment, bess beetles raise their abdomen slightly to rub these patches against hardened folds on their membranous flight wings to produce a clearly audible squeaking noise. At least 14 different signals have been documented in this species that are associated with various behaviors, including aggression, courtship, or responses to threats and other disturbances. The larvae respond to stridulating adults by rapidly vibrating their stumpy, pawlike hind legs over a ribbed area at the base of the second pair of legs. Their incessant squeaking is feeble in comparison to that of the adults but still perceptible to the human ear. Communication between the larvae and adults is thought to help keep them in close proximity to one another, a theory partly supported by the dependence of the larvae on the adults for a steady food supply in the form of chewed wood and feces. Hungry *Nicrophorus* (Silphidae) larvae are also summoned to feed by stridulating parents rubbing a pair of abdominal files against the underside of their elytra.

In beetles, elaborate courtship behaviors are rare; however, some species may engage in nibbling (Cantharidae), licking (Cerambycidae), or antenna pulling (Meloidae) just prior to copulation, with the male typically mounting the female from above and behind. Females usually have enormous reserves of eggs awaiting fertilization, but need to mate only once, in spite of being courted by numerous enthusiastic males responding to

Figure 13. Mate guarding or postinsemination association, *Habroscelimorpha* (Carabidae).

their pheromones. Sperm is usually stored internally in a socklike reservoir called the *spermatheca*. Fertilization does not occur until her eggs travel past the spermatheca, just as they are about to be laid. In these females, it is the sperm of the last male that fertilizes the eggs. To assure their paternity, male tiger beetles (Carabidae) continue to tightly grasp their partners with their mandibles (Fig. 13) after copulation is completed until the eggs are laid, a behavior called *postinsemination association*.

Not all species of beetles must mate to reproduce. *Parthenogenesis*—development from an unfertilized egg—occurs among several families of beetles including leaf beetles (Chrysomelidae) and weevils (Curculionidae). Males of parthenogenetic species are rare or unknown altogether. The females of these species are solely responsible for maintaining the population and do so by producing cloned offspring. Telephone-pole beetles (Micromalthidae) exhibit an extreme form of this type of reproduction. They develop in rotting wood and must multiply quickly to take advantage of the patchy and ephemeral food source. They have evolved the singular ability to reproduce not only sexually as adults, but also asexually as larvae, a phenomenon known as parthenogenetic *paedogenesis*.

PARENTAL CARE

For most species of beetles, care of offspring is limited to selection of the egg-laying site; however, in a select few groups, relatively elaborate provisions are made to ensure the survival of the eggs and larvae. Some ground beetles (Carabidae) deposit their eggs in carefully constructed cells of mud, twigs, and leaves. Some water scavenger (Hydrophilidae) and minute moss beetles (Hydraenidae) enclose their eggs singly or in batches within cocoons made of silk secreted by special glands in the female's reproductive system. Depending on the species, leaf beetles (Chrysomelidae) apply a protective coating of their own feces to the eggs that are laced with distasteful chemicals sequestered from the tissues of the host plant. Leaf-mining metallic wood-boring beetles (Buprestidae) and weevils (Curculionidae) provide their offspring with both food and shelter by sandwiching their eggs between the upper and lower surfaces of leaves. Some longhorn beetles provide their larvae with dead wood by girdling, or chewing, a ring around a living tree branch and laying their eggs on the soon-to-be-dead outer tip. Dying branch tips quickly turn brown, a phenomenon called *flagging*, and stand in stark contrast to healthy green foliage. The girdle eventually weakens the branch, causing it to break and fall to the ground where the larvae can feed and develop inside, undisturbed. Female leaf-rolling weevils (Attelabidae) cut the leaf's midrib before laying their eggs in the rolled-up portion of the leaf.

Dung scarabs (Scarabaeidae) and *Nicrophorus* burying beetles (Silphidae) exhibit varying degrees of parental care well beyond the egg stage. Both males and females may cooperate in digging nests for their eggs and provision them with dung or carrion, respectively, for their brood. Dung and carrion are rich in nutrients, and competition for these resources can be fierce. Many dung- and carrion-feeding beetles have evolved tunneling or burying behaviors to quickly hide excrement or dead animals from the view of other scavenger species. Burial not only secures food for their young, it also helps to maintain optimum moisture levels for successful brood development. *Nicrophorus* beetles exhibit t*he most advanced form of parental care known in beetles.* They meticulously prepare corpses as food for their young by removing feathers and fur, reshape them by removing or manipulating legs and wings, all while coating the carcass in saliva laced with antimicrobials that slow decomposition. Females lay their eggs in the burial chamber and remain with the young larvae as they feed and develop. The brood's first meal consists of droplets of chewed carrion regurgitated by the mother in a broad depression on the carcass.

Ambrosia and bark beetles (Curculionidae) also provide food and shelter for their young, carving elaborate galleries beneath the bark of trees or in galleries that penetrate the sapwood. Adult females cultivate and store ambrosia fungus in their *mycangia*, specialized pits on their bodies. As they colonize and tunnel into new trees, they introduce the "starter" ambrosia fungus into the brood chambers, where it will be used as food for both themselves and their developing larvae.

METAMORPHOSIS AND DEVELOPMENT

Beetles develop by a process called *holometaboly*, or complete metamorphosis that usually involves four distinct stages: egg, larva, pupa, and adult. The egg stage is sometimes absent in telephone-pole beetles (Micromalthidae), while the pupal stage may be greatly modified in female glowworms (Phengodidae) and some female fireflies (Lampyridae). Each developmental stage is adapted to a particular season and set of environmental factors that ultimately enhances the individual beetle's ability to survive extreme conditions. Adults and larvae are seldom found together in the same place at the same time, thereby functioning in the environment as two distinct species. The spatial and temporal separation of the larvae and adults within the same species effectively eliminates competition for the basic resources of food and space.

Females lay eggs singly or in batches (Fig. 14) through a membranous and sometimes very long tube, or *ovipositor*, usually on or near suitable larval foods. Aquatic species lay their eggs singly or in small batches on submerged rocks, plants, or chunks of wood and other objects. Ground-dwelling beetles that scavenge plant and animal materials often deposit their eggs in soil, leaf litter, compost heaps, dung, carrion, and other sites rich in decomposing organic materials and animal waste. Plant-feeding species drop their eggs at the base of the larval food plant or glue them to various vegetative structures; some species carefully apply a protective coating of their own feces on the eggs. Wood borers, such as longhorn beetles (Cerambycidae), deposit their eggs in cracks, crevices, and wounds of bark.

The larvae of most beetles bear no resemblance whatsoever to the adults and function as though they were entirely different species in terms of food and habitat preferences. Growth is typically rapid, and the outgrown exoskeleton is replaced with a new and roomier one

Figure 14. Egg laying or oviposition, *Harmonia* (Coccinellidae).

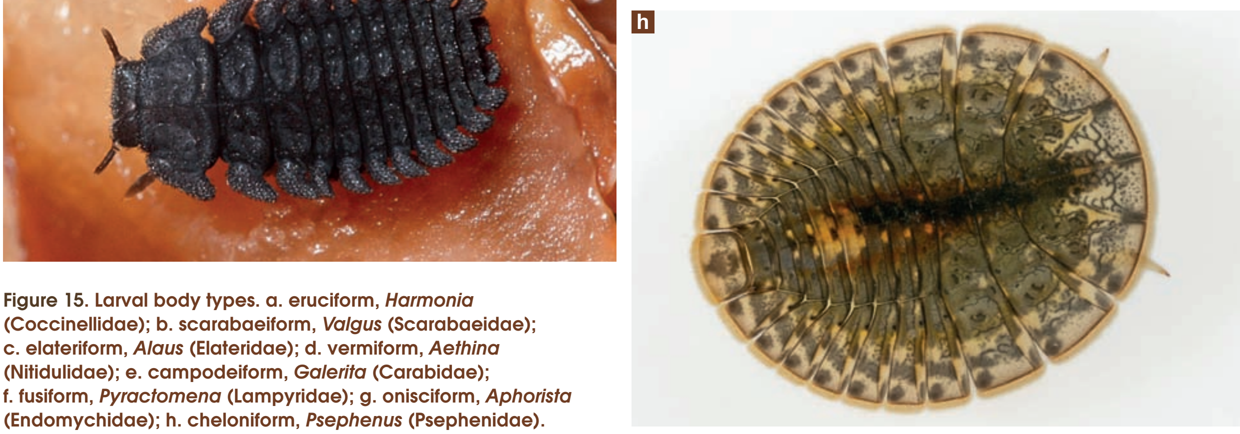


Figure 15. Larval body types. a. eruciform, *Harmonia* (Coccinellidae); b. scarabaeiform, *Valgus* (Scarabaeidae); c. elateriform, *Alaus* (Elateridae); d. vermiform, *Aethina* (Nitidulidae); e. campodeiform, *Galerita* (Carabidae); f. fusiform, *Pyractomena* (Lampyridae); g. onisciform, *Aphorista* (Endomychidae); h. cheloniform, *Psephenus* (Psephenidae).

secreted from underneath by a layer of epidermal cells, a process called *molting*. The stage between each larval molt is called an *instar*. Most species pass through three to five instars, although some may have as few as two (Histeridae) or as many as seven (Dermestidae) or more.

The five basic larval types (Figs. 15a–h) recognized in beetles are based on body form. The slow and caterpillar-like larvae of lady beetles (Coccinellidae) and some leaf beetles (Chrysomelidae) are called *eruciform*; they typically have well-developed heads, legs, and fleshy abdominal protuberances. Sluggish, C-shaped *scarabaeiform* grubs have distinct heads and well-developed legs suited for burrowing through the soil or rotten wood and are characteristic of scarab beetles and their kin (Scarabaeidae, Lucanidae, Trogidae, etc.). The *elateriform* larvae of click beetles (Elateridae) and many darkling beetles (Tenebrionidae) have long, slender bodies with short legs and tough exoskeletons. Thick, legless, maggot-like weevil grubs are called *vermiform*, while the flattened, elongate, and leggy predatory larvae of ground (Carabidae), whirligig (Gyrinidae), predaceous diving (Dytiscidae), water scavenger (Hydrophilidae), and rove beetles (Staphylinidae) are *campodeiform*. The broadly oval and distinctly segmented water penny larvae (Psephenidae) are *cheloniform*, or turtle-shaped, while those of some Silphidae resemble pillbugs, or are *onisciform*. *Fusiform* larvae are broad in the middle and narrowed at the ends.

Each successive instar is generally similar to the last in form, but larger in size; however, the larvae of telephone-pole beetles (Micromalthidae), cicada parasite beetles (Rhipiceridae), blister beetles (Meloidae), and wedge-shaped beetles (Ripiphoridae) develop by a special type of holometaboly called *hypermetamorphosis*. Hypermetamorphosis is characterized by two or more distinct larval forms. The first active, leggy instar is called a *triungulin*, adapted for seeking out the appropriate host. Once the triungulin has located a host, it molts into a decidedly less active larva with short, thick legs and begins to feed. This form is followed by a fat, legless grub that eventually develops into a more active short-legged grub that spends most of its time preparing a pupal chamber.

Although beetle larvae lack compound eyes, most possess from one to six simple eyes on each side of the head called *stemmata*, while others lack any visual organs and are blind. Their mouthparts are adapted for crushing, grinding, or tearing foodstuffs. Predatory larvae are liquid feeders that pierce and drain victims of their bodily fluids. Some species have sickle-like and grooved mouthparts that channel digestive fluids into insect prey to liquefy their tissues and organs. The antennae of larvae consist of only two or four simple segments. Giant water scavenger larvae (*Hydrophilus*), known as water tigers, use their sharp, pointed antennae in concert with their mandibles to tear open insect prey.

The thorax consists of three very similar segments, the first of which may have a thickened plate across its back. Legs, if present, typically have six or fewer segments. Larvae with legs greatly reduced or absent generally feed inside plant tissues or parasitize other insects.

Beetle larvae have 9- or 10-segmented abdomens that are usually soft and pliable, allowing their food-filled bodies to rapidly expand without having to molt. Although legless, the abdomen in some species possesses segments equipped with fleshy wartlike protuberances that afford the larva a bit of traction as it moves about. The last abdominal segment may end in a pair of fixed or segmented projections called *urogomphi* (Fig. 16).

Beetle larvae live in all kinds of terrestrial and aquatic habitats, especially in leaf litter, rotten wood, and various kinds of fungi. They feed on a wide variety of organic

Figure 16. Larval urogomphi, *Dendroides* (Pyrochroidae).

Figure 17. Tiger beetle larva, *Cicindela* (Carabidae).

Figure 18. Glowworm larva, *Phengodes* (Phengodidae), attacking a millipede.

materials, including plant and fungal structures, as well as on living and dead animals. *Phytophagous*, or plant-feeding, larvae attack living and decomposing flowers, fruits, seeds, cones, leaves, needles, twigs, branches, trunks, and roots. Leaf-mining species tunnel between the upper and lower surfaces of living leaves, leaving discolored blotches, blisters, or meandering tunnels trailing in their wake. Wood-boring larvae tunnel between the bark and wood and, depending on species, either pupate there or tunnel their way into the sapwood. Others attack only the heartwood and leave the outer, living sapwood intact. Some larval carrion beetles (Silphidae) feed on accumulations of plant material, while dung-feeding larvae (Geotrupidae, Scarabaeidae, etc.) eat plant materials that have been partially decomposed within the digestive tracts of vertebrates.

The fleet-footed larvae of several families actively hunt for prey in leaf litter or under bark, while decidedly stationary tiger beetle larvae (Carabidae) (Fig. 17) ambush prey that stray too close to the entrance of their vertical burrows. Some larval ground beetles and rove beetles (Staphylinidae) actively seek out and consume the pupae of leaf and whirligig beetles, and flies. A glowworm larva (Phengodidae) overpowers its prey by coiling itself around the front of a millipede's body (Fig. 18). It bites the millipede just behind and underneath the head with sharp and channeled sickle-shaped mandibles that deliver gut fluids laced with paralyzing toxins and digestive enzymes. Immobilized almost instantly, the millipede is unable to release its noxious defensive chemicals and quickly dies as its internal organs and tissues are liquefied. The phengodid larva consumes all but the millipede's exoskeleton and defensive glands. The larvae of blister beetles (Meloidae) attack underground grasshopper egg masses or invade subterranean nests of solitary bees to raid their stores of pollen and nectar. Rhipicerid and ripiphorid larvae are ectoparasitoids that attack cicada nymphs and various mud-nesting wasps, respectively.

Beetle larvae employ a variety of morphological and chemical strategies to defend themselves. Dermestid larvae (Fig. 19) have clusters of bristly hairlike setae that are irritating deterrents to predatory mammals, reptiles, and birds. Located on the upper surface of the abdomen, these setae are arrayed like a defensive fan to ward off potential enemies and entangle the mouthparts of ants and other small arthropod predators. These very same structures are common components of house dust; they trigger allergic reactions and are linked to asthma attacks. Tortoise beetle larvae (Chrysomelidae) carry racks of fecal material and cast larval skins over their backs (Fig. 20) under which they can hide, while other leaf beetles construct protective cases from their waste that cover their entire bodies (Fig. 21).

Figure 19. Dermestid larva, *Anthrenus* (Dermestidae).

Figure 20. Tortoise beetle larva, *Gratiana* (Chrysomelidae), with defensive rack of fecal material.

Figure 21. Case-bearing leaf beetle larva (Chrysomelidae, Cryptocephalinae).

The last larval instar, sometimes called the *prepupa*, develops into the pupa. Dramatic physiological and morphological transformations take place during the pupal stage (Fig. 22), marking the end of a larva adapted primarily for feeding and the beginning of an adult whose life is dominated by reproduction. During this stage, the first physical details of the adult are apparent. Most beetle pupae are of the *adecticous exarate* type and lack functional mandibles (*adecticous*) and have legs not tightly appressed (*exarate*) to the body. Some species (Ptiliidae, some Staphylinidae, Clambidae, Coccinellidae, some Chrysomelidae) have adecticous pupae with legs that are tightly appressed (*obtect*) along the entire length of the body. Many pupae have functional abdominal muscles that allow for some movement. Some of these species have specialized teeth, or sharp edges along the opposing abdominal segments known as *gin-traps* that snap shut on the appendages of ants, mites, and other small predators and parasites.

Figure 22. Pupa, *Harmonia* (Coccinellidae).

In eastern North America, many beetles overwinter as pupae within chambers located deep in soil, humus, or the tissues of plants where they are less likely to be subjected to freezing temperatures. Some scarab beetle larvae (e.g., *Cotinis*, *Cremastocheilus*, *Dynastes*, *Euphoria*) and other species construct protective pupal chambers from their own fecal material. Leaf beetles (Chrysomelidae) generally pupate in the soil, sometimes inside a “cocoon” within a specially dug chamber, although the larvae of *Ophraella* typically anchor their meshlike cocoons up on their host plant. In glowworms (Phengodidae) and some fireflies (Lampyridae), the females undergo a modified pupal stage that closely resembles the last larval instar. Adult *larviform* females emerge without wings and are best distinguished from the larvae by the presence of compound eyes externally and reproductive organs internally.

ADULT EMERGENCE

The requisite combination of time, temperature, and moisture triggers adult emergence, or *eclosion*, from the pupa. Freshly eclosed adults are typically soft and pale, or *teneral* (Fig. 23). Their exoskeleton hardens as it undergoes chemical changes akin to the tanning process and gradually takes on its normal color. Adult beetles are at their full size and never molt again; however, the abdomens of some soft-bodied leaf and blister beetles are capable of limited expansion as they stuff themselves with food or become filled with eggs. Once fully developed, adult beetles may or may not feed, but they are ready to mate and reproduce.

Figure 23. Teneral multicolored Asian lady beetle, *Harmonia* (Coccinellidae).

FEEDING

Equipped with powerful mandibles, beetles are capable of cutting, grinding, or boring their way through all kinds of plant and animal materials, living or dead. Most beetles are herbivores and obtain their nutrition by consuming living plant tissues. Scarabs (Scarabaeidae), blister beetles (Meloidae), leaf beetles (Chrysomelidae), and weevils (Curculionidae) are among the species that are particularly fond of leafy foliage and will strip leaves of their tissues or completely defoliate plants. Pestiferous beetles in these families hungrily consume turf, garden vegetables, ornamental shrubs, and shade trees as well as agricultural or horticultural crops, while their subterranean larvae frequently attack roots.

Pollen- and nectar-producing flowers are particularly attractive to some species (e.g., Scarabaeidae, Cantharidae, Lycidae, Mordellidae, Cerambycidae), but the role of beetles as pollinators (Fig. 24) requires further study. Many wood-boring beetles (e.g., Buprestidae, Cerambycidae, Curculionidae) feed on dead or dying wood. Their tunneling and feeding activities in twigs, limbs, trunks, and roots hasten decay and attract a succession of additional beetles and other insects that prefer increasingly rotten wood. Scavengers prefer their plant foods “cured” by the action of fungi and bacteria. Dung-feeding beetles (some Hydrophilidae, Geotrupidae, Scarabaeidae) consume plant materials already partially broken down by the digestive tracts of horses, cattle, dogs, and other vertebrates. These beetles consume and bury feces as food for their young and are among the most beneficial, yet least appreciated insects.

Several families of beetles are directly or indirectly dependent on fungi as food for themselves and their larvae. Bark beetles (Curculionidae) infect trees with fungal spores that kill twigs and branches or eventually the entire tree. Some of these species have special cavities associated with their head or thorax called *mycangia* that are specifically adapted for storing fungal spores. Ambrosia beetles chew tunnels in wood and introduce into them a specific type of fungus that lines the chambers and serves as food for both larvae and adults. These and other fungi are often dependent on beetles for their distribution. The larvae of some species are unable to complete their development in wood unless the tree has been previously weakened or killed. Featherwing beetles (Ptiliidae), round fungus beetles (Leiodidae), minute brown scavenger beetles (Latridiidae), and others are frequently found with mold and other fungi, and slime mold. Some flat bark beetles (Trogossitidae), pleasing fungus beetles (Erotylidae), handsome fungus beetles (Endomychidae), some darkling beetles (Tenebrionidae) (Fig. 25), tetratomid beetles (Tetratomidae), fungus weevils (Anthribidae),

LEFT: **Figure 24. Jewel beetles on a flower, *Acmaeodera* (Buprestidae).**

ABOVE: **Figure 25. *Neomida* (Tenebrionidae) on fungus.**

and other families are also associated with sac fungi (Ascomycota) and mushrooms, puffballs, bracket fungi, and kin (Basidiomycota).

Ground and tiger beetles (Carabidae) are formidable hunters that rely on speed and powerful mandibles (Fig. 26) to overpower and tear apart a broad range of insect and other invertebrate prey. Rove (Staphylinidae) and clown beetles (Histeridae) hunt for maggots, mites, and other small arthropods living among leaf litter, dung, carrion, under bark, in decaying plant and fungal tissues, and sap flows; some are specialists living in bird and mammal nests. Burrowing water beetles (Noteridae), predaceous diving beetles (Dytiscidae), and whirligigs (Gyrinidae) all attack aquatic invertebrates or terrestrial insects trapped on the water's surface. Many water scavenger beetles (Hydrophilidae) feed on both animal and plant tissues. Predatory scarab beetles (Scarabaeidae) are rare, but adult *Phileurus* have been observed eating various insects, while ant-loving scarabs (*Cremastocheilus*) prey on ant brood. Checkered beetles (Cleridae) and some soldier beetles (Cantharidae) prey on wood-boring and sap-feeding insects, respectively. Lady beetles (Coccinellidae) consume a variety of foodstuffs, especially pollen and molds, but are also predators of aphids, mealybugs, and other plant pests.

Carrion and burying beetles (Silphidae) scavenge freshly dead carcasses, occasionally preying on fly maggots that compete for the same juicy resource. Hide beetles (Trogidae) derive most of their diet from keratin-rich feathers, fur, claws, and hooves. Ham beetles (Cleridae) gnaw on dried tissues and will attack dried meats, while skin beetles (Dermestidae) infest study skins and insect specimens. Natural history museums around the world enlist the services of select dermestid beetles to clean animal skeletons used in research collections and exhibits, while others are strictly monitored and controlled as museum pests.

DEFENSE

Beetles are continually beset by various insectivorous predators, parasites, and pathogens. Birds, bats, rodents, small to medium-sized mammalian predators, reptiles, amphibians, and fishes are among the vertebrates that regularly prey on them, while spiders, ants, and other beetles rank high among invertebrate predators. They often rely on morphological and behavioral adaptations to avoid becoming a meal for a hungry predator. Daytime predation by birds is likely to have played a dominant role in the evolution of cryptic and aposematic coloration in beetles, while the stridulatory, chemical, and non-aposematic

Figure 26. Mandibles of a tiger beetle, *Tetracha* (Carabidae).

BELOW: Figure 27. Padded and adhesive feet of a leaf beetle, *Hemisphaerota* (Chrysomelidae).

defenses of nocturnal species are especially effective deterrents against mammals, amphibians, and invertebrate predators.

Ground and tiger beetles (Carabidae) back up their bursts of speed to evade predators with sprays of noxious chemical compounds. Others, such as *Hemisphaerota cyanea* (Chrysomelidae) (Fig. 27), simply stay put. When attacked, they hunker down by using their oily and bristly feet to cling mightily to the surface of a palmetto leaf. Their tortoise-like carapace is broadly flanged around the edges and completely covers the beetles' appendages, robbing marauding ants of any opportunity to gain purchase.

Adult flea (Chrysomelidae) and some marsh beetles (Scirtidae) have muscular hind jumping legs that quickly propel them out of harm's way in an instant. Click beetles (Elateridae), false click beetles (Eucnemidae), and throscids (Throscidae) all, more or less, have the ability to jump by "clicking" themselves away from danger.

Figure 28. Clicking mechanism of a click beetle, *Alaus* (Elateridae).

They accomplish this feat by contracting ventral muscles that bring a prosternal spine up against a corresponding groove on the mesoternum (Fig. 28). As tension builds, the spine suddenly snaps into the groove with a clearly audible and startling click, propelling the beetle into the air. For some large longhorn beetles (Cerambycidae) and scarabs (Scarabaeidae), size alone—backed up by powerful mandibles, horns, and claws—may be enough to deter all but the most determined predators.

Death feigning, or *thanatosis*, is a behavioral strategy employed by hide beetles (Trogidae), certain fungus-feeding darkling beetles (Tenebrionidae), zopherids (Zopheridae), weevils (Curculionidae), and many others. When disturbed, they "play possum" by pulling their legs and antennae up tightly against their bodies; some of these species have special grooves to receive and protect these appendages. Faced with impenetrable bodies that lack any movement, most small predators quickly lose interest and simply give up.

Other species employ varying degrees of camouflage to blend in with their background and avoid detection by predators. Somber-colored brown or gray wood-boring beetles and weevils blend in perfectly with the rough bark and gnarled branches of their food plants. Pale tiger beetles (Carabidae) almost disappear among the sandy shores of beaches, rivers, and streams. Even a few members of the usually brightly colored lady beetles (Coccinellidae) are tan or striped, enabling them to remain undetected among pine needles. Some seemingly conspicuous bright metallic green beetles (e.g., Scarabaeidae, Buprestidae, Chrysomelidae) disappear among the needles and leaves of their food plants. Longhorn beetles (Cerambycidae) and fungus weevils (Anthribidae) may have markings that resemble lichen-covered bark. Other cryptic beetles, such as the avocado weevil, *Heilipus apiatus* (Curculionidae) (Fig. 29), which looks very much like a bird dropping, are of no interest to predators. The small, dark, and chunky warty leaf beetles *Chlamisus*, *Exema*, and *Neochlamisus* (p.453) (Chrysomelidae) hide right out in the open and are often overlooked by predator and collector alike because of their strong resemblance to caterpillar feces (Fig. 30).

Although incapable of inflicting harm themselves, some beetles mimic the appearance or behavior of stinging or distasteful insects, a phenomenon known as *Batesian mimicry*. Flower-visiting *Acmaeodera* (Buprestidae), scarabs (Scarabaeidae), and longhorns (Cerambycidae) all sport fuzzy bodies, bold colors and patterns, and behaviors that make them striking mimics of stinging bees and wasps. In flight, the American carrion beetle, *Necrophila americana* (Silphidae) looks very much like a bumble bee. Several species of checkered beetles (Cleridae) are boldly colored to resemble pugnacious ants or wingless wasps known as velvet ants. Their quick, jerky movements further

Figure 29. Bird dropping mimic, *Heilipus* (Curculionidae).

Figure 30. Caterpillar feces mimic, *Neochlamisus* (Chrysomelidae).

Figure 31. Eyespots on pronotum of the eyed click beetle, *Alaus* (Elateridae).

Figure 32. Eyespots on pygidium of flower chafer, *Trichiotinus* (Scarabaeidae).

reinforce the charade. But stinging insects are not the only models for beetles seeking protection. Several species of click (Elateridae) and longhorn beetles (Cerambycidae) strongly resemble distasteful fireflies (Lampyridae), soldier (Cantharidae), and net-winged beetles (Lycidae).

Eyespots or sudden flashes of bright colors are thought to startle or confuse would-be predators. The outsized eyespots of the eyed click beetle, *Alaus oculatus* (Elateridae) (Fig. 31), may momentarily confuse a predator trying to direct a sneak attack, allowing the beetle an extra moment or two to escape. *Trichiotinus* beetles (Scarabaeidae) have bold eyespots on their pygidium (Fig. 32) that may suggest the face of a stinging wasp to potential attackers. Some carrion beetles (Silphidae), many dullcolored metallic wood-boring beetles (Buprestidae), and tiger beetles (Carabidae) may also startle predators by revealing flashes of bright iridescent blue, green, or red under their elytra or on their abdomens as they take flight.

Some beetles possess arsenals of noxious chemicals produced by specific glands in the body or extracted from their food and sequestered in special chambers or within the blood (*hemolymph*) that are used as repellents, insecticides, or fungicides. The abdominal defensive glands of ground beetles (Carabidae) produce hydrocarbons, aldehydes, phenols, quinones, esters, and acids and release them as noxious streams through the anus. For example, aposematically colored *Galerita* beetles spray mostly formic acid. Smaller, yet similarly colored bombardier beetles (*Brachinus*) release small, yet potent boiling clouds of hydrogen peroxide gas laced with hydroquinones and various enzymes, among other components, with considerable accuracy through their anal turret with an audible pop. When attacked, carrion and burying beetles (Silphidae) emit oily, smelly anal secretions with a strong ammonia odor. Most rove beetles (Staphylinidae) and darkling beetles (Tenebrionidae) have eversible abdominal or anal glands that produce a wide range of defensive substances.

Many net-winged (Lycidae), soldier (Cantharidae), lady (Coccinellidae), blister (Meloidae), and milkweed beetles (Cerambycidae) are sluggish insects that boldly display their *aposematic*, or warning colors for all to see. Their conspicuously bright and bold patterns serve to warn predators up front of their bad taste. Bright red and black-spotted milkweed borers in the genus *Tetraopes* (Cerambycidae) (Fig. 33) sequester toxic cardenolides from the milky sap of milkweeds. Like the monarch caterpillar, they co-opt the milkweed's defense system by shunting these harmful compounds out of their digestive tract and into their body wall. Lady and blister beetles engage in a behavior known as *reflex bleeding* and will purposely exude bright orange or yellow hemolymph laced with noxious chemicals from their leg joints (Fig. 34) to repel predators.

Figure 33. Milkweed borer, *Tetraopes* (Cerambycidae).

Figure 34. Reflex bleeding from femero-tibial joints, *Meloe* (Meloidae).

Cantharidin is an incredibly caustic chemical compound found in the tissues of blister (Meloidae) and false blister beetles (Oedemeridae). It functions as a powerful feeding deterrent to predators and, even in low doses, will blister and burn mucous membranes and other sensitive tissues. Male antlike beetles (Anthicidae) gather cantharidin from dead or dying blister beetles for their own protection and to attract mates. Males pass along large amounts of cantharidin to the females through copulation that—in turn—is passed along to the eggs and larvae as a defensive chemical compound. Other anthicids have thoracic glands that produce chemicals that are particularly distasteful to ants, the primary predator of ground-dwelling insects. *Neopyrochroa* and *Pedilus* (Pyrochroidae) also sequester cantharidin, possibly from blister beetles (Fig. 35) or other natural, yet unknown cantharidin sources.

LEFT: **Figure 35. *Pedilus* (Pyrochroidae) on an oil beetle, *Meloe* (Meloidae).**

RIGHT: **Figure 36. A pseudoscorpion.**

SYMBIOTIC RELATIONSHIPS

Some beetles have intimate and specialized, or *symbiotic*, relationships with other organisms. Symbiotic relationships that benefit both the beetle and its partner organism are examples of *mutualism*. *Commensalism* is a form of symbiosis where one symbiotic organism clearly benefits while the other is not adversely affected by the relationship. *Parasites*, on the other hand, live at the expense of their hosts.

All plant-feeding beetles, especially wood-boring species, rely on mutualistic *endosymbiotic microorganisms*, such as bacteria, fungi, and yeasts that live within special pockets called *mycetomes* in their digestive tracts and assist in digesting the primary component of all plant-based foods, cellulose. The larvae of these species do not begin their lives with these vital organisms in place and must either obtain them by consuming their eggshells, which were coated by their mothers in residues laden with endosymbionts, or by consuming adult waste (*feces*, *frass*) that is teeming with them.

Larger beetles in the families Scarabaeidae, Elateridae, and Cerambycidae often harbor pseudoscorpions (Fig. 36). These tiny arachnids are occasionally found in a killing jar used to dispatch these large beetles. Pseudoscorpions depend on their insect hosts for transportation, a type of commensalism known as *phoresy*. They hunt under tree bark for small insect larvae and mites among the chewed galleries and frass left in the wake of wood-boring insects. As their prey populations are depleted, pseudoscorpions seek out and attach themselves to a beetle to hitch a ride to another fallen tree where food is more abundant. Burying beetles (Silphidae) possess phoretic mites that prey on the eggs of carrion-feeding flies, thus reducing the competition for their host beetles. The mites found on bess beetles (Passalidae) and longhorn beetles (Cerambycidae) are not phoretic, but feed on the beetle's bodily fluids (Fig. 37).

Figure 37. Mites on a bess beetle, *Odontotaenius* (Passalidae).

Ant-loving beetles, or *myrmecophiles*, in the families Staphylinidae, Histeridae, and Scarabaeidae are more or less adapted for living in the nests of ants. Some myrmecophilous beetles are simply opportunists and live on the fringes of colonies where they scavenge bits of food left behind by the ants. However, other species are much better adapted to living with ants and have evolved various degrees of behavioral, chemical, or tactile mimicry to integrate themselves into the host ants' social system. Host ants tolerate their beetle guests with varying degrees of hospitality, but the benefits derived from the relationship nearly always favor the beetle. Species in these and other families similarly adapted to living with termites are referred to as *termitophiles*.

A few beetle larvae are ectoparasitoids of other animals. For example, the larvae of *Brachinus* and *Lebia* (Carabidae) attack the larvae and pupae of aquatic beetles and leaf beetles, respectively. The larvae of cicada parasite beetles (Rhipiceridae) attack cicadas, while those of wedge-shaped beetles (Ripiphoridae) parasitize solitary wasps. Larval passandrids (Passandridae) and bothriderids (Bothrideridae) attack the larvae and pupae of wood-boring longhorn (Cerambycidae) and jewel beetles (Buprestidae); however, the most specialized ectoparasitic beetle known in eastern North America is a mammal specialist. Both the flattened, louselike adults of the beaver parasite beetle, *Platypsyllus castoris* (Leiodidae) (p.120) and its larvae live on beavers where they feed on their host's skin and bodily fluids.

AQUATIC BEETLES

Aquatic beetles are variously adapted behaviorally and morphologically for living on the surface of, within, or on the bottom of standing and flowing bodies of water. Winged species are generally good to strong fliers and sometimes attracted to lights at night in large numbers. Based on adult modes of locomotion, water beetles are divided into two basic groups: swimmers and crawlers.

The flattened middle and hind legs of swimmers (Haliplidae, Gyrinidae, Noteridae, Dytiscidae, some Hydrophilidae) are fringed with setae and used like oars to propel their mostly smooth, rigid, streamlined bodies through standing or slow-moving waters. All but the gyrinids spend most of their adult lives submerged underwater and must regularly bring fresh supplies of air into contact with spiracles through which they breathe. Water scavengers (Hydrophilidae) accomplish this by breaking through the surface tension headfirst with their antennae to draw a layer of air over the underside of their abdomen. Crawling water (Haliplidae), burrowing water (Haliplidae), and predaceous diving beetles (Dytiscidae) all trap air under their elytra in the *subelytral cavity* by breaching the water surface with the tips of their abdomens.

Whirligigs (Gyrinidae) are adapted for life on the surface of standing and slow-moving waters, although they can dive and remain submerged for short periods of time when threatened. They propel themselves with highly modified and paddlelike middle and hind legs, and steer with the rudderlike tip of the abdomen that bends down almost at a right angle. Their compound eyes are completely divided into two different sets of lenses, allowing them to see in both air and water. With special organs in their antennae, whirligigs can detect surface vibrations emanating from other whirligigs, predators, and struggling insect prey. Dead and dying insects are grasped with *raptorial*, or grabbing front legs.

Contrastingly, beetles that crawl in the water (Hydraenidae, some Hydrophilidae, Elmidae, Dryopidae, some Curculionidae) have legs adapted not for swimming, but for clinging, as evidenced by their long pretarsi tipped with well-developed claws. They are partly or wholly clothed in a dense, velvety, and water-repellent pubescence called a *hydrofuge* that continuously envelops their bodies in a silvery layer of air that draws a steady supply of oxygen from the surrounding water and allows carbon dioxide to diffuse out—a system called *plastron breathing*. Plastron breathing is not very efficient and is largely restricted to sedentary grazers in the families Dryopidae and Elmidae living in shallow, well-oxygenated waters. Once submerged, plastron-breathing beetles seldom, if ever, need to surface or leave the water.

BEETLES AS PESTS

As a group, beetles are among the most beneficial animals, but it shouldn't be a surprise that species that have evolved to scavenge animal nests, carrion, dead insects, seeds, and decaying plant materials in nature are also adapted to exploit these very same materials improperly stored in our pantries, warehouses, and museum collections. Beetles in several families infest and damage stores of grains and other cereal products, dried meats and fruits, legumes, nuts, and spices. Others are serious museum pests that destroy often-irreplaceable study skins, and insect and herbarium specimens.

Wood borers are essential for breaking down and recycling nutrients bound up in dead wood, while other phytophagous species help to keep plant populations in check via consumption of reproductive and vegetative structures; however, when some beetles direct these activities to ornamental and horticultural plants, agricultural crops, forests managed for timber, or wood products, the results are catastrophic in terms of significant monetary losses as a direct result of lost production, trees killed, damaged goods, and pest control efforts. Ptinids and bostrichids that tunnel into dry wood have become pests of wood carvings, furniture, flooring, and paneling. Both native and adventive bark and ambrosia beetles (Curculionidae) regularly attack and kill trees in forests and along city streets, usually focusing their efforts on recently dead, injured, or felled trees, or on trees stressed by drought or overwatering. Others attack the roots and branches of fruit and nut trees in orchards, severely impacting crop yields. The tunneling activity of these and other wood-boring beetles disrupts a tree's ability to transport water and nutrients, and also introduces debilitating and lethal fungal infections.

Figure 38. Asian longhorn beetle, *Anoplophora glabripennis* (Cerambycidae).

Figure 39. Emerald ash borer, *Agrilus planipennis* (Buprestidae).

Two of the most notorious wood-boring beetles in eastern North America were accidentally introduced from Asia. A native of China and Korea, the Asian longhorn beetle, *Anoplophora glabripennis* (Motschulsky) (Fig. 38) (12.0–39.0 mm) is a large, shiny black longhorn beetle (Cerambycidae) with irregular white spots on elytra and bluish or white legs. It has long antennae that are ringed in pale blue or white and extend past the elytra by five antennomeres in the male, but by just one or two in the female. The elytra are smooth, shiny or dull and only rarely densely spotted or spotless. The tunneling activities of the larvae weaken and kill otherwise healthy trees and threaten millions of street trees and the maple syrup industry. Infestations of this beetle were first reported in New York in 1996, but it was probably introduced about 10 years earlier in untreated wood used to crate heavy equipment. Infestations of this destructive beetle have since been reported from New Jersey, southern Ontario, northeastern Illinois, and Ohio, with additional individuals intercepted elsewhere in the Northeast and upper Midwest. Efforts to eradicate this destructive species involve cutting down, chipping, and burning thousands of trees.

The emerald ash borer, *Agrilus planipennis* Fairmaire (Fig. 39) (8.0–14.0 mm), is a slender, bright metallic green, rarely blue-green or violet jewel beetle (Buprestidae), much larger than native species of *Agrilus*. It also has a distinct ridge down the middle of the pygidium that extends beyond the tip. Emerald ash borers were first discovered in Detroit, Michigan, and Windsor, Ontario, during the summer of 2002, but they likely arrived in wood packing materials from eastern Asia in the early 1990s. Since then, this species has become established throughout much of the Northeast and upper Midwest. It has destroyed millions of ash trees in Michigan, southern Ontario, and Québec and threatens to destroy ash trees across North America. Ash species are important street trees and a vital source of wood for making furniture, tool handles, and baseball bats. Efforts are under way to control the spread of the emerald ash borer with the introduction of biological control agents imported from China.

WHEN AND WHERE TO FIND BEETLES

One of the most appealing aspects of studying beetles is that opportunities to discover and observe unfamiliar species and behaviors are everywhere. You can ramble about backyards, vacant lots, and parks, or explore more distant coastal habitats, woodlands, wetlands, or montane regions year-round, especially in the southeast along Atlantic and Gulf coasts where temperatures are relatively mild in winter. Visiting familiar areas and habitats in all seasons year after year will likely produce a breathtaking diversity of species. Even in more northern regions, overwintering beetles are found tucked away under snow-covered bark, buried deep in rotten wood or leaf litter, or hiding under boards and other debris to avoid lethal frosts. Many water beetles remain active throughout winter and are sometimes seen swimming under the ice of frozen ponds and lakes; however, some species are adapted to reach peak activity levels in fall and late winter, at least at lower elevations.

Spring through midsummer is the best time to find the greatest diversity of beetles in eastern North America. The beginning of beetle activity varies depending on weather conditions and location, the latter of which is largely influenced by latitude and elevation. Spring conditions arrive later in the north and at higher elevations. As early as February, the first sustained period of warm weather in northern Florida will drive many small ground beetles (Carabidae), scarabs (Scarabaeidae), weevils (Curculionidae), and other beetles into the air to search for food and mates, while much of the region to the north is still firmly in the grip of winter. The front of spring progresses northward through the Coastal Plain and penetrates the interior uplands via the lower reaches of riverine valleys before reaching southeastern Canada by mid-May. By the middle of June all of eastern North America, save for its northernmost reaches and highest mountains, is or is about to be warmed by a blanket of heat and humidity that drives most beetle populations into high gear for the rest of the summer. The first hints of fall, as evidenced by shorter days, cooler nights, and the turning of autumn leaves, occur in September in southeastern Canada and montane habitats elsewhere in the east, and progresses steadily southward over the next several weeks. By November most of the remaining conspicuous beetle activity in the region is evident only along the coastal states of the southeastern United States.

Time and experience will teach you the best times and places to look for beetles. The following are some of the more productive habitats to search for beetles in eastern North America. Exploring these and other habitats throughout the day and year will likely reveal a surprisingly diverse fauna that will enhance your enjoyment and appreciation of beetles. Be sure not to damage host plants and always return rocks, logs, and bark to their original positions. Such actions not only keep these sites productive for future visits, but also help to preserve the aesthetics of the habitat for the enjoyment of all.

FLOWERS AND VEGETATION

Spring and summer blooms rich in sweet nectar and high-protein pollen are especially attractive to flower-visiting beetles, such as Queen Anne's lace (*Daucus carota*), goldenrod (*Solidago* species), buttonbush (*Cephalanthus occidentalis*), joe pye weed (*Eutrochium*), milkweed (*Asclepias* species), and lizard's tail (*Saururus cernuus*). Several native and introduced blooming shrubs and trees are popular with beetles, including dogwood (*Cornus*), redbud (*Cercis canadensis*), New Jersey tea (*Ceanothus americanus*), autumn olive (*Elaeagnus umbellata*), serviceberry (*Amelanchier*), spicebush (*Lindera*), viburnum (*Viburnum*), hydrangea (*Hydrangea*), cherry (*Prunus*), tulip tree (*Liriodendron tulipifera*), and elderberry (*Sambucus*).

Beetles also exploit many other vegetative structures as food, places to mate and reproduce, or habitats in which to hunt for prey. Carefully examine fruits, seedpods, cones, needles, leaves, and roots of grasses, forbs, vines, shrubs, and trees. The young spring foliage of deciduous shrubs and trees is especially attractive to many plant-feeding species. Some herbivorous beetles are specialists and are seldom found on anything other than the adult or larval host plant. For example, some *Rhyssomatus* (Curculionidae) and all *Tetraopes* species (Cerambycidae) feed on milkweeds in the genus *Asclepias* and seldom occur on other plants.

Slime flux is a bacterial disease of some hardwoods that forces sap attractive to many species of beetles out of tree limbs and trunks through freeze cracks, insect emergence holes, and other wounds (Fig. 40). Check not only the nooks and crannies of sap-soaked bark for beetles, but also the sap-drenched soil and litter beneath for smaller species and their larvae.

FRESHLY CUT AND BURNED WOOD

The smell of freshly cut or recently burned wood is especially attractive to beetles, particularly those looking for mates and egg-laying sites. Slash piles (stacks of freshly cut branches) in wooded areas are particularly productive, especially in spring and early summer. You can also attract

Figure 40. Green June beetles, *Cotinis* (Scarabaeidae), attracted to slime flux.

beetles with bundles of fresh-cut branches placed in forest openings, along woodland edges, or in canopy-covered habitats that are only partially exposed to sunlight. Inspect the bundles at weekly intervals, day and night, and note which beetles are attracted to the branches of which species of tree. Another technique is to lay branches, bark, or a slab of trunk 4 to 6 inches thick across the top of a fresh-cut stump in spring and check the top of the stump regularly for beetles that have taken shelter there. Wood smoke, especially that generated by burning pine trees, also attracts wood-boring and bark beetles.

FUNGI, MUSHROOMS, MOSSES, LICHENS

Species in several families are found commonly on fungi, slime molds, mosses, and lichens. Carefully inspect fungi with a hand lens and leave them in good condition so they continue to lure new beetles. Fleshy and relatively ephemeral puff balls and mushrooms are also attractive, while more durable woody shelf fungi provide food and breeding sites for other species. Still other species seek out fungal tissues growing on or under bark, or in the soil. In addition to *mycophagous*, or fungal-feeding beetles, predatory rove (Staphylinidae) and clown beetles (Histeridae) frequent fungi infested with insects and mites as hunting grounds. Adults and larval pill or moss beetles (Byrrhidae) are obligate moss feeders that graze on vegetative surfaces or burrow in the soils beneath. Tread very lightly in these habitats so that future visits are equally productive. Only when fungal, moss, and lichen examples are in abundance should samples be collected for microscopic examination or extraction of specimens with a Berlese funnel (see p.41).

SNAGS, LOGS, AND STUMPS

Standing snags dry from the top down, and most of their beetles are concentrated at or near the base. Moist rather than dry wood harbors more species. Some species prefer primarily shady habitats, while others prefer more open, sun-drenched wood, although this latter niche dries out more quickly. As the wood decomposes, its quality changes in terms of its suitability as beetle food and egg-laying sites, attracting a progression of beetle species over time. Checking these microhabitats every few weeks over a period of years may reveal an amazing diversity of beetle species.

Recently dead trees with tight-fitting bark are more likely to harbor the adults of smaller or flatter species than those with bark that is easier to remove. As the wood dries and its bark loosens, larger and more robust species are able to take shelter. Peeling back dead bark, or “barking,” is best accomplished during the cooler winter and spring months. Use a broad-blade knife, screwdriver, or dandelion weeding tool to peel back bark and examine all the freshly exposed areas carefully. Whenever possible, replace the bark by nailing or tying it back in place so the site will continue to be colonized by additional individuals and species. Many small species are best found by placing crumbling and rotten wood onto a light-colored surface for immediate inspection or into a Berlese funnel or some other insect extraction system.

Night collecting on dead wood with a headlamp or flashlight, particularly on warm evenings in the spring and summer when beetles are emerging from their tunnels or wandering about limbs and trunks in search of mates, is an especially fruitful activity.

STREAM BANKS, LAKESHORES, AND COASTLINES

Plant debris on the surfaces of streams and rivers contains flying and crawling beetles trapped by floodwaters. Some species typically spend their daylight hours hidden under debris washed up on lakeshores and ocean beaches. Flying beetles of all sorts fly or are windblown out over lakes and oceans only to drown and be washed back up on shore, sometimes by the thousands. The high waterlines along these shores are often littered with thousands of beetles from various families. Burrowing species that are adapted to living in flat sandy, gravelly, or muddy shorelines are flushed from their burrows by splashing water across the substrate. Ground and tiger beetles (Carabidae) are commonly found hunting, flying, or mating on sandy or muddy substrates along the edges of various wetlands.

FRESHWATER POOLS, STREAMS, AND LAKES

While some beetles prefer cold, fast streams, others favor ponds or slow-moving streams. Look for rafts of whirligig beetles (Gyrinidae) on the surface of ponds or protected, slow-moving pools in streams and along the edges of rivers. Predaceous diving beetles (Dytiscidae) are often found on gravelly bottoms or beneath submerged objects, while water scavengers (Hydrophilidae), crawling water beetles (Haliplidae), and long-toed water beetles (Dryopidae) are found swimming near aquatic plants, crawling among mats of algae, or clinging under logs and rocks. Carefully pick up and examine rocks lifted out of flowing waters for larval water pennies (Psephenidae) and riffle beetles (Elmidae) clinging to their surfaces.

COASTAL DUNES, SAND SCRUB, AND SANDHILLS

Various small, sand-loving, or *psammophilic* beetles hide among flowing sand and plant debris at the bases of dune grasses and other plants. They are typically found down in the moisture layers, or in or under accumulations of detritus closer to the surface. They typically move up and down through the sand as they follow the seasonal moisture and temperature gradients to maintain ideal living conditions. Sandhill, sand scrub, and pine barren beetles are variously adapted for living in hot, dry, sandy habitats. Most are burrowers that are active on the surface only for very brief periods of time. These habitats, which stretch from the pine barrens of New Jersey to the isolated pockets of sand scrub in Florida, are habitat for many rare, endangered, poorly known, or undescribed beetle species.

CARRION

Dead animals provide food and shelter for adult and larval beetles. Look for them on, in, and under the carcass, as well as buried in the soil directly beneath the body. Carrion and burying beetles (Silphidae) feed primarily on fresh, juicy flesh, while most skin beetles (Dermestidae) scavenge dried tissues. Hide beetles (Trogidae) are among the last contingent of insects to visit a carcass and gnaw on the keratin-rich hair, feathers, hooves, and horns. Predatory species seek out and devour the eggs of other carrion-feeding insects and mites. Other beetles are attracted to carrion simply because of the available moisture and shelter.

DUNG

The most conspicuous dung beetles in the region belong to the families Geotrupidae and Scarabaeidae. Several genera of smaller dung scarabs feed on the small dung pellets produced by flying squirrels or deer. Deer dung specialists are typically active during the cooler months in fall and spring. Many of our larger species are drawn to the big, juicy feces produced by cattle, pigs, horses, and humans. Dog and cat feces attract only a few, mainly introduced species of dung scarabs. Clown (Histeridae) and rove beetles (Staphylinidae) are commonly associated with dung as predators of fly eggs and larvae.

BENEATH STONES AND OTHER OBJECTS

Many beetles occasionally or habitually take shelter under rocks, logs, boards, and other debris on the ground, especially in grassy areas and habitats along the edges of ponds, lakes, streams, rivers, and other wetlands. For the benefit of the people following your footsteps and the organisms living underneath, always return these objects to their original places and positions. Also look for antlike flower (Anthicidae) and false blister beetles (Oedemeridae) under driftwood that has washed up along coastal beaches and rivers, especially along the lower reaches that are regularly influenced by the tides.

LEAF LITTER, COMPOST, AND OTHER ACCUMULATIONS OF PLANT MATERIALS

Layers of leaves and needles that gather beneath trees, accumulate along streams and rivers as flood debris, or wash up on beaches and lakeshores after storms frequently harbor all kinds of beetles. Beetles overwintering in these habitats are collected by placing debris in plastic bags and bringing the samples inside to check for individuals that have become active. Backyard compost heaps, decaying piles of mulch, and other natural or artificial accumulations of decomposing grass, leaves, branches, and other vegetative structure are particularly productive. Some coastal rove beetles (Staphylinidae) live under decomposing piles of seaweed washed up along the beach.

LIGHTS

Incandescent, fluorescent, and neon lights on porches and storefronts, especially in undeveloped wooded areas, are very attractive to many kinds of beetles. The bright bluish glow of a mercury vapor streetlight is much more attractive to beetles and other insects than the dull yellowish light emitted by their sodium vapor counterparts. Although many beetles will settle on the ground or wall directly beneath or behind the light, others, especially the largest species, may prefer to remain on plants and other surfaces just beyond the light's glow.

INDOORS

Look for living and dead beetles on windowsills and light fixtures inside houses, garages, sheds, and warehouses. Household and structural pests, as well as other beetles trapped indoors are usually attracted to well-lit windows and other light sources. High numbers of skin beetles (Dermestidae) or pantry pest species are indicative of infested stored foods, skins, plant materials, wood products, and insect collections.

OBSERVING AND PHOTOGRAPHING BEETLES

Making a beetle collection (see p.45) is the best way to learn about beetles. Only by having them in hand will you have the opportunity to critically examine the physical features necessary to facilitate accurate species identification and develop an understanding of their evolutionary relationships and classification; however, some readers may prefer instead to simply observe or photograph them alive in the wild.

BEETLES THROUGH BINOCULARS

Close-focusing binoculars allow you to observe beetles on flowers or shorelines less than 6 feet away with amazing color and clarity. The larger the diameter of the eyepiece, or objective, the more light that is gathered to form the image. The best binoculars for handheld use are 8 × 42 or 10 × 42. An objective magnification of 8 produces an image as if the viewer were 8 times closer to the subject. A 10-power binocular will make the image larger, but the smaller field of view can make tracking of moving beetles a bit more of a challenge. Lower power binoculars with smaller oculars (e.g., 7 × 36) are also useful. They are smaller and less expensive, but your subjects will not be as magnified or brilliant. When buying a pair of close-focusing binoculars, compare several brands at the same time to determine which model and magnification works best for you and fits your budget. Close-focusing monoculars are also useful, less expensive, and easily stowed in your field kit.

A pair of compact binoculars with the front lenses closer together than the eyepiece lenses (reverse Porro prism design) can be modified for close-up beetle watching. Screw a two-element Nikon 5T or 6T close-up lens into a soft lens hood, place the hood with lens in front of the binoculars, and affix them using heavy rubber bands to achieve a close-focusing capability.

BEETLE MACRO PHOTOGRAPHY

Macro, or close-up photography was once the domain of highly proficient photographers using expensive and complex equipment. Good quality macro photographs are easier to take, review, and share now than ever. Today, even the most casual photographer can capture good images with relatively inexpensive point-and-shoot digital cameras with macro-like capabilities. However, the very best images, including most of the photos that grace these pages, were taken with a digital single-lens reflex camera with dedicated macro lenses with focal lengths of 50 mm, 90 mm, or 100 mm that allow focusing on beetles just a few millimeters from the lens. The distance between the lens and the beetle is called the *working distance*. When fully extended, macro lenses allow you to fill the frame of your photograph with an up to life-size (1:1) image of a beetle. Some beetles are a bit skittish at these close working distances, while others seem not to notice the camera at all. Macro lenses with longer focal lengths (150 mm, 200 mm) have greater working distances and still offer 1:1 capability, but they are bulky, difficult to hold steady, and very expensive. To obtain magnifications greater than life size, 1:2 or more, doublers, teleconverters, and extension tubes of 25 mm or more are placed between the lens and the camera body. High-quality close-up lenses of varying magnifications screwed on the front of the macro lens can be useful, but will reduce already close working distances and sometimes degrade image quality.

In macro photography, focus is best achieved not by using the camera's autofocus feature, but by selecting the desired magnification in advance based on the beetle's size and the kind of picture you want to take. Once the lens is extended, aim the camera at your subject and look through the viewfinder to compose the shot. Then slowly rock back and forth until the subject is in focus and take the picture. Most beetle images look best when the subject, especially the eyes, and background are both in sharp focus. The depth of focus in a photo, usually referred to as the depth of field, is the distance between the nearest and farthest objects in the photo that are in focus. Think of text on a page photographed at an angle—the sentences in the image that are in focus are indicative of the depth of field. Depth of field is determined by the opening at the back of the lens, or aperture. The aperture is expressed as an *f*-stop; the bigger the *f*-stop number, the smaller the aperture. Decreasing the aperture, or stopping down to *ƒ*/16 or *ƒ*/22, increases the depth of field; however, decreasing the *f*-stop also requires using flash to compensate for the reduced amount of natural light reaching the sensor.

Because of the long barrel of the macro lens, the built-in flash on your camera's body will cast a shadow across your beetle and ruin the image; therefore, additional and adjustable external flashes attached to the end of the lens are your best bet. Two adjustable flashes are better than one and always better than the flat lighting provided by a ring flash. Placing these flashes at a 30-degree angle to the long axis of the lens barrel will create the effect of natural morning or afternoon sunlight; however, you may want to adjust one or both flashes to properly expose your subject and its background. Macro photographers often use one flash on the subject while a second flash provides a weaker "fill light" on a nearby background. Distant backgrounds that are underexposed appear dark or black and the overall impression of the photograph is often not pleasing, even if the subject is in perfect focus and properly exposed. The easiest way to compensate for this is by making sure that the background is close enough to the subject to be properly exposed by the flash. Always try to photograph a beetle resting on a leaf or flower rather than one perched on an isolated branch tip. Whenever possible, make sure the background is not so cluttered or busy that it distracts from your subject. Always use the highest shutter speed (1/125 sec., 1/250 sec., etc.) possible that synchronizes your camera with the flash system to freeze the action of your subject and mitigate camera movement in order to capture a razor-sharp image.

Take lots and lots of pictures. Experiment with different combinations of apertures, shutter speeds, and flash settings under a variety of conditions, and carefully record these in a small notebook. Compare your notes with the resultant images to establish the settings and conditions that work best for your camera. Carefully review all your images either in camera or on your computer, then select and keep only the very best for each species. There is no point in tying up valuable space on your hard drive with inferior images. Store your images using one of many software applications, and be sure to label each image with locality data and any other pertinent information as if it were a specimen in a collection. This way, your images can be easily retrieved and become part of a permanent record of your travels and observations. Your best photos will be those that are well exposed and in focus and tell a story of beetles feeding, mating, laying eggs, or otherwise going about their business undisturbed in their own habitat.

Figure 41. Camera equipment used by the author.

There is no one way to photograph a beetle. Every photographer has his or her own favorite setup and method of working based on a combination of aesthetics, experience, taxonomic interests, available camera equipment, and degree of patience to experiment with said equipment. Most of my images reproduced in this guide were photographed with a Canon EOS Digital Rebel XTi set at ISO 100 with a 100 mm macro lens, up to 50 mm of extension tubes, and a Macro Twin Lite MT-24EX (Fig. 41). Each strobe was placed about 90 degrees apart, aimed at about 30 degrees from the axis of the macro lens, and fitted with Stoffen and Puffin diffusers. Both flashes were further diffused with a sheet of 3/32-inch (2 mm) sheet of polyethylene foam taped to the camera to help reveal subtle surface sculpturing in all but the most shiny of black beetles. I generally used *ƒ*/16–22 and a shutter speed of 1/125 to 1/200 of a second. Instead of lugging a tripod around to steady my camera, I strap on knee and elbow pads to absorb the shock to my joints produced by hunkering down on the ground or bracing myself against trees and boulders.

BEETLE CONSERVATION AND THE ETHICS OF COLLECTING

Commercial and residential development, conversion to agricultural lands, agricultural runoff, grazing, logging, inundation by water impoundments, wetland draining, indiscriminate use by off-road vehicles, and overuse and abuse of pesticides and herbicides in urban and agricultural areas are just a few of the many human activities that adversely affect, alter, or destroy beetle habitats. The ever-growing list of exotic insect introductions, including those purposely introduced as biological control agents, can inflict unintended and possibly catastrophic consequences on indigenous beetle populations by choking out native food plants or outcompeting native beetles for food, shelter, and egg-laying sites. Climate change, too, will certainly affect many beetle populations for better or worse.

Beetles restricted to ever-shrinking habitats are particularly susceptible to habitat destruction and invasive species. Populations of *saproxylic*, or rotten wood-feeding beetles (e.g., Tetratomidae, Melandryidae, Synchroidae, Stenotrachelidae, Scraptiidae) in old growth forests are significantly related to forest structure. The impacts of current forest management practices that fragment these mature growth forests and reduce coarse woody debris could severely impact the availability of food for both the larvae and adults. The sandhill habitats of the southeastern United States also support unique beetle species, yet these habitats are under constant threat of invasive plant species, agricultural conversion, logging, mining, fire and fire suppression, ditching, and recreational use.

Although beetles are among the most conspicuous and charismatic of all insects, our overall lack of knowledge of their biology, ecology, and distribution hampers efforts to identify species in need of conservation. With the exception of some tiger beetles and cave-dwelling ground beetles (Carabidae), relatively few species in eastern North America are recognized as threatened or endangered and afforded legal protection. To find out more about rare, threatened, and endangered beetles in eastern North America, visit the NatureServe Explorer website at www.natureserve.org/explorer/.

ETHICS OF BEETLE COLLECTING

Unlike most birds, butterflies (and some moths), dragonflies, and damselflies that are easily identified on sight, many beetles must be in hand to facilitate close examination or dissection before accurate species identifications are possible. Their capture and preservation not only assures identification, but also represents the first important step toward their conservation. The data associated with these specimens contributes to our understanding of their habitat preferences, activity period, and distribution. Beetle collecting, collections, and collectors all provide critical information that land managers and other decision makers need to develop and implement the best land-use practices that will protect beetles and other natural resources.

Whether you are a professional biologist investigating a particular avenue of research, or a student or amateur naturalist desiring to learn more about insects and the natural world, you need not worry that your collecting activities will adversely affect most beetle populations. Such efforts at beetle collecting pale in comparison to the proficiency demonstrated by hungry insectivorous animals, or to the deleterious effects of pesticide use, mowing, vehicular traffic, artificial lights, and bug zappers. Habitat degradation and destruction, combined with invasive species—not collecting or collectors—pose the greatest threats to beetles and their habitats in eastern North America.

Beetles with small populations living in sensitive, specialized, or patchy and ephemeral habitats, such as those living in sand dunes, wetlands, and vernal pools or dependent on populations of rare plants, are potentially sensitive to adverse changes in their environments, and should be collected only in small numbers; however, the reproductive capacity of most beetles is much greater and differs dramatically from that of vertebrates. Birds, fish, reptiles, amphibians, and mammals all produce relatively few young and must invest enormous amounts of time and effort in nest building and caring for their young to ensure the survival of enough individuals to maintain stable populations. Removal of even a small number of these animals—parents or offspring—can have a major impact on local populations; however, a single female beetle may produce hundreds of young that require little if any parental care at all. Of these, only a few need to survive and reproduce to sustain a thriving population.

Adopt a collecting ethic that embraces the need to conserve beetle populations and their habitats, and recognizes the rights of landowners. Collecting large numbers of the same species at the same time and place adds little to our knowledge of beetles and does not enhance the diversity that is the mark of a good reference collection. Such a collection, supported by accurate specimen label data and field notes, can only be built over time. The collection of beetles listed as endangered or threatened is strictly regulated, and it is the responsibility of the collector to know which species are afforded protection and to adhere to those regulations. When moving beetles, living or dead, be sure to comply with county, state, and federal agricultural and wildlife regulations. Generally speaking, transporting any living beetles or other insects across county, state, or international borders requires written permission from state or federal agricultural authorities, or both.

Always obtain permission to collect on private lands. Collecting on public lands, such as county, state, and national parks, state and national forests, monuments, and recreational areas generally requires written permission, but these requirements may vary depending on locality and the purpose for collecting specimens. Managers of public lands are usually happy to issue permits to individuals conducting beetle surveys or other ecological studies, especially if they are affiliated with museums, universities, and other research institutions. Your efforts will provide data needed to effectively manage and preserve habitats for all wildlife. Always conduct your fieldwork within the conditions set forth in your permit and be respectful of other visitors. Once your project is completed, promptly share your data with the permitting agency and other researchers, and deposit voucher specimens in a permanent museum or university entomology collection.

COLLECTING AND PRESERVING BEETLES

The scientific data generated by professionals and dedicated amateurs collecting beetles are important not only to document the fauna of a given jurisdiction or region, but also to track species diversity and faunal composition over time. The collections of amateur coleopterists working in concert with museum scientists are particularly useful for filling gaps in permanent collections of museums and universities and often provide the basis for both scientific and popular publications. On a more basic level, collecting beetles is a great way to get outside, sharpen your skills of observation, and learn firsthand the biology and ecology of the most diverse group of animals in eastern North America. Beetle collecting is also an excellent way of getting youngsters outdoors and introducing them to the diversity of nature. Many scientists and educators, including the author of this book, cite the activity of collecting beetles and other insects as the spark that launched their lifelong careers of research and public service.

The initial cost of collecting beetles is minimal, since the basic “tools” required are a sharp pair of eyes, patience, persistence, a few containers, and a bit of luck. Nets, beating sheets, and other collecting equipment listed below are also useful. As your knowledge of the seasonal and habitat proclivities of beetles increases, so will your desire to explore new habitats and try out different collecting equipment and techniques. With time and experience, your collecting activities will become more targeted, and these efforts will contribute to the overall diversity of your collection. For detailed information on techniques and equipment for collecting and preserving beetles and other insects, consult *Collecting and Preserving Insects and Mites. Techniques and Tools* (Schauff 1986) or *Collecting, Preparing, and Preserving Insects, Mites, and Spiders* (Martin 1977).

BASIC TOOLS FOR HANDLING AND EXAMINING BEETLES

Forceps made of spring aluminum are known as “featherweights.” They are extremely useful for picking up small beetles without damaging them, while camel-hair brushes are used to probe for and dislodge beetles from their resting and hiding places. Aspirators of various designs are useful tools for sucking small beetles from beating sheets, nets, and other substrates into a glass or plastic vial. Protective gauze over the intake tube prevents the accidental inhalation of beetles and other bits, while an inline fuel filter will extract smaller particles, but neither of these protections will completely prevent the inhalation of molds, spores, insect feces, or the noxious defensive odors produced by many beetles. Blowing aspirators or those using a suction bulb do not involve sucking air through a mouthpiece and alleviate these potential hazards, but they are not widely used. No one who spends any time in the field should be without a good quality hand lens. Available from biological supply companies, hand lenses are small and compact devices for revealing beetle anatomy and other details that might otherwise escape notice by the naked eye. Magnifications of 8× or 10× are ideal, with some units employing several lenses in concert to increase magnification. The trick is to hold the hand lens close to your eye and then move in on your subject until it comes into sharp focus.

KILLING JARS AND KILLING AGENTS

Beetles retained as specimens for a collection must be dispatched quickly and humanely. Freezing is an easy and nontoxic method, but the specimens must be kept cool and calm in a small ice chest until they can be placed in a freezer overnight. Using a killing jar with a bit of loosely crumpled paper that is freshly charged with several drops of ethyl acetate or some other killing agent is often a more practical solution. Ethyl acetate is available from biological and scientific supply houses. Although it is relatively safe to use, avoid getting it on your skin, breathing the fumes, or using it near an open flame. The wadded paper toweling not only holds the killing agent, but also absorbs excess fluids produced by your catch and protects your delicate specimens from jostling. Continually opening and closing the killing jar will result in the loss of its potency, so you will have to recharge the killing jar from time to time. A small, 2-ounce squeeze bottle filled with ethyl acetate makes this task easy. Note that ethyl acetate dissolves anything made of styrene, including clear hard plastic bottles and polystyrene foam. Any jar will serve as a killing jar as long as it has a broad mouth and tight-fitting screw-top lid to retain volatile killing agents. Long cylindrical jars, such as those used for olives, pickled onions, or spices, that are no more than 6 inches tall slip easily into a pocket or collecting bag.

Dark, colorfast beetles with few setae are sometimes killed and temporarily stored by placing them directly in fluid preservative such as 70–95% ethyl alcohol (ethanol) or 70% rubbing alcohol (isopropyl). For long-term storage of larger specimens, pour off the old alcohol and replace it with fresh after a week or two. Although there is no one method for killing beetles for morphological examination, beetles intended for use in tissue studies or molecular analysis must be placed directly in 95% ethanol. Ethanol is generally unavailable to private individuals, with the exception of prohibitively expensive neutral grain spirits, or pure grain alcohol that can be purchased in liquor stores. Isopropyl in concentrations of 70% and 91% is readily available in drug and grocery stores, but over time, 91% isopropyl dries out specimens and makes them quite brittle.

NETS

Nets are essential for capturing beetles on the wing, resting on vegetation, or living in aquatic habitats. Flying beetles are best caught with aerial nets with a rim diameter of 12 or 15 inches and a handle 3 feet long. The rim is usually reinforced with canvas or some other heavy material to prevent the net bag from tearing. The net bag is made of cotton bobbinet or some other soft and translucent material that will hold its shape and is long enough to easily fold over the rim to trap beetles inside. The tip of the bag is typically rounded, not pointed, so that beetles and other insects are easily removed after capture. These lightweight and durable nets are easily maneuvered when swung through the air. Aerial nets are also used to capture tiger beetles by clapping them over the beetle and then holding the tip of the net bag so that the beetle will climb up into the net. Heavy-duty aerial nets are available commercially and have a net bag that is half canvas and half mesh; these are used for light-duty sweeping through herbaceous vegetation.

Sweep nets are used to dislodge beetles from the tops of grasses, shrubs, and tree branches. They have shorter, thicker handles, sturdy net rings, and net bags constructed completely of canvas to endure repeated brushing through dense vegetation. Beetles are more likely captured in a sweep net if the rim is kept vertical to the ground. After completing a series of sweeps, swing the net back and forth several times and fold it over the rim to trap the insects inside toward the tip of the net bag. Slowly open the net to release stinging bees and wasps before removing beetles inside by hand, with forceps, or with an aspirator and transferring them to a killing jar.

Aquarium nets are useful for capturing aquatic beetles swimming along the edges of ponds and slow-moving streams. Long-handled dip nets are helpful for scooping beetles swimming in open water further out. D-frame nets have rims that are flat on one side and are dragged along the bottom of standing and moving waters to dislodge specimens resting on rocks and plants. Each of these nets placed vertically on the substrate in moving waters will capture beetles dislodged by lifting stones or disturbing vegetation upstream.

BEATING SHEET

Beating the branches and foliage of trees and shrubs is an incredibly productive method for collecting beetles. Beating

Figure 42. Author beating vegetation at night with headlamp and aspirator.

sheets (Fig. 42) are typically square sheets of light-colored canvas or ripstop nylon stretched out with two hardwood dowels or plastic tubes as crosspieces, with their ends slipped into reinforced pockets sewn into each corner of the sheet. To collect beetles, place the sheet beneath the foliage and then strike a large branch directly above with another dowel or net handle. Beetles and other insects and arthropods jarred loose from their perches fall onto the sheet where they are collected using forceps or an aspirator. Beating is most productive in the cooler morning or evening hours in spring and summer. During the heat of the day, beetles will usually take flight the moment they hit the sheet.

SIEVING

Beetles are extracted from ground litter, fungi, lichens, mosses, soil, and decaying wood samples using various containers fitted with a screened bottom. The size of the mesh is determined by the size of beetles sought. Place the substrate in the container, shake it gently over a white or light-colored pan, sheet, or shower curtain, and collect the beetles with forceps, aspirator, or camel-hair brush. Kitchen strainers work well for sifting beach sand and other fine, dry soils. Beetles and larger pieces of debris retained in the screen are dumped onto a light-colored surface for further sorting, or placed in a Berlese or Tulgren funnel, or other separator.

Figure 43. Collapsible Berlese funnel for extracting small beetles and other arthropods from litter.

BERLESE FUNNELS AND SEPARATORS

The *Berlese* or *Tulgren funnel* (Fig. 43) uses the combination of light and heat from a low-wattage incandescent lightbulb to extract beetles from debris samples. Place a piece of coarse screen above the opening of the funnel to prevent debris from falling into the jar. Then fill the funnel with beach wrack, fungi, leaf litter, rotten wood, and other plant debris and place the light bulb above to drive beetles and other arthropod inhabitants downward into a glass jar half-filled with a 50-50 mixture of water and 70% isopropyl. The time required to extract all the beetles from a sample varies from hours to days and depends on the size and moisture content of the sample.

Separators known as *photoeclectors* or Winkler/Moczarski eclectors also extract beetles from organic samples but require no electricity to generate light or heat. Using a cloth sleeve open on both ends, attach a strong drawstring to each end. Affix a coarse screen sieve over the mouth of a one-quart canning jar half-filled with a 50-50 mixture of water and 70% ethanol or isopropyl. Attach the sleeve to the jar using the drawstring at one end of the bag. Fill the bag about halfway with a lightweight litter sample and tie off the top of the bag. Hang the photoeclector in a well-ventilated place where the material inside will air dry and drive the beetles down into the jar.

FLOATING

Another useful method for separating beetles from plant materials—particularly clumps of grass, but also fungi, bark, and dung—is to drop the materials into a bucket of water. Beetles and other insects will float to the surface, where they can be scooped up with a small kitchen strainer or collected by hand.

COLLECTING AT LIGHTS

The most productive method of collecting beetles at night involves attracting them with a light suspended in front of or over a white sheet or cloth shower curtain. Almost any light will attract night-flying beetles, but ultraviolet light, or black light (Fig. 44) is the most effective. Commercially available black lights operate on house current or 12-volt batteries. Mercury vapor lights using 175-watt bulbs are also very attractive to beetles and other night-flying insects and require house current or a generator to operate. Note that these bulbs will become extremely hot and break should they come into contact with rain or other sources of moisture. Suspend a freshly laundered sheet between two trees or poles over a ground sheet. Suspend the light

FAR LEFT: **Figure 44. Blacklight sheet for attracting nocturnal beetles and other insects.**

LEFT: **Figure 45. 12-volt blacklight bucket trap.**

BELOW: **Figure 46. Pitfall array.**

about a foot away and parallel to the upright sheet at about eye level to achieve maximum illumination. Be sure to regularly patrol the ground and nearby shrubs just beyond the illuminated area with a headlamp to free both your hands for collecting beetles crawling on the ground or wandering about plants, trees, stumps, and logs. Spring and summer nights that are warm (65 °F or higher), especially with little or no moon, are the most productive. The bulk of species will come in within 2 hours of sunset, but other beetles, especially large species, fly later in the evening. Light traps (Fig. 45) use a black light suspended over a funnel placed on a 3- or 5-gallon bucket. Acrylic or metal vanes help to direct beetles and other insects down the funnel and into the bucket. By supplying the bucket with plenty of wadded-up paper towels, you can reduce the wear and tear on beetles and other insects caught in the trap.

TRAPPING BEETLES

Methods for trapping beetles, with or without the use of baits, lures, lights, and other attractants, are just as diverse as the beetles themselves. The performance of these traps is dependent on season, local conditions, and trap site. Pitfall traps are designed to capture beetles crawling on the ground. Using a trowel or small shovel, dig a small hole just large enough to accommodate a 16-ounce plastic deli or drink cup. Place the cup in the hole so the rim is flush with the surface of the ground. Then place an identical cup within the first cup. Nesting the cups in this fashion allows easy inspection of the trap without having to redig the hole at every visit. Cover the trap with a flat stone or slab of wood raised on small stones, leaving a space large enough for beetles but small enough to keep out larger animals. Place unbaited pitfall traps along natural barriers, such as rock ledges and logs. Wood, metal, or plastic drift fences, will also increase the effective surface area for each trap (Fig. 46). Pitfalls baited with small amounts of fresh dung, carrion, rotting fruit, or chopped mushrooms will attract and capture beetles over a large surface area without the aid of physical obstacles. Solid and liquid baits are wrapped in cheesecloth or placed in small plastic sauce cups, respectively, and suspended over the trap opening with sticks, wires, or string (Fig. 47). Liquid baits consisting of equal parts molasses and water, or malt with a pinch of yeast, will attract species naturally drawn to sap flows. For traps that are checked daily, place crumpled paper towels or leaves at the bottom of each trap to provide beetles with a bit of cover. Pitfalls left out for a week or more should be supplied with a preservative to prevent struggling beetles from damaging each other and decomposing shortly after they die. Add an inch or two of a 50-50 mix of propylene glycol and water to kill and preserve beetles. Unlike ethylene glycol (antifreeze), propylene glycol is not toxic to wildlife.

Fruit traps (Fig. 48) made from plastic drink bottles or cups and hung at various heights in trees and shrubs are very attractive to beetles. Be sure to check these traps regularly and provide a rain guard of some sort to prevent specimens from being washed out of the trap. Pan traps (Fig. 49) consisting of shallow plastic bowls, especially bright yellow ones, filled with an inch or two of water, are especially attractive to some jewel beetles (Buprestidae), tumbling flower beetles (Mordellidae), and other flower-visiting insect species. A drop or two of dish soap added to the water will break the surface tension, making it harder for the beetles to escape.

Flight intercept traps (Fig. 50) are extremely useful for sampling small, crepuscular beetles that are seldom attracted to light. They comprise a dark mesh nylon screen suspended between two poles or trees and are placed across a trail, next to a log, or in a field. A shallow trough or a series of roasting pans containing soapy water or propylene glycol are laid end to end directly below the screen. Beetles flying into the screen will fall down into the fluid, where they are killed and temporarily preserved. A plastic roof placed over the top of the screen will prevent rainwater from diluting the fluid. A Malaise trap (Fig. 51) is

LEFT: **Figure 47. Pitfall trap of soapy water baited with feces on a stick.**

RIGHT: **Figure 48. Fruit trap made from plastic soft drink bottle.**

BELOW LEFT: **Figure 49. Yellow pan trap filled with soapy water to attract flower-visiting and other beetles.**

BELOW RIGHT: **Figure 50. Flight intercept trap.**

essentially a tent with a wall or partition on the inside. Flying beetles strike the interior walls and fly up into a collecting jar filled with 70% ethanol or isopropyl alcohol. Shallow troughs or roasting pans filled with fluid are sometimes placed under the wall of the trap to capture specimens that drop to the ground rather than fly up into the collecting jar. This trap produces large numbers of diurnal and nocturnal species that are not readily collected via other methods. Several styles are available commercially and all are somewhat expensive.

Lindgren funnel traps (Fig. 52) consist of a series of four or more black funnels suspended over one another and hung from a branch, rope between two trees, or some other hanger. At the bottom of the funnels is a collecting container that is either dry or partially filled with propylene glycol or some other preservative. The stack of funnels resembles a tree trunk and is attractive to wood-boring beetles and other species that crawl or land on tree trunks. They are sometimes baited with chemicals that mimic those released by dead and dying conifers and hardwoods, such as turpentine and alcohol. Specimens in dry containers are best removed every few days.

ABOVE: **Figure 51. Malaise trap.**

LEFT: **Figure 52. Lindgren funnel trap.**

TEMPORARY STORAGE OF SPECIMENS

Beetles should be prepared immediately after they are collected, but this is not always possible. Specimens left in killing jars charged with adequate amounts of ethyl acetate will remain relaxed for several days or weeks and can be handled without damage. They can also be transferred to a tightly sealed container and stored in the freezer. For longer periods of storage, carefully place specimens between layers of paper towels moistened with a few drops of ethyl acetate or preserved by adding chlorocresol crystals and store in soft plastic storage boxes with airtight lids. Specimens stored in this manner will keep indefinitely, but delicate colors will fade and setae become matted. Large numbers of beetles collected from Berlese funnels, pitfalls, and blacklight traps can be placed in 70% ethanol or isopropyl alcohol. After about a week, replace the fluid with fresh alcohol. Always include basic collecting information (locality, date, collector) inside each container, using pencil or permanent ink on good quality acid-free paper. Samples without this information are of little value and should be discarded.

RECORDS AND FIELD NOTES

Always record the date, place, and collector's name for your specimens. Be sure to include the country, province or state, and county or parish, as well as the name of the nearest city or town, mileage and direction from the nearest road junction, latitude and longitude, and any other locality data that will help fix your collecting locality on a map. These data will become the basis for the locality labels for your specimens and serve as directions to others who may want to retrace your steps to find a specific locality to search for a particular beetle.

Dead beetles in collections reveal little of their lives, so it is important to spend some time observing their behaviors whenever possible and record them in your field notes. Your observations should always include time of day, temperature and humidity, plant or animal associations, and reproductive and feeding behaviors; such details are all worthy of note and could easily be new to science.

Whenever possible, record your observations in the field, as they are happening. Never trust your memory for long because it is all too easy to confuse bits of information in time and place. With practice, you will settle on a routine for noting and recording pertinent observations.

Maintaining a detailed and accurate field notebook is an important component of a carefully curated beetle collection, and the value of the notes is enhanced if they are clearly associated with specific specimens, especially those identified to species. Select a well-bound notebook with acid-free paper that is small enough to pack in your field kit, but large enough not to be easily lost or misplaced, and will withstand the rigors of field use. Fine-tip marking pens with permanent ink, such as the Pigma Micron available in art supply stores, or pencils are the most reliable for writing in all sorts of weather.

MAKING A BEETLE COLLECTION

There is still much to learn about the beetles living in eastern North America. Carefully prepared collections supported by accurate label data, field notes, and photographs will add enormously to our understanding of their seasonality, distribution, and food and habitat preferences, as well as provide a historical record that will offer insights into the possible impacts of climate change. If properly cared for, beetle collections will last hundreds of years to inspire and inform future generations of coleopterists and naturalists. Coleopterists—professionals and amateurs alike—are but temporary caretakers of collections that ultimately belong to the greater scientific community. Should you lose interest, lack adequate storage space, or simply want to preserve the legacy of your hard work long after you are gone, consider donating your collection and its associated records to an appropriate research institution dedicated to housing permanent insect collections and making them available to researchers and students. Below are some tips and tools for building and maintaining a scientifically valuable and aesthetically pleasing insect collection.

PINNING AND POINTING SPECIMENS

Dead, dried beetles are very brittle, and touching them will result in broken and lost appendages that will make their identification difficult, if not outright impossible. In order for specimens to be manipulated without damage, they must be mounted on pins that are safely used as handles. Always use black-enameled or stainless steel insect pins because sewing pins are too short and thick and will corrode. Insect pins are available through entomological supply houses in packets of 100 in several sizes (diameters). Sizes 0–3 are suitable for most of the species found in eastern North America. Sizes 00 and 000 bend easily and are not recommended for mounting beetles.

Pin beetle specimens when their appendages are still pliable enough to manipulate without damage. Working only with beetles collected at the same place and time, temporarily place your specimens on a folded tissue or paper towel for several minutes to absorb excess moisture. After selecting the appropriate-size pin, grasp your specimen firmly between the thumb and forefinger or brace it on the table with its topside up. With your other hand, push the pin through the base of the right elytron so that it will exit underneath between the middle and hind legs. Before driving the pin all the way through, check relative alignment of the specimen carefully to make sure that the

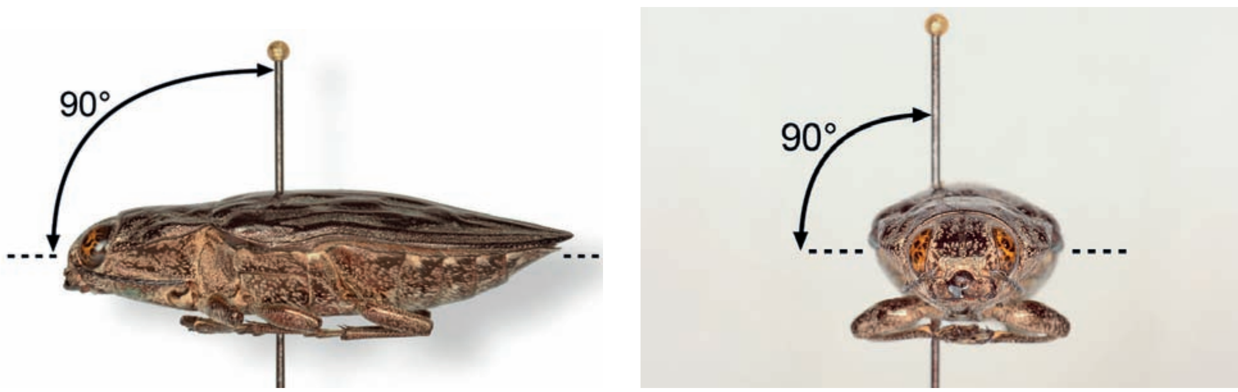


Figure 53. Proper longitudinal and transverse orientation of a beetle specimen on pin.

Figure 54. Pinning block.

shaft of the pin is perpendicular to the long and transverse axes of the body (Figs. 53a–b). Once the pin is all the way through, use the highest or shortest step of your pinning block to adjust the height of the beetle on the pin so about a quarter-inch space is left between the top of the specimen and the head of the pin. A pinning block (Fig. 54) is a small block of hardwood with three or four fine holes drilled successively deeper in quarter-inch increments, beginning with one-quarter inch. Using this simple tool will enable you to consistently space the head of the pin above the specimen and the intervals between the specimen and its labels underneath.

Figure 55. Proper longitudinal and transverse orientation of a beetle specimen on a point.

Specimens that are 5 mm or less or very narrow and likely to be damaged by direct pinning are best preserved on points (Fig. 55). Points are isosceles triangles of acid-free cardstock that are about 7 mm long and 2 mm wide at the base. The occasional point can be cut with sharp scissors, but a point punch, available from entomological supply houses, is desirable for making large numbers of uniform points. Push an insect pin (no. 2 or 3) through the broad end of the point and adjust its height on the shaft using the highest step on your pinning block. Using fine-tipped forceps, slightly bend down the tip of the point before attaching it to the specimen. For the sake of convenience, prepare several dozen points in advance to have them ready. Affixing a beetle to a point is best done under well-illuminated magnification provided by an optical visor or binocular dissecting microscope. Place the specimen to be pointed on its back (dorsum) or underside (ventrum) on a smooth, light-colored surface so the head is to the right and you have unfettered access to the beetle's right-hand side. Then dip the tip of the point into adhesive that is soluble in water (e.g., Elmer's blue gel) or alcohol (shellac, polyvinyl acetate) and affix it to the area of the thorax between the middle and hind legs. Be sure that there is enough glue to securely attach the specimen to the point, but not so much that it spreads and obscures important features needed for identification. Alcohol-soluble adhesives normally thicken with use and can be thinned by adding a bit more alcohol. If too thin, leave the container open for a brief period to allow excess alcohol to volatilize. Once the beetle is glued to the point, minor adjustments can be made so that its body axes are perpendicular to the shaft of the pin.

SPREADING SPECIMENS

Accurate species identification in beetles often requires careful examination of a specimen's appendages, mouthparts, body segments, and genitalia. Familiarity with these features will help to guide and improve your efforts to properly prepare and spread specimens. A spreading board (Fig. 56) is the best way to position and set a beetle's antennae and legs in place. Purchase a small sheet (no more than 12 × 18 inches) of polystyrene foam 1 inch thick (30 × 46 × 2.5 cm) from a craft store and wrap it in newsprint to prevent claws and mouthparts of dried specimens from catching on the board's rough surface and breaking off. Start by pinning a temporary locality label in the upper left corner of the spreading board. To the right of the label, push the first pinned beetle into the spreading board so the underside of the body rests directly on the board's surface. Carefully position the legs and antennae

Figure 56. Spreading board with beetle specimens.

with brace pins so that these structures are symmetrical and observable from all angles. Tuck in legs and antennae, since specimens with outstretched appendages take up valuable space and are likely to be broken. Be sure to keep spread specimens from each locality separate so they can be accurately labeled when they are dry. It may take a week or so for specimens to dry, depending on the size of the specimen and relative humidity. You may want to keep your spreading boards in a protected yet airy space, such as in a covered box, in a cupboard, or on shelves with doors so that your specimens don't get dusty. Once the specimen is dried, carefully remove the brace pins to avoid damaging the now brittle appendages.

LABELING

To be of any scientific value, each and every specimen must have a permanent, carefully composed, and neatly produced locality label. Laser printers set to print at 1200 dpi or 600 dpi professional using a bold sans serif font (Arial, Geneva, Helvetica) of 4 or 5 point size on acid-free 65 lb. (176 g/m^2) card stock give good results. Each finished label should be no more than 0.8 inches across and five lines long, although some adjustments may be required depending on the length and the nature of the data. Cut the labels into strips and then individually with sharp scissors so that all four sides are neatly trimmed right up to the text.

Locality labels should include the following information on the first line: country (abbreviated as USA or CAN), state or province (e.g., VA for Virginia, ON for Ontario), and county or parish. The remaining four or five lines of the label includes the general locality, specific locality (if applicable), elevation (in feet [′], or meters [m]), latitude and longitude (in degrees, minutes, and seconds or decimal degrees), date (with month spelled out, or as a Roman numeral [ex., vii for July] and full year), collector(s) name, and collecting method. A sample locality label is shown below:

USA: VA, Charles City Co.
VCU Rice Center, elev. 45′
N37.32605° W077.20593°
4 July 2014
A.V. Evans, under pine bark

An additional label may be added to more fully flesh out the method of collection, host plant data, other ecological data, and a cross-reference number that connects the specimen to photographs and field notes. Once the beetle is identified to species, a determination label containing the species name, name of determiner, and year of determination (as shown below) can be added as the very last label:

Dynastes
tityus
(Linnaeus, 1767)
det. A.V. Evans, 2014

Align the pinned specimen and its label so the beetle's head is directed toward the label's left margin. Center the specimen over the label and push the pin part way through. Select the appropriate step on the pinning block to adjust the height of the label on the pin. When labeling pointed specimens, both the beetle and the point are centered over the label with the point directed toward the label's left margin and the beetle's head off to the right of the point.

RELAXING SPECIMENS

To prepare dried specimens, or to reposition appendages or dissect those already mounted, specimens must first be "relaxed." Beetles that are not delicately patterned or colored, or those lacking any kind of setose or waxy vestiture that could become matted, discolored, or dissolved are placed directly in hot water. Simply bring filtered or distilled water to a boil and then add a drop of dish soap as a wetting agent. After several minutes, specimens submerged in this solution should become pliable enough to manipulate safely; larger and bulkier specimens may take longer. Another method is to use a relaxing chamber. Place a layer of clean sand, cardboard, blotter paper, or some other relatively sterile and porous substrate in a soft (polyethylene) plastic shoe box or food storage container. Saturate the substrate with warm water and pour off the excess. Place dry specimens in a plastic jar lid so they will not come into direct contact with wet surfaces. Add a couple of mothballs to the chamber to discourage mold. Smaller beetles with more delicate bodies will become sufficiently relaxed overnight, but larger, heavier-bodied specimens may take several days to soften. Inspect the chamber every few days for mold that will damage or destroy specimens. Insect pins that corrode in a relaxing chamber should be replaced.

PRESERVING LARVAE AND PUPAE

Larvae and pupae, especially those with ecological data and positively associated with adult voucher specimens, are extremely valuable and should be permanently preserved. Place them in boiling water to fix their tissues and kill the microorganisms that will hasten tissue decay. Then place them directly in 70% ethanol or isopropyl alcohol. After a day or so, place these specimens (one species per collection) in glass vials with screw caps or neoprene stoppers supplied with a fresh supply of alcohol for permanent storage. Each vial must have its own label inside to be of any scientific value. Long shelf life for wet labels can be problematic because of the effects of preservatives on various papers, ink, and laser-printed text and is still undergoing study. For now, the simplest solution is to use acid-free 100% rag paper with pencil or to print laser labels at 1200 dpi or 600 dpi professional. Before cutting the sheet into individual labels, coat it with clear acrylic spray sealer to increase its durability. Those interested in building and maintaining extensive collections of beetle larvae and pupae would do well to keep up with published literature and LISTSERV discussions on the latest materials and techniques.

COLLECTION STORAGE

Sturdy, airtight specimen boxes with tight-fitting lids are a must for the permanent storage of beetle specimens. Dermestids, both larvae and adults, and booklice (Psocodea) can slip through the narrowest of spaces and, in a relatively short period of time, reduce pinned beetle collections to dust. Fluctuating temperatures, humidity, and sunlight will also destroy collections over time, so it is important to store them in dark and temperature-controlled spaces.

Storing specimens in tightly sealed glass-topped drawers that are kept in sealed cabinets is the best hedge against light and pest damage, but these systems are expensive. Wooden specimen boxes with tight-fitting lids, known as Schmitt or Schmitt-type boxes, also provide adequate protection for specimens, but are also expensive. Entomology departments at museums or universities occasionally offer surplus drawers and boxes at reasonable prices. A relatively inexpensive system consists of

Figure 57. Beetle collections are stored in cardboard specimen boxes or glass-topped drawers supplied with unit trays.

commercially available cardboard specimen boxes with separate lids and foam bottoms that are slipped into 2-gallon resealable plastic bags to keep out pests (Fig. 57).

None of these systems is completely effective, especially if beetles are left out on spreading boards or open trays and become infested with the eggs or larvae of pests and are then introduced into otherwise pest-proof containers. Constant vigilance for fine powder accumulating beneath specimens is essential for identifying those infested with booklice or dermestid larvae. Remove these specimens immediately, take their labels off the pin, and immerse them in alcohol for at least one day. If several specimens within the same box are affected, place the entire box in a very cold freezer for at least a week. This process may need to be repeated, as freezing will usually kill all the dermestid larvae present but may leave eggs unaffected.

CURATING YOUR COLLECTION

Align your specimens in neat columns and rows using either the label or specimen itself as a guide to create neat, straight rows. Orient each specimen so that the head of the pinned beetle or the tip of the point is directed toward the top of the box. Avoid entangling legs and antennae by not overcrowding specimens. Organize your collection first by family and subfamily, then by tribe, genus, and species. A good reference collection not only contains well-prepared specimens accompanied by accurate label data, but also is organized to facilitate the easy retrieval of specimens and data. As your collection grows in size and diversity, you might consider adopting a glass-topped drawer system housed in cabinets. These drawers are supplied with interchangeable cardboard unit trays of various sizes lined with polyethylene foam bottoms called unit trays. Unit tray systems simplify curation and are easily expanded to accommodate the addition of new taxa and specimens. Glass-topped drawers with pinned beetles intended primarily for display must be kept dry and away from extreme temperatures to avoid the growth of mold, and out of direct sunlight to prevent fading. Display cases fitted with UV-filtered Plexiglas will slow, but not prevent, the fading of specimens exposed to sunlight.

KEEPING AND REARING BEETLES IN CAPTIVITY

Live beetles kept at home, in a classroom, or in a laboratory provide numerous opportunities to observe and photograph beetles as they undergo basic life processes. They require little space and are easy to display and maintain. In young students, caring for beetles instills a basic sense of awareness of the natural world by bringing into sharp focus the basic environmental and nutritional needs of organisms. For older students, captive beetles provide opportunities to engage in directed and open inquiry investigations into their behavior. Although few species of live beetles are sold commercially in North America, an amazing diversity of native species is available in nearby vacant lots, parks, and natural areas. Transporting live beetles may be regulated within counties, states, and provinces, and is strictly regulated across state, provincial, and international borders (see Beetle Conservation and the Ethics of Collecting).

TRANSPORT FROM THE FIELD

When transporting live beetles from the field, it is important to remember that even the briefest exposure to direct sunlight or the temperatures inside a closed car at the height of summer will quickly kill them, especially those species adapted to cool or moist habitats. Half- or 1-pint deli cups or similar resealable plastic food containers (Fig. 58) are perfect for transporting beetles so they arrive alive and unharmed. They are inexpensive, lightweight, unbreakable, and easily nested for packing. Before placing beetles in the container, supply it with a piece of paper towel, some leaf litter, or a piece of moss and slightly moisten this substrate with water to provide your animals with a bit of comfort and protect them from the rigors of travel. Always use moistened paper towels or moss when transporting aquatic beetles. Placing them in even small amounts of water for short periods may lead to their death by drowning. Then put the containers in an ice chest supplied with one or more frozen water bottles to keep them cool in transit. As long as the beetles are kept cool and not crowded in their containers, it is not necessary to punch air holes in the lids of their containers, especially for day trips.

Figure 58. Plastic food containers are perfect for transporting live beetles.

HOUSING FOR ADULT TERRESTRIAL BEETLES

Keeping beetles in captivity requires some knowledge of their food and moisture requirements so that these conditions can be duplicated in captivity. Supply at least 1 inch (25 mm) of a 50-50 mixture of sterile sand and potting or forest soil on the bottom of an appropriately sized terrarium or deep plastic food container. Based on your observations of the beetles in the field, add rocks, bark, chunks of moss, or dried leaves for shelter, and branches and twigs for climbing. Beetles don't require a lot of air, but they do require good ventilation to release heat and control humidity. A secure screened lid attached with binder clips will not only prevent the escape of your animals but also provide plenty of ventilation to minimize the growth of harmful mold and fungi. Regularly mist the enclosure with distilled or filtered water and install a vial of water plugged with cotton and placed on its side. The cotton enables beetles to drink from the vial and also acts as a wick that allows moisture to evaporate from the vial into the enclosure to help maintain humidity.

Offer predatory species appropriately sized adult and immature insects as food. Remember that the feeder insects must spend most of their time where they will be found by your beetles. Climbing and flying species are likely to be missed by mostly ground-dwelling predators. Provide plant feeders with fresh cuttings of their host plants placed in small jars or vials of water to maintain freshness as long as possible. Stuffing cotton into the top of the jar to hold the plants in place will prevent beetles from crawling or falling inside and drowning. Some phytophagous species will accept romaine lettuce or other leafy greens, oatmeal, potato slices, and various kinds of fruit. Always remove uneaten plant and animal foods after a day or two to prevent the buildup of mold, mites, and other pests.

Bess beetles (*Odontotaenius disjunctus*), green June beetles (*Cotinis nitida*), eastern Hercules beetles (*Dynastes tityus*), caterpillar hunters (*Calosoma* species), and tiger beetles (*Cicindela*, etc.) are all relatively large and hardy species that do well in captivity. Bess beetles are kept in well-ventilated containers (Fig. 59) supplied with moist but not wet chunks of decaying wood to provide them with both food and shelter. Green June beetles thrive in a terrarium supplied with several inches of sandy loam, branches to climb, and a variety of soft fruits (peaches, grapes, strawberries, bananas, etc.) to eat. They will mate and lay eggs readily in their enclosure. The C-shaped grubs will develop in a deep, organic substrate supplied with a mixture of leaf litter, grass clippings, and crushed dry dog food. Eastern Hercules beetles (*Dynastes tityus*) are kept in similar enclosures with thicker branches for climbing and will also eat soft fruits, especially peaches and bananas. They will accept cotton balls or sponges soaked in a 50-50 solution of water and real maple syrup as food. Several caterpillar hunters can be kept together in an open terrarium supplied with branches to climb and plenty of prey. They prefer to eat caterpillars, but will accept commercially available crickets and mealworms. Tiger beetles will do well in a terrarium filled with several inches of clean sand. Keep one corner of the terrarium moist and cover the entire enclosure with a lid fitted with a 40-watt aquarium bulb to supply heat and light. A rock or piece of wood will give them something to burrow under, if they so choose. They will accept a variety of live insects every other day, as long as the prey items are no larger than the beetles themselves.

Figure 59. Keep bess beetles in well-ventilated containers supplied with moist chunks of wood.

SETTING UP AN AQUARIUM

Aquatic beetles are relatively easy to keep in an aquarium and will provide hours of great beetle watching and photography. A light hood on the aquarium is essential for illuminating your beetles and preventing their escape. Although several filtration systems are available, under-gravel filter systems are particularly easy to maintain for beginners. After assembling and installing the under-gravel filter plate and snapping the clear filter stack pipes in place, place 1 or 2 inches of sealed aquarium gravel on the filter plate. Then half-fill the tank with distilled or filtered water, or tap water that has been allowed to stand in a clean bucket for 24 hours. Add artificial or real plants and some larger rocks, and then top off the water level of the tank. Branches and aquatic vegetation added to the tank may be attractive, but they are likely to introduce unwanted algae to your aquarium.

Whirligigs (Gyrinidae) and predaceous diving beetles (Dytiscidae) will eat living or frozen crickets placed on the surface of the water. Mosquito and mayfly larvae are excellent sources of wild insect food, if they are sufficiently available on a regular basis. Hungry predators and scavengers alike readily accept bits of raw meat, fish, and shellfish, but these items will quickly foul the water, requiring frequent water and filter cartridge changes. Water scavenger beetles (Hydrophilidae) will also devour bits of romaine lettuce or aquatic plants. Living aquarium plants or submerged rocks covered with algae will provide food for most herbivorous beetles (Elmidae, Dryopidae), but the presence of algae will require greater vigilance to keep the aquarium clean.

KEEPING BEETLE LARVAE

Unlike butterfly and moth collectors who dedicate much of their time to searching for and rearing caterpillars, coleopterists seldom collect and keep beetle larvae in captivity, partly because of their varied and often specialized feeding requirements, secretive habits, and extended periods of time needed to reach adulthood; however, taking the trouble to rear beetle larvae leads to a better understanding of their biology and is a way of securing adults of species that are otherwise difficult to obtain. The challenge of rearing beetle larvae is in recognizing and duplicating natural conditions in captivity, and maintaining optimal conditions and food quality for the duration of larval and pupal development. Too little moisture results in dehydration that hampers hatching, molting, and pupation, while excess moisture often leads to fatal fungal infections or drowning. Eggs, larvae, pupae, and teneral adults should be handled as little as possible and with great care by using featherweight forceps to avoid inflicting injury.

REARING GROUND-DWELLING BEETLES

Place mating pairs or gravid females of predatory ground beetles (Carabidae) and rove beetles (Staphylinidae) in small transparent plastic containers with airtight lids supplied with about a quarter inch (1 cm) of moist soil consisting of sand, loam, forest soil rich in organics, or peat moss. The substrate should be moist enough to remain compacted when squeezed, but without dripping water. To prevent these carnivorous beetles from eating their own eggs, keep their appetites sated with chopped mealworms. Females usually begin laying eggs right away and are removed immediately, or left in the container until the eggs hatch. Place the eggs and young larvae in their own containers to avoid cannibalism. The containers should be kept cool, about 68 °F (20 °C). Check for and remove dead eggs and larvae immediately, especially those attacked by fungi, to avoid spreading infections. Uneaten food should also be removed every other day to limit fungal growth and the proliferation of mites. Species that undergo winter diapause may require an extended cold period to complete their development.

REARING AQUATIC LARVAE

Predaceous diving beetles (Dytiscidae), whirligigs (Gyrinidae), and water scavenger beetles (Hydrophilidae) generally lay their eggs on the water's surface or on submerged rocks or vegetation. Their larvae are predatory and require a steady supply of live insect food to complete their development. You can collect feeder insects from natural habitats, or can purchase mealworms and flightless fruit flies from dealers or pet shops. Be sure to remove uneaten food to avoid fouling the water. The mature larvae leave the water to pupate in relatively dry subterranean chambers or other protected places just beyond the shoreline. Successful rearing of these beetles requires removing mature larvae and placing them in a container with moist soil, or providing them with the means for crawling out of the tank and into a moist but not wet substrate covered with chunks of wood or moss.

REARING LARVAE FROM STEMS

Some species of tumbling flower beetles (Mordellidae) are reared from larvae developing in pithy stems. Identify plants in late summer while they still have leaves and flowers, then return to the site in late winter and early spring to select large, upright stems and cut them off at ground level. Cut the stems into sections (Fig. 60) and place them in 2-gallon resealable bags. To maintain the stems under reasonably natural conditions, place the bags outdoors in a protected area that is exposed to ambient temperatures, but not direct sunlight. Add a few drops of water to avoid dehydration, or open the bags to dry out samples showing signs of condensation or mold.

Figure 60. Mordellids are reared from pithy galls and stems.

REARING LARVAE FOUND UNDER BARK

The larvae and pupae of several beetle families (Lycidae, Elateridae, Pythidae, Tenebrionidae, Stenotrachelidae) found under loose bark on snags, stumps, and logs are often more commonly encountered than the adults. One method of rearing these larvae is to place them in a covered petri dish containing a small amount of the substrate in which they were collected. Another method involves using glass vials, each filled with approximately a quarter inch (1 cm) of compact, moist paper towel covered with a quarter inch of loose substrate found under the bark from which the larvae were collected. The size of the vials and type of tree material can be altered depending on species. The tops of the vials are either left open or loosely plugged with crumpled paper towel and kept upright in a lidded box at room temperature. Both the paper toweling and natural substrate not only serve as food, but also help to regulate the moisture content of each vial. Many species require cold before completing their development. These vials are stored in a box and placed in a plastic bag punched with holes and set outside in the fall for exposure to cold winter temperatures. In spring, the larvae are brought back indoors to complete their life cycle. Because the larvae are kept individually, accurate notes can be kept regarding their behavior and length of life cycle with minimal disturbance during examination.

REARING LARVAE FROM WOODY FUNGI AND DECAYING WOOD

Late winter and early spring are good times to gather woody fungi, dead limbs, and rotten logs and stumps containing pupae or mature larvae preparing to pupate. Plastic food containers with resealable lids are practical and inexpensive rearing chambers. Cheesecloth or window screen stretched over the tops of these containers and secured with heavy rubber bands allows excess moisture to escape, but requires a bit more vigilance to avoid dehydration, especially in air-conditioned and heated environments. Keep containers away from outside doors, windows, and heating and cooling ducts to avoid exposing your animals to extreme temperatures. Depending on species, consistently warm indoor temperatures may accelerate or hinder their development.

For larger rearing operations, place dead limbs in large, sturdy black or blue plastic storage or filing bins with snap-on lids; clear plastic boxes can be wrapped with black garbage bags to keep out light. Make sure these containers have tight-fitting lids or wrap them in plastic to prevent emerging beetles from escaping. Cut a hole in the end of each container and screw in the neck of a small jar or vial so the bulk of the jar is on the outside. Beetles emerging from the rearing materials inside are drawn to the light and find their way into the jar where they are easily seen and collected. Adding a bit of water to the rearing material from time to time will prevent it from completely drying out. Keeping rearing chambers indoors is likely to speed up the emergence of some beetles, but it may delay those that require a period of cold temperatures to complete their development. Accurate records of host plants and parasitoids are important contributions to beetle study, especially for species with poorly understood or unknown biologies.

TAKING AN ACTIVE ROLE IN BEETLE RESEARCH

The natural history notes that appear in peer-reviewed journals, newsletters, and coleopterological LISTSERVs are not only written by professional biologists, but also contributed by observant students and naturalists who keep meticulous notes. Although the beetles making up the fauna of eastern North America are relatively well known taxonomically, there is still much to be learned about various aspects of their lives, including reproduction and development, food preferences and foraging behavior, adult and larval habitat selection, seasonality, number of generations produced annually, and distribution. The bold and distinctive color patterns of some adults have been noted for decades, but little experimental work has been carried out to determine how potential predators of beetles perceive these colors. Geographic variation within beetle populations is poorly documented in most families. Behavioral, ecological, and distributional data gleaned from carefully executed beetle surveys and mark-recapture studies, especially those conducted over a period of several successive years on school grounds, parks, vacant lots, or nearby woods can be of considerable value. Coordinating such efforts through citizen science organizations or with researchers at universities and natural history museums will facilitate the inclusion of these data into ongoing scientific research.

Traditionally, the study of larvae and of adults have been treated as separate endeavors, but more and more coleopterists today have come to embrace the value of studying both the adult and immature stages simultaneously, especially when studying their evolutionary relationships. Students and naturalists with a knack for rearing beetle larvae associated with reliably identified adults can make enormously important contributions to our understanding of the development of beetles and their evolutionary relationships.

A bioblitz is a very popular and expedient way of gathering beetle and other invertebrate data for national and state forests, parks, and other natural areas that lack this information. Because of their short duration, the findings of these intensive one-day surveys are unduly influenced by season, lunar cycle, local weather conditions, and personnel available to gather samples. As such, these events provide only a snapshot of beetle diversity and thus are not substitutes for well-managed, long-term monitoring efforts. Still, bioblitzes do generate useful species lists that support effective natural resource management and suggest avenues for sustained research programs and conservation measures in the future. These events also provide opportunities for students and naturalists to meet professional biologists and work with them in the field.

It is hoped that books such as this and other regional identification manuals will increase general interest in beetles and inspire citizen scientists, students, and naturalists to take up the cause of their study and conservation.

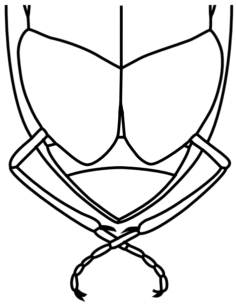
ILLUSTRATED KEY TO THE COMMON BEETLE FAMILIES OF EASTERN NORTH AMERICA

This key is intended to serve only as a “quick guide” to the most commonly encountered families (**bold** type), while less common families are suggested within square brackets in plain type. As such, the key includes only 68 of the 115 families known to occur in eastern North America. It should be used in combination with the “Similar families” sections included in each family diagnosis for proper family placement. For detailed keys, see *American Beetles* (Arnett and Thomas 2001; Arnett et al. 2002).

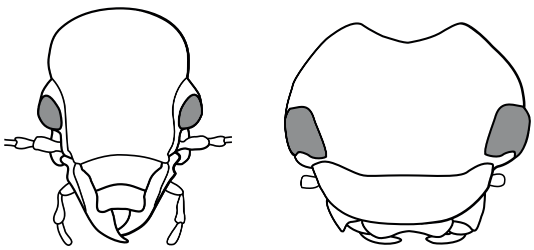
1. Metacoxae may or may not be enlarged, basal half of hind femora and ventrites clearly visible .... **GO TO 2**

1'. Metacoxae greatly enlarged to conceal basal half of legs and most of first three ventrites:

Haliplidae (p.96)

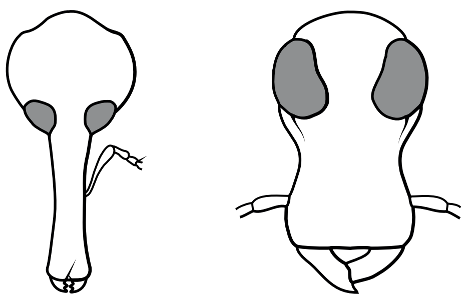


2. Head without rostrum .... **GO TO 3**



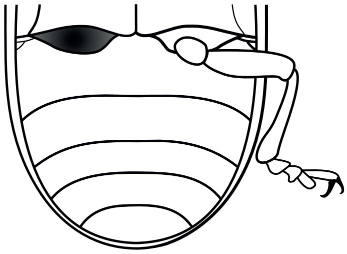
2'. Head with distinctly long or broad rostrum:

Curculionidae (p.469); Anthribidae (p.458); Brentidae (p.466)
[see also Nemonychidae (p.457); Belidae (p.462); Attelabidae (p.462)]



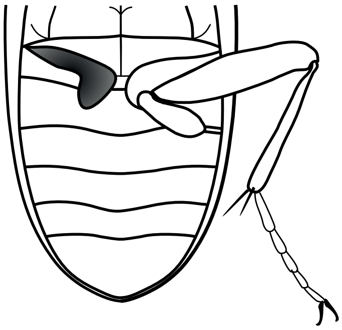
ILLUSTRATED KEY TO THE COMMON BEETLE FAMILIES OF EASTERN NORTH AMERICA (*CONTINUED*)

3. Hind coxae not immovably fused to metathorax and not dividing the first ventrite .... **GO TO 4**



3'. Hind coxae fused to metathorax and dividing the first ventrite:

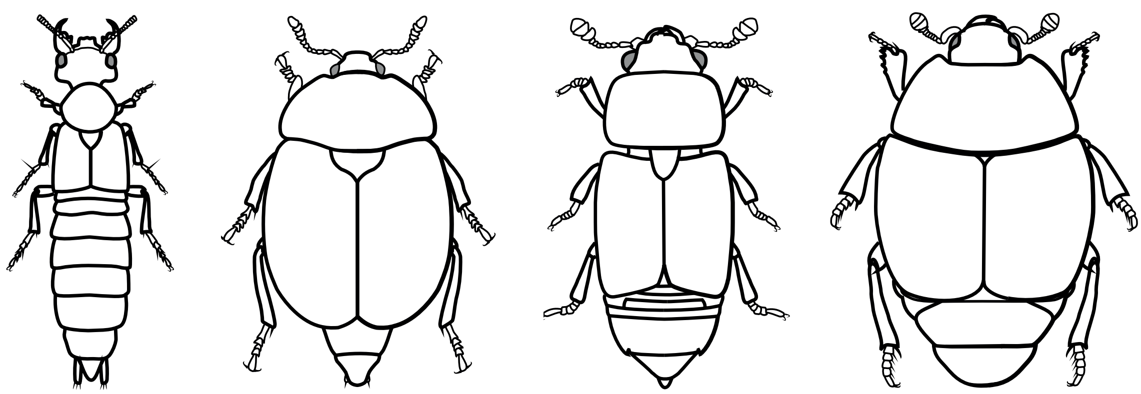
Carabidae (p.63); Dytiscidae (p.99); Gyrinidae (p.94) [see also Noteridae (p.97)]



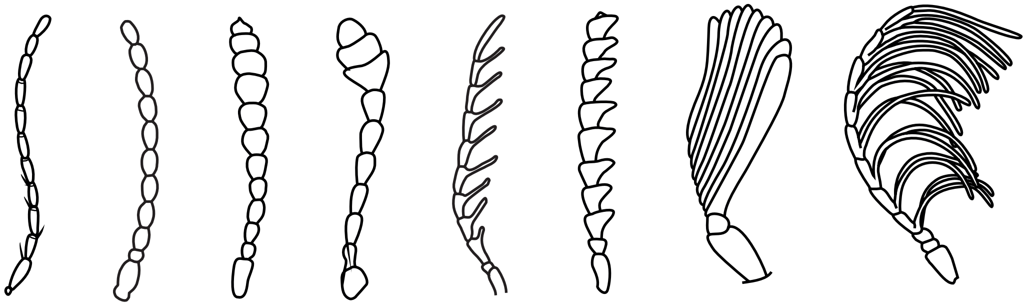
4. Elytra long, covering all or nearly all of the abdomen .... **GO TO 5**

4'. Elytra short, exposing two or more terga:

Staphylinidae (p.124); Silphidae (p.120); Histeridae (p.110); Nitidulidae (p.295); Mordellidae (p.333) [see also Buprestidae (p.184); Phengodidae (p.233); Cantharidae (p.238); Ripiphoridae (p.338); Cerambycidae (p.388)]

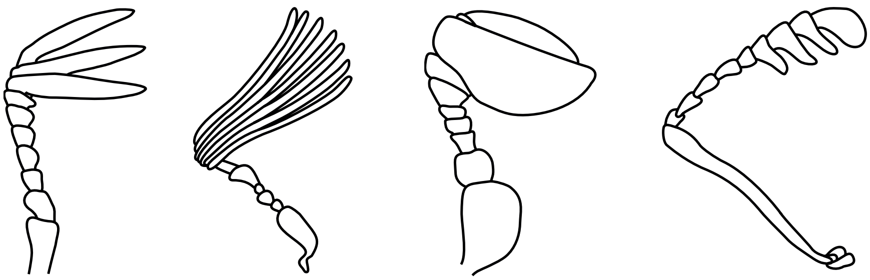


5. Antennae not lamellate .... **GO TO 6**



5'. Antennae lamellate with apical three to seven antennomeres forming club:

Scarabaeidae (p.156)
[see also Lucanidae (p.142); Passalidae (p.145); Glaresidae (p.146); Trogidae (p.147); Geotrupidae (p.149); Ochodaeidae (p.152); Hybosoridae (p.153); Glaphyridae (p.155)]

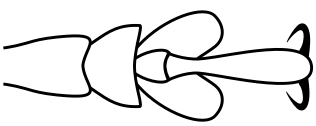


6. Tarsal formula not 5-5-4 .... **GO TO 7**
6'. Tarsal formula 5-5-4:

Tenebrionidae (p.344); Melandryidae (p.329); Synchroidae (p.359); Meloidae (p.365)
[see also Mycetophagidae (p.323); Tetratomidae (p.327); Mordellidae (p.333); Ripiphoridae (p.338); Zopheridae (p.340); Stenotrachelidae (p.360); Oedemeridae (p.362); Pyrochroidae (p.373); Anthicidae (p.377); Aderidae (p.382); Scraptiidae (p.384)]

7. Tarsal formula variable; maxillary palps long, usually conspicuous; antennae variable, not more than half the length of the body .... **GO TO 8**
7'. Tarsal formula often appears 4-4-4, actually 5-5-5 with small fourth tarsomere surrounded by bilobed third tarsomere, or distinctly 5-5-5; maxillary palps short, often not conspicuous; antennae never clubbed and more than or less than half the length of body:

Cerambycidae (p.388); Chrysomelidae (p.429)
[see also Megalopodidae (p.428); Orsodacnidae (p.429)]

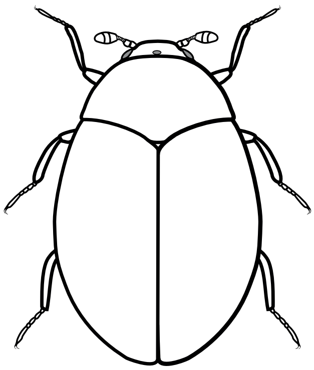


ILLUSTRATED KEY TO THE COMMON BEETLE FAMILIES OF EASTERN NORTH AMERICA (*CONTINUED*)

8. Body with scattered setae or scales, if present at all; head without ocelli .... **GO TO 9**

8'. Body densely covered with setae or scales; head often with one ocellus

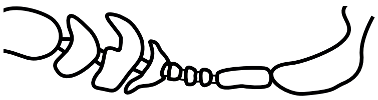
Dermestidae (p.246)



9. Antennae not clubbed or club not velvety; maxillary palps much shorter than antennae; legs not modified for swimming .... **GO TO 10**

9'. Antennae with antennomeres 7–9 forming loose, velvety club; maxillary palps long, always half the length of antennae, usually as long or longer; legs often fringed with setae, modified for swimming:

Hydrophilidae (p.105)



10. Elytra hard and shell-like .... **GO TO 11**

10'. Elytra soft and leathery:

Cantharidae (p.238); Lampyridae (p.234); Lycidae (p.229)
[see also Omethidae (p.237); Melyridae (p.271)]

11. Ventrites variable, never iridescent or metallic .... **GO TO 12**

11'. Ventrites 1 and 2 fused with no trace of suture between, all iridescent or metallic:

Buprestidae (p.184)

12. Body variable .... **GO TO 13**

12'. Body strikingly flat:

Cucujidae (p.288)
[see also Laemophloeidae (p.291)]