Taxonomy Principles and Methods

Taxonomy

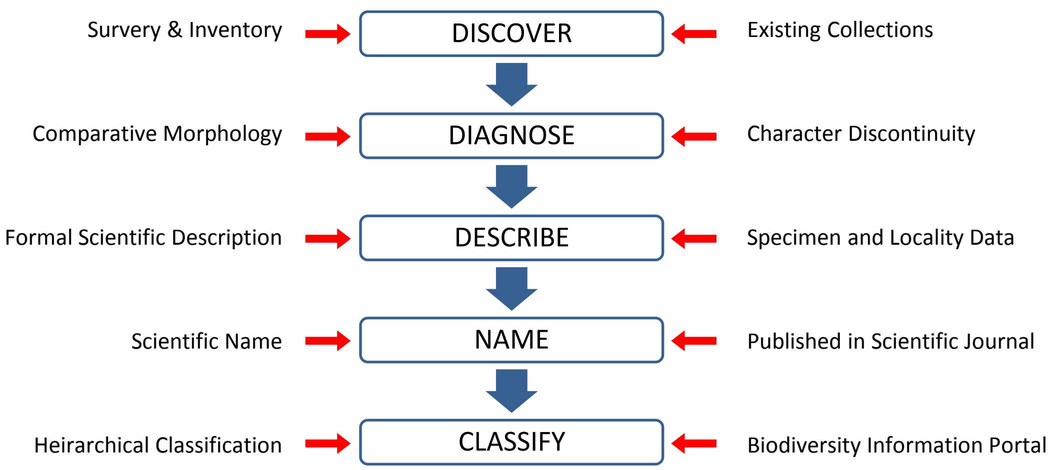
Taxonomy is the science of classifying organisms. Taxonomy results in classifications, which allow for storage, retrieval and communication of information about organisms. A key function of taxonomy is to provide correct identification of organisms. This workshop introduces participants to the taxonomic process, how to accurately identify insects to order, and what steps can be taken to identify insects to a finer taxonomic level.

The methods of taxonomy include: the discovery of species, the recognition and diagnosing of taxa on the basis of characters (e.g., morphological, molecular, behavioural, etc), the formal description and naming of species, and the placement of species within a **hierarchical classification**.

The purpose of classifications is to order organisms on Earth into a stable and universal system that enables scientists and other members of society to communicate about them. Biological classifications have high information content which allow us to store information about a taxon's morphology, genetics, distribution, hosts, ecology and life cycles.

Taxonomic methodology follows a trajectory from species discovery to the formation of classifications:

DISCOVER, DIAGNOSE, DESCRIBE, NAME & CLASSIFY



Classification

The most fundamental category in classification is the species. Species follow a system of naming called **binomial nomenclature**. This is a two-part name that includes the genus name (the first name) and the species epithet (the second name), and both are required in combination for a species name. For example, the human bedbug is known as *Cimex lectularius*, with *Cimex* being the genus name, and *lectularius* the species epithet; both are required in communicating about a species. It is critical that scientific names are unique. No two species can have the same name, otherwise confusion would result. In cases where names are independently duplicated, the younger name is replaced to maintain uniqueness in nomenclature.

It is important to understand the hierarchical nature of classifications. There are multiple categories above the species level, which indicate the placement of subordinate taxon. In classifications a taxon is a formal name at any level of the taxonomic hierarchy. The hierarchical system allows us to place taxa within the **Tree of Life**, so that all taxa are placed with their nearest relatives. For example, there are many species of bedbugs, which are related and therefore placed in a single genus, *Cimex*, but *C. lectularius* is the unique name for common human bed bug.

The hierarchical classification of the human bedbug is as follows:

PHYLUM Arthropoda

SUBPHYLUM Hexapoda

CLASS Insecta

ORDER Hemiptera

SUBORDER Heteroptera

INFRAORDER Cimicomorpha

SUPERFAMILY Cimicoidea

FAMILY Cimicidae

GENUS *Cimex*

SPECIES *lectularius*

In this case, *lectularius* is nested within *Cimex*, and *Cimex* is nested within the family Cimicidae, and so forth and so on.

Placing species into the correct place of the hierarchy involves the method of systematics, whereby the phylogenetic position of species is determined.

In practical taxonomy of the Class Insecta, the important ranks are Order, Family, Genus and Species, so we will concentrate on those.

Systematics

Systematics is the study of relationships among organisms. This includes computer-based analyses using studies of morphology and/or molecules such as DNA.

The key principles and methods of systematics are:

- phylogenetics which determines the relationships of natural taxa based on their evolutionary history
- a **natural taxon** is a group of organisms that are a result of evolution
- natural taxa are called **monophyletic** groups (or **clades**) which is a group of species that includes the most common ancestor and all of its descendants
- **artificial groups** are those that do not confirm to evolutionary processes or history (**polyphyletic** and **paraphyletic** groups)
- phylogenies are expressed as treelike diagrams, and represent the genealogic relationships of the study taxa

Zoological nomenclature

The system of giving taxa scientific names is based on a set of rules called nomenclature. In Zoology this is zoological nomenclature and the rules are called the **International Code of Zoological Nomenclature, generally referred to as the Code**. This is available online (http://iczn.org/code). For a scientific name to become available for use in science it must meet the rules of the Code. Zoological nomenclature covers the naming of taxa at all levels of the taxonomic hierarchy. There are conventions of name endings for different levels of the taxonomic hierarchy above the genus level and all family-group names (i.e., superfamily, family, tribe, subtribe), which allows users to recognise what level is being referred to.

The following hierarchical level endings that are standardised are:

Level	**Ending**	**Example**
Superfamily	-oidea	Miroidea
Family	-idae	Miridae
Subfamily	-inae	Mirinae
Tribe	-ini	Mirini
Subtribe	-ina	Mirina

Genus-group and species-group names are unique and have no standardised endings, unlike family-group names. However, there are rules governing the formation of both genus-group and species-group names, that originally followed Latin and Greek grammars; these rules are now more flexible (in the Code).

Classification of insects

The Class **Insecta** is placed in the subphylum Hexapoda in the Phylum **Arthropoda**, which includes five subphyla:

1) Pycnogonida (sea spiders, marine)
2) Euchelicerata (spiders, mites, scorpions, ticks, harvestmen, horseshoe crabs, solifugids)
3) Myriapoda (centipedes, millipedes, symphylans, pauropods)
4) Crustacea (crabs, lobsters, ostracods, amphipods, shrimp, malacastrocans, barnacles)
5) **Hexapoda** (insects, springtails, proturans, diplurans)

Arthropods (Phylum Arthropoda) are defined morphologically by the following characters:

- bilaterally symmetrical body
- rigid exoskeleton
- jointed limbs

Hexapods (subphylum Hexapoda) are composed of two classes, the Entognatha and the Insecta. They are recognised by the following characters:

- body divided into head, thorax and abdomen (tagma)
- one pair of antennae
- three pairs of mouthparts
- three pairs of **uniramous** (unbranched) limbs
- **tracheal system** of respiration

The **Entognatha** have enclosed mouthparts and includes three orders, the springtails (Collembola), proturans (Protura) and diplurans (Diplura).

The **Insecta** comprise 27-30 orders of insects, depending on the classification used. For example, some authors maintain the termites as a separate order (Isoptera), but modern classification has them nested within the order Blattodea, which includes the roaches.

There are **25 orders of insects known from Papua New Guinea**. The orders not currently known from Papua New Guinea include the Raphidioptera, Mecoptera, Megaloptera, Grylloblattodea, and Mantophasmatodea. The Zoraptera and Plecoptera are each represented in Papua New Guinea by a single species.

Insect morphology

To identify insects a student of entomology has to have a proficient understanding of morphology. Nonetheless, an understanding of basic characters and terms will enable students to identify insects to order.

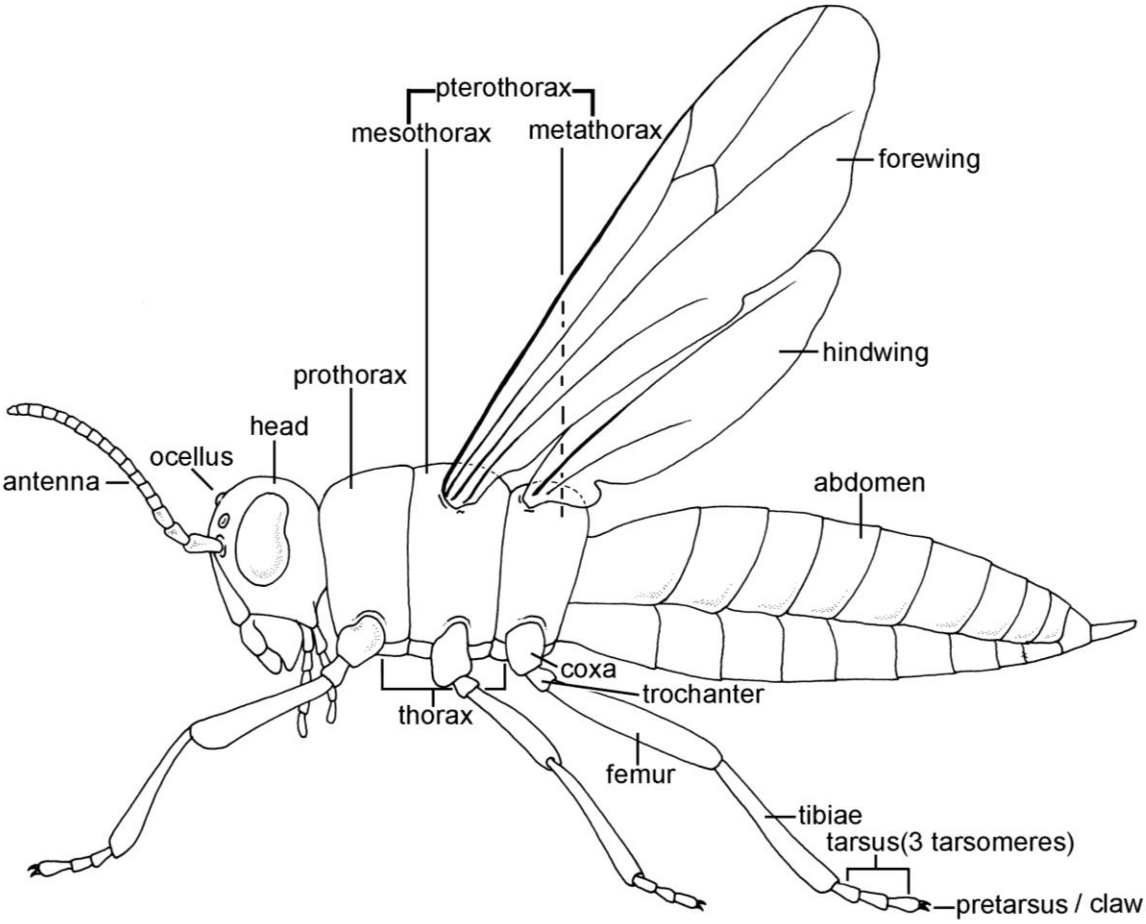
It is best to try to identify insects to the higher-level categories, such as order and family, before attempting to identify insects to genus or species.

Body organisation

The basic organisation of the insect body is as follows:

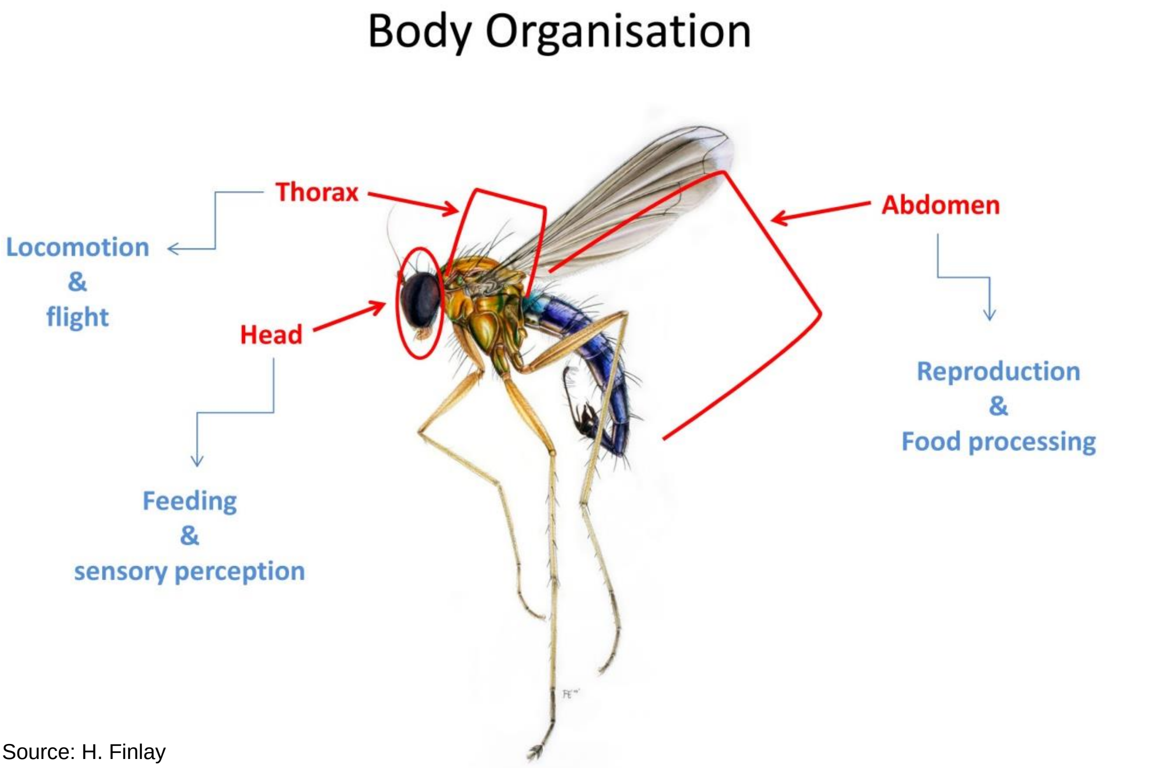
- The body in insects is organised into **head**, **thorax** and **abdomen**
- Head is apparently a single segment
- Thorax has 3 segments (often highly modified to accommodate legs and wings)
- Abdomen has 11 segments (some segments can be lost or fused)

See the following image of a generalised insect body showing the tagma (regions) and segmentation



Redrawn from Gullan & Cranston (2006)

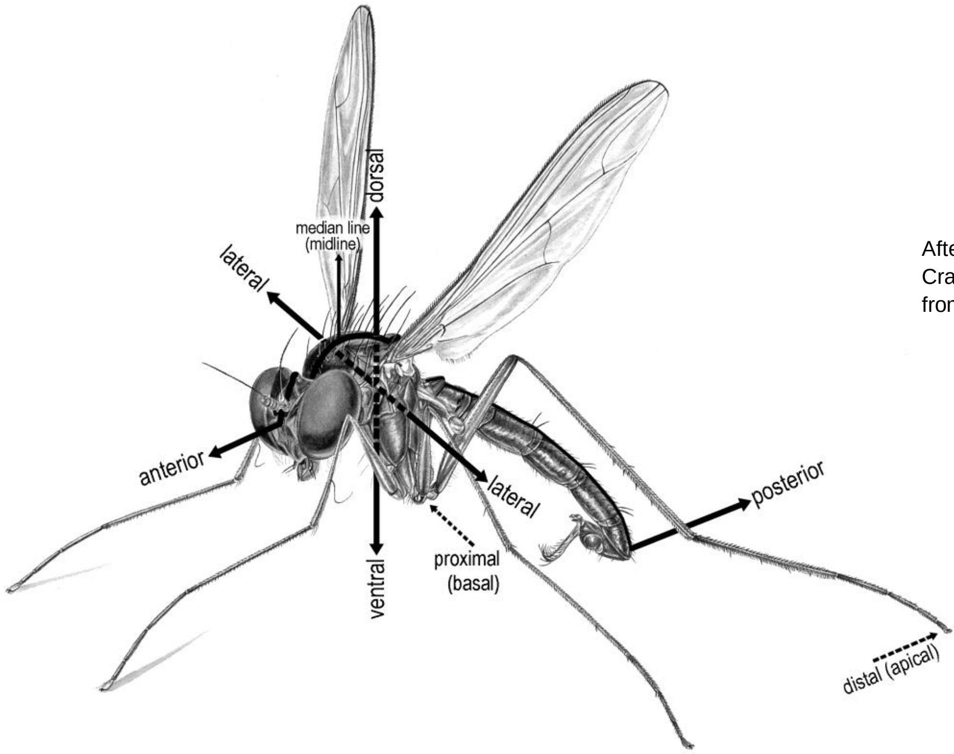
Tagmosis in insects has given them a competitive advantage and is central to their adaptive radiation. There are key functions that are associated with the head, thorax and abdomen, as shown in the following illustration.



Source: H. Finlay

How to describe positions on the body

To be able to describe, understand and communicate the morphology of an insect, a student or worker needs to understand the orientation descriptors. The following diagram provides the key descriptors that you will need to memorise.



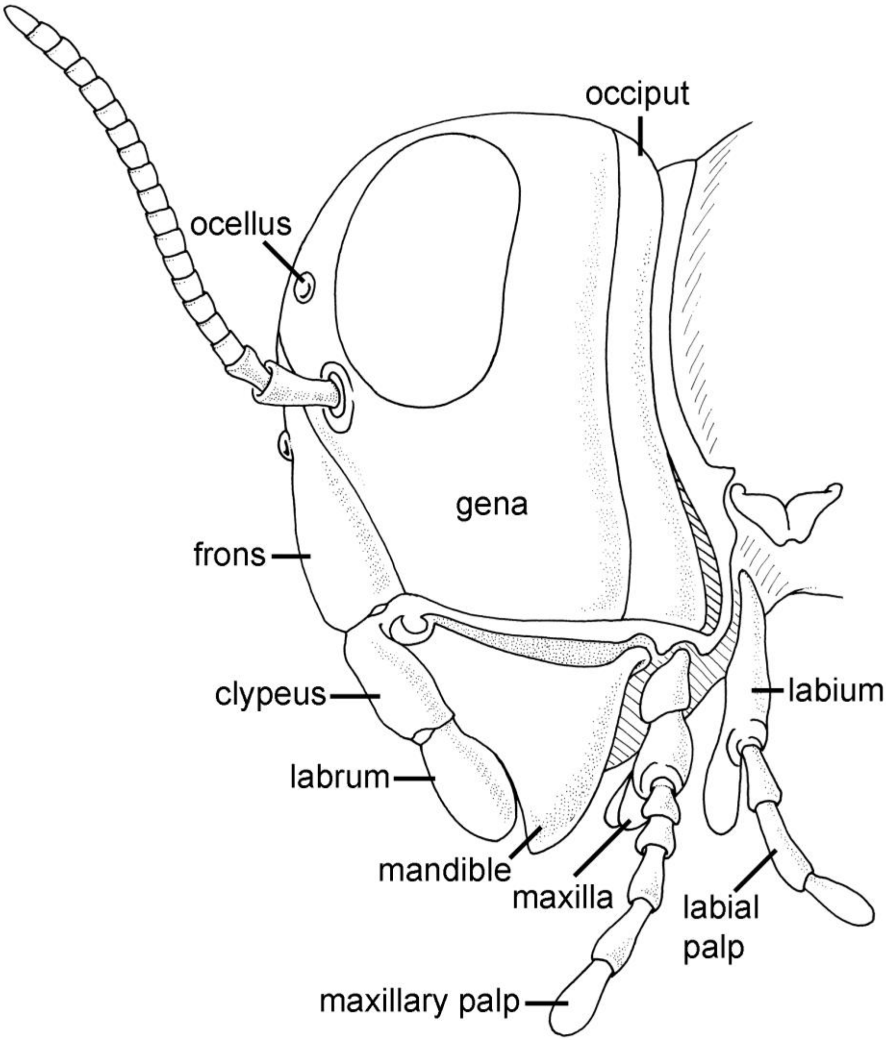
After Gullan and Cranston 2006, from McAlpine 1987

Head

Primary functions of the head include feeding and sensory perception (by sense organs). The mouthparts are for feeding and the eyes and antennae are for sensory perception of the environment. All these character systems have undergone great evolutionary modifications, and show many morphological types, particularly the mouthparts and antennae. These types are often diagnostic at the ordinal level and knowledge of them is important for achieving successful identifications.

Mouthparts

The basic insect mouth should be imagined as the entrance to a rectangular box. On top edge is a flap, the upper lip, called the **labrum**. At the sides are the opposed pair of **mandibles.** On the lower edge are two sets of appendages. First is the pair of opposed **maxillae,** each carrying a multi-segmented palp (**maxillary palps**). Below that is lower lip, the **labium**, which carries a pair of shorter palps with fewer segments (**labial palps**). This basic structure can be seen in Orthoptera for example, but is often highly modified so that the origins of the mouthparts are not clear.



Redrawn from Gullan & Cranston (2006)

Insects feed on most food sources, and the following functional feeding groups exist:

- predators
- herbivores (or phytophagous)
- omnivores (or zoophytophagous)
- saprophages, necrophages or detritivores
- parasites (ecto- and endoparasites)

We can group insects by their mode of feeding and associated mouthparts, as follows:

- Biting/chewing (**mandibulate** mouthparts)
- Piercing/sucking (through modification of various combinations of mouthparts **into a rostrum**, or **proboscis**)
- Sponging (**labellum**)

Biting and chewing mouthparts (mandibulate)

- Handle and chew solid food
- Predators, herbivores, scavengers and parasites can have mandibulate mouthparts
- Insect herbivores with chewing mouthparts are ecologically and economically important herbivores and include: grasshoppers (Orthoptera), moth and butterfly larvae (Lepidoptera) and beetles (Coleoptera)
- Predatory insects with chewing mouthparts include: mantids (Mantodea), beetles (Coleoptera), ants and wasps (Hymenoptera)
- Several insect groups are able to consume wood, using chewing mouthparts, such as termites (superfamily Termitoidea)

Piercing and sucking, or siphoning mouthparts (rostrum, labium, proboscis, stylet, haustellate)

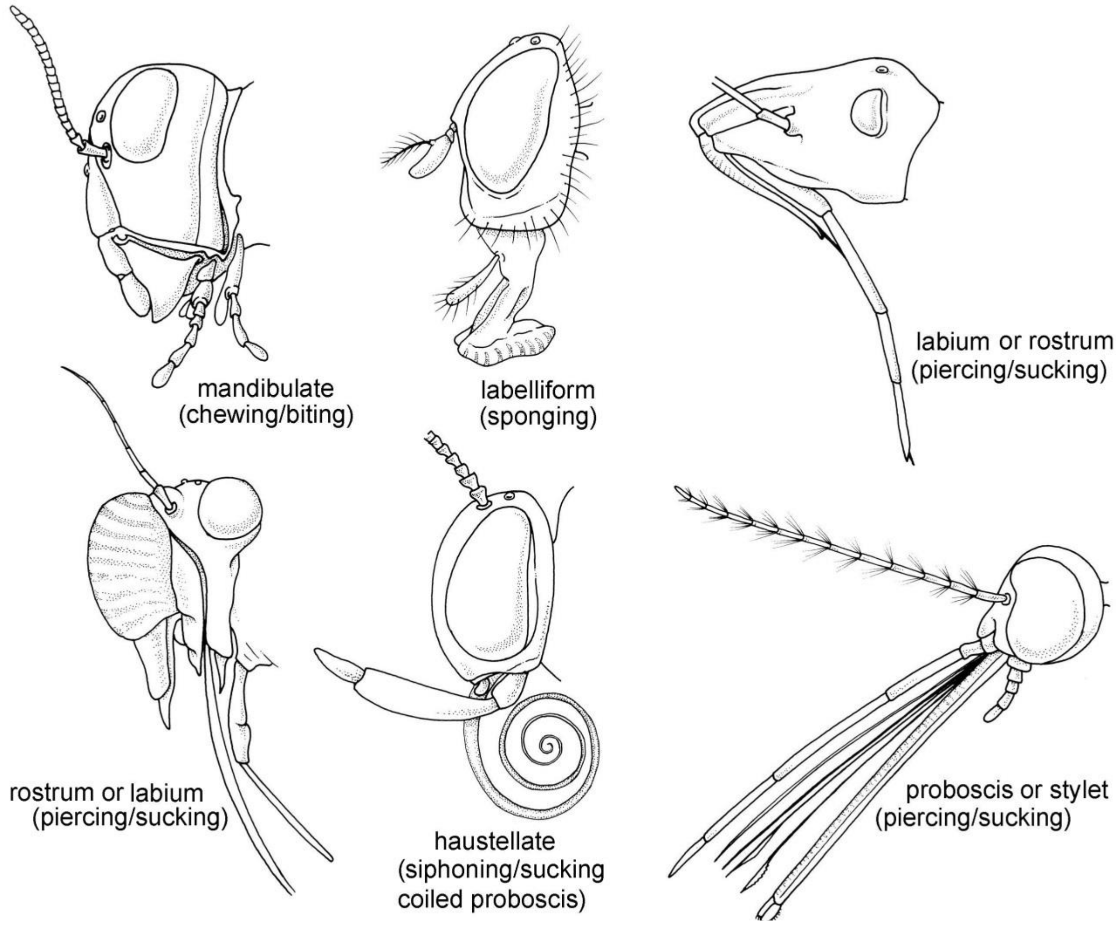
- Mouthparts modified to consume liquid food
- Predators, parasites, herbivores of different insect groups have piercing and sucking mouthparts
- Feeding method has evolved independently many times among the insects

- Different arrangements of mouthparts involved in different groups
- Orders of insects with piercing/sucking mouthparts include Thysanoptera (thrips), Hemiptera (bugs), Diptera (some flies), Lepidoptera (moths and butterflies)
- Several insect groups specialise on nectar, including butterflies (Lepidoptera) and bees (Hymenoptera)

Sponging mouthparts (labellum, labelliform)

- Mostly scavengers or parasites
- Labium modified to form labellum
- Some groups of flies (Diptera)

The following illustrations show the structures associated with these modes of feeding and mouthpart types:



Antennae

Insects have a pair of antennae, which are moveable and segmented, and ancestrally might have been only eight segments. Modern insects can have 0 to 50 segments.

The most basal segment is called the **scape**, the next segment the **pedicel**, and the remaining segments are referred to as the **flagellum**.

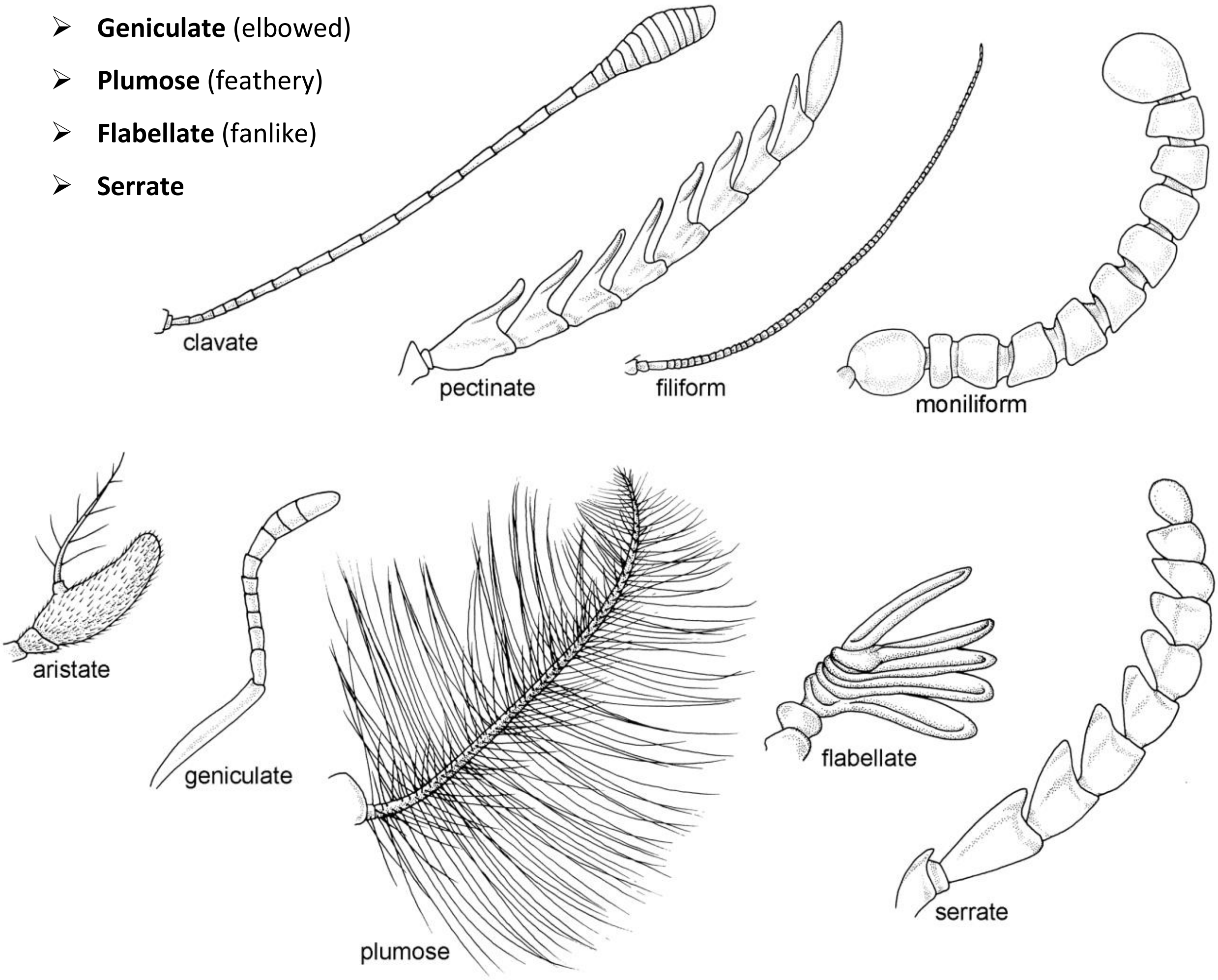
The variation in the antennae in insects is remarkable, not only in the number of segments, but also shape. For example each segment can have long lateral projections, particularly common in some moths.

Some antennae are so specialised and distinctive that insect orders can be identified on antennal morphology alone. For example, some groups of flies, have three segmented antennae plus a bristlelike structure, called the **arista**.

Other antennal types include:

- **Clavate** (clubbed)
- **Pectinate** (comblike)
- **Filiform** (threadlike)
- **Moniliform** (beadlike)
- **Geniculate** (elbowed)
- **Plumose** (feathery)
- **Flabellate** (fanlike)
- **Serrate**

Note: some insects may have a combination of different antennal types, especially beetles. An example being: moniliform and loosely clavate apically



Visual system

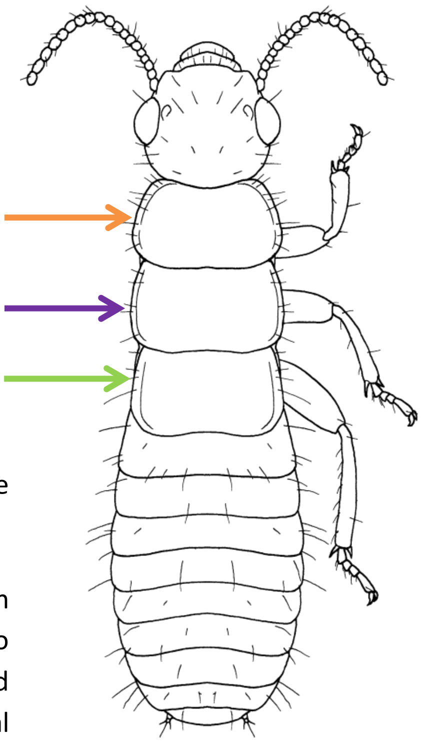
The visual system of insects comprises light gathering organs which may differ between adults and immatures. These include

- 1- 3 **ocelli** (lost in some groups)
- Larval **stemmata**
- **Compound eyes, which are dense clusters of** many light receptive units (**ommatidia**)

The structure of the visual systems is useful in identifying insect groups but shows considerable variation.

Thorax

The thorax of insects is comprised of three segments, which are alike in the most 'primitive' insects.



The three segments are referred to as the:

- **prothorax**, the anteriormost segment, which bears the anterior legs or forelegs
- **mesothorax** is the middle segment and bears the anterior pair of wings, and the middle legs
- **metathorax**, the posteriormost segment bears the hind wings and the hind legs

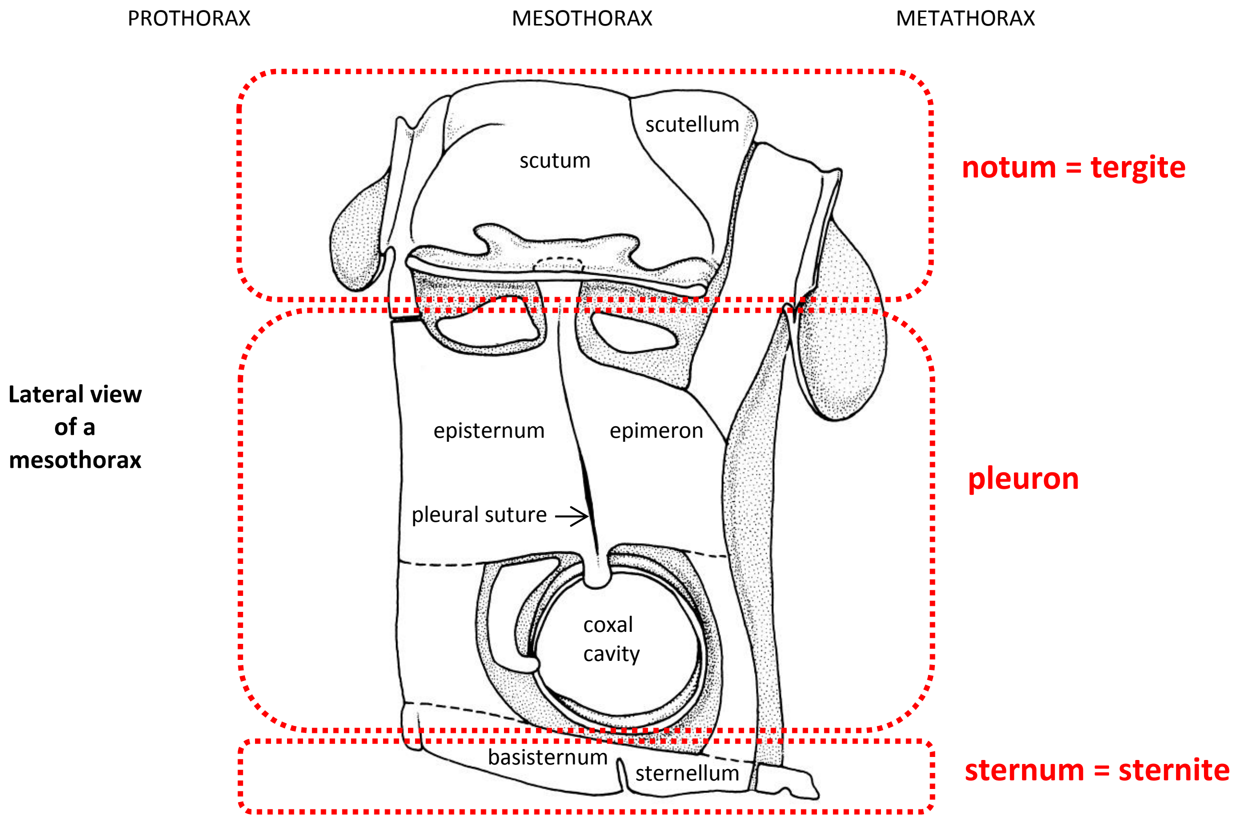
The last two segments are collectively referred to as the **pterothorax**; the prefix **ptero–** is meaning winged.

The exoskeleton of the thorax is box-like and accommodates both the legs and wings, and the enlarged musculature required to move them. It is often heavily sclerotised. The legs are inserted into cavities on the side or underside of the body, called coxal cavities. The wings are articulated on the dorsolateral edge of the pterothorax.

Each of the three thoracic segments bears a pair of legs:

- The legs of the prothorax are called the prolegs or forelegs, and the components of the forelegs have the prefix **fore**-, e.g., forecoxae, forefemora etc
- The legs of the mesothorax, are called the midlegs, and the components have the prefix **meso**-, e.g., mesocoxae, mesofemora
- The legs of the metathorax are called the hind legs, and the components have the prefix **meta**-, e.g., metacoxae, metafemora

Each of the three thoracic segments is divided into three sections or plates from the dorsal to ventral surfaces, the **notum** (dorsal plate), **pleuron** (lateral plate) and **sternum** (ventral plate). These are often sclerotised, and further divided again into different sections. These plates and their component parts follow the same naming conventions using the **pro-**, **meso-** and **meta-** prefixes denoting which thoracic segment they are from. For example, the dorsal plate of the **mesothorax** is called the **mesonotum**, lateral plate of the mesothorax is called the **mesopleuron**, and ventral plate of the mesothorax is called the **mesosternum**.



Redrawn from Gullan & Cranston (2006)

The **pronotum** is therefore the dorsal plate of the first thoracic segment or **prothorax** and its structure is important in insect identification.

Legs

Nearly all insects have three pairs of legs, although some insects, particularly larvae, have become greatly specialised, occupying microhabitats were legs are of little use, and they can be secondarily lost.

The legs are however not just confined to movement. Insects use their legs for capturing and holding their food. The legs are involved in male-male sexual combat. The legs are packed with sensory units. They are specialised in bees to collect pollen.

The leg of an insect is divided into six segments:

1) **Coxa** (pl. coxae) – the coxa is most often cone like, and is the point of articulation with the thorax, and has varying degrees of mobility depending on the insect group.

2) **Trochanter** (pl. trochanters) – articulate the coxa to the femur, usually small and triangular

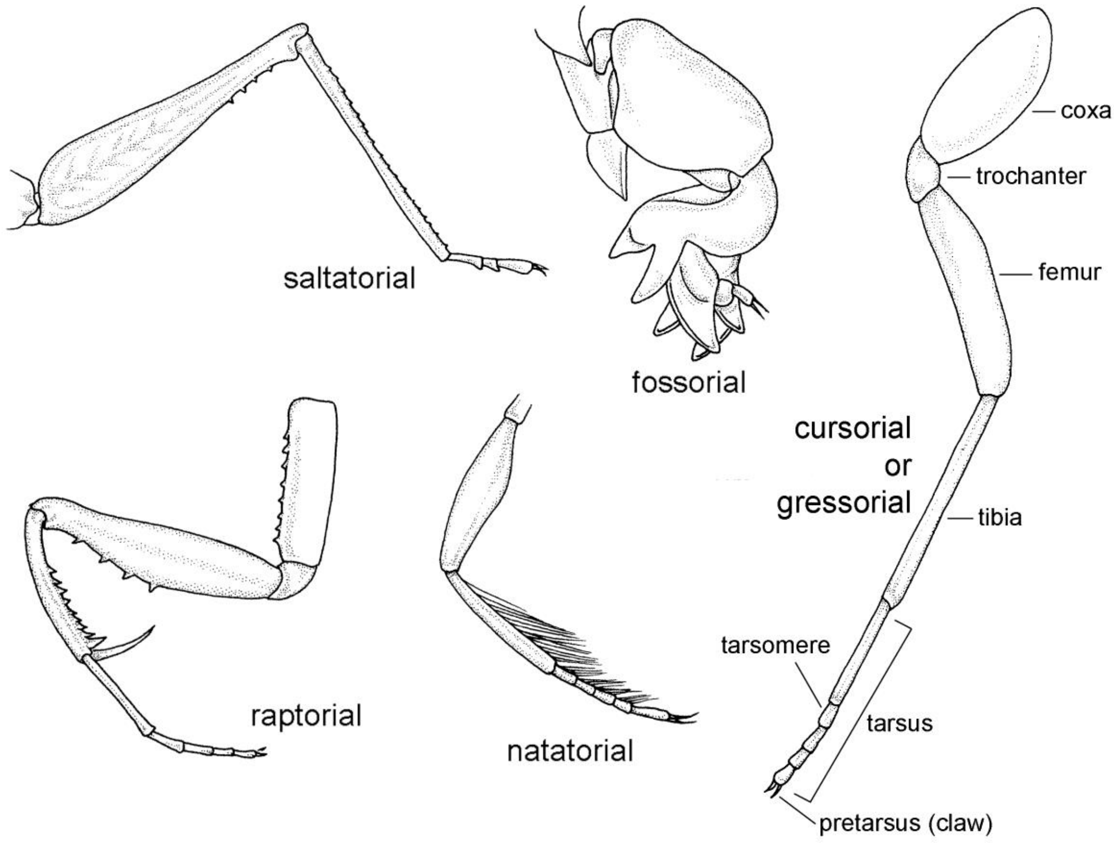
3) **Femur** (pl. femora) – is generally small in larval insects, but in most adult insects is the most robust segment of the leg.

4) **Tibia** (pl. tibiae) – is the long shank of the leg and it moves in the vertical plane.

5) **Tarsus** (pl. tarsi) – the tarsus is divided into 1-5sub-segments, which are called **tarsomeres**. The tarsomeres can move independently.

6) **Pretarsus** (pl. pretarsi) – is the apical most segment, and the smallest. It is the point of contact between the insect and its environment. It is most often composed of 1-2 claws, and there may be a lobe-like structure between the claws, called the **arolium**, which has a supporting or attaching function.

Insect legs are specialised for different modes of locomotion, including walking (= **gressorial**), running (= **cursorial**), jumping (= **saltatorial**), digging (= **fossorial**) and swimming (= **natatorial**). These leg types are consistent with some taxonomic groups of insects (e.g., aquatic bugs have natatorial legs), and by the same token, different taxonomic groups can have the same leg type (e.g., dung beetles, burrowing bugs, and mole crickets have fossorial legs). In a few groups, notably the Mantodea, the fore legs are modified for ambush predation (**raptorial**).



Wings

Insects were the first animals to evolve flight and are the only invertebrates that have the ability to fly. Flight evolved only once in insects, early on in the evolution of insects (the Pterygota) during the Devonian over 350 million years ago. The evolution of flight is a major reason for the evolutionary and ecological success of insects.

Insect wings are characteristic of many groups of insects. This is particularly the case at the ordinal level, where the wings of groups such as Odonata, Ephemeroptera, Blattoidea, Dermaptera, Psocoptera (Psocodea), Coleoptera, Diptera and Lepidoptera could not be confused with any other insect order.

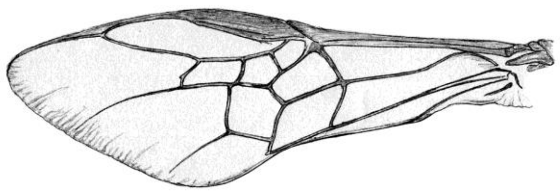
Major wing types of insects are (and see following page):

- Dragonflies (Odonata) have two large wing pairs, equal or about equal in size, with the hindwing without an anal lobe, and with complex venation, including multiple cross veins.
- Roaches (Blattodea) have leathery, protective forewings, which are called **tegmina**, and have complex venation but without cross veins. Earwigs (Dermaptera) also have tegmina, but in their case there is no forewing venation.
- True bugs (Hemiptera: Heteroptera) have the forewing divided into a hard proximal part and a soft membranous distal part; this type of forewing is called the **hemelytron** (pl. **hemelytra**). The hemelytra overlap distally.
- Beetles (Coleoptera) have the forewings hardened, without venation, and they meet along the midline (do not overlap), and are called **elytra.**
- Moths and butterflies have the forewings have a closed proximal cell with radiating veins, which are covered on both surfaces with overlapping scales.
- Flies (Diptera) have the hindwings reduced to a paddle-shaped structure, called the **haltere**, which counterbalances the forewings.
- Booklice (Psocodea) and psyllids (Hemiptera: Psylloidea) have membranous wings held tent-like over the body, but each group has its own distinctive venation.
- Thrips (Thysanoptera) have fringed wings that are very narrow, narrower than the body.

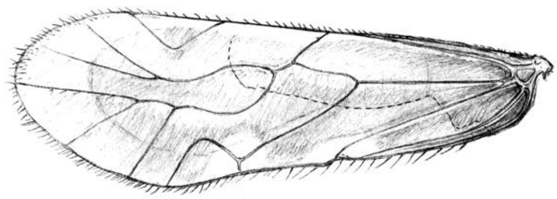
Wing Shortening, loss and polymorphism

In some taxa that have become specialised and do not need to fly, there is a shortening or even loss of the wings. Some orders such as fleas (e.g., Siphonaptera) are exclusively wingless. Some eusocial insects have winged and wingless castes (e.g., ants, termites). Some insect species exhibit wing polymorphism, and can have fully winged and short winged individuals. Wing polymorphism can complicate the correct identification of species. In the ordinal key you will need to differentiate between winged and wingless taxa. In winged taxa there is always at least a stub of the wing present, articulated on the thorax.

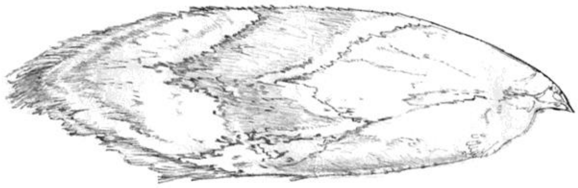
Examples of some of the variety of different forewings found amongst the insect orders:



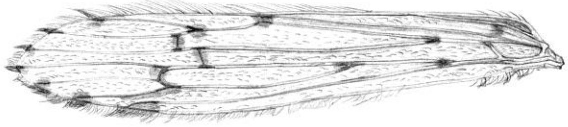
Hymenoptera



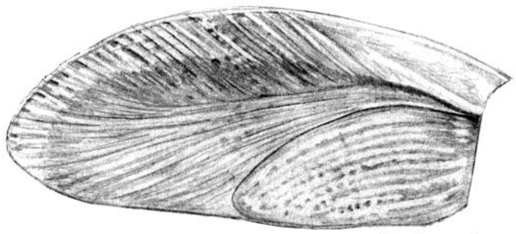
Psocodea



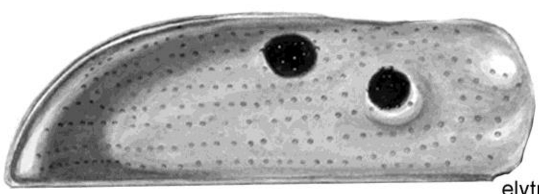
Lepidoptera



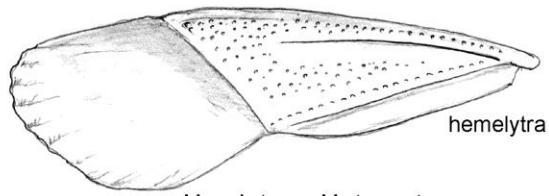
Trichoptera



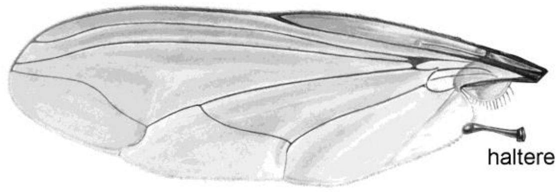
Blattoidea leathery tegmina



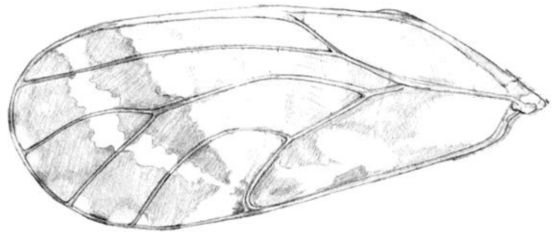
Coleoptera elytra



Hemiptera: Heteroptera



Diptera



Hemiptera: Psylloidea

Thysanoptera

Abdomen

The insect abdomen was ancestrally composed of eleven segments. The first seven segments in females and the first eight segments in males are referred to as the **pregenital abdomen**. The segments beyond are called the **terminalia**, and house the **female** and **male genitalia** respectively. In more primitive insects like mayflies, the apex of the abdomen has long multisegmented appendages, cerci. The female terminalia may be modified into an egg-laying tube, called the ovipositor, from which the eggs can be deposited on various substrates. The terminalia in many insects are internal.

The male and female genitalia are often used in distinguishing insect taxa. In this workshop we will not focus to any great extent on the morphology of the abdomen and its value in identifying insect taxa.

Insect life stages and development

Insect growth and development varies with three main types of development: **ametabolous**, **hemimetabolous and holometabolous.** Insect growth is discontinuous as it is limited by the relatively rigid skin, so growth progresses by moulting the skin. Each immature period between moults is referred to as an **instar** or **stadium**.

Ametabolous development

In the basal (= 'primitive') orders Archaeognatha (bristletails) and Zygentoma (silverfish) growth is indeterminate (individuals continue to moult until they die), although they do increase in size when they reach adulthood. In ametabolous insects, the larvae resemble adults but lack genitalia.

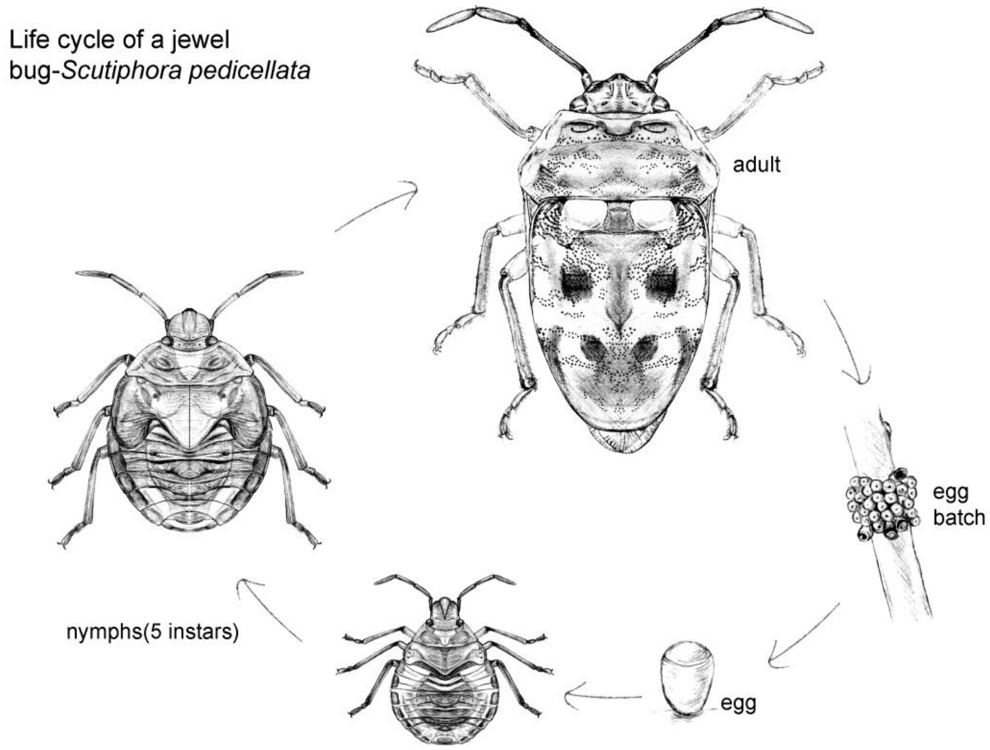
Hemimetabolous development

Hemimetabolous or incomplete development involves repeated stages of moulting and growth, where the immatures (= nymphs) and adults are similar in morphology, but the nymphs lack wings and genitalia. The wings are developed externally, with nymphs having wing buds, which explains why such insects are called **exopterygotes**. There are five nymphal stages. Hemimetabolous orders include the Ephemeroptera (mayflies), Odonata (dragonflies), and the orders of the Polyneoptera (= Orthopteroid orders) – Plecoptera (stoneflies), Dermaptera (earwigs), Embioptera (webspinners), Blattodea (cockroaches & termites), Mantodea (praying mantis), Phasmatodea (stick insects) and Orthoptera (grasshoppers & crickets); and Paraneoptera (= Hemipteroid orders) – Psocodea (bark lice, true lice), Thysanoptera (thrips) and Hemiptera (bugs, cicadas, scales & others).

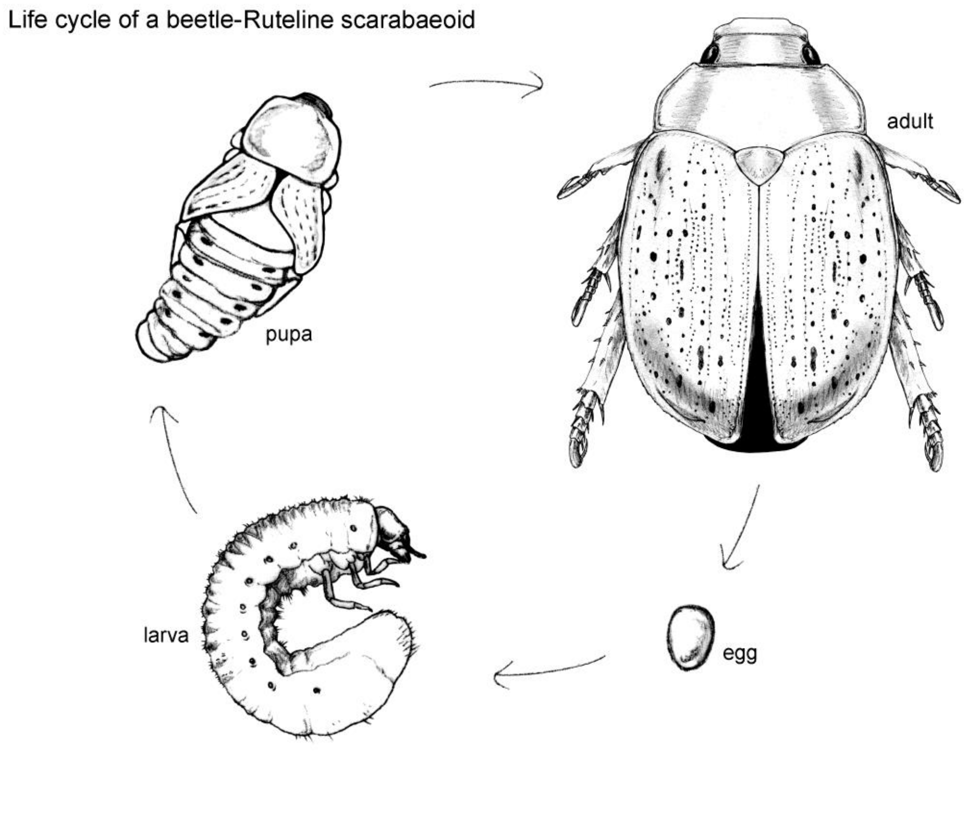
Holometabolous development

The majority of insects undergo holometabolous or complete metamorphosis, where there is a major reorganisation of the body. This results in very different bodies of the immatures (= larvae) and adults of the same species (e.g. caterpillars and butterflies). This dramatic metamorphosis occurs during the inbetween pupal stage. The wings are developed inside the body hence the name **endopterygotes.** Holometabolous development occurs in the 'Big 4' insect orders – Coleoptera (beetles), Diptera (flies), Hymenoptera (bees & wasps) and Lepidoptera (butterflies & moths), as well as Neuroptera (lacewings), Siphonaptera (fleas) Trichoptera (caddisflies), Raphidioptera (snakeflies), Megaloptera (dobsonflies), Mecoptera (scorpionflies) and Strepsiptera (strepsipterans).

Hemimetabolous:



Holometabolous:



How to identify an insect

The identification of organisms is one of the most important outcomes of the taxonomic process. It is critical that other taxonomists and biologists can reliably and accurately identify taxa. This workshop introduces the students on the process of identifying organisms through a variety of information sources and processes.

The most commonly used tool employed to identify insects is the **identification key**. These are constructed by taxonomists to aid specialists and non-specialists alike to differentiate between taxa by the recognition of differentiating characters (i.e., **diagnostic** characters). The above documentation of morphological characters serves as a basis for understanding the diagnostic characters given in the following key to insect orders.

Up until the last 20 years, most identification keys were **dichotomous**, which were designed for the user to differentiate between characters within a **couplet**. Sometimes a couplet will be two states of one character. (e.g., antennae pectinate vs antennae clavate). However, in many cases one character is insufficient to differentiate all taxa on either side of the couplet, and supporting diagnostic characters are provided. There are also many cases where there are exceptions, and qualifying options are given (e.g., antennae mostly pectinate, or if filiform never with spines on the legs).

In the last 20 or so years, there has been the development of what are called **matrix keys** (e.g., LUCID, DELTA), where all characters of each taxon are recorded, and the identification process can begin with any character. This is in contrast to dichotomous keys, where the identification pathway is fixed, and prior knowledge of character states is required. Matrix keys are popular and generally easy to use. They usually require less background knowledge of morphology to operate, however, they are significantly more time consuming to construct. Some taxonomists prefer dichotomous keys because they are more expert based and can be more efficient, depending on the quality of the key.

In this workshop we will expose participants to both dichotomous and matrix keys. For this workshop we focus on the identification of insect orders.