

Laboratory 4, 21 February 2017

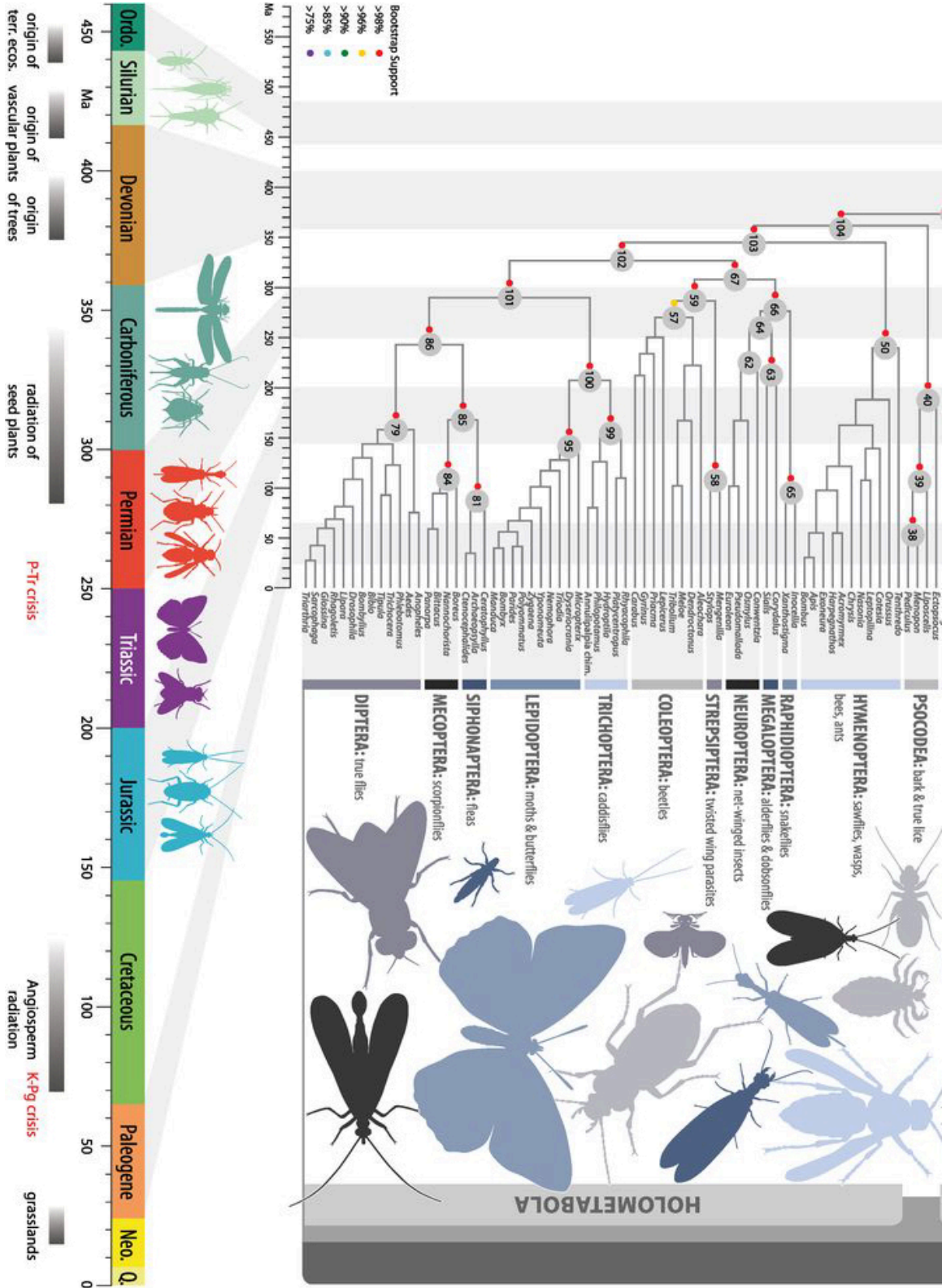
Systematics of holometabolous orders, identification of families, statistics to analyze diversity, develop techniques for forensic entomology experiment.

Today you will:

- Listen to the presentations on statistics involving biological diversity.
- Work through the statistics based on your data.
- Gain experience point-mounting insects.
- Listen to the presentation on Holometabolous insect orders
- Use the collection to identify holometabolous insects.
 - Hymenoptera: Ants, bees, wasps, & sawflies
 - Coleoptera: Beetles
 - Neuroptera: Lacewings
 - Megaloptera: Alderflies, Fishflies, Dobsonflies
 - Raphidioptera: Snakeflies
 - Diptera: True flies
 - Lepidoptera: Butterflies & Moths
- Discuss hypotheses for implementing a forensic entomology experiment

You will be responsible for all of the taxa in the following handout. You should know how to recognize them and how to identify them. The phylogeny is from Misof *et al.* (2014).¹

¹ Misof, B. S. Liu, K. Meusemann, R.S. Peters, A. Donath, C. Mayer, P.B. Frandsen, J. Ware, T. Flouri, R.G. Beutel, O. Niehuis, M. Petersen, F. Izquierdo-Carrasco, T. Wappler, J. Rust, A.J. Aberer, U. Aspöck, H. Aspöck, D. Bartel, A. Blanke, S. Berger, A. Böhm, T.R. Buckley, B. Calcott, J. Chen, F. Friedrich, M. Fukui, M. Fujita, C. Greve, P. Grobe, S. Gu, Y. Huang, L.S. Jermiin, A.Y. Kawahara, L. Krogmann, M. Kubiak, R. Lanfear, H. Letsch, Y. Li, Z. Li, J. Li, H. Lu, R. Machida, Y. Mashimo, P. Kapli, D.D. McKenna, G. Meng, Y. Nakagaki, J.L. Navarrete-Heredia, M. Ott, Y. Ou, G. Pass, L. Podsiadlowski, H. Pohl, B.M. von Reumont, K. Schütte, K. Sekiya, S. Shimizu, A. Slipinski, A. Stamatakis, W. Song, X. Su, N.U. Szucsich, M. Tan, X. Tan, M. Tang, J. Tang, G. Timelthaler, S. Tomizuka, M. Trautwein, X. Tong, T. Uchifune, M.G. Walz, B.M. Wiegmann, J. Wilbrandt, B. Wipfler, T.K.F. Wong, Q. Wu, G. Wu, Y. Xie, S. Yang, Q. Yang, D.K. Yeates, K. Yoshizawa, Q. Zhang, R. Zhang, W. Zhang, Y. Zhang, J. Zhao, C. Zhou, L. Zhou, T. Ziesmann, S. Zou, Y. Li, X. Xu, Y. Zhang, H. Yang, J. Wang, J. Wang, K.M. Kjer, and X. Zhou. 2014. Phylogenomics resolves the timing and pattern of insect evolution. *Science* 346: 763-767.



HYMENOPTERA

Bees, Wasps, Ants, Sawflies

(Greek, *humen* = membrane; *pteron* = wing)

This is another extremely diverse group of holometabolous insects. Due to the parasitic Hymenoptera, this is probably the group with the highest proportion of undescribed taxa. In addition, they have a rather large diversity in overall form and an extraordinarily diverse biology. There are leaf feeders, miners, gall formers, parasites, predators, pollen and nectar gatherers, fungus gardeners, and insect farmers; but there are very few scavengers except among the ants. There are three main groups: “Symphyta” refer to the sawflies which are all plant feeders. “Parasitica” refers to the parasitoids of other arthropods; Aculeata refers to the bees, ants, and wasps that hunt arthropod prey or gather pollen and nectar on which to feed larvae.

These insects can be absolutely minute (smaller than a *Paramecium*) to quite large (think of some bumblebees). They are usually dark brown or black, but they are often marked yellow, red, white, metallic blue or green. Other orders with membranous hindwings include the Isoptera (termites), the Psocoptera (booklice & barklice), some Hemiptera (especially aphids and male scale insects), Neuropterida (the orders Neuroptera, Megaloptera, and Raphidioptera), and the Diptera. Hymenoptera are readily distinguished from the Isoptera, Psocoptera, Hemiptera, and Neuropterida by the reduced hindwings and lapping mouthparts. They are readily distinguished from the Diptera by the latter’s halteres. With the exception of the Symphyta (sawflies), Hymenoptera can be diagnosed by their constricted waist. Diagnostic characters include the fusion of maxillae and labium to form a flexible maxillo-labial complex: **the lapping tongue** of Hymenoptera; the fusion of the first abdominal segment with the thorax: the **propodeum**; and the small hindwings coupled to the larger forewings by **hamuli**.

There are approximately 200,000 species of Hymenoptera placed within 90 families. Note that the larger groups are a series of nested paraphyletic groups (see Figure 1). You should be familiar with the following taxa:

Order Hymenoptera

Suborder ‘Symphyta’: sawflies. All sawflies have a thorax that is broadly joined to the thorax. These are the most difficult Hymenoptera to identify to order—you really need to look at the wings. This suborder is paraphyletic with respect to the remaining groups.

Suborder ‘Apocrita’: parasitic wasps. This paraphyletic group makes up the vast majority of hymenopteran diversity. Some 75 of the 90 families are parasitic wasps. Recognize them primarily by their small size and often extended ovipositor. You will not be required to identify them to family.

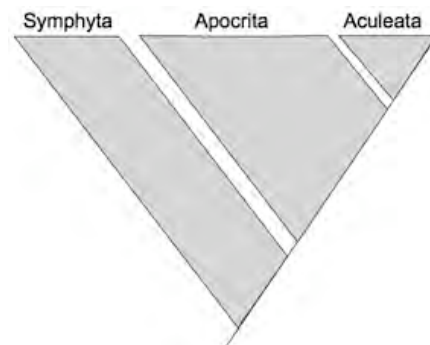


Figure 1: The classification of the Hymenoptera is essentially a series of paraphyletic grades.

Suborder Aculeata: Bees, Ants, Stinging wasps. This monophyletic group is defined by the modification of the ovipositor into a venom-delivering stinger. It is the most readily encountered and noticed by us.

Family Mutillidae: Velvet ants. These wasps are antlike in appearance; they are very hairy and generally brightly colored. The females are wingless and the males are winged. They are parasitic on ground-nesting bees and wasps. They are armed and dangerous—they deliver one of the most venomous stings in all of the Hymenoptera.

Family Formicidae: Ants. Identify these by the fact that the first **or** first and second abdominal segments are node-like or with a hump (the pedicel). Antennae of the females are elbowed with an extended first segment.

Family Pompilidae: Spider wasps. These are best distinguished from other vespid wasps in having a transverse groove dividing the mesopleuron (a region of the thorax) into halves. Females are often larger than the males, with coloring and wing appearance varying greatly among the many species, though black is the most common color, with contrasting aposematic markings of orange, red, yellow, or white also being fairly common. Spider wasps are long-legged, solitary wasps that use a single spider as a host for feeding their larvae. They paralyze the spider with a venomous stinger. Once paralyzed, the spider is dragged to where a nest will be built – some wasps having already made a nest.

Family Vespidae: Hornets, paper wasps, potter wasps, yellowjackets. Readily encountered and often considered pests. These can be aggressive and often have aposematic coloration. They can be recognized by the long first discoidal cell. The wings are folded longitudinally at rest.

Family Sphecidae: Thread-waisted wasps and mud daubers. These can be difficult to characterize because they are quite diverse in form. Many are thread-waisted, but others are vespid-like. All have a short and collar-like pronotum.

Family Apidae: Honey bees, stingless bees (which are also cultured for honey), sweat bees, carpenter bees, orchid bees, cuckoo bees, bumblebees. Recognize by appearance: usually hairy. Also with an extended glossa.

COLEOPTERA

Beetles

(Greek, *koleos* = shield; *pteron* = wing)

This is an exceptionally large clade of animals, as more than one in every four *animals* is a beetle. It includes terrestrial and aquatic species; parasites, predators, herbivores, fungivores, caprophages, detritivores, xylovores (wood eaters), etc.; extensive range in size: from the 0.0025mm long feather-winged beetles to 150mm long rhinoceros and hercules beetles.

Despite their diversity, they have a remarkable uniformity in body form. With the exception of some bizarre paedomorphic forms, they all have their forewings modified into highly sclerotized elytra (hence the name Coleoptera), that meet down the midline of the dorsum. They are fairly difficult to confuse with other orders: the Heteroptera (true bugs) have partially sclerotized forewings (hemelytra) that fold over each other; the Dermaptera (earwigs) have similar forewings, but have cerci extended into pincers, whereas Coleoptera lack cerci. They all have mandibulate mouthparts, although these can be highly modified (e.g. in the weevils); and the external genitalia are withdrawn into the abdomen.

There are approximately 170 families of Coleoptera, although this number is constantly in flux as new families are constructed or old families demoted (note that 'family' is the construct of taxonomists, not of evolution).

You will be required to recognize the following common California taxa, including their rank and nesting relationships. Families indicated with a * are ones that you will be unlikely to see but are included here because of their phylogenetic importance.

Order Coleoptera

Suborder Archostemata

1. *Cupedidae: Reticulated beetles.

Suborder Myxophaga

2. *Sphaeriidae: Minute bog beetles.

Suborder Adephaga

3. Carabidae: Ground beetles; including Cincindellinae, Tiger beetles
4. Dytiscidae: Predacious diving beetles
5. Gyrinidae: Whirligig beetles

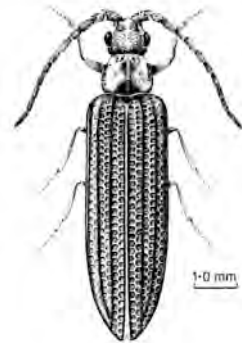
Suborder Polyphaga

6. Hydrophilidae: Water scavenging beetles
7. Staphylinidae: Rove beetles
8. Silphidae: Carrion beetles
9. Histeridae: Hister beetles
10. Lucanidae: Stag beetles
11. Scarabaeidae: Scarab beetles
12. Buprestidae: Metallic wood-boring beetles
13. Elateridae: Click beetles

14. Cantharidae: Soldier beetles
15. Lampyridae: Lightning beetles
16. Melyridae: Soft-winged flower beetles
17. Nitidulidae: Sap beetles
18. Coccinellidae: Ladybird beetles
19. Tenebrionidae: Darkling beetles
20. Meloidae: Blister beetles
21. Cerambycidae: Long-horned beetles
22. Chrysomelidae: Leaf beetles
23. Curculionidae: Weevils or snout beetles

Note that there are MANY, MANY other families of beetles. You may want to check out the key in Borror *et al.* (Borror, D.J., C.A. Triplehorn, N.F. Johnson. 1989. *An Introduction to the Study of Insects* (6th Edition). Saunders College Publishing, Orlando, FL) to help you get to these if you so desire. The list below includes a diagnosis of the families above, and you should be able to recognize them if presented to you. Illustrations are from Borror *et al.* 1989 and from the CSIRO publication “The Insects of Australia” (1991).

1. *Cupedidae: Reticulated Beetles. You will not see these and will not need to recognize them. They are particularly interesting because they represent one of the earliest branching lineages to all of the other beetles: the Archostemata are the *sister-group* of the rest of the beetles. You can still see the plesiomorphic wing venation in their forewings. They are rare, with only 30 species worldwide, and only 4 in the United States. One species is found in the Sierra Nevadas in California.

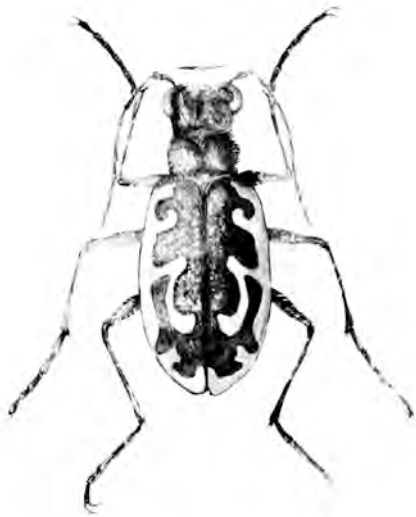
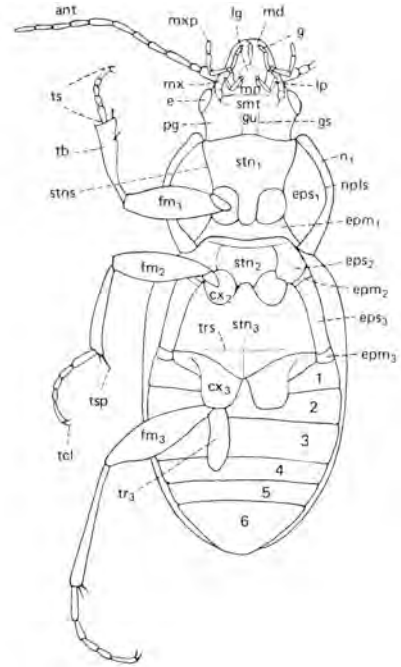
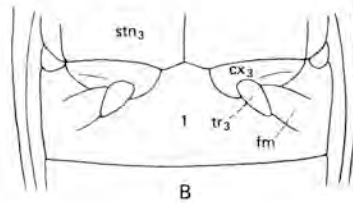
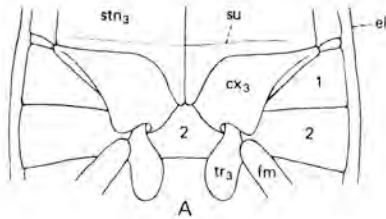


2. *Sphaeriusidae: Minute Bog Beetles. These are the most common members of the suborder Myxophaga that are found in California (wrinkled bark beetles in the family Rhysodidae are also found in California where they feed on slime molds). These are tiny, oval beetles with a large, prominent head and capitate antennae that are found in mud and under stones near water. They have three-segmented tarsi.



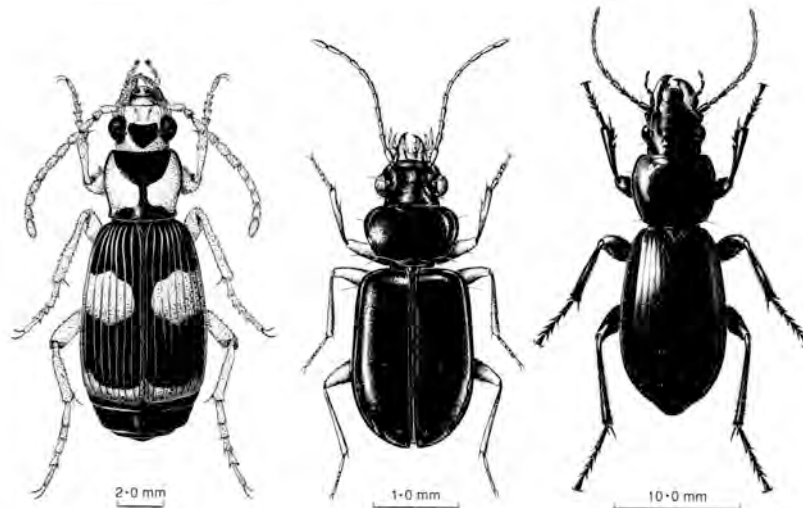
ADEPHAGA This suborder is characterized by having the hind coxae divide the first visible abdominal sternum, they have a notopleural suture (see npls to the right), 5-5-5 tarsi (5 tarsal segments on the fore-, mid-, and hindlegs), and filiform antennae.

Compare the abdominal sterna below to distinguish between Adephagan (A) and Polyphagan (B) orders:

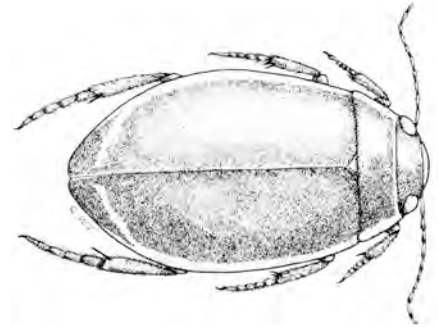


3. Carabidae: Ground Beetles; including

Cincindellinae: Tiger Beetles. These are extraordinarily common and diverse in California. They are the third most diverse family (after Staphylinidae and Curculionidae) in the state. Most species are dark, often shiny, and somewhat flattened, with striate elytra. They are commonly found under stones, logs, leaves, bark, or debris or running about on the ground. When disturbed, they run rapidly, but seldom fly. The tiger beetles (left) have been considered a family in the past, but are clearly nested within the ground beetles. They are usually metallic or iridescent in color and often have a definite color pattern. They can usually be recognized by their characteristic shape, bulging eyes, and large mandibles.

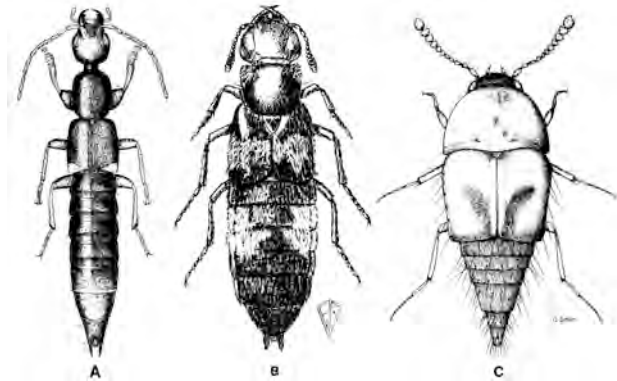
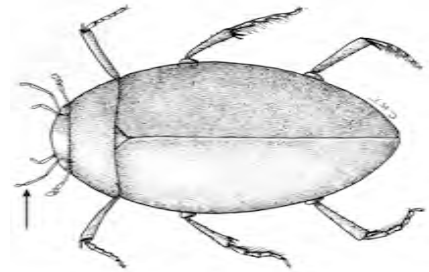


4. Dytiscidae: Predacious diving beetles. These are often large (but not always) and distinctive. The tarsi are 5-5-5, they have an elongate **oval shape, convex above and below**; threadlike antennae, and **hind legs flattened and with fringes of hairs for swimming.**



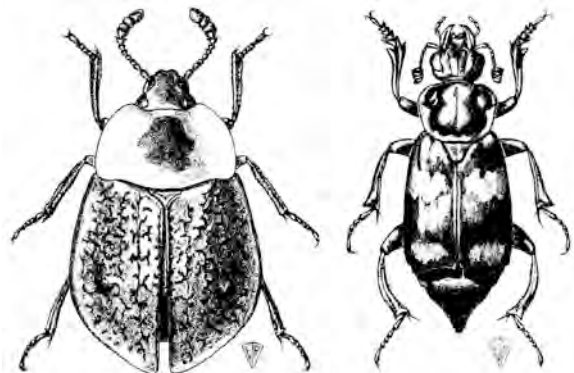
5. Gyrinidae: Whirligig beetles. Tarsi 5-5-5; eyes and legs distinctive: **eyes divided into two parts** (for above and below water viewing); **forelegs long, middle and hindlegs short**; antennae short and clubbed.

6. Hydrophilidae: Water Scavenging Beetles: Body **generally oval in shape, convex above, and usually flat below**; **antennae short and with 4-segmented, clubbed apex** (often concealed). Key feature is the **maxillary palps elongate** (usually longer than antennae and easily confused with antennae by novices).



7. Staphylinidae: Rove Beetles: These are very distinctive and characteristic: usually elongate, slender, parallel sided; **elytra short**, exposing 5-6 abdominal segments; antennae threadlike or clubbed; very large family of mostly small beetles (usually 1-10mm, but up to 30mm).

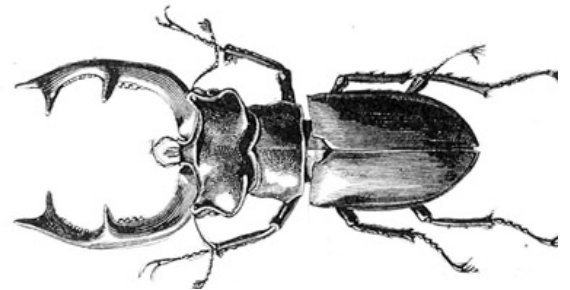
8. Silphidae: Carrion Beetles: These may well be nested within the Staphylinidae, but they are quite distinct. They are generally rather large beetles with **flattened shape** and soft body, frequently **black** or blackish in color with yellow, orange, or red markings, and often with the last few segments of the abdomen exposed. Antennae clubbed, with last 2-3 segments pubescent.



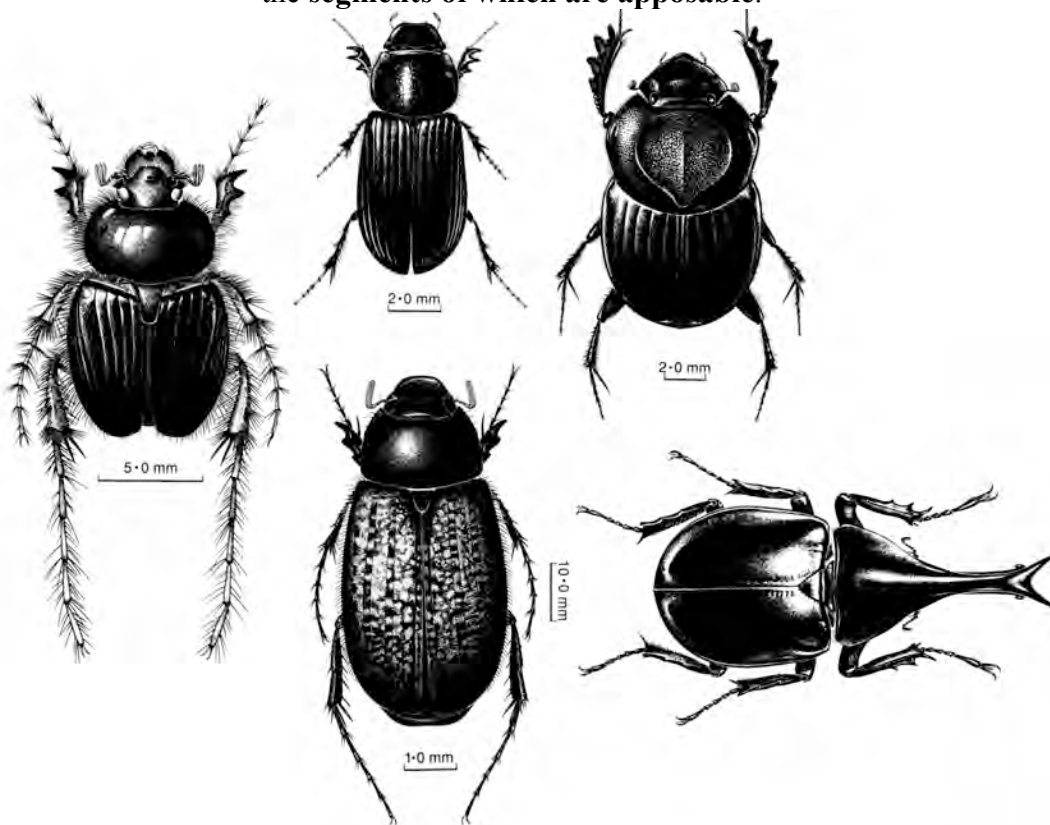


9. Histeridae: Hister Beetles: These are rather common in California and feed on dung or decaying flesh. They are black, shining beetles with **truncate elytra**, and **elbowed, clubbed antennae**. They are usually oval or elliptical in shape, but they are greatly flattened in some species. The legs seem to fit well in grooves in the body.

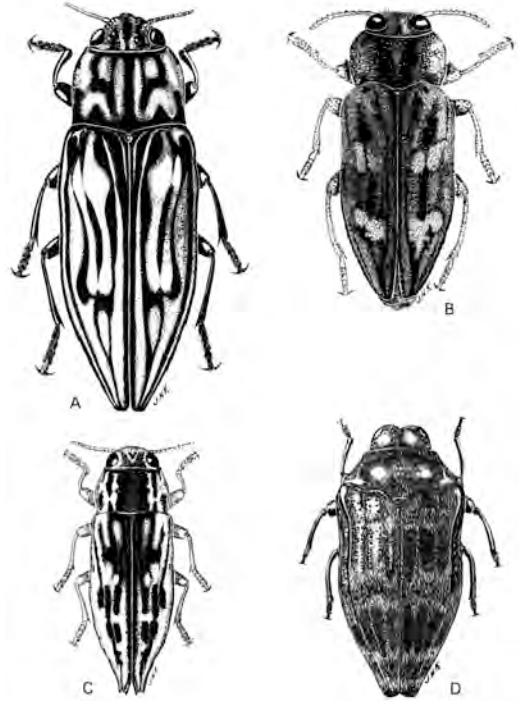
10. Lucanidae: Stag Beetles: While these are not often encountered in the wild, especially in California, no class in entomology is complete without knowing what these amazing beetles are. These are elongate, robust beetles, usually with a **large head** and greatly **enlarged mandibles in males** of most species; the thorax is usually evidently separated from the abdomen by a waist; the antennae are geniculate (**elbowed**) with 3-4 segmented **club** whose segments are **not** capable of being **apposed** (held together) in a tight ball.



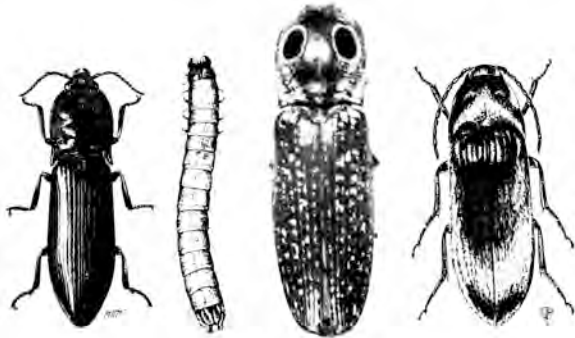
11. Scarabaeidae: Scarab Beetles: These are quite diverse in terms of overall form and the subfamilies are frequently raised to family status. They are variable in size, but are typically oval or elongate and **heavy bodied**; Antennae 8-11 segmented with **club that is lamellate** (platelike), the **segments of which are apposable**.



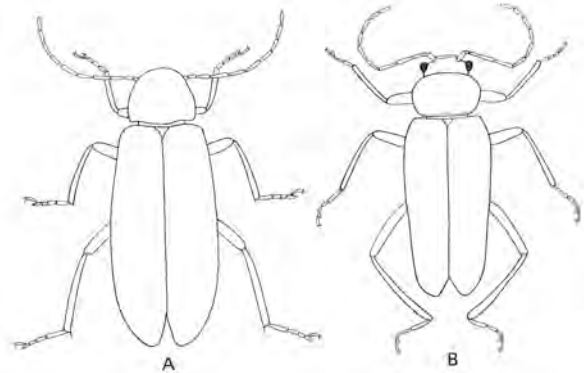
12. Buprestidae: Metallic Wood-Boring Beetles: Distinctive bullet-shaped form. Tarsi 5-5-5, hard-bodied, usually elongate oval or parallel sided, nearly always shiny and with **metallic** or bronzed color, especially ventrally; antennae short, serrate or threadlike. Elytra often tapered.



13. Elateridae: Click Beetles: Distinctive shape and usually black or brown in color: **parallel-sided and flattened**, rounded at each end; **posterior corners of pronotum prlonged backward** into sharp points, **clicking** mechanism ventrally between pro- and mesonotum, antennae usually serrated, sometimes threadlike or pectinate.

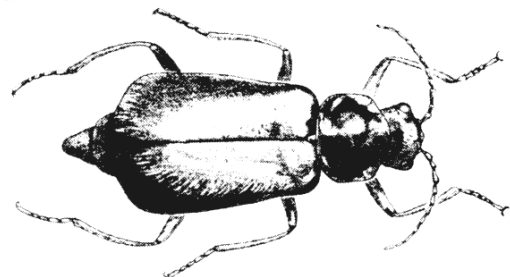


14. Cantharidae: Soldier Beetles: **Soft-bodied, body elongate, parallel sided**; head NOT concealed; margin of pronotum often flattened disklike; usually largely black or brown with red, yellow, or orange, especially on margin of pronotum (or sometimes predominantly yellow overall. Contrast a soldier beetle (on the left) with a lightning beetle (on the right). The latter's head is concealed.

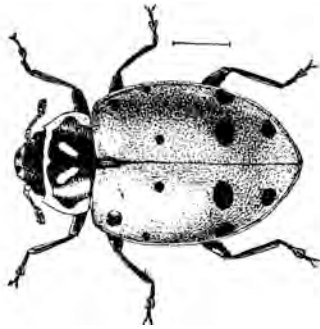
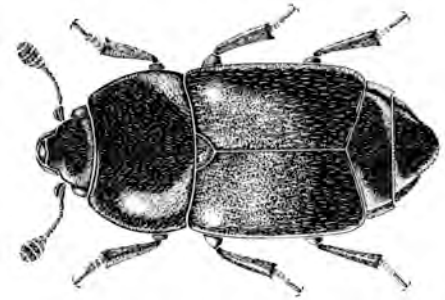


15. Lampyridae: Lightning Beetles: Soft-bodied, similar to cantharids, but head concealed from above by pronotum, last 2-3 abdominal segments often luminous; color usually brownish or blackish with yellow or orange. Contrast with a soldier beetle (on the left).

16. Melyridae: Soft-Winged Flower Beetles: Elytra quite soft, **loosely covering abdomen and widest toward rear of insect**; black, blue, or green, often with red yellow or orange markings, often covered with **erect, stiff hairs**; antennae sawtoothed or threadlike.

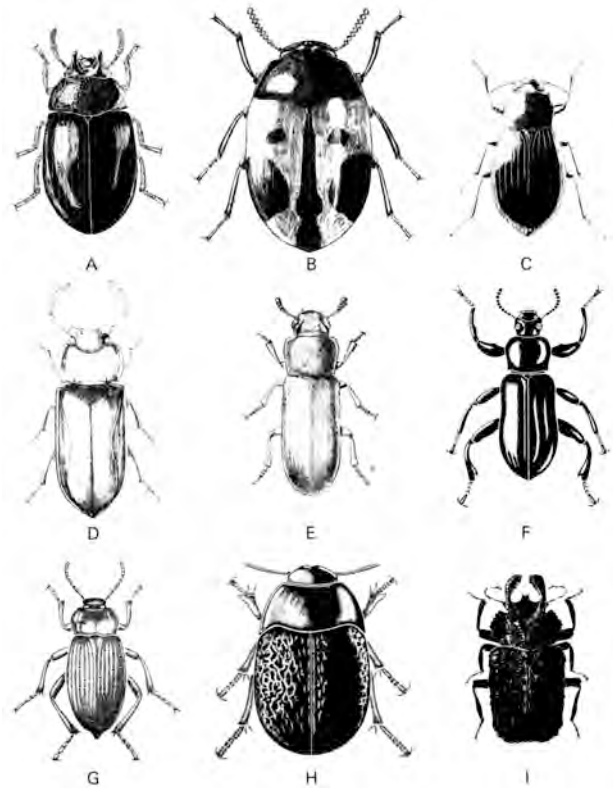


17. Nitidulidae: Sap Beetles: These are quite common and tend to hang around on tree sap. The tarsi are 5-5-5 or 4-4-4, are relatively small (with some exceptions), variable in shape but frequently broadly oval, sometimes with **the last few abdominal segments exposed**; color usually brown or black, often marked with yellow or red; **antennal club with abrupt, 3-segmented apex, front coxae transverse**.



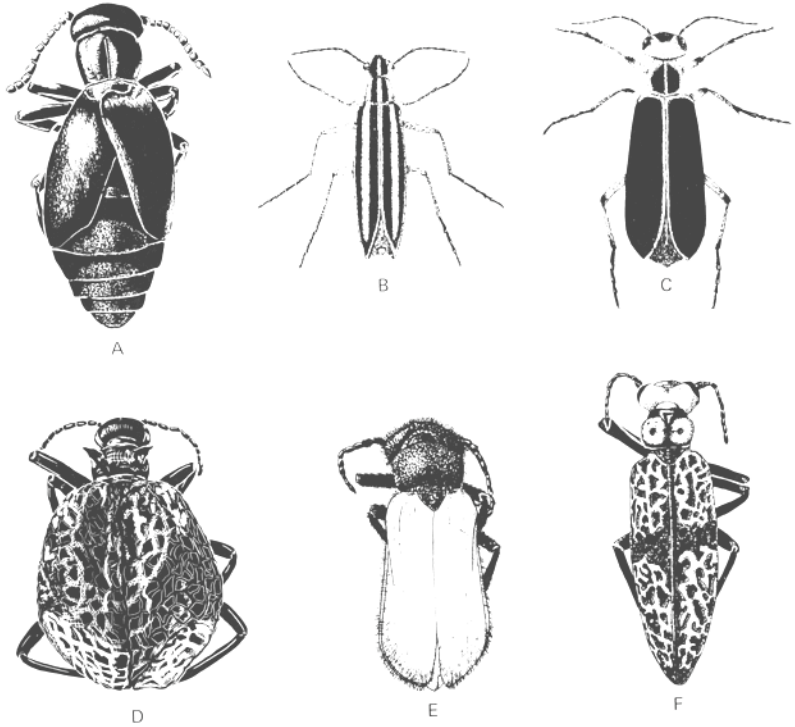
18. Coccinellidae: Ladybird Beetles: Fairly common and well-known to most people. Tarsi **apparently** 3-3-3 (actually 4-4-4), oval or nearly spherical in shape and convex dorsally; color yellow, orange, red, or black (frequently with contrasting spots or markings); head partly or totally concealed by pronotum; **antennae short and with 3-6 segmented club**.

19. Tenebrionidae: Darkling Beetles: These beetles are quite variable in shape and form. The most distinctive character about them is that their **eyes are notched by a projecting shelf, under which the antennal insertions are located**. In general they are medium to large in size and generally rather dull black or brown. The antennae are 11-segmented and threadlike, beadlike, or slightly clubbed.

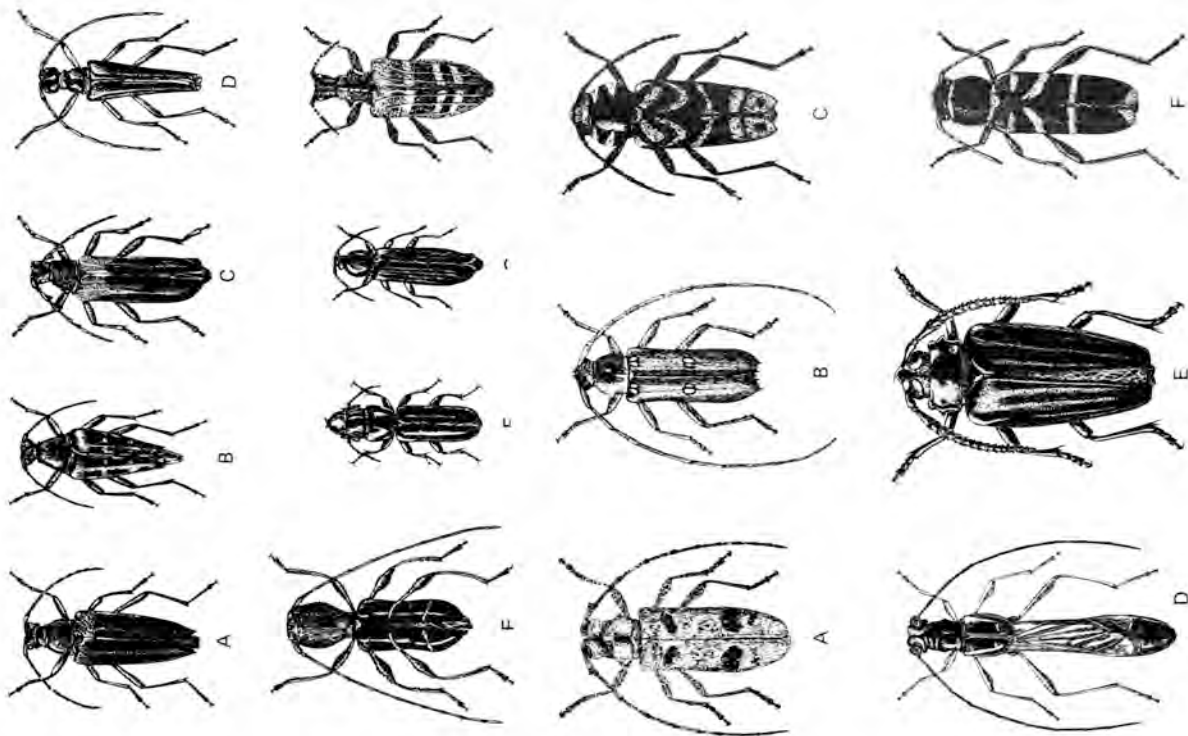


20. Meloidae: Blister Beetles:

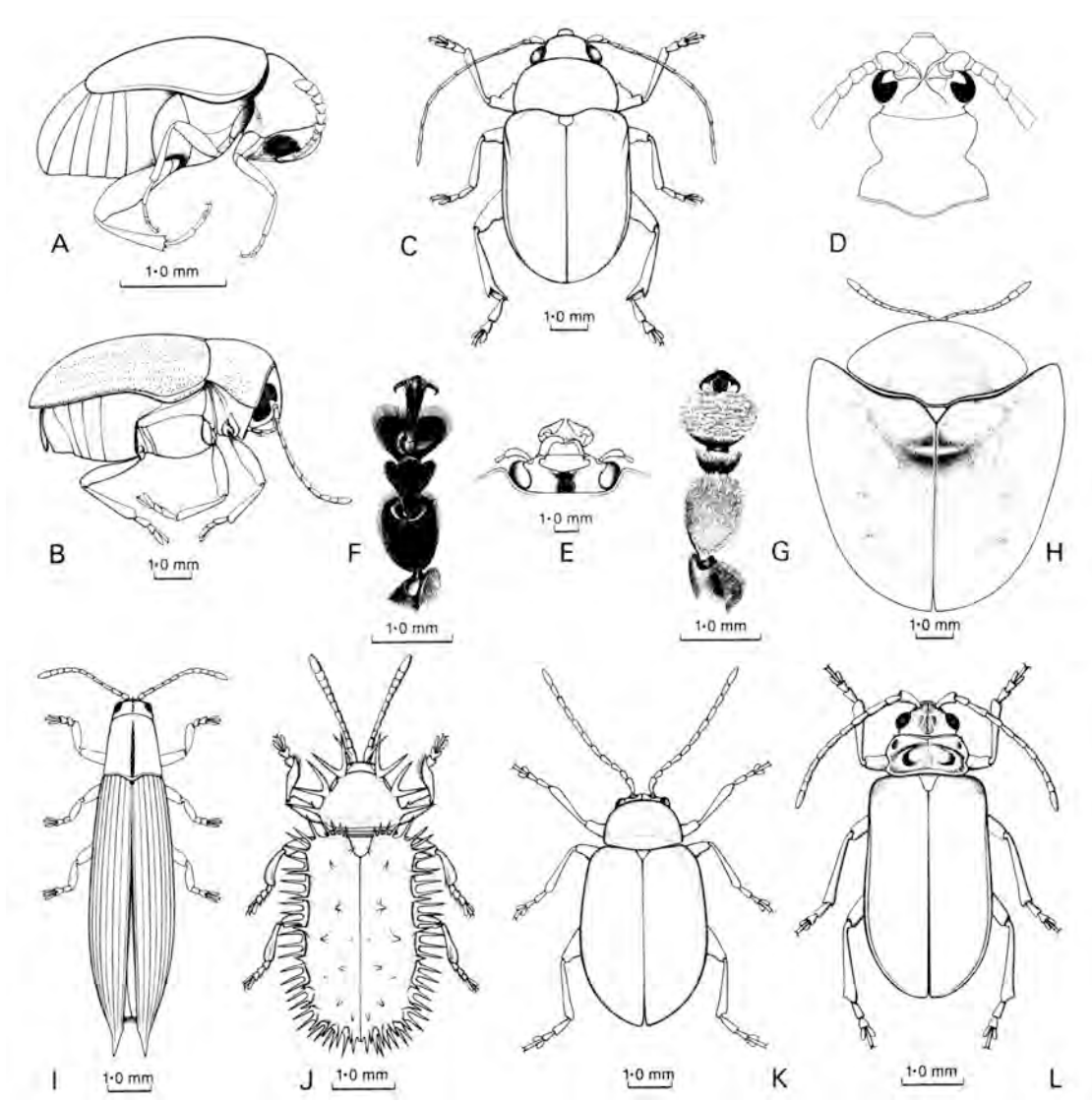
Tarsi 5-5-4, body soft, often leathery; **shape usually distinctive: head broad and wider than thorax, elytra elongate and wider than thorax with “rolled” edges;** antennae threadlike or beadlike; legs long and slender; head points downward.



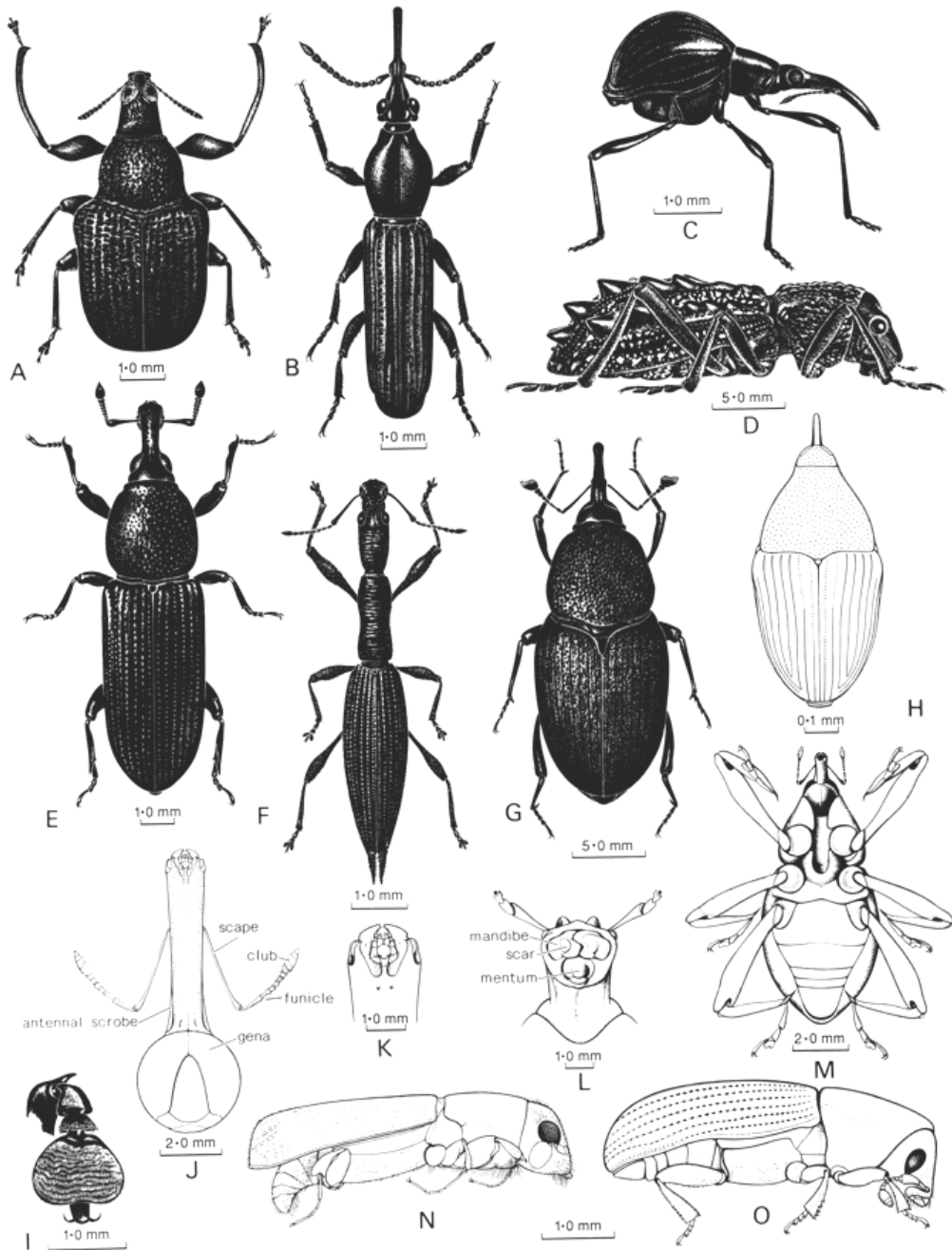
21. Cerambycidae: Long-Horned Beetles: Generally quite distinct, with **eyes usually notched and antennae arising in notch**. The **antennae are elongate**, at least half the length of the body. The tarsi are apparently 4-4-4 (actually 5-5-5), but the fourth segment is hidden.



22. Chrysomelidae: Leaf Beetles: Tarsi **apparently** 4-4-4 (see figure below), variable in shape and color, but generally somewhat oval shaped; antennae usually less than half the length of the body. This is a VERY large and diverse family. Members are often (but not always) metallic. Much like the Scarabaeidae, some of the subfamilies have traditionally been considered families.



23. Curculionidae: Weevils or Snout Beetles: Tarsi, again **apparently 4-4-4**, usually with a **well-developed, curved snout**; **antennae clubbed and almost always elbowed**, often recessed into a groove along the snout; palps small and often concealed, labrum absent. This is the largest family in the world with numerous subfamilies, some of which are often raised to family status.



NEUROPTERIDA

The Neuropterida is composed of three orders that make a clearly monophyletic group: the Neuroptera, the Megaloptera, and the Raphidioptera.

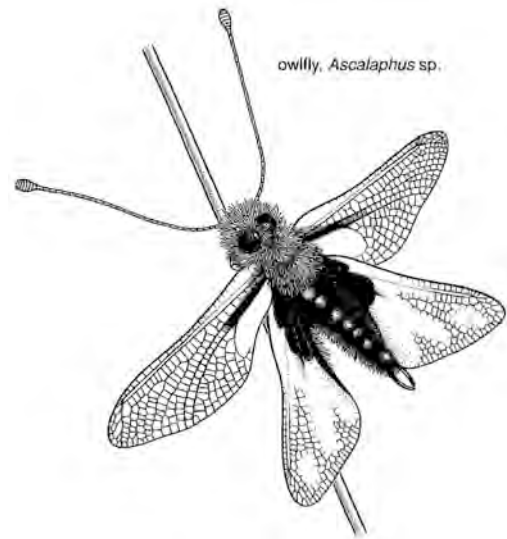
Neuroptera: Lacewings

(Greek, *neuron* = sinew; *pteron* = wing)

These are predaceous in the larval stage, particularly on hemipterans (especially aphids); some feed on insect eggs. Adults and larvae are found most often on vegetation. Sisyridae (spongillaflies) have aquatic larvae that feed on freshwater sponges. Mantispid are parasitic on spider egg masses. Antlion larvae live in dry sand where they construct conical pits used to capture insect prey. Brown lacewing larvae carry debris on hooked spines and bristles on back for concealment. Green lacewings have stalked eggs and larvae feed on aphids.

The forewings and hindwings are similar in size and shape, with many veins and crossveins. The hindwing anal area is not folded. Larvae have grooved elongate mandibles covered by elongate maxillary lobe, forming piercing-sucking tubes. If the prothorax is lengthened then the forelegs are raptorial and arise from anterior end (Mantispidae), otherwise they are Raphidioptera.

There are approximately 5000 species of Neuroptera in the world, with about 400 in the U.S. and Canada.



Megaloptera: Alderflies, Fishflies, Dobsonflies

(Greek, *mega* = large; *pteron* = wing)

All the larvae of this order are aquatic, but they pupate in cells out of water. Larvae of fishflies and dobsonflies are found in clear flowing water and are predaceous. Male dobsonflies have very large sickle-like mandibles. Alderfly larvae inhabit turbid waters with soft, silty bottoms and prey on small insects.

These are large grayish-brown or smaller dark brown-black, soft-bodied insects. The larvae are aquatic with abdominal gills. The hindwing is broader at the base than the forewing; the anal area of the hindwing is folded fanlike. The tips of the wingveins have no bifurcations.

There are approximately 300 known species in the world.

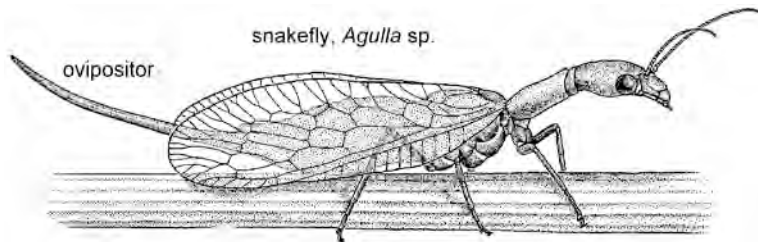


Raphidioptera: Snakeflies

(Greek, *raphid* = needle; *pteron* = wing)

Snakefly adults all prey on small insects, such as aphids. They lay their eggs in clusters under bark where the larvae feed on small arthropods. They undergo numerous molts (10 or 11). A period of comparatively low temperature is required in the pre-pupal stage for successful development and this has presumably limited their distribution to temperate biomes.

Snakeflies are readily identified by their very elongated prothorax with forelegs at posterior end. Note that the legs are *not* raptorial.



LEPIDOPTERA

Butterflies & Moths

(Greek, *lepidos* = scale; *pteron* = wing)

These insects are perhaps the most readily familiar to just about anyone. The bright colors, active day flying, and large size of the butterflies makes them difficult to miss. They are accessible enough to have justified the publications of bird-book style field guides, including one of the better ones out there—“Butterflies through Binoculars” (by Jeffrey Glassberg) for both the eastern and western U.S. These are popular subjects of amateur collectors, even to the point where some species are seriously threatened with extinction as a result. The Baron Charles Rothschild was a famous (and extraordinarily wealthy—have you heard of Chateau Lafite Rothschild wines?) collector and the novelist Vladimir Nabakov (of “Lolita” fame) was a pre-eminent butterfly authority.

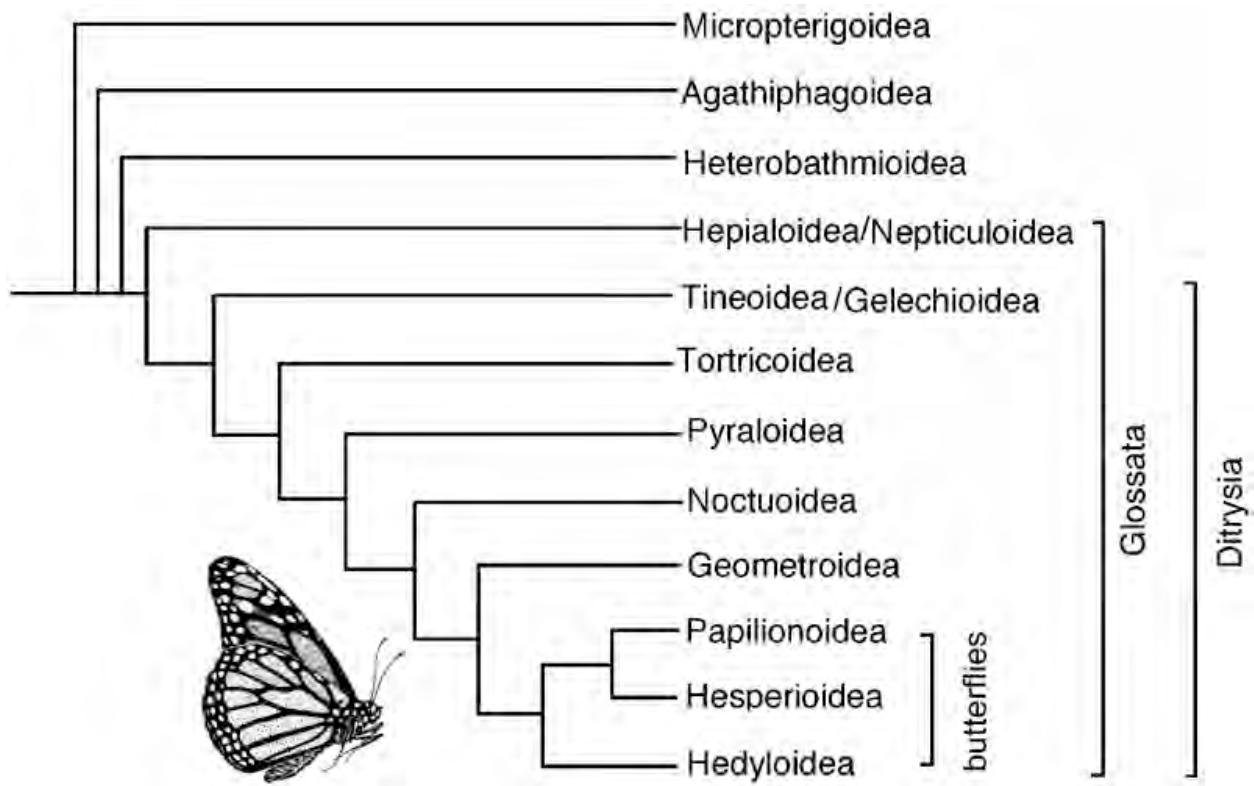
The Lepidoptera are considered one of the big four, along with the Diptera, Coleoptera, and Hymenoptera. Adult moths are generally nocturnal, butterflies and skippers are generally diurnal. Adults suck nectar or feed on pollen; some noctuids suck blood. Habits and habitats of the larvae are very diverse and include external leaf feeders; leaf, woody stem, and fruit and nut borers; stored products and detritus feeders; fungus and lichen feeders; decomposing plant and animal matter (including clothes moths, bone moths, and horn moths); and there are a very few parasites and predators. Many are of great economic importance.

The most obvious characteristics, and a defining synapomorphy of the Lepidoptera is that their body and wings are covered with scales. They form a sister relationship with the caddisflies, order Trichoptera, with whom they share dense setae on the wings (modified to scales in Lepidoptera), particular wing venation patterns on the forewings, and both have larvae with mouth structures and glands to produce and manipulate silk. **In addition, these two orders (known collectively as Amphiesmenoptera) all have heterogametic females.** Females are ZW and males are ZZ (note the different terminology to reflect the different sex determination system).

Collect adult moths at lights; collect butterflies during the day with aerial nets. You can also set out baits or other attractants. Minimize handling of specimens and use ethyl acetate kill jars for rapid killing in order to avoid rubbing off the scales. Pinch the thorax or inject it with alcohol with a hypodermic syringe. Paper specimens and keep them moist. Wings must be spread. Collect larvae live, record the host plant, and you can attempt to rear the adult. Kill larvae by boiling first in water for a minute or so; preserve permanently in 80% ethanol. NEVER place live larvae directly in alcohol (unless you are preserving for DNA purposes).

The monophyly of the Lepidoptera is well-established: Kristensen (1984) lists 26 morphological synapomorphies. The group probably diverged from the Trichoptera in the late Jurassic. The oldest, most basal lineages of Lepidoptera have as adults, not the curled tongue or proboscis characteristic of most members of the order, but chewing mandibles (Micropterigidae, Agathiphagidae and Heterobathmiidae). Micropterigidae larvae feed on decaying leaves (much

like the Trichoptera), fungi, liverworts or live leaves. The adults chew pollen or spores of ferns. In the Agathiphagidae, larvae feed inside seeds of kauri pines, and in Heterobathmiidae the larvae mine leaves of *Nothofagus*, the southern beech. These families also have mandibles in the pupal stage, which help the pupa emerge from the seed or cocoon just before adult emergence. The remaining lineages have a coiled proboscis with a gradual reduction in the presence and functionality of mandibles with the coiled proboscis gaining intrinsic musculature (as described in your textbook (p. 34) with the evolution of the Ditrysia.



There are approximately 180,000 described species of Lepidoptera placed within roughly 120 families. You will not be required to know all of these. Instead, I will require you to know the following taxa:

Order Lepidoptera

Tineoidea: Including the clothes moths, horn and hoof moths, and tortoise-shell moths (family Tineidae). You will not be required to recognize these

Torticoidea: All members of this superfamily are in the family Tortricidae. Some of the most devastating pests of orchards are found amongst the 6300 species of tortrix moths, including the apple codling moth. This is the largest family of the microlepidoptera (very small moths). The moths are small, usually gray, tan, or brown; their wings have dark bands or mottled areas, or are occasionally colorful with metallic spots. The front wings are usually rather square-tipped. The wings at rest are held rooflike over the body.



Pyraloidea: The Pyraloidea consist of four families but are best represented by the family Pyralidae, the snout and grass moths. This family of moths is the third largest in the order, with 16,000 species described and many more likely remaining to be discovered. Most pyralids are rather small and delicate moths, and all have abdominal tympanal organs and a *scaled proboscis*. The front wings are elongate or

triangular, with the cubitus appearing four-branched and the hind wings usually broad. Since the **labial palps are often projecting**, these moths are often called snout moths.

Bombycoidea: The Bombycoidea are not listed in the phylogeny above, but would probably form a polytomy with the Noctuoidea + (Geometroidea + Butterflies). Not including them would be remiss in that they include some of the most important economic Lepidoptera and some of the most impressive moths.



Lasiocampidae: Tent caterpillars, 2000 species. These moths are medium-sized and stout-bodied, with the body, legs, and eyes hairy. The antennae are somewhat feathery in both sexes, but the processes on the antennae are longer in the male. Most of these moths are brown or gray in color. The larvae feed on the foliage of trees, often causing serious damage. The young that hatch from a given egg cluster are gregarious and construct a tentlike nest of silk near the eggs. This tent is used as a shelter, with the larvae feeding during the day in nearby branches. The western tent caterpillar (*Malacosoma californicum*) is an important insect in our region.



Bombycidae: Silkworm moths. Only a single species in this family occurs in North America, *Bombyx mori*. This is a native of Asia that is occasionally reared in the US. The adult moth is creamy white with several faint brownish lines across the front wings, and it has a wingspread of about 50mm. The body is heavy and very hairy.



Saturniidae: Giant silkworm moths and royal moths, 1500 species. This family includes the largest moths in North America and some of the largest lepidopterans in the world. The largest in North America have a wingspread of about 150mm or more, while some tropical species can reach 250mm. Many members are conspicuously or brightly colored, and many have transparent eyespots in the wings. The antennae are feathery for about half or more of their length and are larger in the male than in the female. *Hemileuca* are common associates of buckwheat (*Eriogonum*) in California chaparral (below).



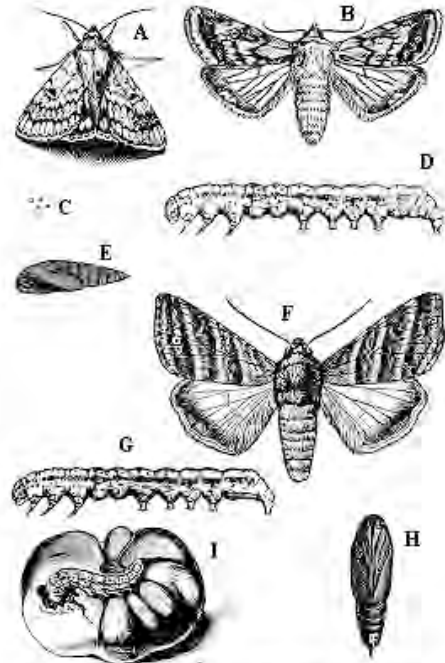
Borrego.

Sphingidae: Sphinx or hawk moths, hornworms, 1200 species. You now have extensive experience with both the larvae of this family (tobacco hornworm) and adults (sphinx moths at the lights in Anza Borrego). These are medium-sized to large, **heavy-bodied** moths with long narrow front wings. Some have a wingspread of 160 mm or more. The body is somewhat spindle-shaped, tapering, and pointed both anteriorly and posteriorly. The proboscis in many species is very long (recall Darwin's orchid hawkmoth). The white-lined sphinx moth (*Hyles lineata*) should look familiar to you from Anza

Noctuoidea: This superfamily includes the Arctiidae (tiger moths, 11,000 species) and the Noctuidae (owlet moths, 35,000 species) and as a result is the most species-rich superfamily within the Lepidoptera. Note that while not discussed below, the gypsy moth and brown moth (family Lymantriidae) are in this superfamily and are some of the most serious pests and invasive species in North America.

Noctuidae: Owlet moths. These moths are mostly nocturnal in habit, and the majority of the moths that are attracted to lights at night belong to this family. These are mostly heavy-bodied moths with the front wings somewhat narrowed and the hind wings broadened. The labial palps are usually long; the antennae are generally hairlike; and in some species there are tufts of scales on the dorsum of the thorax.

Arctiidae: Tiger moths. Many of these are rather destructive to trees and shrubs. Many are colorful and thus popular with collectors. Most tiger moths are small to medium-sized and brightly spotted or banded. Some are white or rather uniformly brownish. They are principally nocturnal and, when at rest, hold the wings rooflike over the body (see figure below with butterflies).



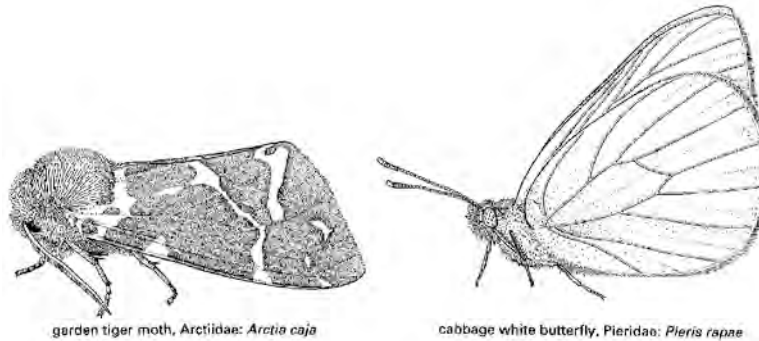
Tomato fruitworm (corn earworm). A-B, Adults. C, Eggs. D, Larva. E, Pupa. F-H, Tobacco budworm. F, Adult. G, Larva. H, Pupa. I, Tomato with fruit worm damage.

Geometroidea: The geometers, inchworms, and measuring worms are largely represented by the family Geometridae and represent the sister taxon of the butterflies. The 26,000 species in this



family make it one of the more diverse lineages of Lepidoptera. These moths are mostly small, delicate, and slender bodied. The wings are usually broad and often marked with fine wavy lines. These are principally nocturnal and are often attracted to lights. The larvae are familiarly known as inchworms or measuringworms. One lineage of Hawaiian geometrids is strictly carnivorous (mostly on fruit flies) and use this characteristic inching to coil back and catch prey.

The Butterflies: Unlike the taxa above, the following monophyletic group holds their wings together vertically above the body. The paraphyletic moths hold their wings flat or wrapped around the body. The figure below (from Box 11.11 in your textbook) illustrates this. This clade altogether (with Hedyloidea) is also known as the Rhopalocera).



garden tiger moth, Arctiidae: *Arctia caja*

cabbage white butterfly, Pieridae: *Pieris rapae*

Papilionoidea: True butterflies. These five families are distinctive by their straight and clubbed antennae (Hesperoidea have hooked antennae) and their large wings. These are generally the Lepidoptera most familiar to many people.

Papilionidae: Swallowtail butterflies and snow apollo, 550 species. Swallowtail butterflies are large, colorful butterflies that form the family Papilionidae. The family includes the largest butterflies in the world, the birdwing butterflies of Australia and Papua New Guinea. Swallowtails differ from all other butterflies in a number of anatomical traits. Most notably, their caterpillars possess a unique organ behind their heads, called the osmeterium. Normally hidden, this forked structure can be everted when the caterpillar is threatened, and emits smelly secretions containing terpenes. This has often given them the name devil-dogs. The adults of the subfamily Papilioninae are often tailed like the forked tail of some swallows, giving the insect its name. Parnassiinae is the other subfamily found in our area. These are medium-sized butterflies that are usually white or gray with dark markings on the wings. Most have two small reddish spots on the wings. They are high altitude and are found in California in the Sierras.



Pieridae: Whites, sulfurs, and orange-tips (1100 species). These are medium-sized to small butterflies, usually white or yellowish in color with black marginal wing markings. The front legs are well developed. Many are very common and abundant butterflies (e.g. the cabbage whites).

Many of the following three families form associations with ants that can range from mutualistic to parasitic (the caterpillars eat the ant grubs).

Riodinidae: Metalmarks, 1,000 species. The common name "metalmarks" refers to the small metallic-looking spots commonly found on their wings. Like the lycaenids, the males of this family have **reduced forelegs** while the females have full-sized, fully functional forelegs. The foreleg of males is often reduced and has a uniquely shaped first segment (the coxa) that extends beyond its joint with the second segment, rather than meeting it flush.



Lycaenidae: Coppers, hairstreaks, blues, harvesters, 6,000 species. These make up about 40% of known butterfly species. These are small, delicate, and often brightly colored butterflies, and some are quite common. The body is slender, the antennae are usually ringed with white, and there is a line of white scales encircling the eyes. Like Riodinidae, the front legs are normal in the female, but shorter in the male.



Nymphalidae: Browns, fritillaries, admirals, and monarchs. This is a fairly large group (about 5,000 species) and includes many common butterflies. The front legs are much reduced and lack claws, and only the middle and hind legs are used in walking. Many species are brightly colored. However, the underwings are dull and in some species look remarkably like dead leaves, or are much paler, producing a cryptic effect that helps the butterfly disappear into its surroundings.



Hesperioidea: Skippers, all in the family Hesperiidae, 3,500 species. The skippers are for the most part small and stout-bodied, and they get their name from their fast and erratic flight. They differ from Papilionoidea in having the antennae widely separated at the base, and the tips are usually recurved or hooked. Most skippers at rest hold the front and hind wings at a different angle.



Kristensen, N. P. 1984. Studies on the morphology and systematics of primitive Lepidoptera (Insecta). *Stenstrupia* 10: 141-191.

DIPTERA

True Flies

(Greek, *di* = two; *pteron* = wing)

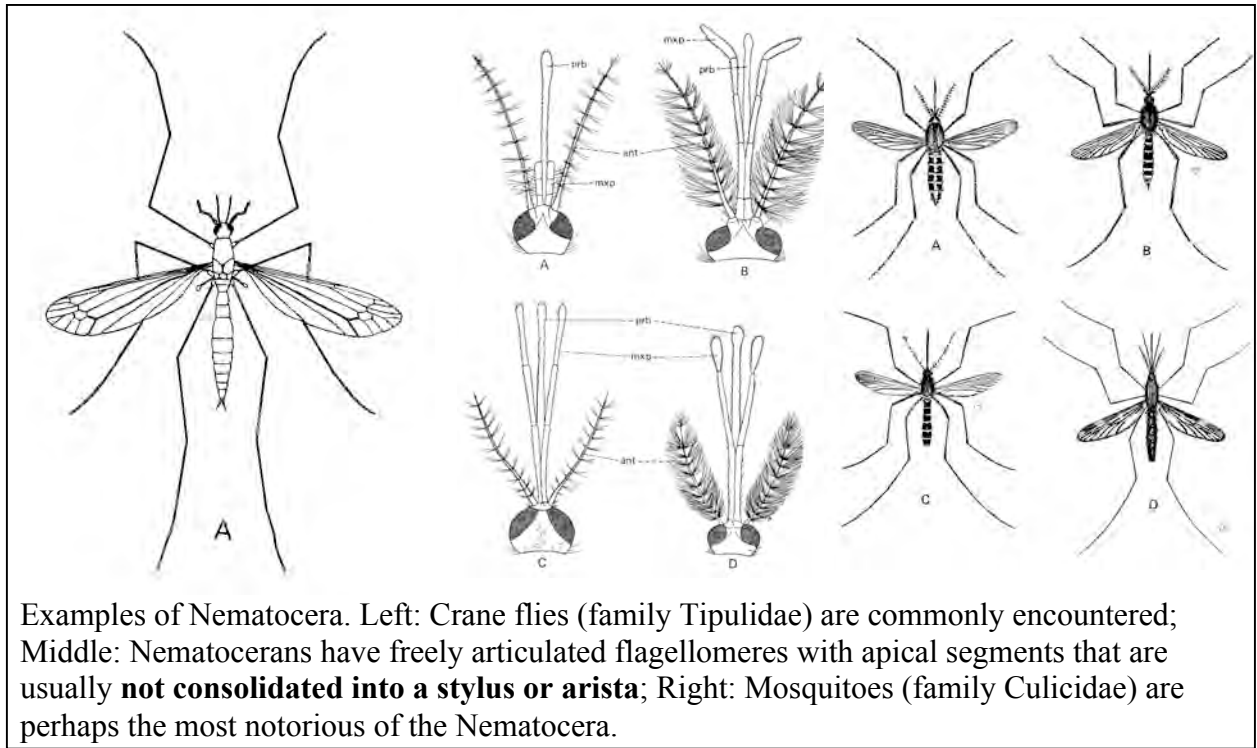
This is another diverse order of insects, being similar in diversity to the Hymenoptera and Lepidoptera (although it is considered the 4th largest order). Only the Coleoptera are considerably more diverse. Much like the parasitic Hymenoptera, this group has a high proportion of undescribed taxa, particularly in the small and/or parasitic lineages. They are very ecologically diverse, especially in the habits of their larvae. Most larvae are detritus feeders and include fully aquatic species, including those found in brine and oil; there are stem, leaf, and fruit borers; there are gall formers, flower, and sap feeders; there are carrion, feces, and garbage feeders; there are mucus feeders, parasitoids, predators, endoparasites, and ectoparasites. Adults, especially primitive species, occur in moist, shady areas and are primarily crepuscular or nocturnal. Others are diurnal. Most adult Diptera feed on honey dew, nectar, or pollen, while others are blood suckers.

The most obvious characteristic (indeed a defining synapomorphy) of the Diptera is the presence of hind wings that are reduced to halteres. Their overall shape is surprisingly uniform: the head is more or less globular, the thorax is oval or humpbacked, and the abdomen is elongate, cylindrical, or oval. They are usually dull in color (black, brown, or pale) although there are a few brightly colored forms. The body is often covered with spines, setae, and often scales. These are arranged in definitive patterns and are very important taxonomically—indeed the study of this gets its own name: **chaetotaxy**. The head has many features that are useful in identification: setae, ocelli, ptilinal fissure (which allows emergence from the pupal case), and antennae. The mouthparts are often highly modified, but are derived from a common groundplan. These include piercing sucking (mosquitos), sponging (houseflies), stabbing (horseflies), and they can even be nonfunctional. The thorax, especially the mesothorax, and wing venation are very important taxonomically.

The monophyly of the Diptera is well-established, with the first attributable fossils from the Permian. There are approximately 180,000 described species of Diptera placed within roughly **165 FAMILIES!!!** You will not be required to know all of these... Instead, note that as is often the case there is a series of nested paraphyletic groups in these. I will ask you to be familiar with the following taxa:

Order Diptera

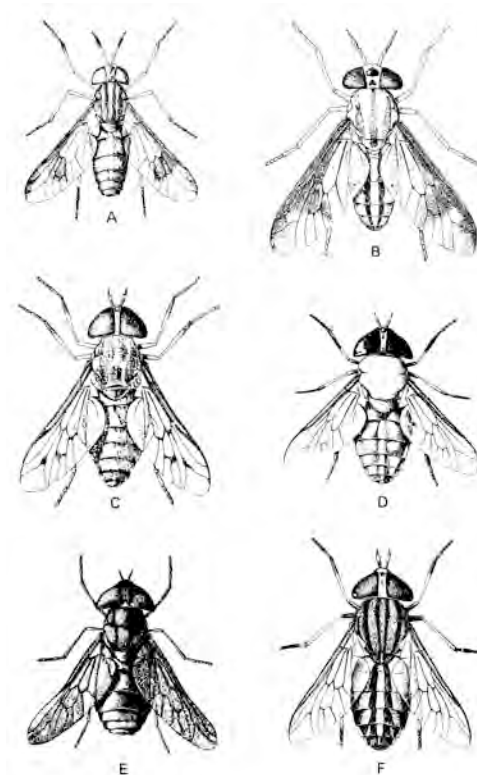
I. Suborder “Nematocera”: Examples of the Nematocera include the mosquitoes (Culicidae), crane flies (Tipulidae) and black flies (Simuliidae) - many of the remaining families (esp. Mycetophilidae, Anisopodidae and Sciaridae), are called gnats, while others (esp. Chironomidae, Cecidomyiidae and Ceratopogonidae) are called midges. Nematocera are generally primitive flies, typically recognized by filamentous, multi-segmented antennae which may be plumose in some males. This suborder is paraphyletic with respect to the remaining groups.



II. Suborder Brachycera: This suborder is monophyletic and can be distinguished from the Nematocera by the reduced antenna segmentation.

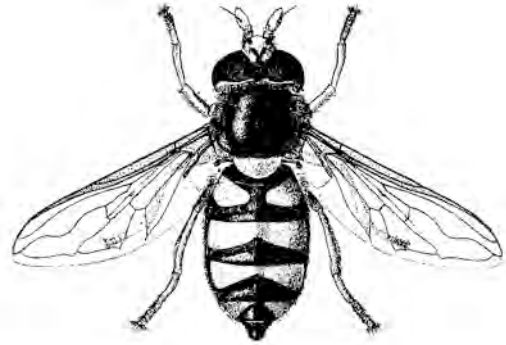
A. Infraorder Tabanomorpha: This is a small group that consists primarily of two large families, the **Tabanidae** (horse and deer flies) and **Rhagionidae** (snipe flies), and an assortment of very small affiliated families, most of which have been (or could be, or sometimes are) included within the Rhagionidae. The Tabanomorpha is one of the two Brachyceran groups outside the Hippoboscoidea that contain blood-feeding (hematophagous) species, though they are not important disease vectors.

Horse flies & deer flies (right) are rather stout-bodied, medium to large flies. The females are bloodsucking and are often serious pests of livestock and people. Note the small *aristate* antennae.



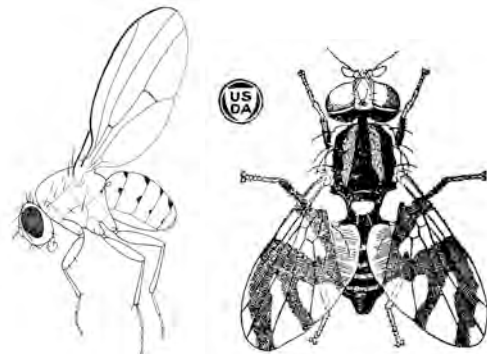
B. Infraorder Muscomorpha: The Brachyceran infraorder Muscomorpha is a large and diverse group of flies, containing the bulk of the Brachycera, and, in fact, most of the known Diptera. It includes a number of the most familiar flies, such as the housefly, the fruit fly and the blowfly. The antennae are short, usually 3-segmented, with a dorsal arista. Their bodies are often highly setose, and the pattern of setae is often taxonomically important.

1. **Section 'Aschiza':** There are two large families in this group, Syrphidae and Phoridae, and a number of smaller taxa. They are similar to most of the familiar Muscomorpha with one notable exception; they do not possess a ptilinum, and therefore lack the prominent ptilinal suture on the face as in other muscoid flies. They do still have a puparium with a circular emergence opening, but it is not as precisely ellipsoid in shape as is typical for other muscoids. Syrphidae (right) are called hover flies and are often bee mimics.



2. **Section Schizophora:** The defining feature of the Schizophora is the presence of a special structure that is used to help the emerging adult fly break free of the puparium; this structure is an inflatable membranous sac called the ptilinum that protrudes from the face, above the antennae. The inflation of the ptilinum (using fluid hemolymph rather than air) creates pressure along the line of weakness in the puparium, which then bursts open along the seam to allow the adult to escape. Once the adult emerges, the fluid is withdrawn, the ptilinum collapses, and the membrane retracts entirely back inside the head. The large, inverted "U"-shaped suture in the face through which it came, however, is still quite visible, and it is this ptilinal suture or frontal suture from which the name "Schizophora" ("split-bearers") is derived.

a. **Subsection Acalyptratae:** This is a very large assemblage, exhibiting very diverse habits, with one notable and perhaps surprising exception; there are no known acalyptrates that are obligate blood-feeders (hematophagous), though this is a life history that is common throughout the remaining Diptera. The synapomorphies of this group are somewhat obscure and we will not get into distinguishing them individually. The antennae are 3-segmented, with an arista. They lack the enlarged lower **calypter** (a small membranous flap at the base of the hind edge of the wing in some flies; it covers the halteres), longitudinal suture on second antennal segment, and greater ampulla (a swelling or blister at the base of the pleural wing process) that characterize the Calyptratae. This group includes some taxa that we have encountered numerous times or are important economically, including the **Diopsidae** (stalk-eyed flies), the **Tephritidae** (fruit flies, far right), and the **Drosophilidae** (vinegar flies, small fruit flies, near right).



- b. **Subsection Calyptratae:** this group consists of those flies which possess a calypter that covers the halteres, among which are some of the most familiar of all flies, such as the house fly. They have 3 segmented antennae, with an arista. Wings usually have a prominent lower calypter; can also be identified by a longitudinal suture on the second antennal segment and by the presence of the greater ampulla on the thorax. We commonly encounter the houseflies (**Muscidae**, below), the dung flies (**Scanthophagidae**), the blow flies (**Calliphoridae**), and the flesh flies (**Sarcophagidae**).



