Biodiversity Capacity Building in Papua New Guinea and Sustainable Development of its Primary Industries

INSECT DIAGNOSTICS WORKSHOPS

2014 - 2016

PAPUA NEW GUINEA

UNSW AUSTRALIA
pestnet
AUSTRALIAN MUSEUM
NARI
Australian Aid
Australian Government
Department of Foreign Affairs and Trade

Foreword – About This Manual

This is the fifth version of the manual. Working versions of this manual were created for the four capacity building workshops in Lae, November 2014, Madang, June 2015, Keravat, November 2015 and Port Moresby, May 2016.

The purpose of this manual is to provide workshop participants with a guide on how to collect, preserve, curate and identify insects in Papua New Guinea. This manual also includes information in each section on where to find further entomological resources, including materials from the primary taxonomic literature to websites, tablet and smartphone apps, blogs and books. It serves as a framework for the workshops as well as definitive information on insects that can be used after the workshop. The information is tailored to be relevant to Papua New Guinea.

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Acknowledgements

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Project Website

For more information about this project go to our website below. All the information in this manual has been made available at this site online. Full PDF copies of both this manual and the insect order key separately are available to download.

http://unsw.discoverlife.org/png/

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Introduction

Project overview

Sustainable development of primary industries and protection of natural resources are fundamental to Papua New Guinea's future. Insects likely represent over 60% of Papua New Guinea's biodiversity, however the insect fauna remains poorly known. Capacity building, to enhance knowledge of insect biodiversity in Papua New Guinea and to develop skills in the identification of pest and beneficial insects, will ultimately enhance the development of Papua New Guinea's agricultural, forestry, conservation and quarantine sectors in a sustainable way.

Capacity building insect diagnostic training workshops have been developed for this purpose and will be undertaken in four regional centres across Papua New Guinea, Lae, Madang, East New Britain and Port Moresby, from 2014 to 2016.

This training will provide participants with essential skills to accurately identify insects, in particular species of economic significance, and to more efficiently access, record, retrieve and share biodiversity information for diagnostic and development purposes. The capacity building concept also provides trained workers to pass on knowledge through appropriate integration with extension services within Papua New Guinea.

The project brings together expertise in insect taxonomic and tropical agricultural pest identification and management through the University of New South Wales (UNSW), Australian Museum (AM), PestNet and Discover Life and is being undertaken in collaboration with the National Agriculture Research Institute (NARI). The Project is being managed by UNSW, with NARI as the counterpart organisation.

This project has been made possible by funding support from the Australian Government through the Department of Foreign Affairs and Trade (DFAT) and the Pacific Public Sector Linkages Program (PSLP).

Collecting Insects

Overview of major techniques

There are two major collecting approaches to sampling insects: **active collecting,** such as sweep netting, foliage beating, searching the ground, under rocks, sifting leaf litter, peeling tree bark; and **passive collecting,** where traps are set to either attract or intercept insects including pitfall traps or baited pitfall traps, malaise and flight intercept traps, light traps and collecting at a light sheet, sticky traps, pheromone traps and yellow pans.

Different collection methods are used to target **different types of insects,** such as crawling insects, flying insects, plant inhabiting insects, ground dwelling insects, and cryptic insects.

The most suitable method used in any particular situation will always be dependent on the aims of the collecting and the types of insects that are being targeted.

For example, a biodiversity assessment of an area would more likely use a range of broad scale passive trapping methods targeting a range of insect groups. Whereas, agricultural pest monitoring for one particular insect species or targeted collecting of one particular group may involve more active collecting and less of a range of methods, for example sampling a crop with a beating sheet and active searching of foliage, or for butterfly collecting, simply a sweep net and a great deal of patience!

And it should be noted that in many situations more than one method of collection may be required or may result in more success in targeting a particular species or group of species, especially as different life stages of the same insect often inhabit different habitat niches and have different modes of life (e.g. flying butterflies and moths with (usually) plant eating crawling caterpillar larvae).

There are **advantages** and **disadvantages** to all of the methods, and unless one is undertaking a broad insect biodiversity assessment of an area it's generally a good idea to design sampling / collecting (and also specimen processing) so as to **minimise "by catch" of non-target species** as much as possible, for a more efficient working practice.

Whilst there are many excellent references that cover all collecting methods in detail (some given at the end of this section), below we focus on collection methods that will be used in the workshop and that target the collection of flying insects and insects associated with plants.

Collection techniques for plant associated and flying insects

Active plant sampling:

Foliage Beating or Beat Sampling: A beating sheet or beating net is held under vegetation and the foliage firmly tapped with a beating stick to dislodge insects from the branches falling into the net. Insects are collected off the sheet or net using an aspirator or by hand into a container if they are too large to fit through the aspirator tube. Samples from each plant species should be kept separate, as discussed in the following section. This is an effective method for many plant inhabiting insects including beetles, bugs, psyllids, caterpillars, and bug and beetle larvae.

Sweep Netting: Generally a net with a long pole and deep mesh bag is used, either to collect large flying insects individually (butterflies wasps, flies, dragonflies) or by sweeping over foliage in a back and forth / figure of 8 pattern many small insects hidden in the foliage will be collected.

Hand Collecting or Visual Checking: A useful method in support of beating and sweeping and plays an important support role in agricultural sampling, being useful for detecting pests such as aphids and silverleaf whitefly, *Bemisia tabaci* (Hemiptera: Sternorrhyncha). While checking leaves for adult or larval leaf feeding insects, buds and flowers should be separated to search for eggs or small larvae too. This may also incorporate looking around on the ground for insects and digging around the base of the plant and checking roots of crops. Collect specimen samples into either ethanol or dry vials (see Appendix on page 189).

Passive sampling of flying insects:

Yellow pans: Small yellow plastic dishes are placed on the ground (see photo right). Dishes are half filled with water and a drop or two of detergent (to break the surface tension). Collect the yellow pans at the end of the day. Transfer specimens to an alcohol vial. Salt may be added to the water as a preservative if yellow pans are left out for longer. Note that many insects are attracted to yellow and pan traps are very efficient collecting devices for flies, small wasps and certain groups of beetles.

Setting a line of yellow pan traps for the day

Light trapping:

(i) Light sheet: Use of a light next to a white sheet. This involves setting up a white sheet, usually using tent poles and ropes, beside which a mercury vapour (MV) or fluorescent light is fixed. Insects attracted can be collected into specimen vials. Note: safety glasses should be worn when working at a MV light to protect eyes because of the UV emitted. Light traps attract a myriad of insects, primarily moths, but also terrestrial and aquatic bugs and beetles, wasps and mantids, while different species may arrive at different times throughout the night. To some extent this is not passive sampling, as the insects have to be found and collected by the collector at the sheet.

A mercury vapour light trap setup at sunset

(ii) Black light (UV) bucket traps: This is a passive collecting method using light, which can be left unattended. A UV-strip light is held vertically between 3 vanes which balance the light over a large funnel placed over a bucket shaped container. Many insects attracted to the light will fall downwards into the bucket through the funnel. Inside the bucket crunched up newspaper or cardboard (broken egg cartons are good) are placed to increase surface area for the insects to shelter, lessening the amount of damage they may cause each other. This is important, because bucket traps tend to collect beetles which can damage moths simply by running around. The insects are killed as they accumulate. A slow

Collecting at a light sheet after dark

release method of killing the insects over a long period of time is ideal, for example, using a wick in a bottle of ethyl acetate. Some of the vaporising chemical should be put on the paper or egg-cartons to stun or kill the first arrivals.

Malaise Trapping: A malaise trap is a tentlike trap, which captures aerial insects. This is a mass trapping exercise where all specimens are captured in a large jar, which is usually filled with ethanol. These can be set up for a varying amount of time, for example a week. These traps work by intercepting insects in flight and so work best when positioned in natural flight paths of flying insects, such as forest edges or clearings, on forest tracks or riverbanks. They are particularly good for collecting wasps, flies, beetles, and bugs.

Sticky Traps: Adhesive (paint on or as pre-prepared strips) surface designed to collect insects that may wander or alight onto the surface and are often attached to tree trunks or attached to poles amongst crops (see phot below right). Although not widely used for general insect collecting (hard to handle and easy to damage insects in the process of removing them), they can be good for capturing flies, wasps and beetles, as well as other flying insects ants and other flightless inhabitants of tree trunks. A yellow substrate (card or plastic) is often used to attract insects.

Pheromone Traps: Used for pest monitoring, these traps attract insects with a specific chemical lure based on the sex pheromone of a particular species. They therefore generally only trap one sex of one species, usually males. They are usually designed with a sticky surface around the chemical lure so that numbers of individuals can be estimated. Trap designs include pots and shelters, so that trapped insects are not destroyed by rain. Pheromone traps can quickly attract large numbers of species that are not evident from general collecting, such as the sweet potato weevil, *Cylas formicarius* (Coleoptera: Brentidae).

Bucket light trap powered with 12V battery

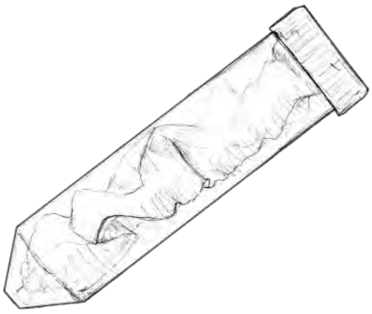
Malaise trap

Setting yellow sticky traps in an agricultural field

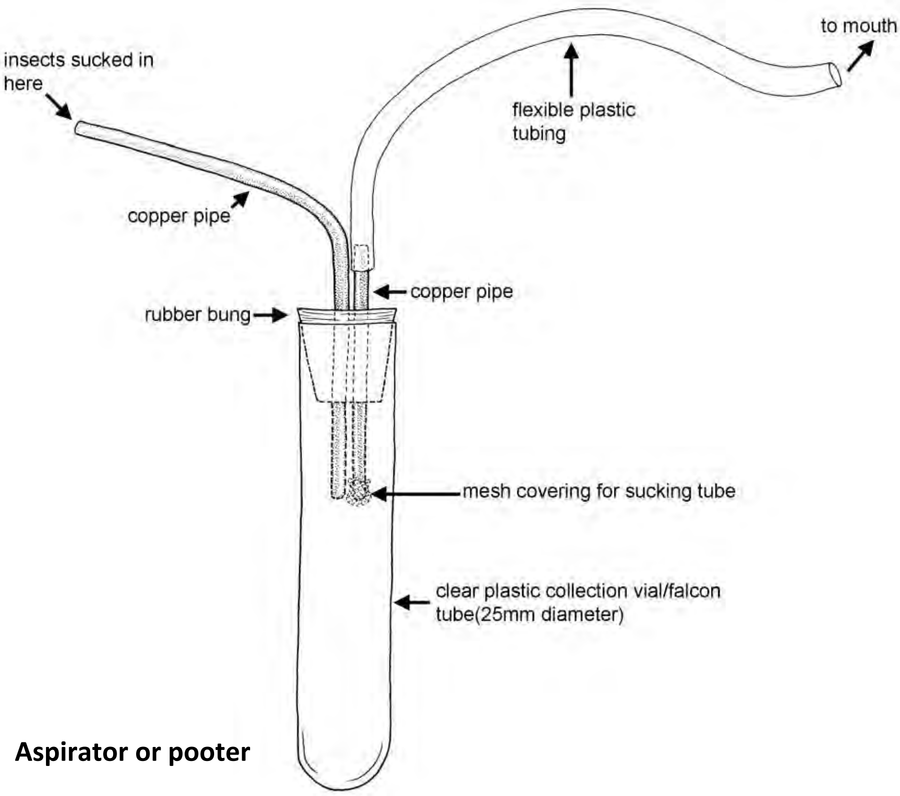
Method for collecting insects from host plants

Packing list for field sampling

- Beating net and stick – a shallow calico or nylon bag on a metal hoop with a short wooden handle.
- Aspirator.
- Prefilled ethanol vials – to collect some specimens straight to ethanol in field.
- Collecting transfer tubes with strips of tissue or toilet paper inside – for dry collecting.
- Notebook.
- Pen/Pencil.
- Label card – small squares pre-cut is a good idea.
- GPS (if you have access to one, not essential).



Collection transfer tube with tissue inside – empty and ready for collecting



Aspirator or pooter

Beat sampling method and handling of samples

When targeting host specific insects, keep beat samples from different plant species separated. At a site sample multiple individuals of a particular plant species using the foliage beating or beat sampling technique. Once sampling has been completed from a particular plant species, transfer the specimens from the aspirator tube to a collection transfer tube, before commencing from another plant species.

When using an aspirator it's a good idea to have the flexible tube in the mouth ready and then place the copper tube end behind an insect, before sucking air through the plastic tube into the mouth which then sucks the specimen through the pipe and into the aspirator vial.

To transfer specimens easily, it helps to tap on the aspirator before opening and have the lid off the collection tube already and then once the aspirator tube is over the collection tube then tap on the aspirator tube again to dislodge specimens into the collection tube, before quickly closing.

The tissue in the transfer tube, provides protection for the specimens from being damaged in transit and also provides an absorbent substrate if using ethyl acetate to kill specimens.

Avoiding sucking up spiders into the aspirator as they may attack insects and make a mess in the tube with their webs! Ants also may attack other insects in your tube so it's best to collect these separately and / or treat the sample tube with ethyl acetate promptly to prevent damage to other specimens from predation in the tube.

Note taking in the field

Always carry a dedicated field notebook with you when out collecting and write up notes and label specimens once finished collecting, recording all field data at a site before moving on.

The **baseline information** that is required when collecting insects in the field is the **location, date and collector.**

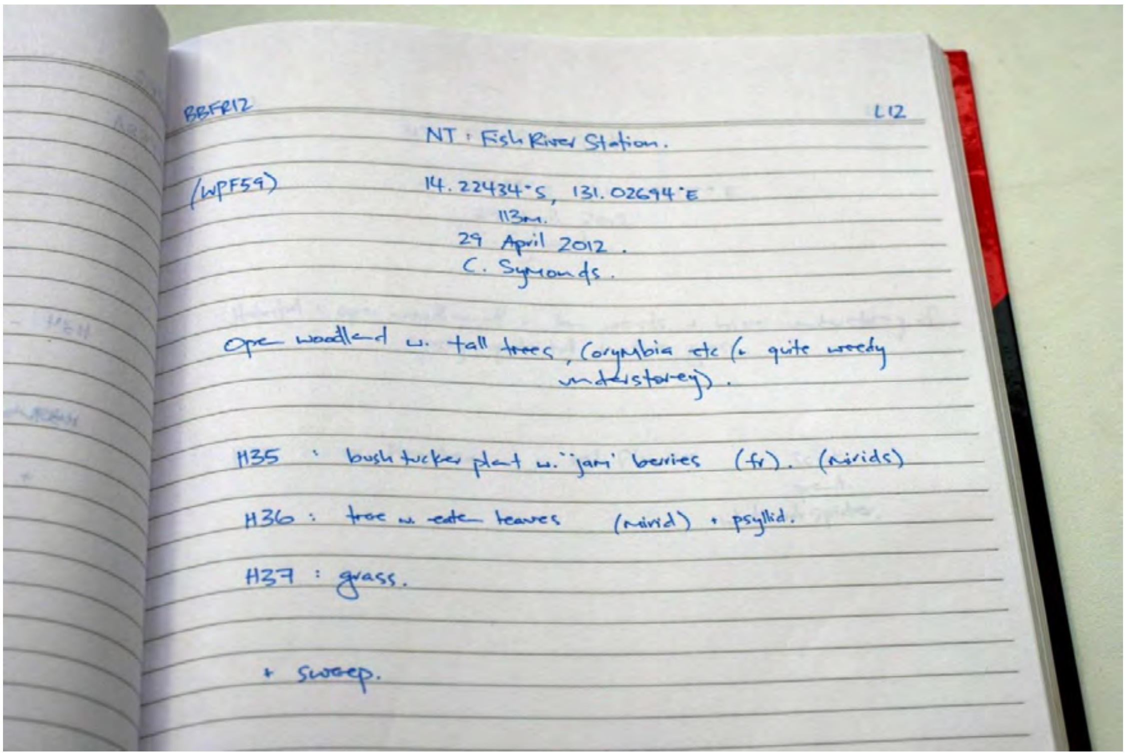
This **combination of information** for collected specimens may be referred to as a **"collection event".**

Collecting further **supplementary information**, is also important, such as **habitat, collection method, and host plant** adds more value to the specimen data and may also assist in identifying that insect.

For broad scale surveys it may serve to develop coding systems by which you can temporarily label and then refer back to the notebook later when preparing permanent labels for the specimens.

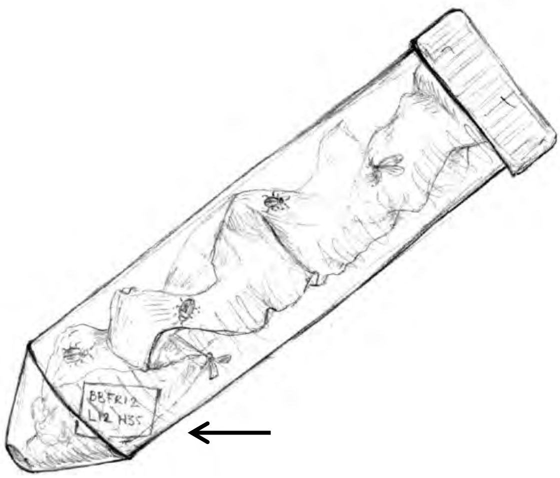
For **host plant specific insect sampling**, for example, we have created a system of codes that comprise of 3 components which make up a unique collection event: a **trip code, locality number** and **host number**. Note that on any one trip the localities and hosts are labelled individually and successively from 1 onwards.

Example of a **field notebook**, recording insects collected from different host plants at a site using this coded system (with a trip code, locality numbers and host numbers):



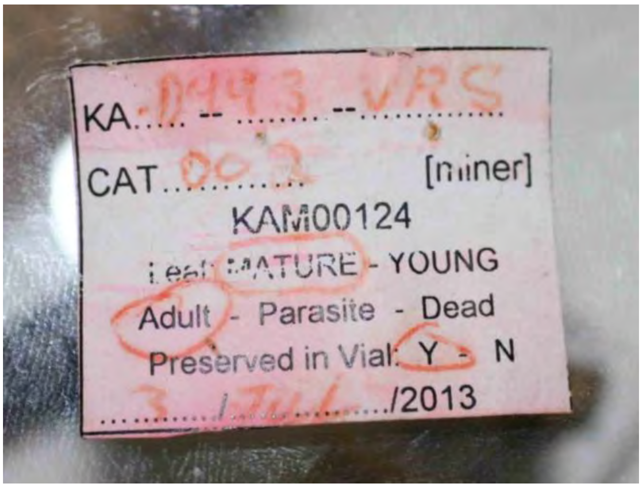
Labelling specimens in the field

Always label specimens at the time of collection before departure from a site, using **temporary field labels**. Temporary field labels can be created using your collection codes from your field notes, written onto small pieces of cardboard or paper, which includes the locality and host information. Always place labels inside tubes:



Collection transfer tube with insect specimens sampled from a plant species and a temporary field label added with collection information, e.g. code from field notebook entry as above: BBFR12 L12H35

Temporary field labels can be created using collection codes from field notes (as above), or using basic collection information (i.e. collector, locality, date and relevant host/habitat information). Temporary field labels can also be created and printed prior to going into the field, which can be useful, for example, in ecological survey work where detailed information is required for a number of variables, or where localities have been predetermined.



Example of a temporary field label used in insect collecting, investigating host specific of Lepidoptera in New Guinea rainforests, by the New Guinea Binatang Research Centre (NGBRC), Madang. The pre-printed labels incorporate collection codes and ecological information.

Note: use pencil or a permanent pen.

Further references and resources for insect collecting

Internet resources:

Collecting Ants – Ants (Formicidae) of the southeastern United States
http://mississippientomologicalmuseum.org.msstate.edu/Researchtaxapages/Formicidaepages/Collecting.tips.htm#.VGTAG8nRbRl

Insect Collecting – Queensland Museum
http://www.qm.qld.gov.au/Find+out+about/Animals+of+Queensland/Insects/Collecting+insects

Insect monitoring techniques for field crops - DAFF QLD
http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/insect-monitoring

Books:

Dahms, E. C., Monteith, G. & Monteith S. 1983. *Collecting Preserving and Classifying Insects*. Queensland Museum.

Upton, M. S. & Mantle, E. L. 2010. *Methods for Collecting, Preserving and Studying Insects and Other Terrestrial Arthropods.* Australian Entomological Society. 83pp

Killing and Preserving Insects

Insects may be collected and preserved dry or in ethanol and different methods of killing and preservation are used for different orders (see table in Appendix, page 189). As a general rule, soft bodied insects (including immature stages of most orders) should be preserved in ethanol and hard bodied insects should be pinned, although many hard bodied insects will also preserve well in ethanol.

Killing insects

The killing process is determined by the way in which the material will be preserved and what it will be used for. Therefore it helps to know what the orders being collected are beforehand. In general, any insect with scales on the wings (moths, butterflies) is unidentifiable if collected or preserved in liquid, unless it is going to be identified from DNA only. Otherwise wet collecting is by far the easiest way to manage bulk sampling of insects and is the normal method for immatures. Dry collecting is the only safe method for butterflies and moths and is the preferred method for some Hemiptera (plant bugs, scales) and Diptera (flies).

Dry killing

Since dry killing is trickier to deal with than wet, it is discussed first.

For general purpose dry killing, one method is to **place the samples of specimens in the freezer**. Freezing is not recommended if the samples include mixed insects that may have been damaging or even eating each other. Time required depends on the size and type of insect but several hours (e.g. overnight) is enough. Take care when removing specimens from the freezer as they are brittle when frozen and allow time to thaw before handling.

Dry killing is more done often with an evaporative poison, the safest and most frequently used and easily accessible being ethyl acetate. This is highly flammable, and should not be directly inhaled. Follow safe working procedures and follow recommended guidelines for handling contained in the SDS (safety data sheet) for the chemical. Ethyl acetate has the additional advantage of leaving specimens relaxed for mounting for several hours after death. It has the disadvantage of dissolving some plastics, so vials should be tested first before use. Use polyethylene (PE) or polypropylene (PP) and avoid polycarbonate plastics. Death rates of specimens vary according to size and type of insect but ideally specimens should be left in the killing bottle for an hour or so after immobility.

2 to 3 of drops of ethyl acetate onto tissue in a sealed collection tube is enough to kill most small insects. It’s important not to add too much ethyl acetate to avoid wetting small delicate specimens (it doesn’t matter with beetles) and tubes should be kept out of light and away from heat as much as possible.

Larger insects may require a larger wide mouthed killing bottle with a larger amount of ethyl acetate to kill the insects as quickly as possible. A small ball of cotton wool is a good absorbent material for the liquid but the fibres get tangled up in legs and mouthparts of some insects (e.g. beetles). Tissue or paper towel would be fine. Keep Lepidoptera separate where possible as their scales will get on other insects, or clean the jar first before using for other insect groups. Lepidoptera and other fragile insects should be placed in separate jars to larger and more robust insects such as grasshoppers and beetles, to prevent damage to the specimens.

Butterflies, some moths and some dragonflies can be rendered immobile by pinching the thorax under the wings between the thumb and a finger, breaking the propulsion system for the wings. This is a quick method for collecting butterflies in particular but requires carrying a sealed box of paper envelopes in the field. **Paper envelopes** are rectangles of paper folded so that they are reduced to a triangle with flaps over each edge to prevent the specimen from falling out. The pinched immobile specimen is placed inside, making sure wings are upright and collection data written on the envelope. This is placed in a sealed box (e.g. plastic lunch box). The box needs to be kept out of the sun to avoid condensation damaging specimens and the sealed lid prevents ants from entering.

Temporary storage of field collections

Specimens should only be left as long as necessary in killing bottles. If specimens are not going to be immediately pinned then they should be transferred from the killing jars to temporary storage containers such as pill boxes (see below) or paper envelopes (as above). This storage in the field will protect specimens from damage, especially in transportation and is a way to keep the specimens safe and in good condition indefinitely. Pill boxes or paper envelopes can then be placed in a larger waterproof container, however it should be noted that specimens should be allowed to dry out first before sealing in a plastic bag or airtight container. Silica gel may be added to the larger container and checked and changed regularly to remove humidity and assists in drying out specimens too. 'Dettol' and ethyl acetate can also act as antifungals and could be added to a ball of cotton wool and sealed inside the larger container.

'Pill boxes' are small cardboard boxes that are useful temporary storage for most small to medium dry collected specimens. Pill boxes can be made using any small cardboard boxes, such as matchboxes, and filling with layers of some kind of soft tissue, tissue paper or toilet paper, so that specimens do not move around inside the box. Specimens are laid between the tissue layers. Transfer temporary field labels to the top of tissue layers inside the box and also write the field collection data or codes on the pill box lid. Groups of these small sample boxes should be stored in airtight containers to prevent damage from ants.

Specimens may be kept for long periods in paper envelopes or pill boxes as long as they are in a pest and moisture free environment i.e. an airtight plastic container, a wooden insect box or drawer with naphthalene and desiccant (silica gel) that is regularly inspected and replaced as required.

Wet killing

Wet killing directly into **ethanol (preferably 100% concentration for most insects)** in vials is a convenient and fast method in the field for most insects (See Appendix), such as beetles, ants, wasps, bees, flies. Prepare different diameter vials of ethanol prior to fieldwork and small paper labels and a pencil. Specimens may be kept in ethanol indefinitely and when removed from ethanol for pinning their structure will be preserved. However 100% ethanol makes some specimens too brittle to prepare, e.g. scale insects, so these should be collected or at least preserved in 70-80% ethanol. Another small problem is that killing directly in ethanol can make larval insects turn black. This can be avoided by killing them in a mixture of ethanol (10 parts) kerosene (1 part) and acetic acid (2 parts) then transferring them after 24 hours to 100% ethanol. Specimens collected for DNA analysis should always be collected into 100% ethanol.

Wet preservation

Wet killed insects can generally be maintained in ethanol for years. They need to be checked regularly to monitor evaporation of the ethanol. If kept in a dark place they will only fade slightly.

When removed from ethanol storage for pinning or mounting they will be brittle. Specimens will be less brittle if passed through more dilute ethanols to water, before drying on tissue. Small Diptera (flies) and other soft bodied insects may shrivel badly when removed from 100% ethanol for drying and mounting. This can be prevented by placing then directly in ethyl acetate for a few hours then drying them.

Also, some hard-bodied insects can be stored in ethanol temporarily before drying and pinning, such as beetles, ants and some hemipterans and thus can be collected in the field as such. However some insects such as plant bugs (Hemiptera: Heteroptera: Miridae) once in alcohol cannot easily be dried for pinning without shrivelling up.

For long term wet preservation specimens should generally be placed in **100% ethanol**, which is also required for DNA preservation. Eggs, larvae, nymphs and pupae should all be stored in ethanol. Soft bodied adults such as bristletails, silverfish, stoneflies and caddis flies should be preserved in ethanol as well. Ethanol is the most commonly used wet preservative although, some groups may benefit from or require a slightly different liquid preservative for better long term storage, e.g. aphids and scale insects are recommended to be preserved in lactic-alcohol, a mixture of ethanol and lactic acid. Therefore, it is important to read up on specific techniques for a particular group you may be working on.

See Appendix (page 189) for summary guide on preservation methods for different insect orders.

Dry preservation

The longer material is kept dry in temporary storage, the more brittle or exposed to damage it becomes. So pinning or other mounting for long term maintenance is best done as soon as possible.

Specimens kept in a freezer will remain relaxed for some time as well as being protected from pest attack and mould. Once thawed, these specimens will be soft and easy to pin without damage.

Relaxing dried specimens before pinning

Dry stored specimens in pillboxes or paper envelopes will become very brittle if stored for some time. These dry specimens will need to be relaxed before pinning or mounting and wing setting. A **relaxing chamber** is used for this purpose and can be made easily from any airtight container such as a wide mouthed glass jar or any kind of plastic crate or food storage container, sized to your needs. The bottom of the relaxing chamber is filled with either water, wet sand or wet paper towel. Specimens should then be set inside the container on a platform above the wet substrate, such as on the lid of another smaller container placed inside the relaxing chamber. One to two or up to three days will be required to relax insects depending on the size and body type. Specimens should be checked daily and **mould growth is the biggest concern**. Larger specimens such as butterflies can take 2 full days and it can help to turn them over after a day. Most traditional antifungal agents are highly toxic and should not be used. 'Dettol" with antifungal properties could be added to the relaxing chamber.

Robust insects like beetles and ants can be immersed in water to relax them rather than needing to go into a relaxing chamber and **quick relaxing** of some hard bodied insects such as robust beetles can be done by dropping them in near boiling water for up to a minute or so.

Note: Hot or warm water will also speed up the relaxing process if added to the relaxing chamber.

Note: smaller insects in pill boxes, especially more robust specimens like beetles, may sometimes be point mounted without needing to be relaxed first.

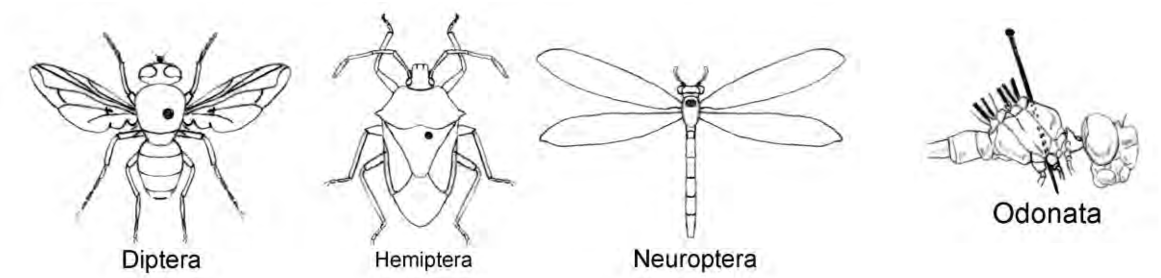
Insect pinning

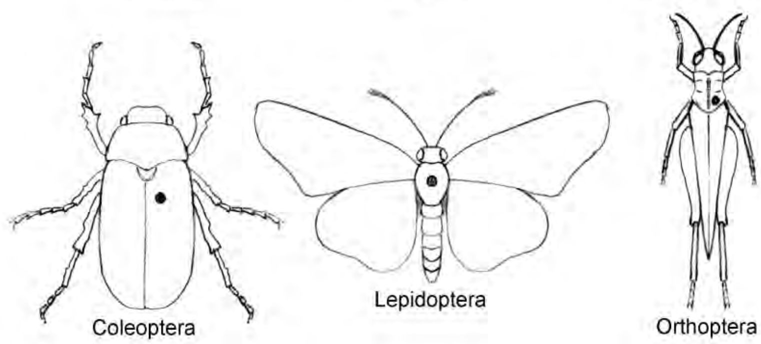
To pin or not to pin?

Specimens that are about 8mm or larger if elongate-oval, or 10mm or longer if thin and narrow, may be pinned without damaging the body. Pinning insects involves the insertion of an insect pin through the thorax, right of centre, aside for butterflies, moths, dragonflies and lacewings which are pinned through the centre of the thorax.

Exact pin positioning for different groups of insects is as follows and illustrated in the figure below:

- **Bees, wasps, flies** — Pin through the thorax between bases of fore wings and slightly to right of midline.
- **True bugs** — Pin through the scutellum, which is the triangular area between the bases of the wings.
- **Grasshoppers, crickets** — Pin through the prothorax or "saddle" slightly to the right of the midline
- **Beetles** — Pin through the forepart of the right wing cover (elytra) near the midline.
- **Butterflies, moths, dragonflies, damselflies and lacewings** — Pin through centre of thorax between the bases of forewings.

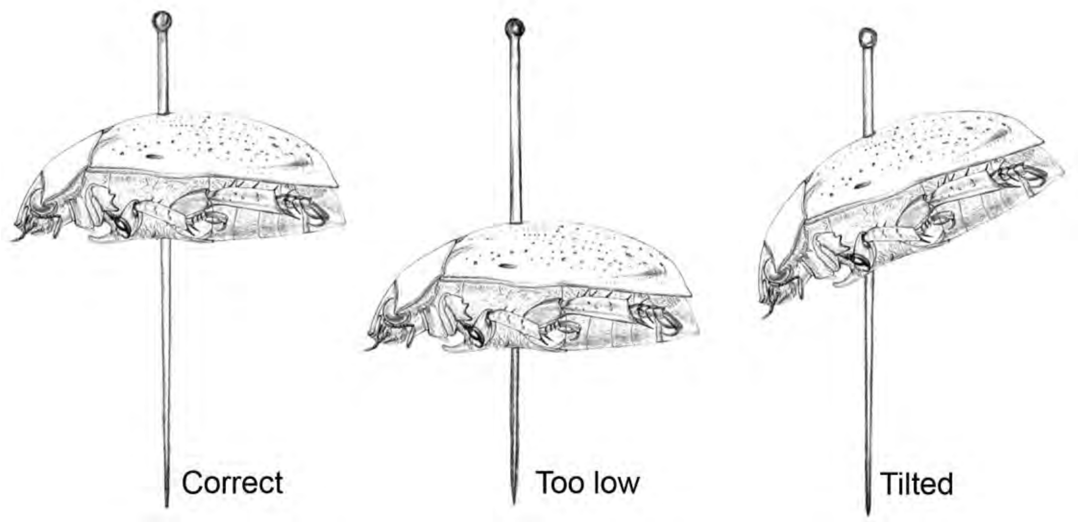




Pining position on thorax for different insect orders

Place your insect on a styrofoam sheet with its ventral surface closest to the styrofoam. Place your pin through the thorax in the above positions and ease the pin through the body until you push through the styrofoam. Once the specimen is secured push the pin further to about ¾ pin length or use forceps to move the specimen up the pin. Make sure the specimen is straight on the pin as shown in preceding illustration.

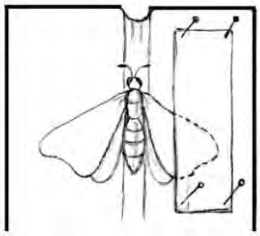
Correct orientation and height of specimen on the pin – straight, ¼ from top of pin



Wing setting

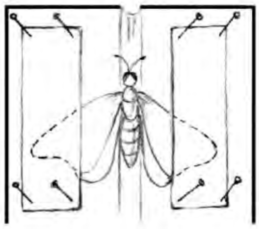
Setting out wings of specimens is commonly done for a number of orders as follows and generally for larger specimens or particular subgroups within the order, depending on the group. A setting board, either purchased readymade or constructed from styrofoam sheets with a medial groove, is used. The position for setting wings varies slightly for different orders as follows:

- **Bees, wasps (Hymenoptera)** - both pairs of wings set, with front edges at right angles to the body. Note that the forewings and hindwings are often linked by a series of tiny hooks, and stay together when set.

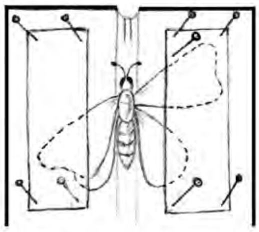


- **Dragonflies, damselflies (Odonata)** - both pairs of wings set, with front edges of hindwings at right angles to the body and forewings then set just a little in front of the hindwings.

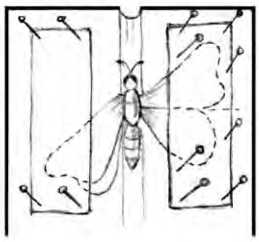
- **Flies (Diptera)** - one pair of wings, set with the front edges around 60° to body.



- **Butterflies, moths (Lepidoptera)** - both pairs of wings set, with hind margin of forewings set at right angles to the body, and front edges of hind wings tucked under forewings.



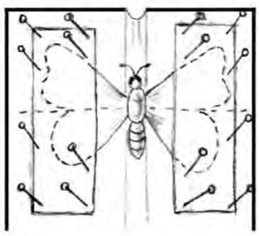
- **Grasshoppers, crickets (Orthoptera), cockroaches (Blattodea), mantids (Mantodea), stick insects (Phasmatodea)** – setting both pairs of wings is optional. One pair is sufficient, with hindwing at right angle to the body, then forewing set a little in front of the hindwing. Legs may also be positioned and held in place by pins to set.



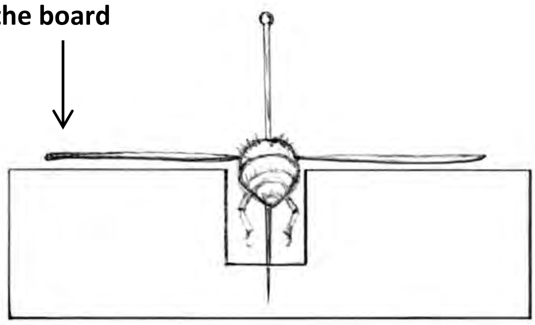
The abdomen of large specimens can be supported by cross pinning.

One to three weeks is needed for drying depending on the size of the specimen.

Strips of tissue paper or tracing paper pinned over wings to hold in place as they are spread out →



Pinned to height where underside of wings rests on the top of the board

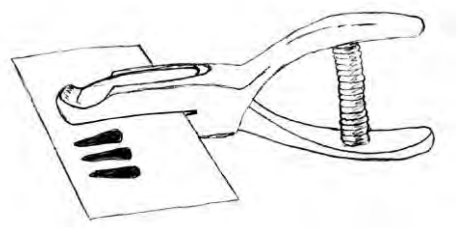


Point mounting insects

Insects that are smaller than about 8mm if elongate-oval or larger if thin, are usually mounted on a point.

Although there are other mounting methods, the most common and straightforward method that can be used for small specimens across most pinned insect orders, is to point mount. Consult other suggested references at the end of the chapter for further information on other mounting (e.g. card) and micro-pinning techniques.

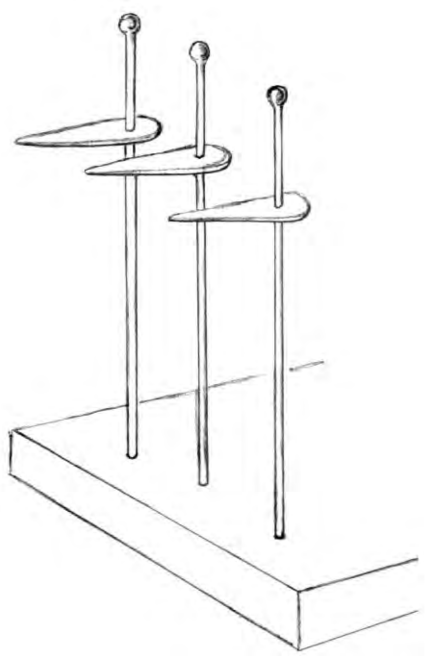
A point is a triangular card through which a pin is inserted. The **free end of the point is dabbed in wood glue** (only a very small amount) before then touching onto the right side of thorax. The insect is pointed always on the **right hand side of the thorax between the middle and hind legs**. The point needs to be **attached to the body and not the legs**. For most insects **bend the tip of the point downwards with forceps** before gluing. For some beetles with flat venters (e.g. lady beetles) and very small insects the tip of the point does not need to be bent.

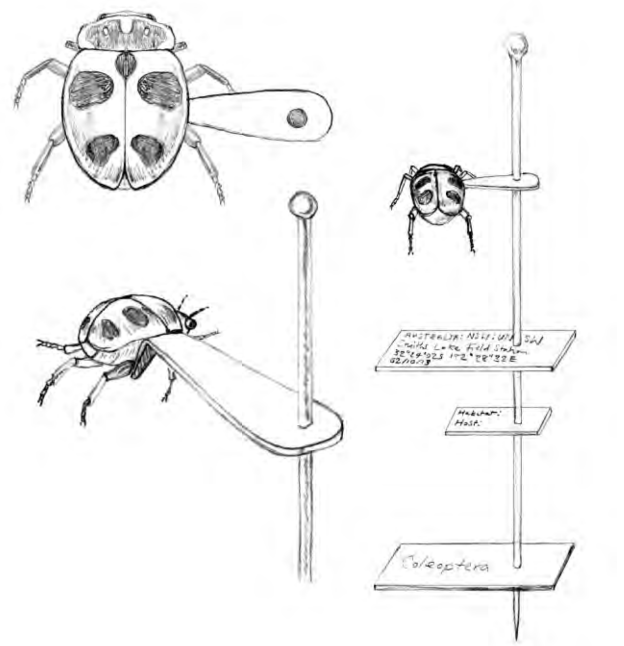


Points are made with a point punch or by cutting small triangles from acid-free archival card

Points are placed through the pin using a foam board on pinning block

The tip is bent (usually) and glued to the right side of the thorax between the mid- and hind legs

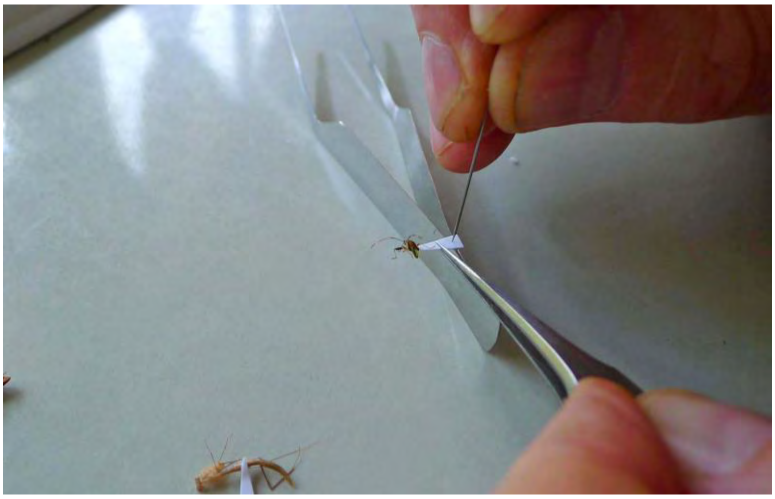




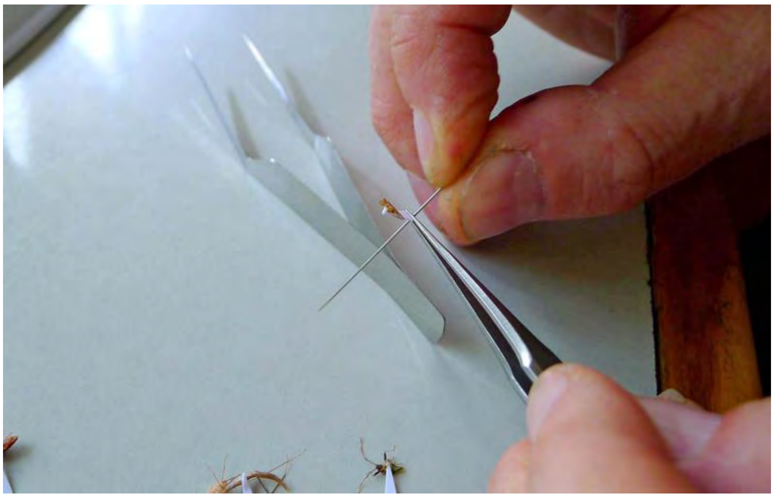
Alternate point mounting method for heavier insects

Many insects although small, are too heavy to sit on the point card before it dries and slide off. Therefore an alternate method is to lay the insect upside down, glue the specimen to the point card, wait for the glue to dry, and then place the pin through the card using forceps to assist as shown in image series below. Two pairs of forceps required for this technique:

- lay specimens on back or left side
- glue bent tip of point card to right side of thorax between mid and hind legs
- wait for glue to dry



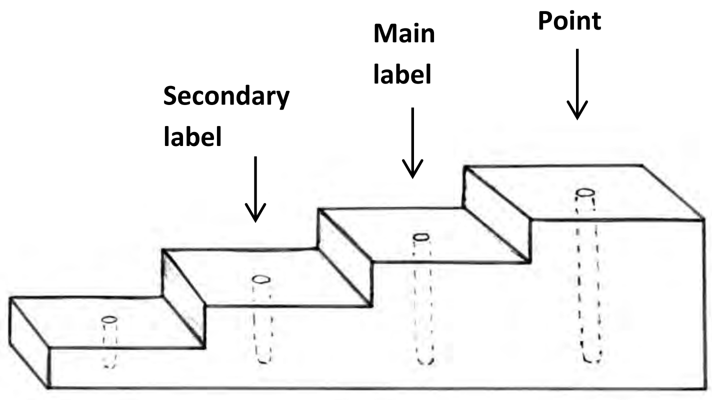
- pick up pointed insect with forceps from the middle of the point
- position end of point over base of forceps
- place pin through end of point card and down between gap in forceps
- **note:** using forceps as a guide to place the pin prevents the point card bending when the pin goes through.



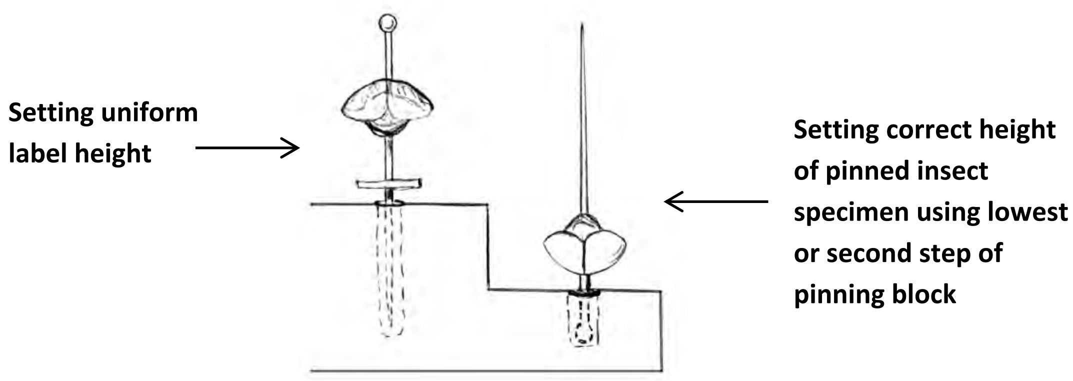
- move the point up the pin to the correct height, ¼ from top of pin

The pinning block

Using a pinning block ensures uniform height of points and labels on pins across a collection. These are generally made of wood and purchased from entomological suppliers but can be easily made with soft timber and a fine saw and drill tip. Drill depths for a four step block for use with standard insect pins (38 mm in height) could be 5, 12, 19, and 27 mm. The last will bring the point to ¾ of the way up the pin. Refer to suggested references at the end of this section which also contain dimensions and specifications for such pinning gauges.



The pinning block can also be used to gauge the correct height for pinned insects from the top of the pin by turning them upside down and placing the pin head in the lowest hole and lowering the specimen carefully along the pin (it can be a good idea to use forceps especially for smaller specimens) until it meets the surface of the pinning block:



Temporary labelling of pinned specimens

Always keep temporary field labels with pinned specimens until permanent labels are written or printed, as shown below. Here, the temporary label from the collecting tube (see page 14) with the collection code, is placed in the pinning tray in front of all specimens from that collection event, until they are permanently labelled. Transfer of the original label will reduce transcription error.

Place the field label at the start of a series of specimens in the unit tray until permanent labels are prepared, as shown below (note: the pinned specimens would be placed facing head up in the unit tray once permanent labels are attached). Before removing, double check that all the information on the permanent labels printed corresponds with the field labels and leave temporary labels with the specimens if possible until the collections are sorted.

Drying pinned and mounted specimens

Especially for larger specimens this can be essential in tropical climates. A drying cupboard can be used and can be easily constructed from plywood with open lattice shelves and fittings for incandescent 40 watt light bulbs installed at the base.

Curating Insect Collections

Labelling specimens

Information required on insect labels

Insect labels can be handwritten or printed on card. All pinned specimens must have a label which includes the basic collection information: **locality, date** & **collectors name**. Supplementary information such as a host plant, habitat or collecting method can be included on a secondary label. **Keep labels as small as possible** to preserve space in collections.

For **locality**, always include as precise a location description as possible. Remember (especially if you do not have a GPS to record the location coordinates) that the location given needs to be able to be found by someone else at a later stage. Think and ask yourself - "If I didn't know anything about the place where this specimen was collected, would I be able to find the locality from the information that is given on the label?".

Locality information to include on a label: Latitude and Longitude, Country, State/ Province, Town/Village. If the location is outside of a town or village use a combination of distances, direction by compass, landmarks, waterways, reserve name or roads to describe accurately and succinctly as possible the location, e.g. 6.68^{o}S 146.92^{o}E (or -6.68, 146.92) PNG: Morobe Province: 10km NW of Lae on Highlands Hwy at Wau Rd.

Upton & Mantle (2010) also suggest including "GPS" on the label next to latitude and longitude if a GPS device was used to determine this. They also suggest for the locality description, to use a reference in km from the "nearest unambiguous point of reference" using compass points (where each point representing 11.25 degrees and 11.25 x 32 equals a full circle of 360 degrees) e.g. 10km NNW of Lae. It's another approach and may work better if you have a GPS to record the locality at site.

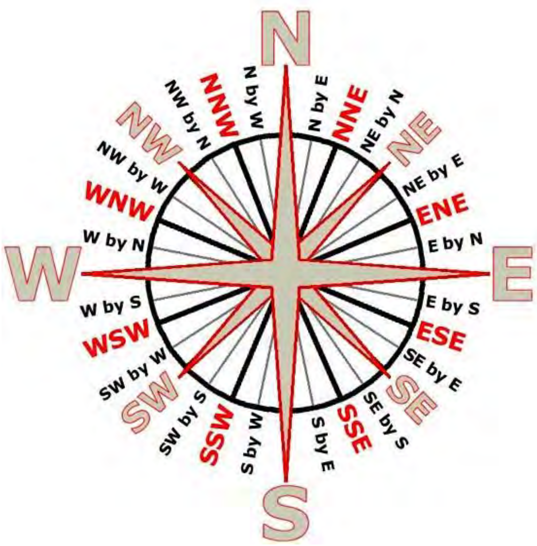


Image source: http://www.wavelengthphotography.com.au/bush&AlpineResources/Technical/CardinalPoints.asp

We recommend using a combination of both direction from a point of reference and landmarks or roads. If you don't have a GPS, recording information about the nearest cross roads etc in your notebook at the time of collection will help you to locate the spot on a map or Google Earth later (see Georeferencing resources below) and may also be more helpful for others to find the location at a later stage once the specimens are labelled and in collections (assuming the road names don't change too much).

For **date**, to avoid confusion between the day, month and year use the following format, with a number for the day, first three letters for the month and the year number in full without abbreviation, e.g. **24 Nov 2014**.

For **collector**, use their initials for first name and full surname, e.g. **S. Sar**.

Insect label examples

So, a resulting label may look as follows:

6.68°S 146.92°E PNG: Morobe Province: 10km NW of Lae on Highlands Hwy at Wau Rd, 24 Nov 2014, S. Sar

Examples of insect labels generated from coded information collected in a field notebook as in above example (page 14), where the collection codes are also included in the label as a reference:

Main label

AUSTRALIA: Northern Territory: Fish River Station, transect M, 113m, 14.22°S 131.03°E, 29 Apr 2012, C. Symonds [BBFR12_L12]

Secondary label

With supplementary information e.g. host plant, including who identified the plant and the herbarium voucher number for the plant sample identified

MALVACEAE *Grewia retusifolia* Kurz, Det.: NT Herbarium, D0217471 [BBFR12_H35]

Insect label specifications and formatting

Label card recommended specifications are: a fairly thin card around 200gsm weight, acid free archival quality, or made of 100% cotton or linen rag.

For **handwritten labels**, preferably use either a fine pencil or permanent (ideally archival) ink pen. These will also be fine to put in ethanol vials of wet preserved specimens.

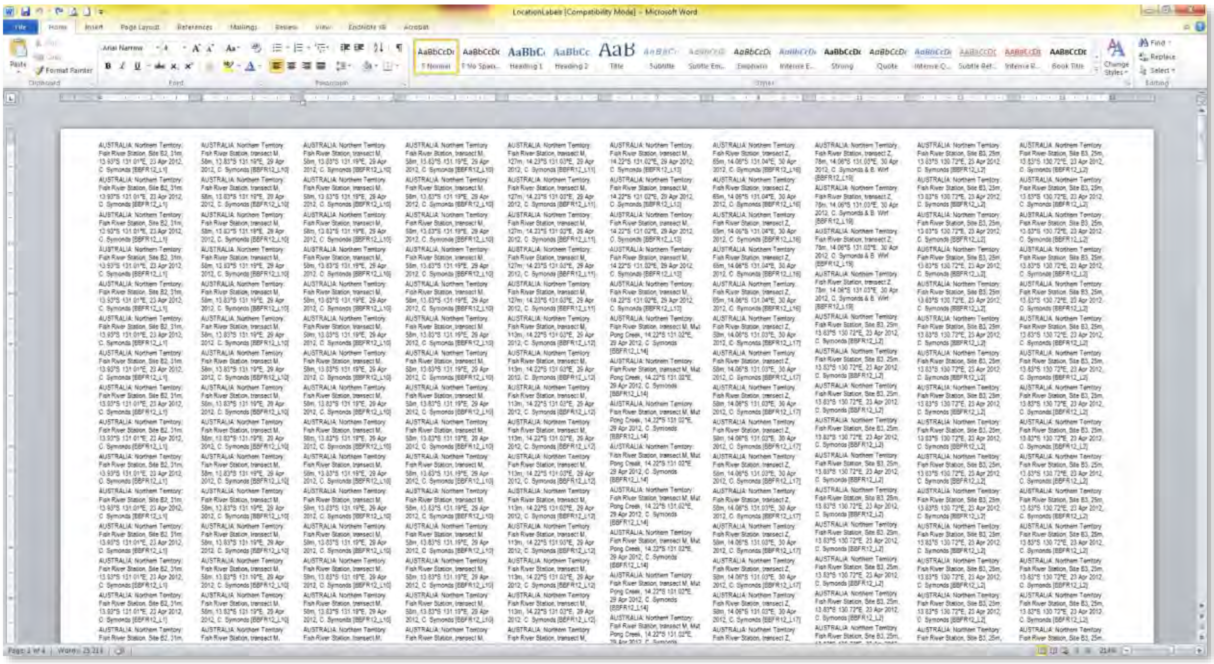
For **printed labels**, use a laser printer and set up a MS Word template label file as follows:

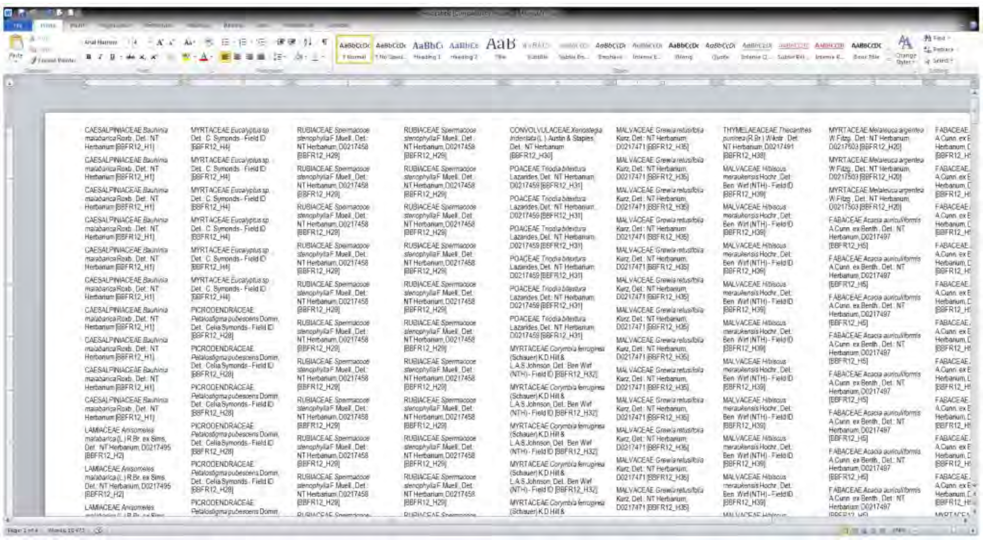
- Use columns (generally 10)
- Minimise page margins
- Minimise column margins
- Minimise space between labels
- Try not to make labels bigger than 2cm wide by 1cm high
- Font: Ariel or Ariel Narrow, Font size: 5 or 4.

For the font, keep it as large as possible and this may depend on how much information is on the label. Ariel Narrow is good, when there is a lot of detail in the location or host information, to keep the label small.

Enter all the collection information into your Word label template once and then copy and paste this till you have the required number of labels.

MS Word label sheets as examples for main locality labels and secondary host plant labels:





Setting the ink on laser printed labels

For laser printed labels it can be a good idea to bake them in an oven low for 10 minutes or microwave at high for 1 minute 50 seconds, to set the ink to the card more strongly and this is a good idea if the labels are going in with wet specimen vials of ethanol.

Georeferencing resources to find latitude and longitude coordinates without a GPS

If you have a locality name without geo-coordinates or if you don't have a GPS to record your location in the field, there are some different options to georeference a given locality.

The most useful, are:

- **Google Earth**, https://earth.google.com, an interactive world atlas with satellite photo layers. This is a free software application that can be downloaded to your computer.

- **Gazetteers**, e.g. *Papua New Guinea: national gazetteer of place names* by National Mapping Bureau, Port Moresby (1990) 669 pp.

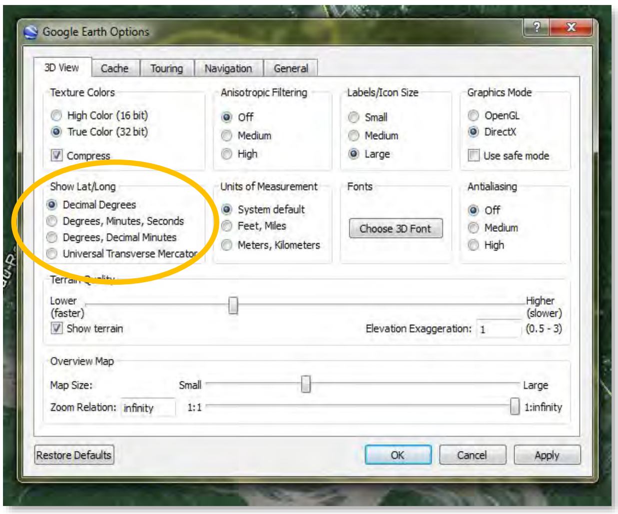
Other methods include using the GPS contained in newer mobile phones and digital cameras, GPS apps for smartphones and Google Maps to obtain geo-coordinates.

Using Google Earth

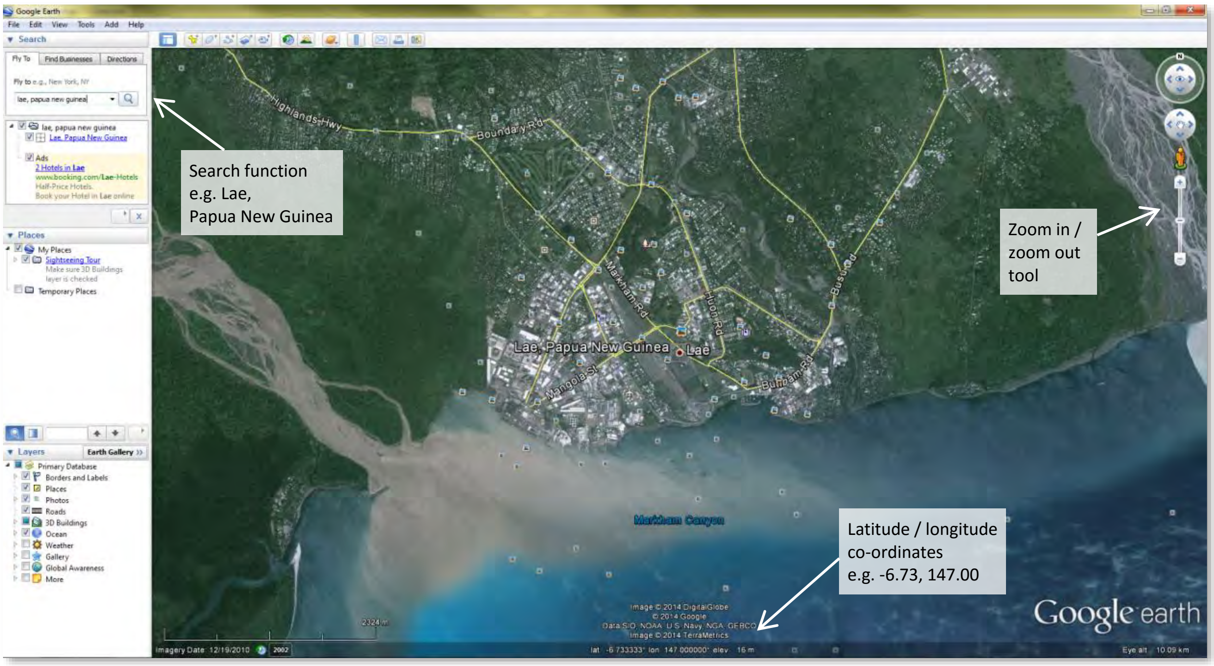
Go to https://earth.google.com on the web and click on the link to download. There are versions for Mac and PC computers.

Once Google Earth is installed on your computer you can search for locations to gather geo-coordinates. If you are after a specific location - e.g. on a small side road off the main highway just outside Lae - then it would be best to search first for "Lae, Papua New Guinea" and locate the exact point you are after using the satellite imagery with the mouse pointer by clicking and dragging across the page which moves the map (the mouse pointer (hand symbol) tracks the geo-coordinates as it moves across the map).

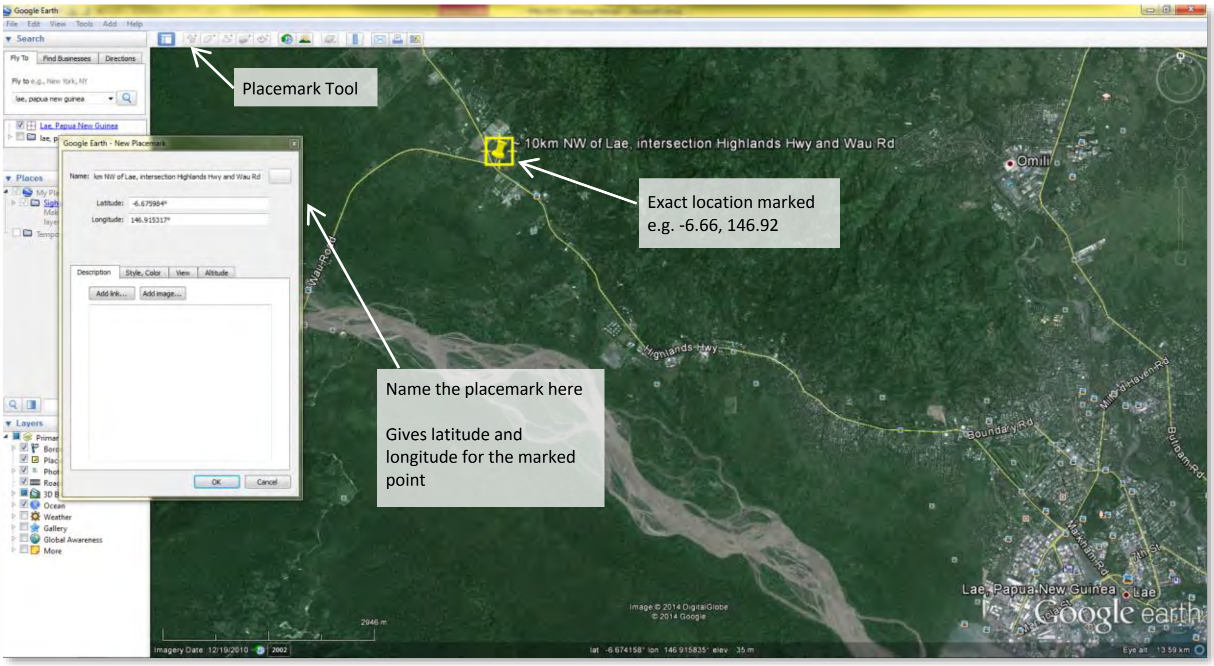
Note: Geo-coordinate format may be changed in the Options menu from between decimal format or degrees, minutes, seconds. Form the file menu select: Tools / Options / Show Lat/Long (make sure to click on the "Apply" button if you make any changes):



Screen capture image of Google Earth, searching for Lae, Papua New Guinea:



Screen capture of Google Earth, after panning across to NW of Lae, on Highlands Hwy at Wau Rd:



Note as above you can also set a placemark and permanently label (in popup box) placemark locations and they will be saved in your Google Earth.

Correct positioning of insect labels

Specimens are always labelled **first with the main locality label**, then any secondary label with supplementary collecting information and then further labels as the specimens are identified or databased.

Label position varies depending on the specimen mount or pinning. Use the following photographs as a guide and note that it is important to always keep the text in the same direction. For pinned insects the top line of the label is always to the specimen's right, and if point mounted the top of the label is in the same direction as the top of the head:

Positioning the labels with the text in this direction, will ensure that the labels of both pinned and point mounted specimens are all facing the same way when the specimens are placed in a drawer, as below.

Label height can be determined and kept uniform across collections by using a stepped pinning block, with spacing left between additional labels added to the pin. It's a good idea to leave more room between the specimen and the locality label if it is a larger specimen but have the locality label at a height close to the specimen so there is room for other labels to be added later when specimens are subsequently identified and databased.

Organising specimens in a collection

Specimens should be curated so as to use the space available as economically as possible whilst protecting the specimens from damage. Position specimens as close together as possible, but without touching and giving enough space for a specimen to be removed from the tray by hand without damaging surrounding specimens. Position pinned specimens so that the head is facing the top of the unit tray or drawer. Position point mounted specimens so that the tip of the point is facing the top of the unit tray or drawer, and position unit trays so the left side of the labels are all facing the back of the drawer, as in the following images:

Storage of wet collections

To help prevent evaporation of ethanol from vials, the best type of vials to use for storage are those with tight fitting stoppers or screw caps such as scintillation or O-ring caps which seal better than other types of screw caps or press cap type vials. Vials should be stored in upright containers or within larger jars filled with ethanol (no image). As ethanol evaporates over time, wet collections need to be monitored from time to time and ethanol levels replenished when they are low.

O-ring screw cap vials

Rubber seal in cap helps prevent leakage and ethanol evaporation

Plastic is HDPE (High Density Polyethylene) suitable for long term ethanol storage

Glass scintillation vial

Note: Specimen labels should be placed inside vials always and never attached on the outside

Specimen vials of ethanol should be stored upright for long term storage

Specimen storage and collection management in tropical environments

Insect collections need to be protected from **heat, light, humidity and insect pest damage**. This is of particular importance for dry insect collections and presents a greater challenge in a tropical environment such as in PNG, with high heat and humidity which in particular encourages fungal growth.

For this reason it is advisable to keep the bulk of specimen samples in your collections in ethanol. One collection management approach may be to store the bulk of sample series collected in ethanol and pin representative specimens as vouchers and for examination, whilst labelling the pinned specimens and ethanol vials for the same sample series in a way that they can be cross referenced at a later date.

Dry pinned specimens must be stored at all times in sealed storage boxes or drawers. **Naphthalene** is commonly added to storage containers – boxes or drawers - to prevent insect pest damage. Insect collections should preferably be housed in drawers, in air tight cabinets in an air-conditioned room. This will prevent fungal growth, insect attack and slow the evaporation of the naphthalene.

Further reading:
Carter, D. & Walker, A. K. (1999). *Care and Conservation of Natural History Collections*. Oxford: Butterworth Heinemann.
A comprehensive treatment of all aspects of management and conservation for natural history collections. All chapters of this book available online at the Natural Sciences Collection Association:
http://www.natsca.org/care-and-conservation

Further references and resources for insect preparation and curation

Internet resources:

Museum Specimen Preparation Guidelines (incl. vouchers) – Entomology Research Museum, University of California Riverside
This includes a comprehensive guide for best practice preparation and labelling of specimens, and in particular covers labelling requirements for quarantine and biological control voucher specimens and a guide to different preparation techniques for very small specimens e.g. chalcid wasps https://entmuseum.ucr.edu/specimen_preparation/index.html

Preserving Insects – Queensland Museum
http://www.southbank.qm.qld.gov.au/Find+out+about/Animals+of+Queensland/Insects/Preserving+insects

Specimen Preparation and Labelling in Ants (Formicidae) of the southeastern United States
Step by step guide, with photographic images, to preparing point mounted specimens from field samples and curating series of specimens. Presented for ants but is a good general guide for point mounting procedure for small insects.
http://mississippientomologicalmuseum.org.msstate.edu/Researchtaxapages/Formicidaepages/Specimen.prep.htm#labeling

Northwest Butterflies – Collecting & Mounting Specimens
Guide to collecting and humanely killing butterfly specimens, with photos showing pinning and wing spreading of specimens.
http://northwestbutterflies.blogspot.com.au/p/spreading-and-preserving-lepidoptera.html

Collecting and Preserving Insects and Arachnids – A Manual for Entomology and Arachnology by SAFRINET
A very practical introductory extension guide to entomology, with simple illustrations, for collecting, preparing, curating, storing and posting specimens. This guide was targeted to workers in plant protection in Southern Africa and also includes a very basic key to insect orders.
www.spc.int/lrd/publications/doc_download/339-bat-inse-scr

Books:

Dahms, E. C., Monteith, G. & Monteith S. 1983. *Collecting Preserving and Classifying Insects*. Queensland Museum.

Upton, M. S. & Mantle, E. L. 2010. *Methods for Collecting, Preserving and Studying Insects and Other Terrestrial Arthropods.* Australian Entomological Society. 83pp.

Borror, D.J., DeLong, D. M. & Triplehorn, C. A. 1976. *An Introduction to the Study of Insects*. Fourth Edition. Holt, Rinehart and Winston, New York. 852pp

Taxonomy Principles and Methods

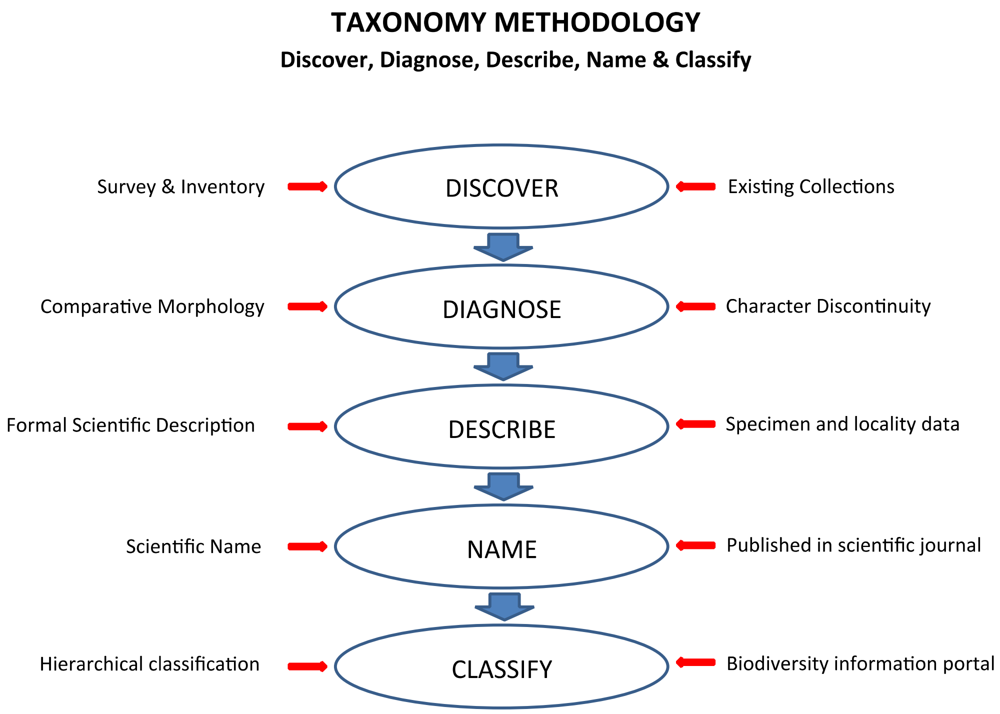
Taxonomy

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 (see below).



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.

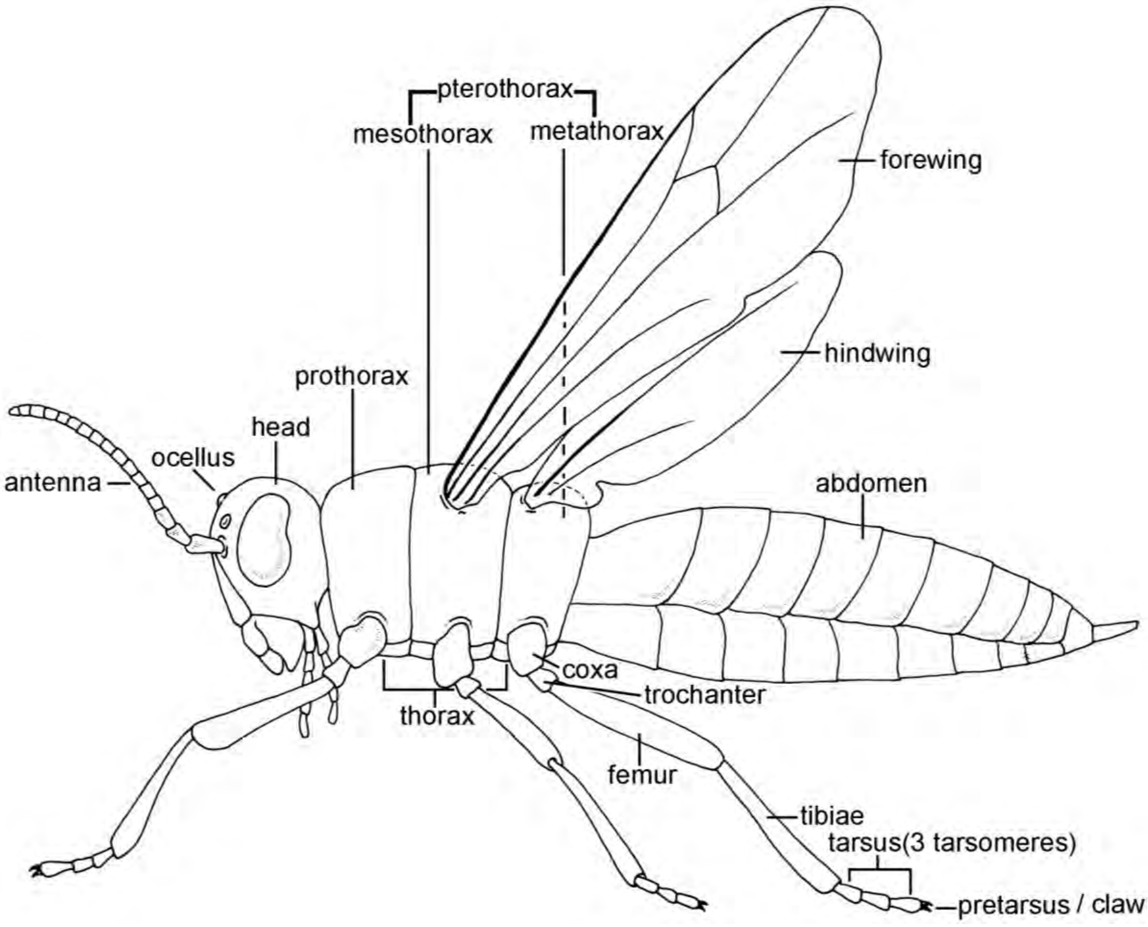
It is best to try to identify insects to the higher-level categories, such as order and family, before attempting to identify insects to genus or species.

Body organisation

The basic organisation of the insect body is as follows:

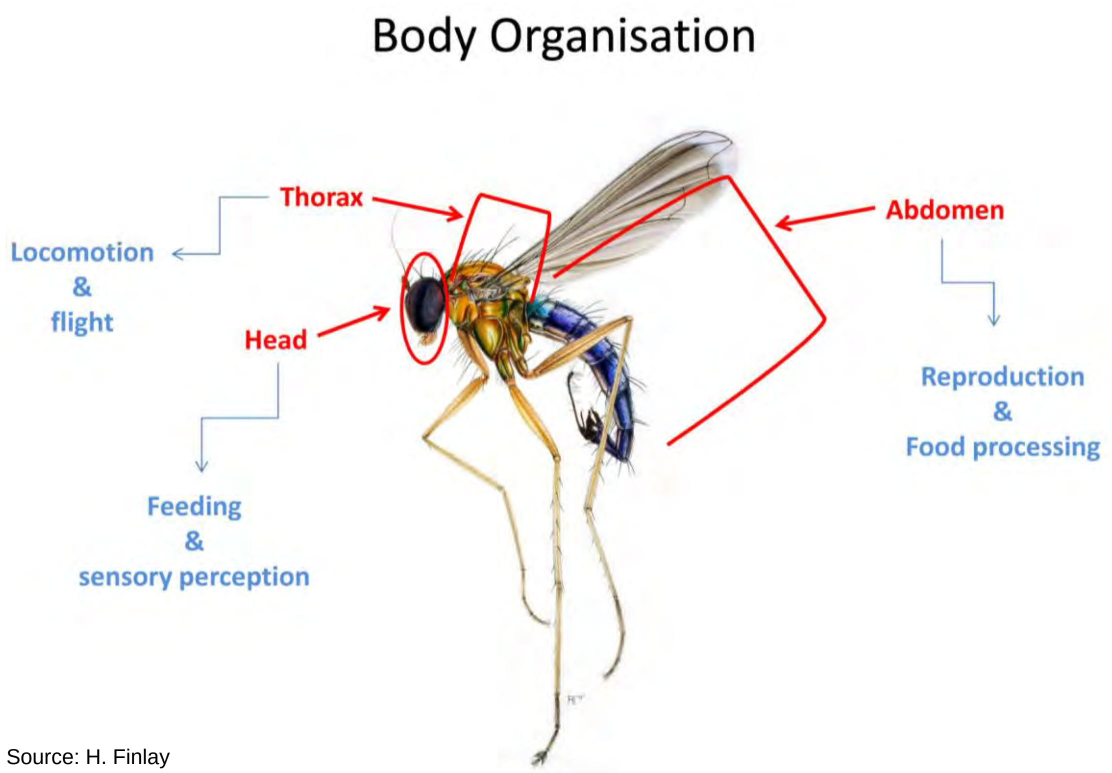
- The body in insects is organised into **head**, **thorax** and **abdomen**
- Head is apparently a single segment
- Thorax has 3 segments (often highly modified to accommodate legs and wings)
- Abdomen has 11 segments (some segments can be lost or fused)

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



Redrawn from Gullan & Cranston (2006)

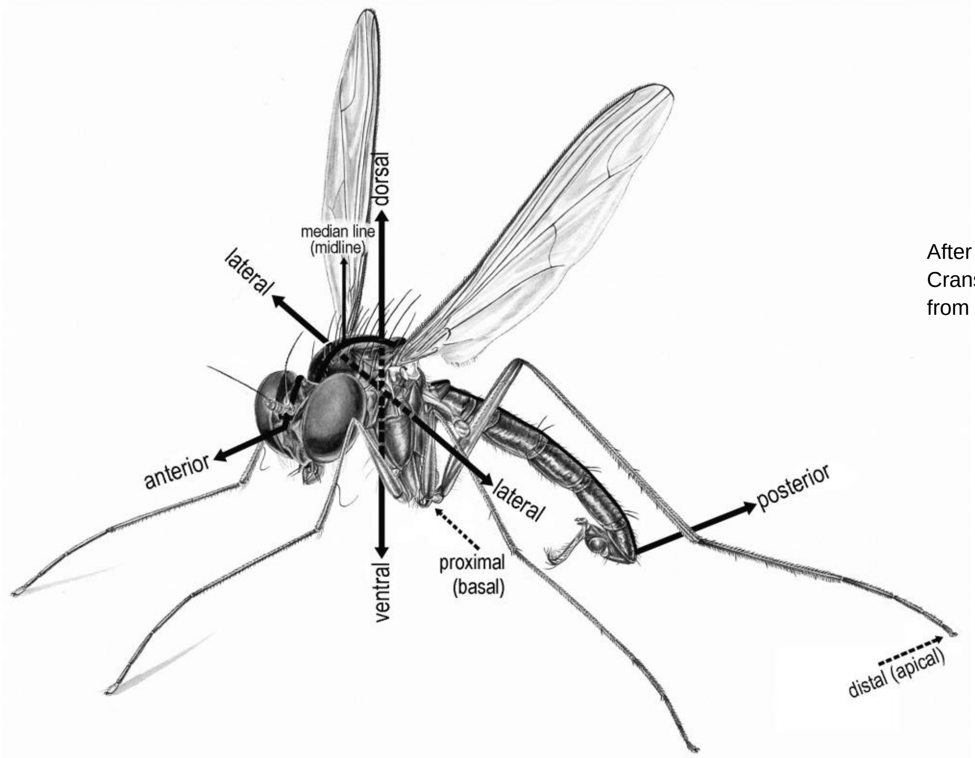
Tagmosis in insects has given them a competitive advantage and is central to their adaptive radiation. There are key functions that are associated with the head, thorax and abdomen, as shown in the following illustration.



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.



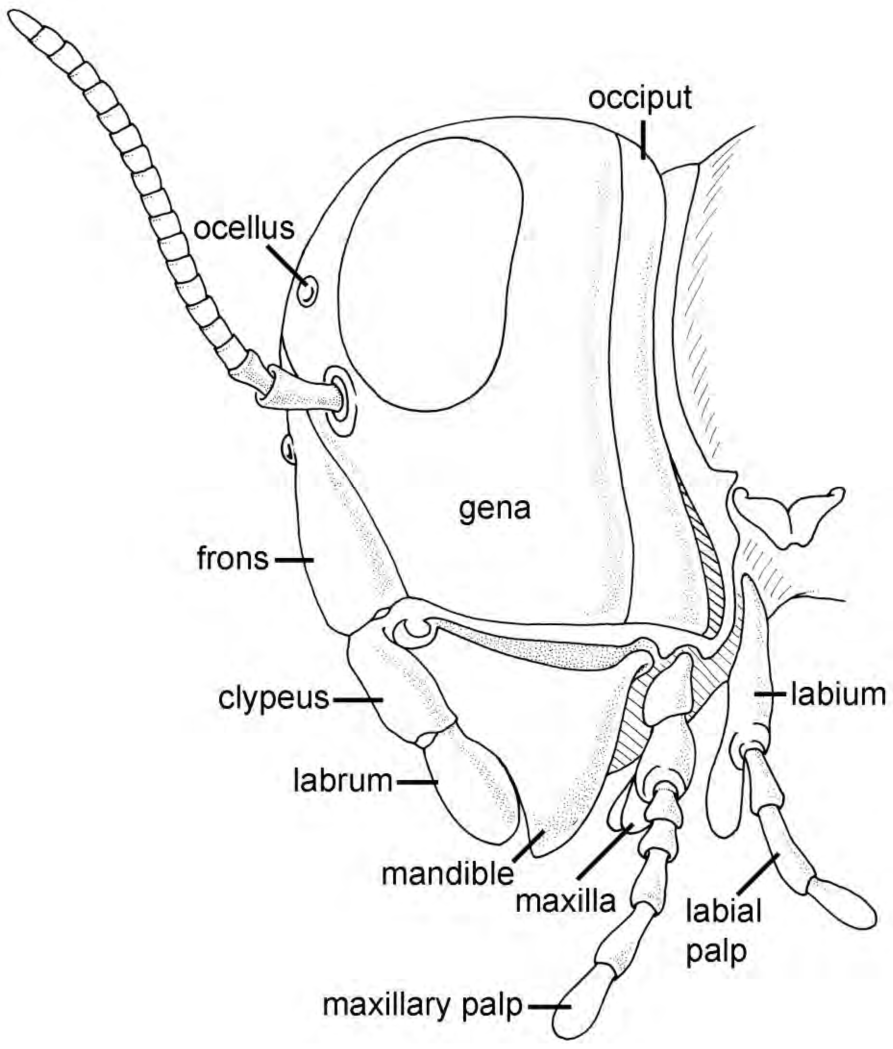
After Gullan and Cranston 2006, from McAlpine 1987

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)

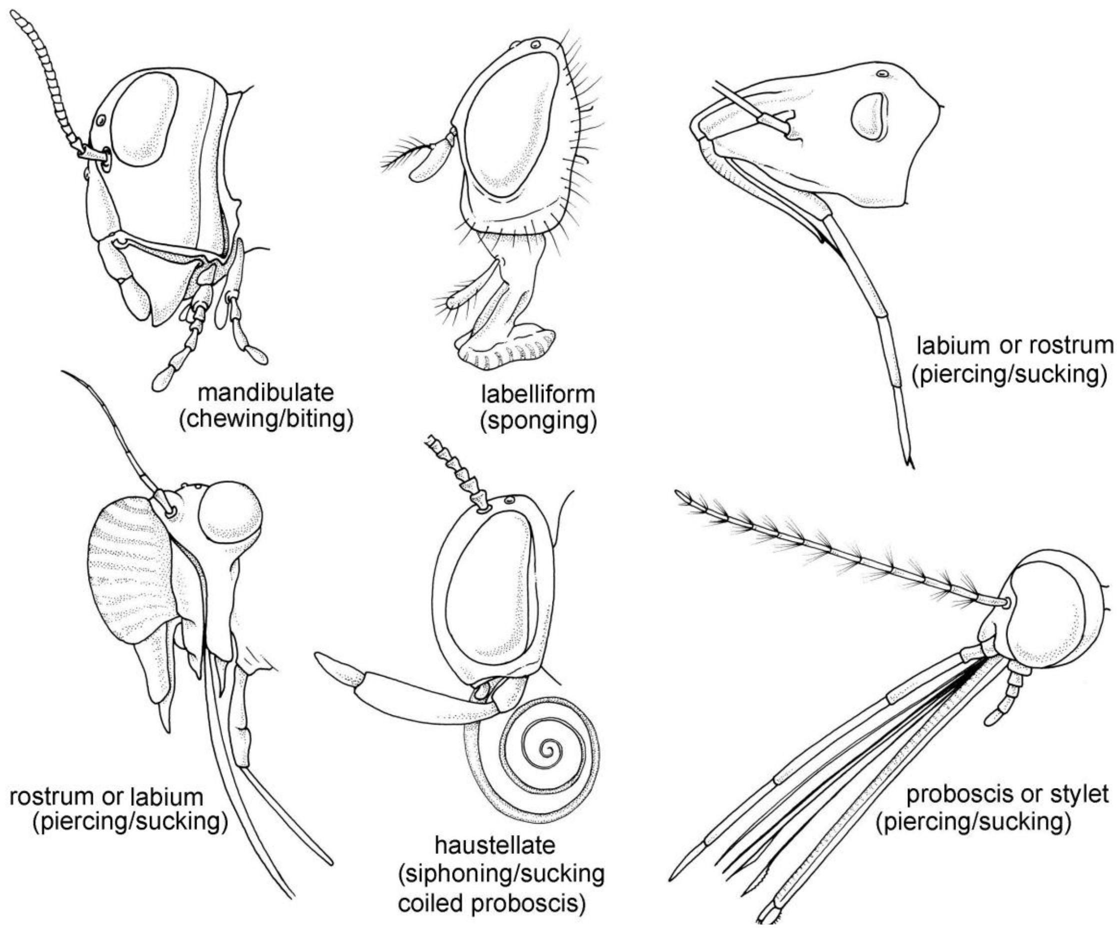
Sponging mouthparts (labellum, labelliform)

➢ 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**.

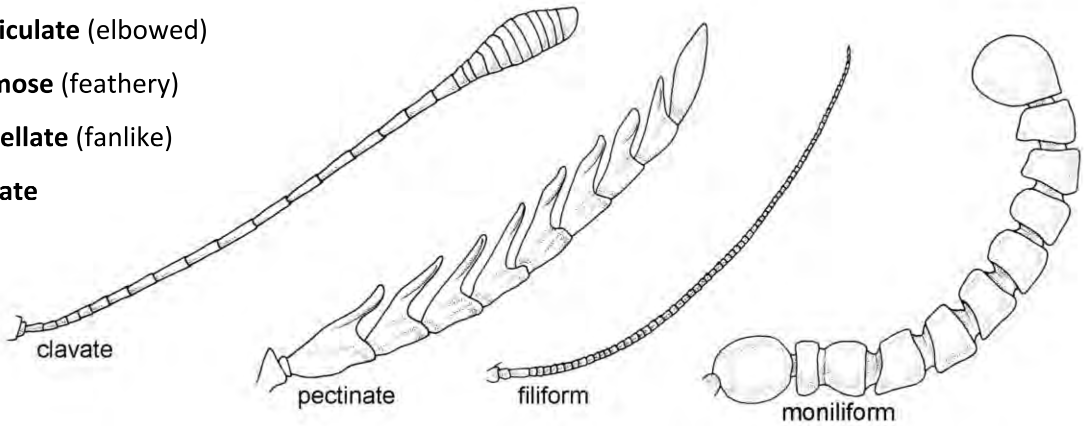
The variation in the antennae in insects is remarkable, not only in the number of segments, but also shape. For example each segment can have long lateral projections, particularly common in some moths.

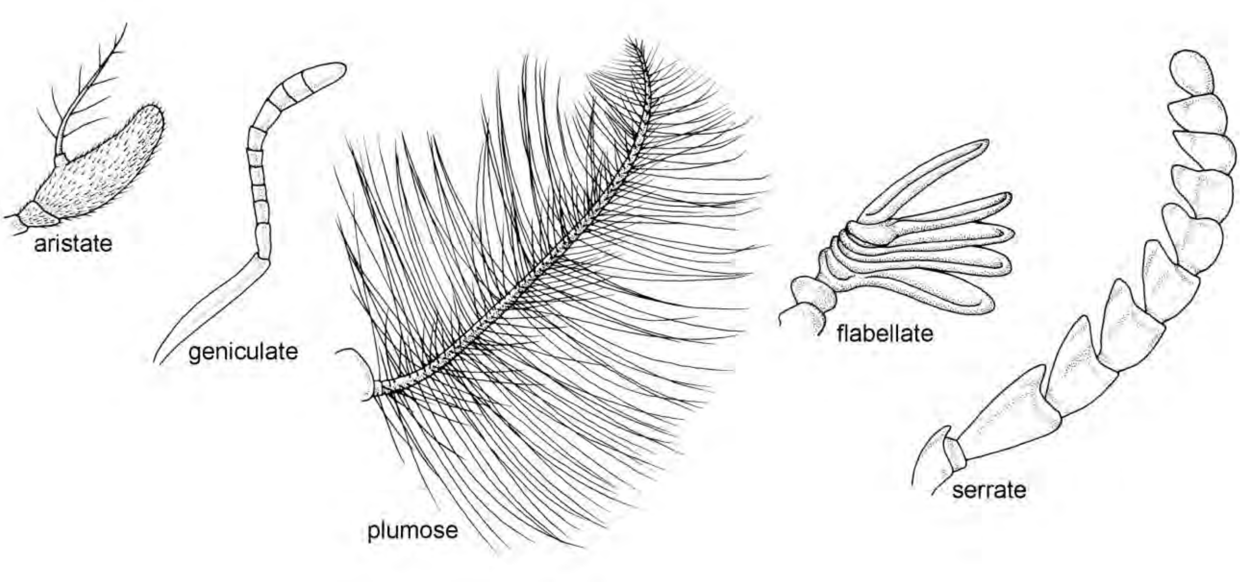
Some antennae are so specialised and distinctive that insect orders can be identified on antennal morphology alone. For example, some groups of flies, have three segmented antennae plus a bristlelike structure, called the **arista**.

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

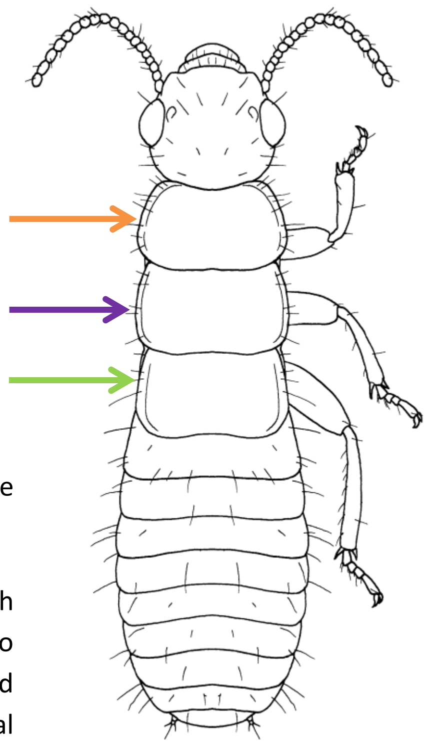
The visual system of insects comprises light gathering organs which may differ between adults and immatures. These include

- 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

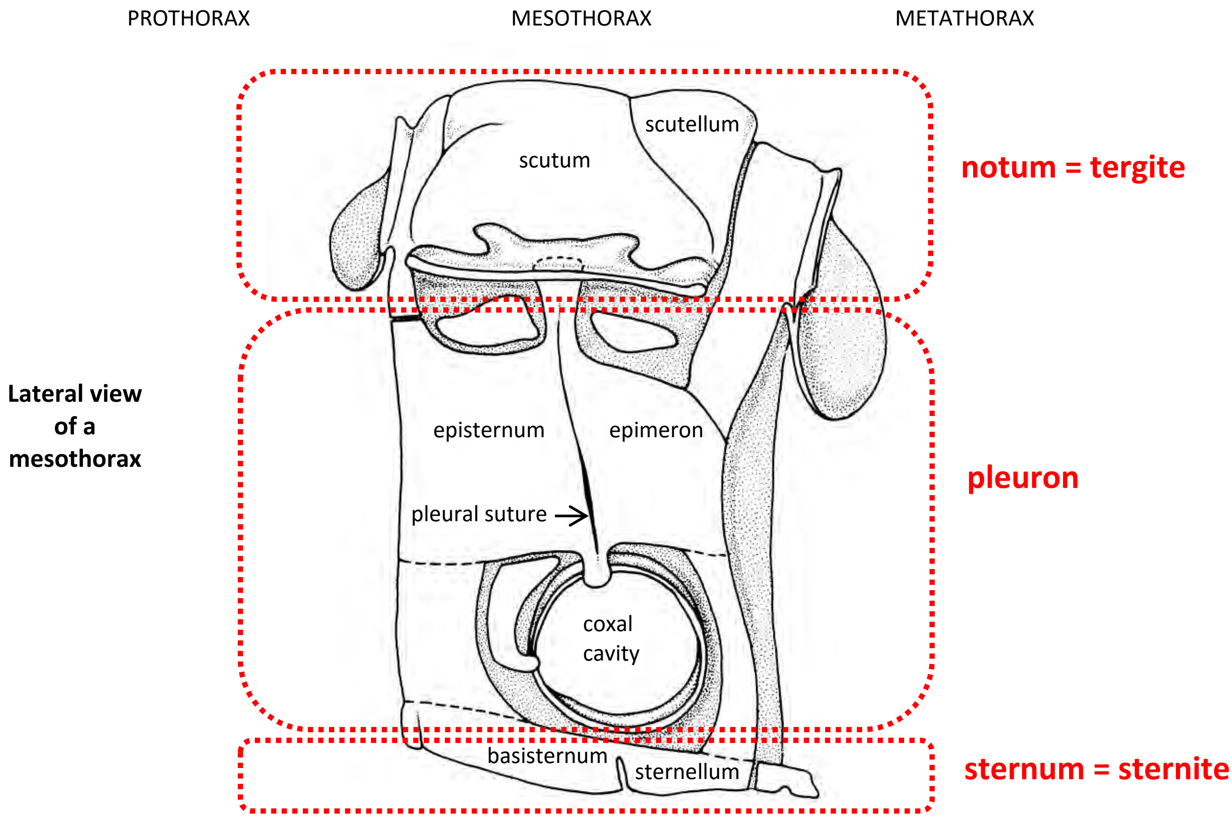
The last two segments are collectively referred to as the **pterothorax**; the prefix **ptero–** is meaning winged.

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

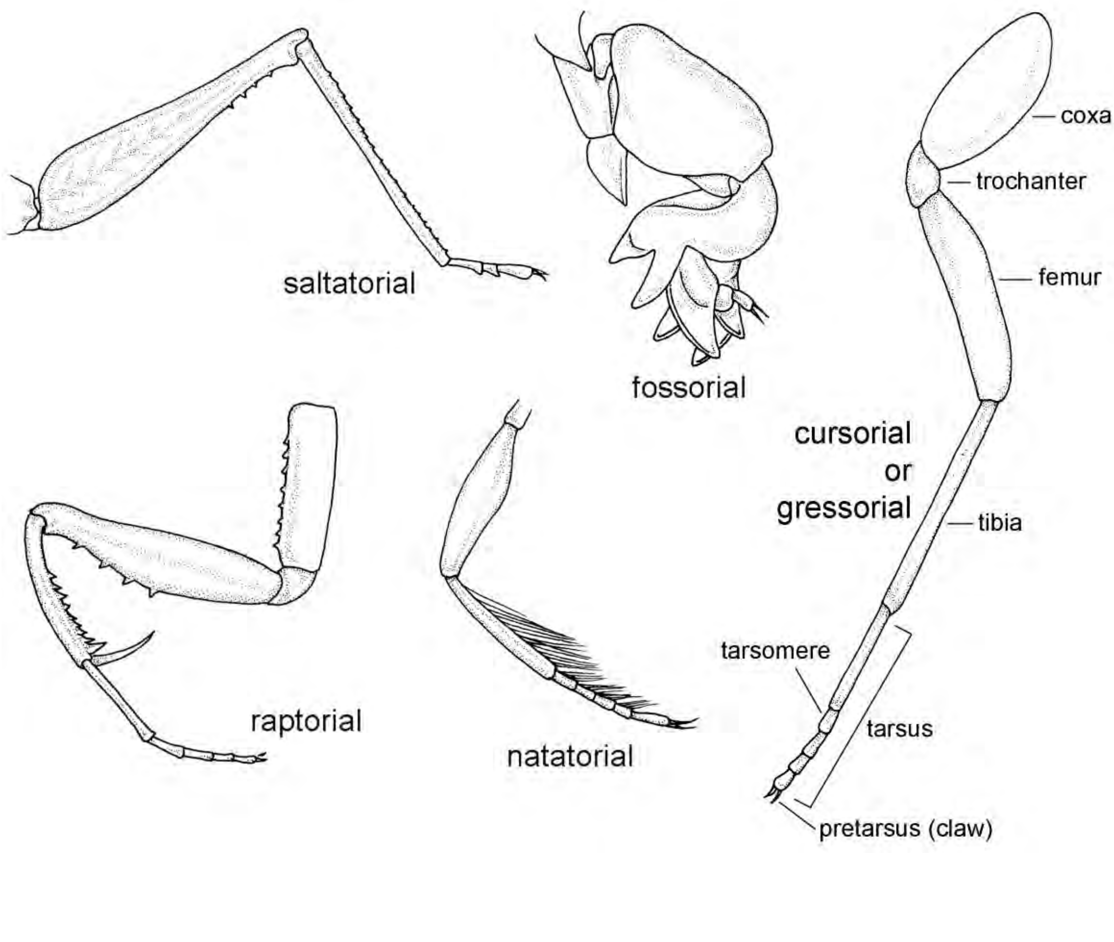
3) **Femur** (pl. femora) – is generally small in larval insects, but in most adult insects is the most robust segment of the leg.

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.

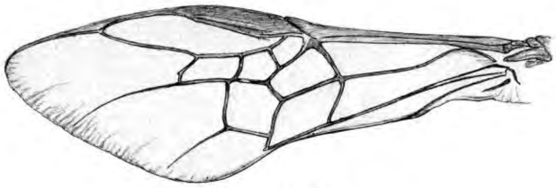
- Booklice (Psocodea) and psyllids (Hemiptera: Psylloidea) have membranous wings held tent-like over the body, but each group has its own distinctive venation.

- Thrips (Thysanoptera) have fringed wings that are very narrow, narrower than the body.

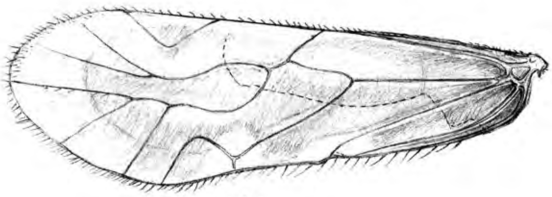
Wing Shortening, loss and polymorphism

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.

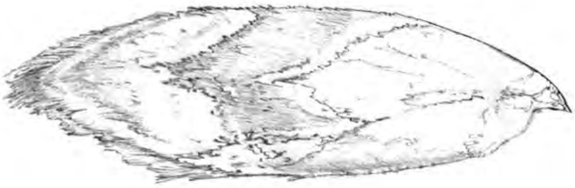
Examples of some of the variety of different forewings found amongst the insect orders:



Hymenoptera

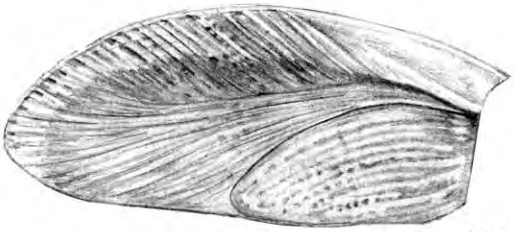


Psocodea

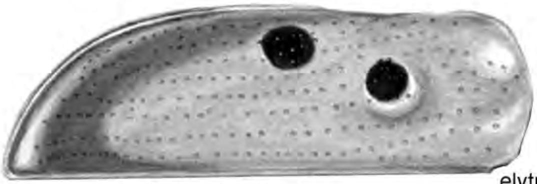


Lepidoptera

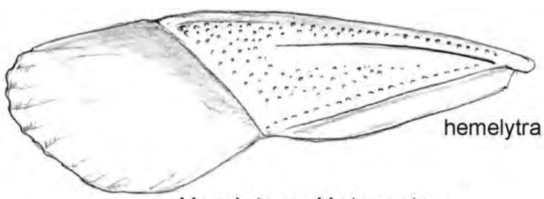
Trichoptera



Blattoidea leathery tegmina

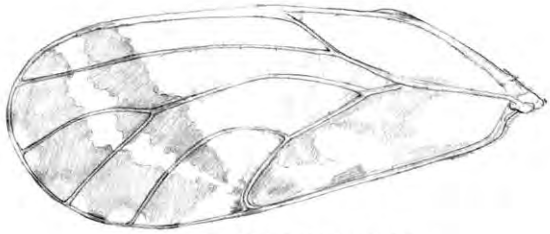


Coleoptera elytra

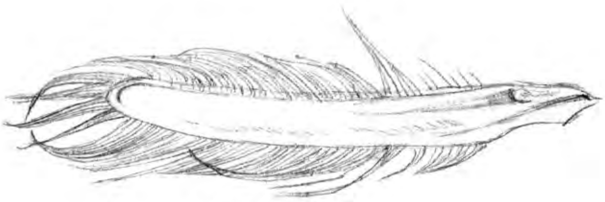


Hemiptera: Heteroptera

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.

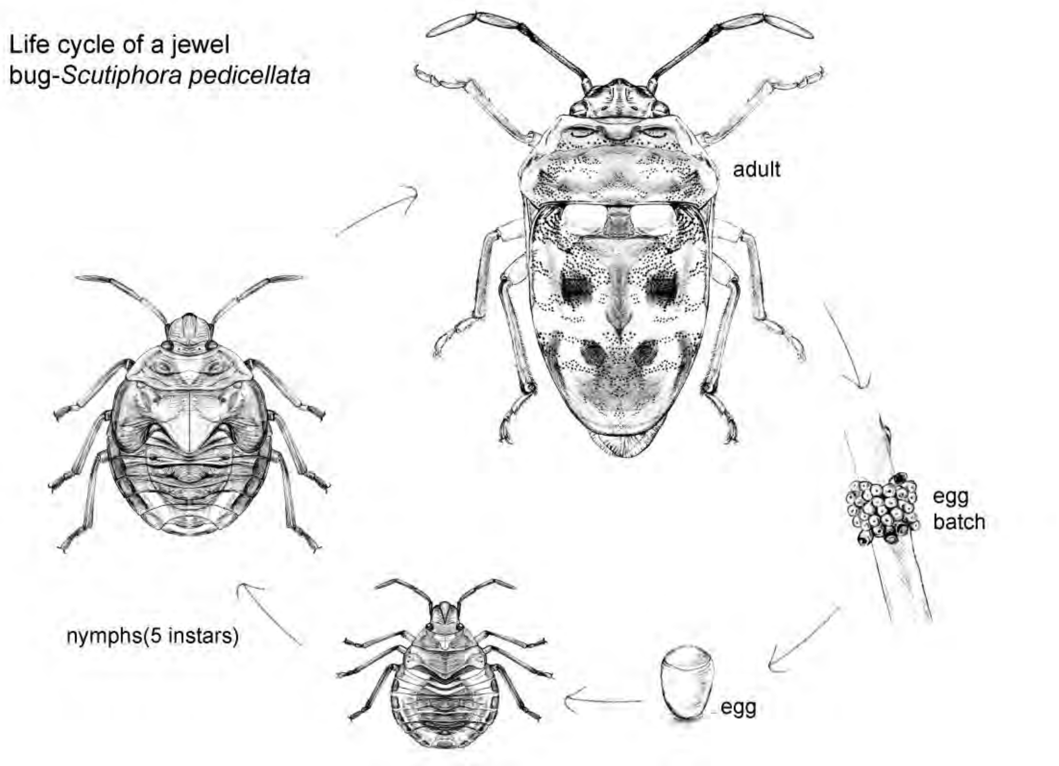
Hemimetabolous development

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).

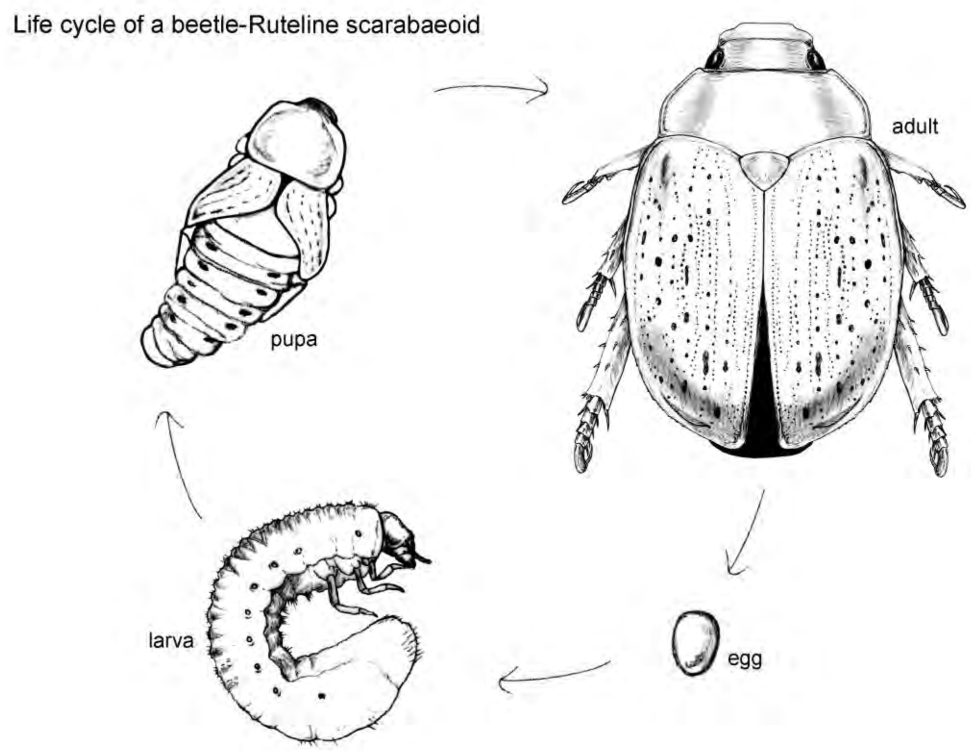
Holometabolous development

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.

A Key for Larvae, Nymphs and Adults of Insects for Papua New Guinea

Note that this key excludes **pupae**. Pupae are the resting phase (generally non-mobile) of endopterygote insects (Neuroptera, Diptera, Siphonaptera, Coleoptera, Strepsiptera, Hymenoptera, Lepidoptera, Trichoptera) and a few Hemiptera. **Exarate pupae**, with the developing adult appendages free from the body, are usually identifiable from their developing adult features. This forma of pupa is found in Neuroptera, Trichoptera, Siphonaptera, almost all Hymenoptera, most Coleoptera, a few Diptera and a few Lepidoptera. **Obtect pupae** are smooth walled and have the developing appendages fused into the body – these are difficult to identify but are only present in some Coleoptera, almost all Lepidoptera, and a few chalcidoid Hymenoptera. In Strepsiptera, most Diptera and a few Hemiptera, the pupa is described as a **puparium** because it develops within the tightly enfolding last larval skin. Pupae of many phytophagous insects occur on the host plant and are likely to be countered in field crops. Note that larvae are distinguished from adults by lack of genitalia (usually at apex of abdomen) and never have wings (adults are with or without wings).

1. One or two pairs of wings present, as articulated (moveable point of attachment) membranes or lobes from the meso- and metathorax (forewings and hind wings respectively); forewings may be thickened (opaque) and incapable of flight, covering hind wings (if these are present); genitalia present (may be hidden in apex of abdomen) **2**

\- Wingless, although posterior margins of meso- and metathorax may have short unarticulated lobes (wing buds of nymphs); genitalia present or absent **26**

Full-winged or Brachypterous (short winged) Adults

This part of the key to adults of insects with wings (whether modified as abdomen covers, shortened or fully formed for flight), is relatively simple compared with the rest of the key. However it relies on examination of the whole insect, so requires some time spent learning the basic anatomy of insects. We include all insect orders known to occur in New Guinea, including Plecoptera (a single record from West Papua) and Zoraptera (a single species known from one locality in New Britain). Two additional insect orders are found in Australia (Megaloptera and Mecoptera) but are south-eastern in distribution and absent from the tropics and therefore not in this key.

2(1). Apex of abdomen with two or three very long multi-segmented thread-like appendages (= paired cerci or paired cerci and terminal filament) **(Figs 1A, 1B)**, usually longer than body **(Fig. 1A)**; antennae short, shorter or not much longer than head **(Fig. 1C)**; wings held upright at rest, without scales (= flattened setae) or setae (= small articulated hairs); hind wing much shorter and smaller than forewing **(Fig. 1A)**, or absent; mouth parts reduced (= without paired mandibles or sucking rostrum or proboscis) **(Fig. 1C)**; usually swarming over water surface or resting on water-side plants, attracted to light................................... **Ephemeroptera (adults and subadults) (Fig. 1)**

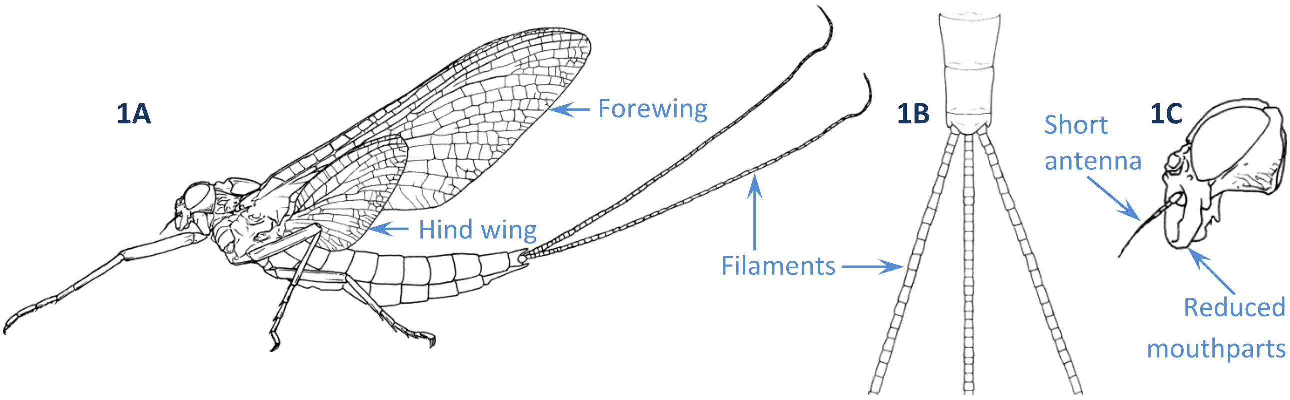


Fig. 1. EPHEMEROPTERA

Abdomen most often without very long thread-like terminal appendages, at most with two appendages; if terminal appendages present, usually much shorter than body, or if terminal appendages as long as body, then antennae longer than body, wings at rest held flat over body, and mandibles fully developed (some Orthoptera: Gryllidae: ground crickets); wings usually flat or tent-like at rest, if held vertically above body, without very long terminal appendages................. **3**

3(2). Only single pair of wings present, which are membranous, visible and not folded; second pair of wings absent or reduced to hair-like or club-like (expanded at apex) appendages......................... **4**

- Both pairs of wings developed, sometimes forewings hardened (= elytra), partially hardened (= hemelytra) or leathery (= tegmina); sometimes hind wings reduced, but not knob-like (many Hymenoptera), hind wings sometimes absent, in this case forewings hardened or leathery (some Coleoptera, e.g. Staphylinidae, some Hemiptera).. **7**

4(3). Forewings small and club-like **(Figs 2A, 2B)**; hind wings well-developed, venation reduced, without cross-veins **(Fig. 2A)**; antennae fan-shaped, with one or more finger-like lobes (sometimes flabellate) **(Fig. 2C)**; mouth-parts almost absent, not piercing, biting or sponging; delicate insects, rarely seen or collected ....**Strepsiptera (adult males) (Fig. 2)**

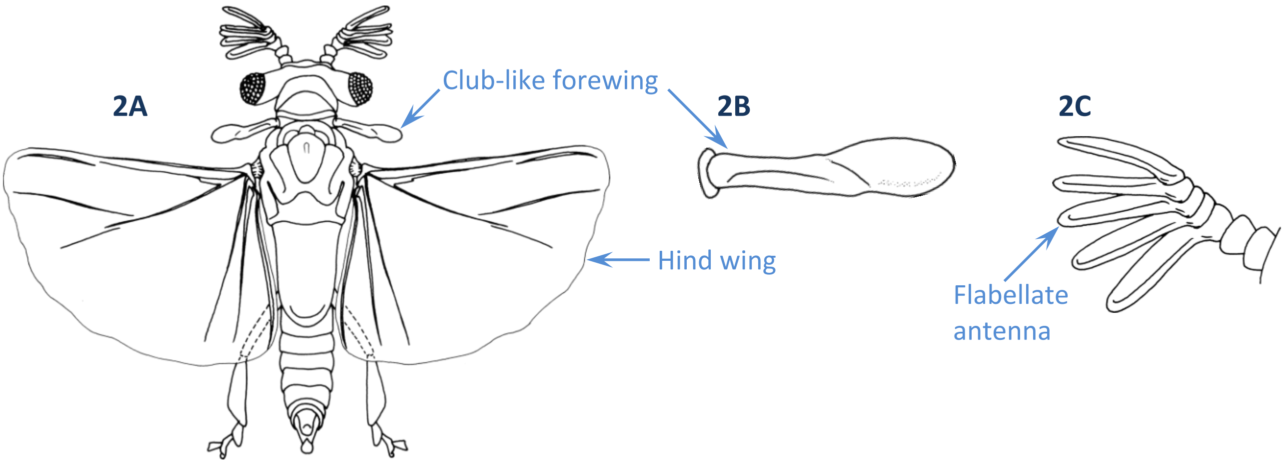


Fig. 2. STREPSIPTERA

- Forewings well developed, venation with or without cross-veins; hind wings reduced to small knobs (= halteres), or hair-like; mouthparts either mandibulate (chewing and biting), piercing, sucking, sponge-like or reduced **5**

5(4). Abdomen waisted, constricted basally (at junction with thorax) **(Fig. 3A)**; wings fringed with long hair-like setae **(Figs 3A, 3B)**; reduced hind wings hair-like **(Figs 3A, 3C)**.. ....**Hymenoptera (adult Mymarommatidae – microscopic) (Fig. 3)**

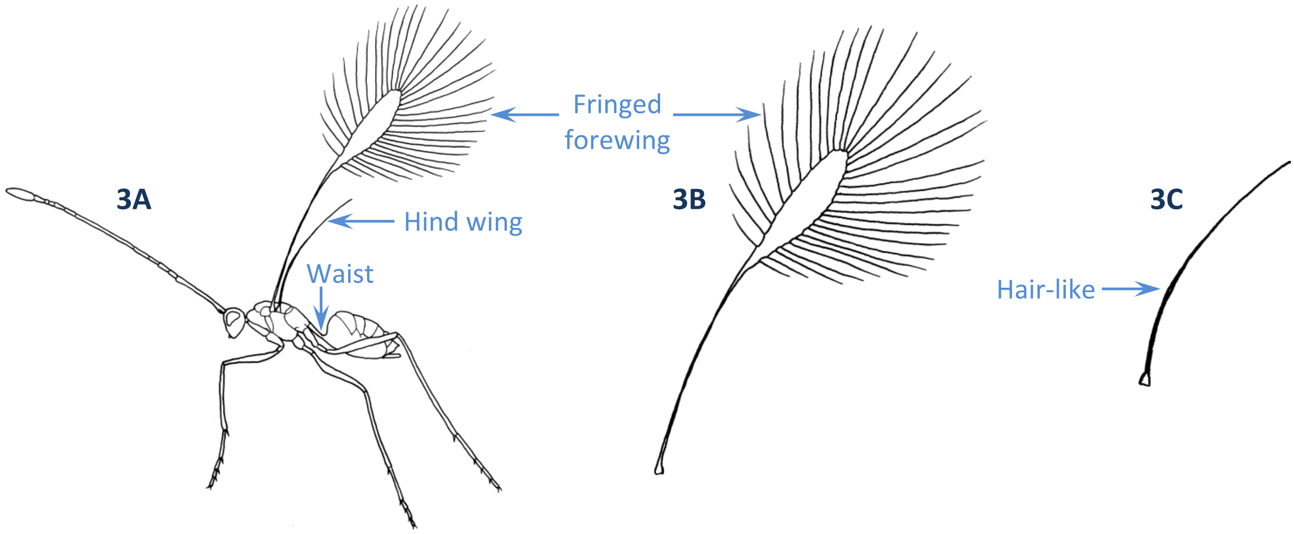


Fig. 3. HYMENOPTERA (adult MYMAROMMATIDAE – microscopic)

\- Abdomen not constricted, wings not fringed with long hair-like setae; reduced hind wings club-like (= haltere).. **6**

6(5). Mouth parts sponge-like **(Fig. 4B)** or piercing **(Fig. 4C)**, adapted for sucking, sometimes not developed; mesonotum swollen **(Fig. 4A)** and pronotum greatly reduced, often not visible from above; antennae bristle-like (= aristate) or bead-like (= moniliform) or thread-like (= filiform) or clubbed (= clavate); forewings almost always translucent, nearly always with more than 2 veins and with cross-veins **(Fig. 4D)** .... **Diptera (adults) (Fig. 4)**

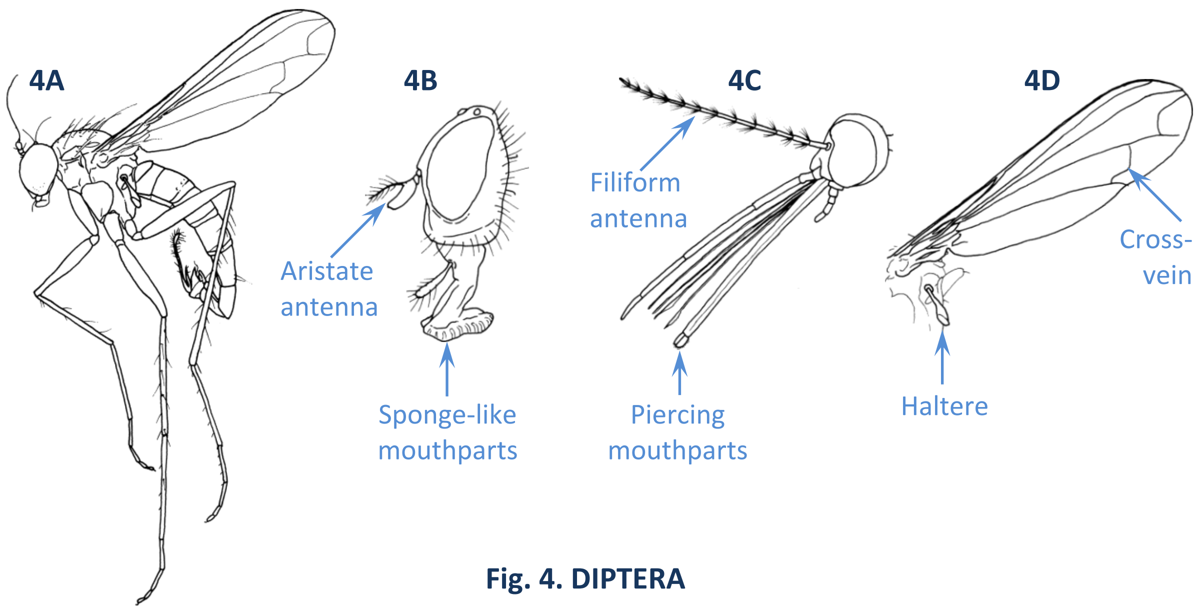


Fig. 4. DIPTERA

- Mouth parts reduced, not functional; pronotum short but visible from above; antennae filiform (= thread-like); forewings membranous with only 2 or 3 veins, without cross-veins, thickened and opaque at base **(Fig. 5A)**; rarely seen or collected .... **Hemiptera (male Coccoidea) (Fig. 5)**

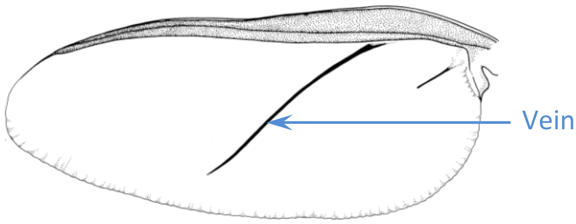


Fig. 5. HEMIPTERA (male COCCOIDEA)

7(3). Wings narrow (= thinner than body width), strap-like, with reduced venation, always with fringe of long setae (= hairs), at least on hind margin, wings never with scales **(Figs 6A, 6B)**; mouthparts minute (microscopic), cone shaped, positioned near thorax ventrally **(Fig. 6C)**; body usually shorter than 5 mm; tarsi 1-2 segmented **(Fig. 6A)** .... **Thysanoptera (Fig. 6)**

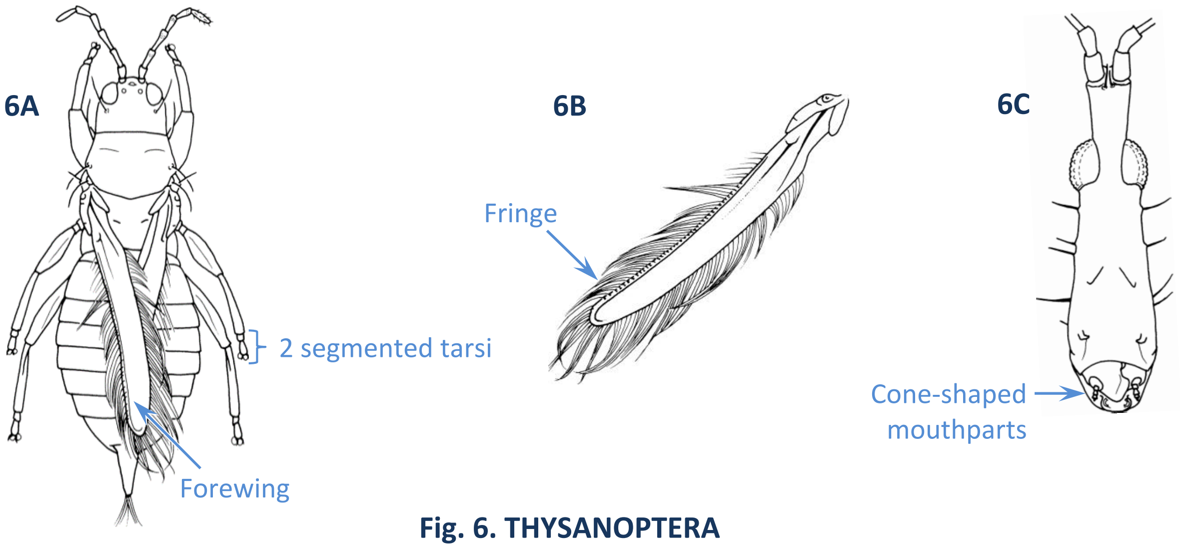


Fig. 6. THYSANOPTERA

- Wing shape variable, usually wider than body, very rarely fringed; if wings fringed, then with scales (Lepidoptera) or abdomen constricted or waist-like (some Hymenoptera, e.g., Scelionidae) or only hind wing fringed and folded under hardened forewing (= elytra) (Coleoptera: Ptiliidae); mouthparts various, but rarely minute and conical **8**

8(7). Mouthparts modified into a straight tube-like rostrum or proboscis, articulated at base (only mouthparts, not head projection as in some beetles, such as weevils), anteriorly or ventrally positioned but directed posteriorly, without palps, either short or long, nearly always segmented **(Fig. 7A)**; forewings often partly or entirely hardened (= hemelytra) and held flat over the body at rest (Hemiptera: Heteroptera, Coleorrhyncha), or forewings thickened or membranous and held tent-like at rest (Hemiptera, most Auchenorrhyncha, some Sternorrhyncha) **(Fig. 7B)** or held upright over the body at rest (Hemiptera, most Sternorrhyncha, few Auchenorrhyncha) .... **Hemiptera (most adults) (Fig. 7)**

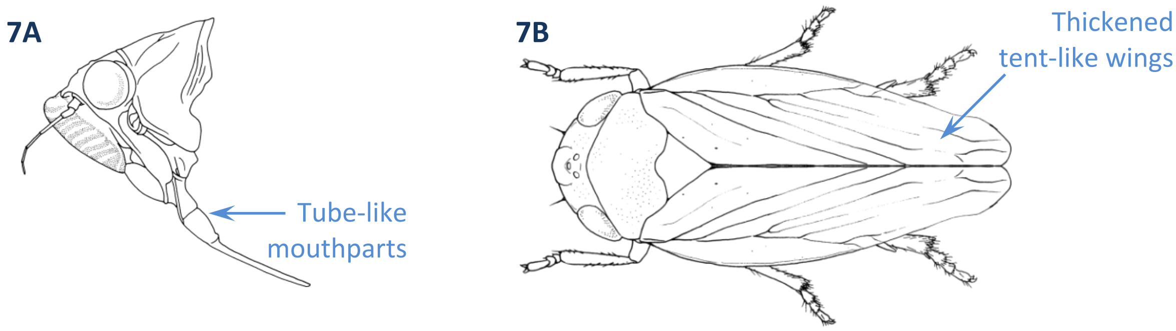


Fig. 7. HEMIPTERA

\- Mouthparts usually chewing or biting (= mandibulate) **(Fig. 8A)**, sometimes proboscis-like and coiled at rest (= haustellate) **(Fig. 8B)** (Lepidoptera), or sometimes straight but mouth with palps and body with branched hair-like setae (Hymenoptera: Apoidea); narrow elongation of some weevil (also called rostrum) heads not articulated at base and with mandibulate mouthparts at apex **(Fig. 8C)** **9**

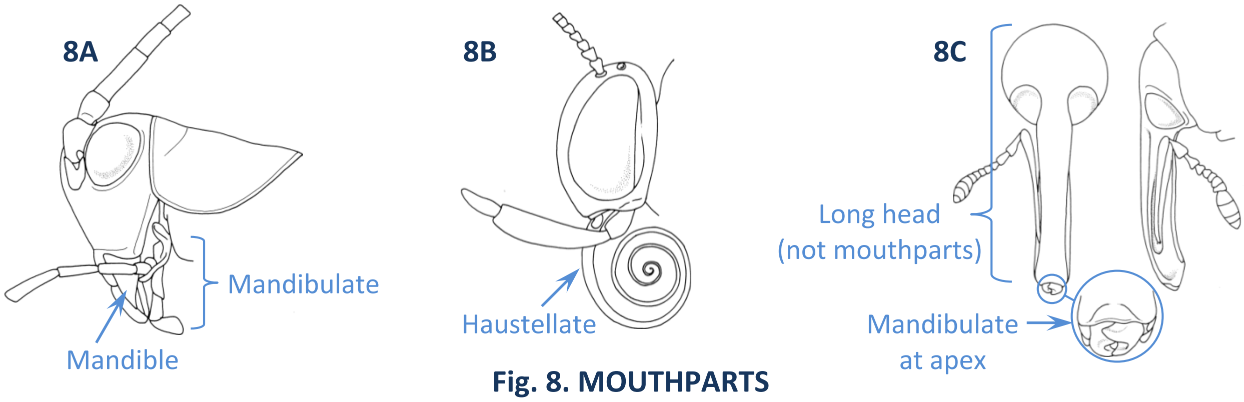


Fig. 8. MOUTHPARTS

9(8). Wings membranous and veined, densely clothed with hair-like setae in-between veins and nearly always held tent-like over the body (Trichoptera) **(Fig. 9A)**, or with overlapping scale-like setae on both surfaces of the wings (Lepidoptera), sometimes scales reduced to patches (also Lepidoptera); tarsi 5-segmented **(Fig. 9B)**;.. **10**

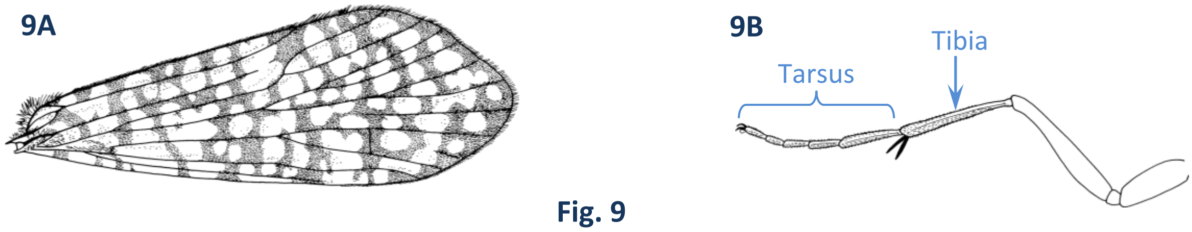


Fig. 9

\- Wings, if membranous and veined, without scales or hair-like setae, or at most with hair-like setae on wing margins or veins (some Hymenoptera & Neuroptera), or with very short setae visible only under the microscope (some Psocodea, some Hymenoptera); or rarely wings sparsely covered with distinct hair-like setae or scales, but if so, tarsi 2- or 3-segmented **(Figs 10A, 10B)**, eyes small with head projected in front of eyes (i.e., expanded rounded postclypeus, some Psocodea) **11**

Fig. 10. TARSAL SEGMENTS

10(9) Wings (on both surfaces) with overlapping, usually broad and flat scales (usually densely distributed) **(Figs 11A, 11B)**, venation usually hidden by scales; body also usually with scale-like setae, sometimes intermixed with hair-like setae; mouthparts usually in the shape of coiled tube or proboscis (= haustellate) **(Fig. 11C)**, occasionally reduced or distinctly mandibulate; middle of foretibia with large articulated lobe (= epiphysis) in some mandibulate species; wings held horizontally, vertically, flat or tent-like at rest .... **Lepidoptera (adults) (Fig. 11)**

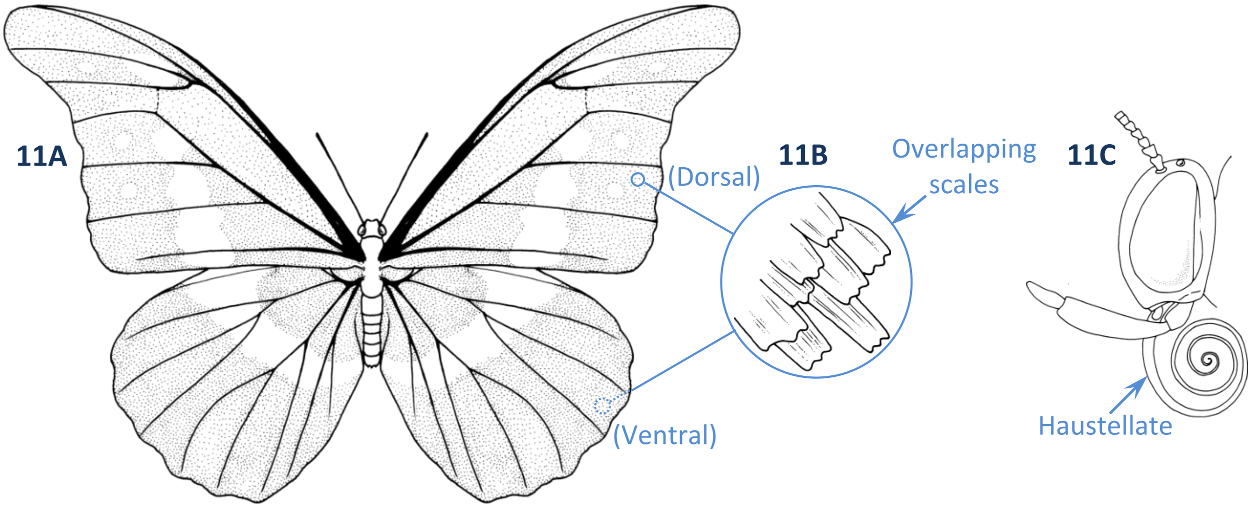


Fig. 11. LEPIDOPTERA

\- Wings clothed with long hair-like setae, without flat scales, venation clearly visible **(Fig. 12A)**; mouthparts reduced (mandibles vestigial) and never haustellate (= coiled proboscis) **(Fig. 12B)**; middle of foretibia without large articulated lobe (= epiphysis); wings held tent-like over body, rarely flat **(Fig. 12A)** .... **Trichoptera (adults) (Fig. 12)**

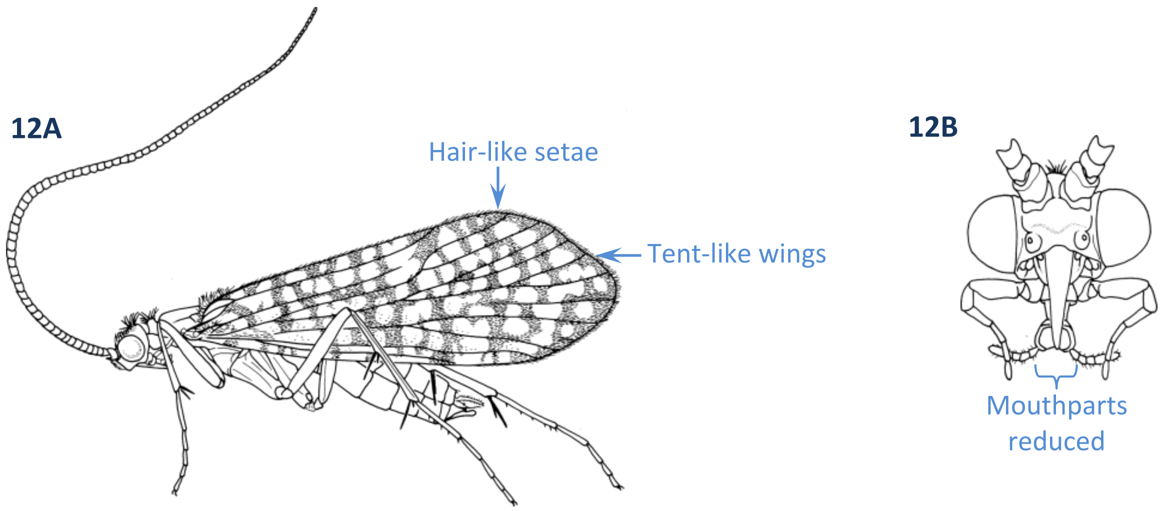


Fig. 12. TRICOPTERA

11(9). Forewings opaque, hardened or leathery, or if forewings transparent then hind legs enlarged for hopping and antennae longer than body (some Orthoptera); hind wings membranous, but generally folded under forewings and therefore hidden; hind wings sometimes reduced or absent **12**

\- Forewings membranous, transparent, two pairs always present; hind legs not enlarged for hopping and antennae not longer than the body **17**

12(11). Forewings opaque, hardened, thick, without venation (= elytra or tegmina) **(Figs 13A, 13B)**; forewings not overlapping, with inner margins meeting along midline at rest (sometimes fused in Coleoptera) **(Figs 13A, 13B)**; without multisegmented cerci at apex of abdomen **13**

\- Forewings with visible venation **(Fig. 13C)**; forewings often overlapping at rest **(Fig. 13C)**; pair of short multi-segmented cerci usually present at apex of abdomen (some Orthoptera, Blattodea) or body extremely elongated (Phasmatodea) **14**

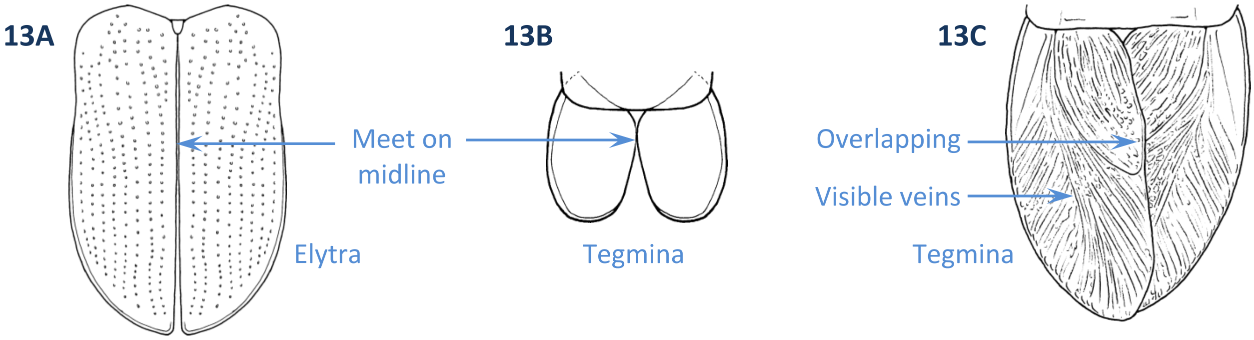


Fig. 13. SPECIALISED FOREWINGS

13(12). Terminal abdominal appendages present as paired symmetrical or asymmetrical forceps (= robust unsegmented cerci) **(Figs 14A, 14B)**; forewings short and leathery with no venation (= tegmina) **(Fig. 14C)**, exposing 7-8 abdominal segments **(Fig. 14A)**; hind wing large and semi-circular when expanded, with fan-like veins radiating from base, folding under tegmina with apices of folded hind wings projecting beyond apices of tegmina; hind wings sometimes reduced or absent; tarsi 3-segmented with the 2nd segment shortened .... **Dermaptera (adults) (Fig. 14)**

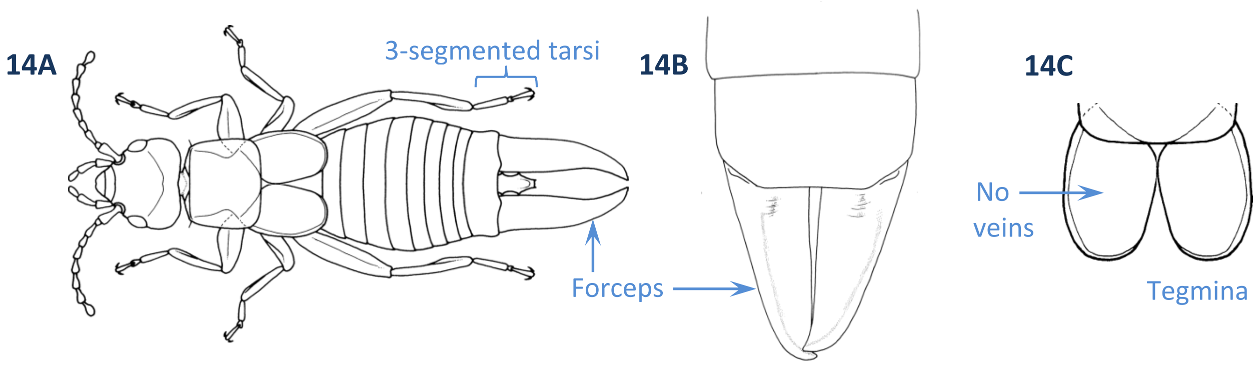


Fig. 14. DERMAPTERA

\- Terminal abdominal appendages nearly always absent, if present then short (not longer than apical abdominal segment) and not forceps-like **(Fig. 15C)**; forewings (= elytra) usually long and covering all or most of abdominal segments **(Figs 15A, 15B)**; if elytra short then hind wings not projecting beyond apices of elytra at rest; if short elytra and paired terminal appendages present (some Staphylinidae) **(Fig. 15C)**, then tarsi 5-segmented; hind wings not semi-circular when extended, without radiating veins; hind wings sometimes reduced or absent .... **Coleoptera (adults) (Fig. 15)**

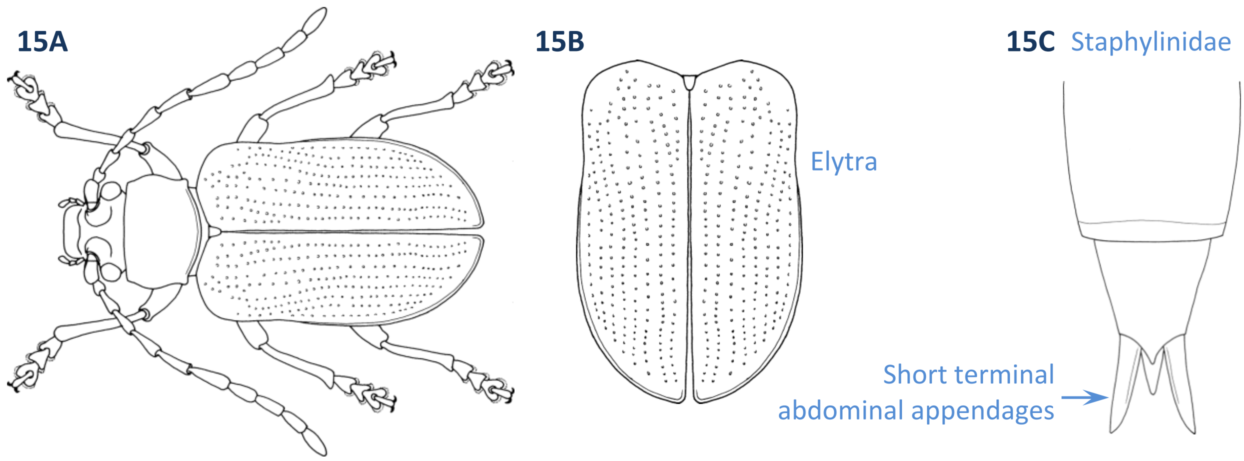


Fig. 15. COLEOPTERA

14(12). Forelegs raptorial (= grasping), much larger than mid and hind legs, with large elongated coxae, internally spined femora, hooked tip of tibiae and long tarsi, usually held together anteriorly in characteristic flexed position **(Fig. 16B)**; forelegs contrasting with simple thin and non-spined mid and hind legs **(Fig. 16A)**; (pronotum usually elongate and freely articulated, longer than relatively short mesothorax) .... **Mantodea (adults) (Fig. 16)**

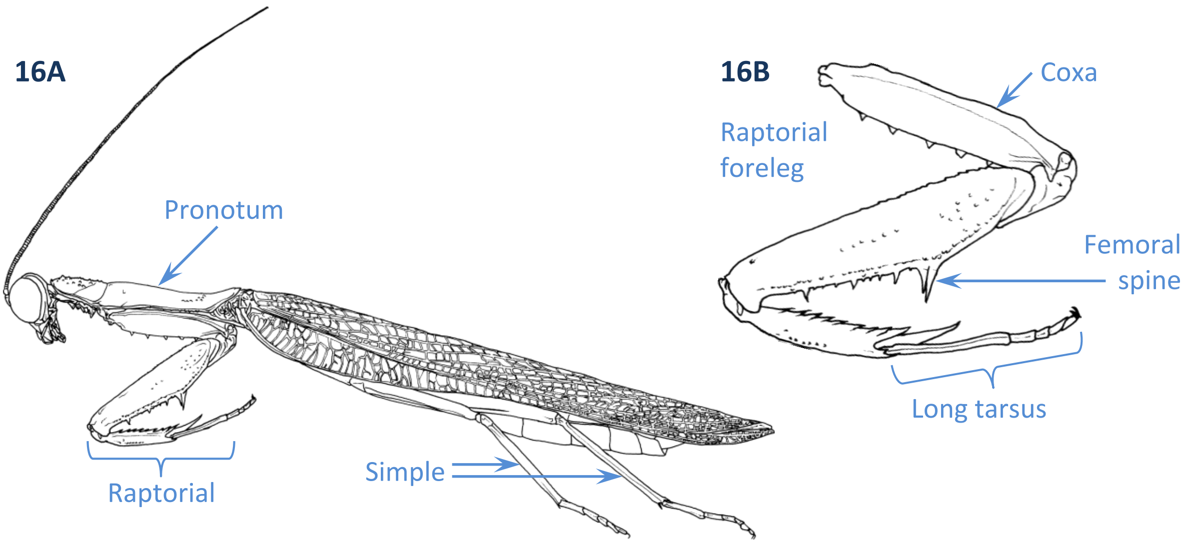


Fig. 16. MANTODEA

\- Forelegs not raptorial, with small hidden forecoxae, and apex of tibiae not hooked; sometimes relatively enlarged compared with mid legs, if so front legs modified for digging without femoral spines and with short tarsi (Gryllotalpidae in Orthoptera), or flattened and expanded and whole animal imitating leaves (Phylliidae in Phasmatodea) **15**

15(14). Pronotum relatively small, not covering mesonotum, which is elongate and freely articulated on metathorax, and not overlapping base of wings **(Figs 17A, 17B)**; body either stick or leaf mimicking; head prognathous (oriented horizontally, mouthparts pointing forward), not concealed beneath pronotum **(Fig. 17B)**; hind legs generally similar sized to mid legs; cerci unsegmented **(Fig. 17A)**... **Phasmatodea (adults) (Fig. 17)**

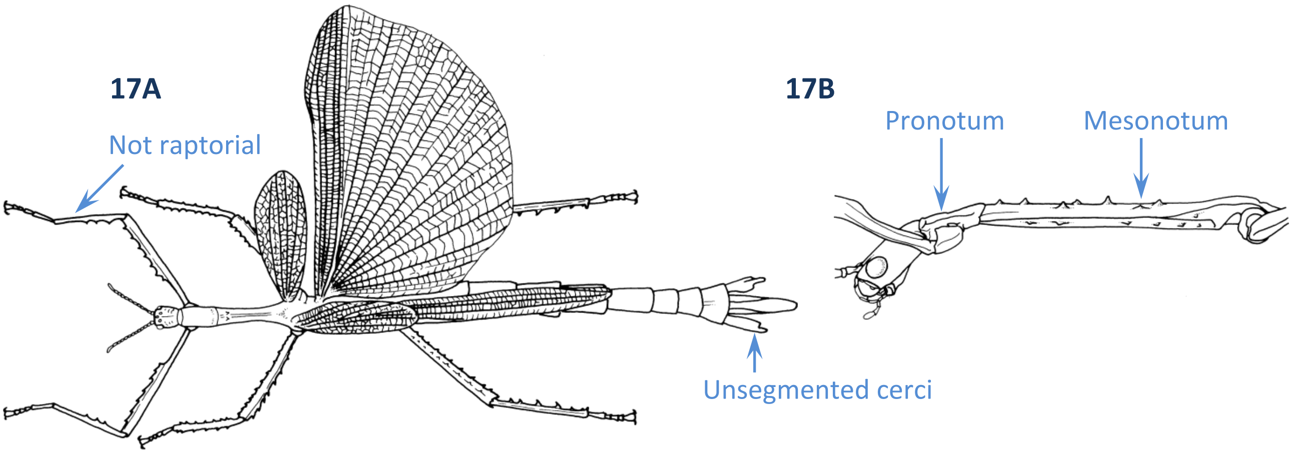


Fig. 17. PHASMATODEA

\- Pronotum relatively large, entirely or partially covering mesonotum (if latter, only small triangular scutum visible), overlapping bases of wings **(Figs 18A, 18B)**; mesothorax fused to metathorax; body usually robustly cylindrical (Orthoptera) **(Fig. 18A)** or strongly flattened (Blattodea) **(Fig. 18B)**; hind legs generally larger than mid legs; cerci multi-segmented **16**

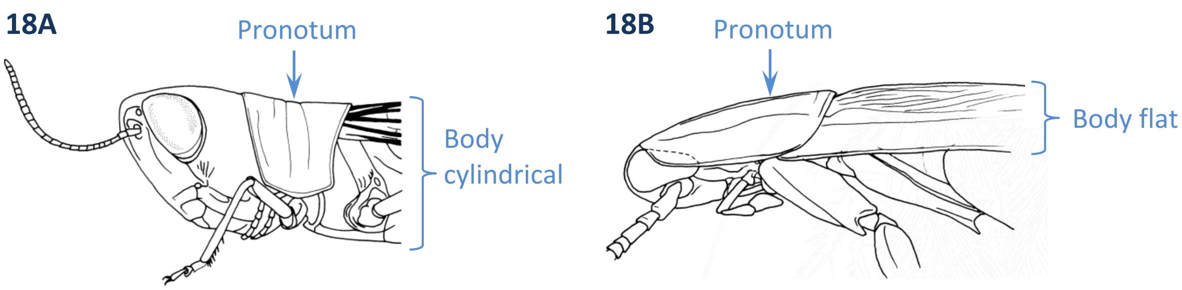


Fig. 18. PRONOTUM

16(15). Hind legs modified for jumping (= saltatorial), with femora elongated and thickened compared with middle femora and tibiae relatively elongated **(Figs 19A, 19C)**; sides of pronotum projecting ventrally as descending lobes **(Fig. 19B)**; anterior of pronotum not concealing head, eyes visible from above; body usually cylindrical .... **Orthoptera (adults) (Fig. 19)**

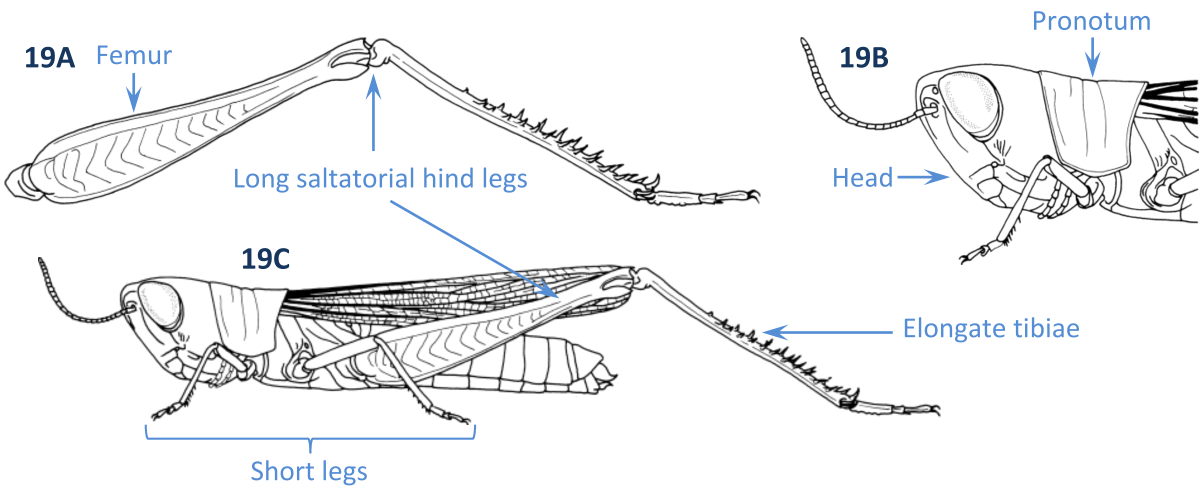


Fig. 19. ORTHOPTERA

- Hind legs not specially modified, similar in shape to middle legs, although often slightly larger **(Fig. 20A)**; pronotum flat, sides without ventrally directed lobes; anterior of pronotum generally concealing head, eyes not usually visible **(Fig. 20B);** body flat .... **Blattodea (adults) (Fig. 20)**

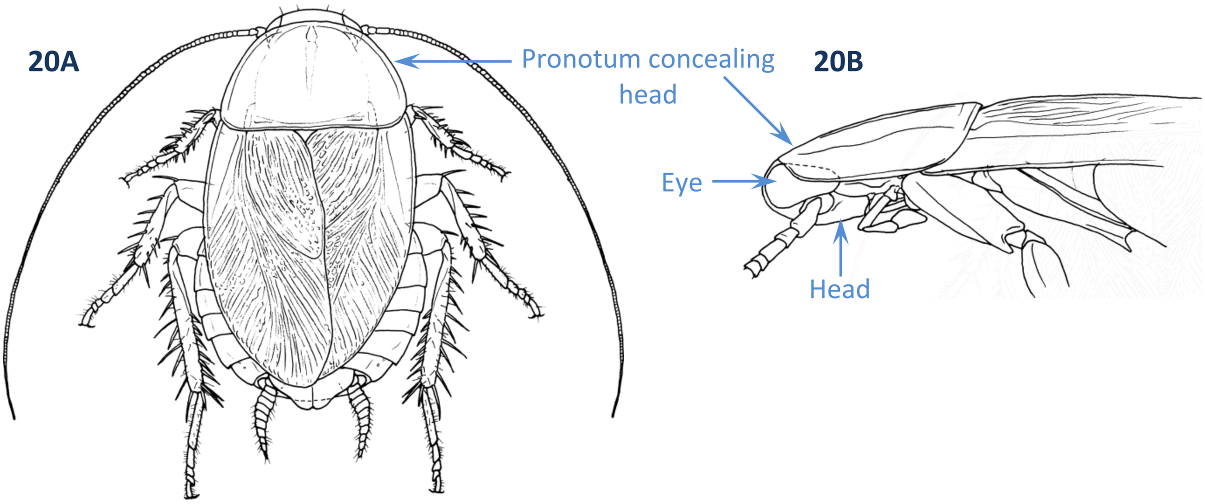


Fig. 20. BLATTODEA

17(11) Forelegs raptorial, usually held in characteristically flexed position, enlarged compared with mid and hind legs, with long elongated coxae, forefemora with row of spines; pronotum elongate **18**

- Forelegs not raptorial, without elongated coxae, forefemora without row of spines; pronotum not elongate **19**

18(17) Fore tarsi longer than foretibiae **(Fig. 21A)**; apex of foretibiae with large curved spine **(Fig 21A)**; segmented cerci present .... **Mantodea (Fig. 21A)**

- Fore tarsi shorter than foretibiae **(Fig. 21B)**; apex of foretibiae simple, without spine; cerci absent .... **Neuroptera (Mantispidae) (Fig. 21B)**

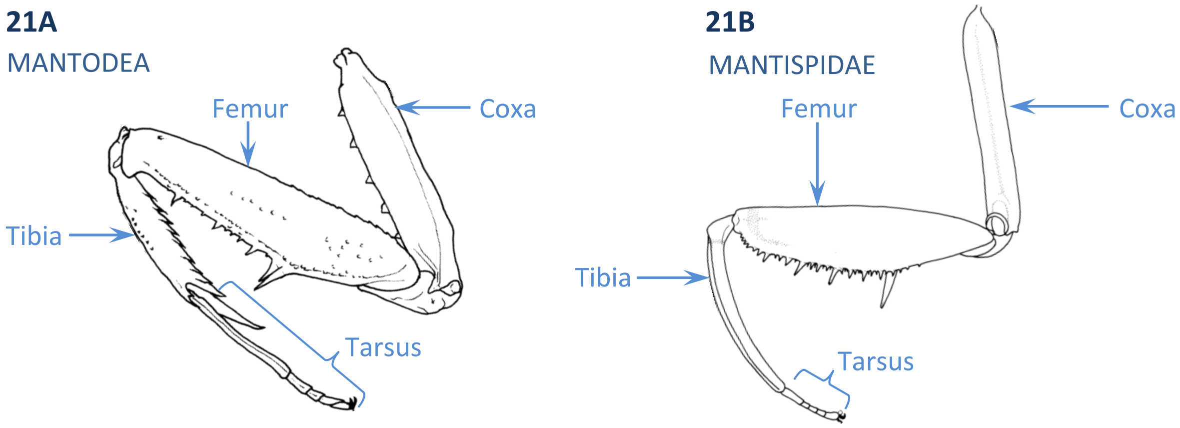


Fig. 21. RAPTORIAL FORELEGS

19(17). Apex of abdomen with pair of long multi-segmented cerci (>5 segments) **(Figs 22A, 22B)**; pronotum large, almost as long as mesonotum; wings with numerous cross-veins, hind wings larger than forewings (rarely brachypterous); tarsi 3-segmented **(Fig. 22C)**; wings usually folded flat along body **(Fig. 22A)**; body relatively flat .... **Plecoptera (adults) (Fig. 22)**

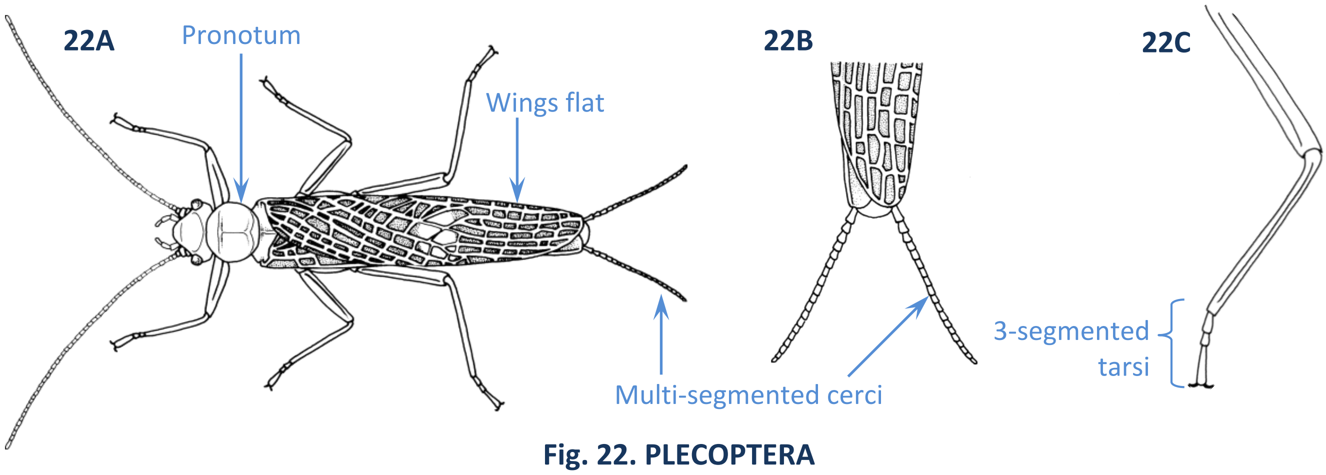


Fig. 22. PLECOPTERA

- Apex of abdomen with minute 1-5-segmented cerci, or cerci absent; pronotum, wings & tarsi variable, but hind wings rarely larger than forewings; wings rarely folded flat along body **20**

20(19). Pronotum large, half length of mesonotum, or longer; mesothorax loosely articulated with metathorax (except Neuroptera, with 5-segmented tarsi and without narrow 'waist' between thorax and abdomen) **(Fig. 23A)**.. **21**

- Pronotum very short, much shorter than mesonotum; at least mesothorax and metathorax fused into a spherical pterothorax **(Fig. 23B)**; tarsi 2-5 segmented, if tarsi 5-segmented then usually with narrow 'waist' between thorax and abdomen **24**

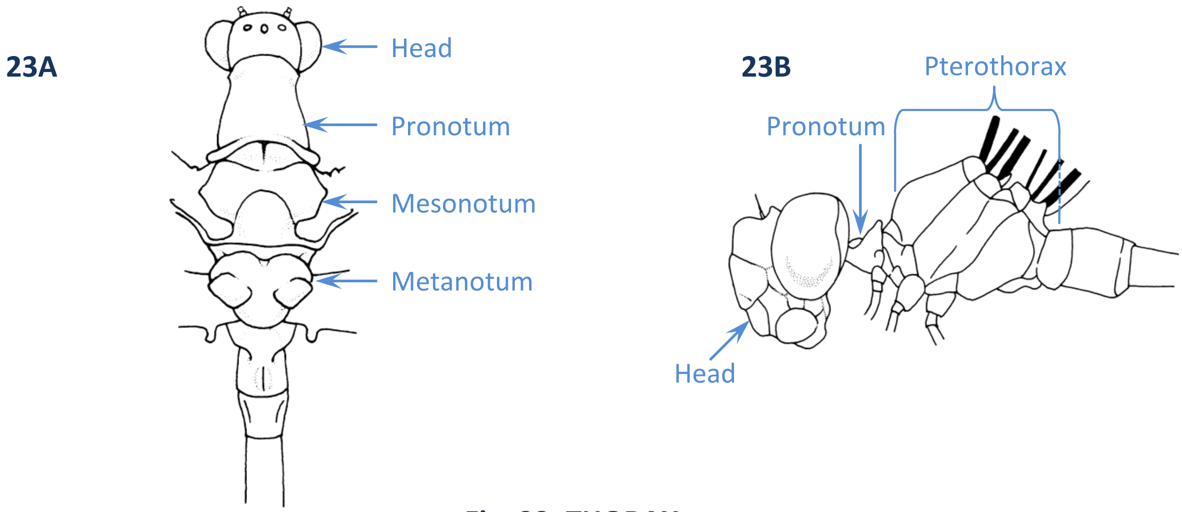


Fig. 23. THORAX

21(20). Tarsi 2-3 segmented; wings with 5 or less longitudinal veins, with 1-3 veins reaching hind margin of wing; rarely seen or collected insects **22**

- Tarsi 4-5 segmented; wings with more than 5 longitudinal veins, with more than 4 veins reaching posterior margin of wing; common insects **23**

22(21). First segment of foretarsus swollen compared with other tarsi **(Figs 24A, 24B)**; tarsi 3-segmented; abdomen flat, tergites thickened, surrounded by membrane; cerci asymmetrical **(Fig. 24A)** ....**Embioptera (male adults) (Fig. 24)**

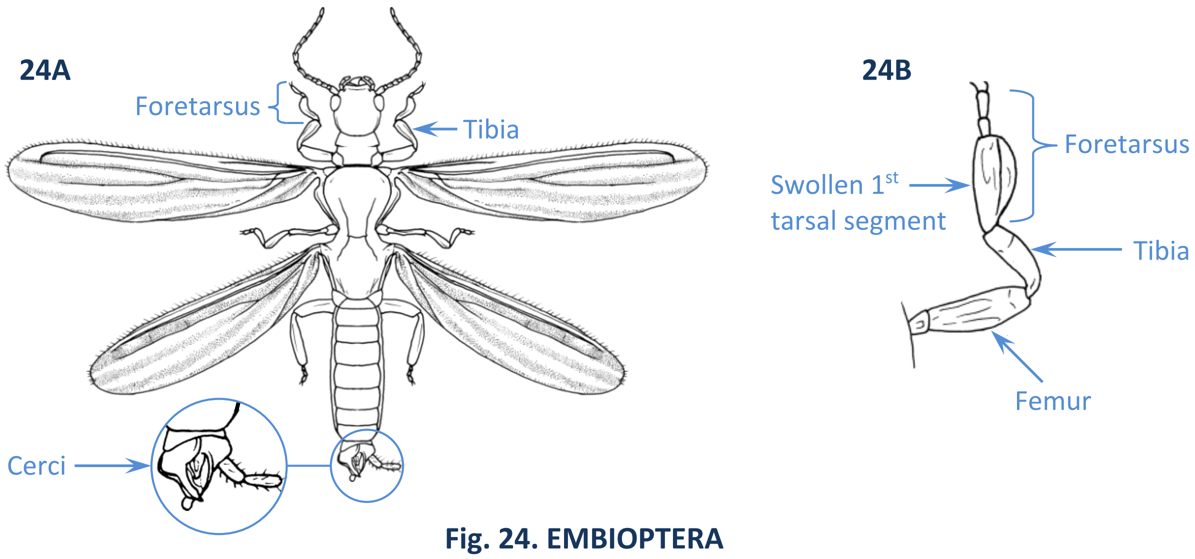


Fig. 24. EMBIOPTERA

- First segment of foretarsus not swollen; tarsi 2-segmented; abdomen cylindrical and tergites fused with sternites; cerci symmetrical .... **Zoraptera (adults) (Fig. 41)**

23(21). Several cross-veins present in wings **(Fig. 25A)**, giving net-like effect (small species with relatively few cross-veins have waxy whitish wing surfaces); cerci absent; eyes large; tarsi 5-segmented **(Fig. 25B)**; wings folded roof-like over body **(Fig. 25A)** or held away from body, not flat along body when at rest; wings not dehiscent.. **Neuroptera (adults) (Fig. 25)**

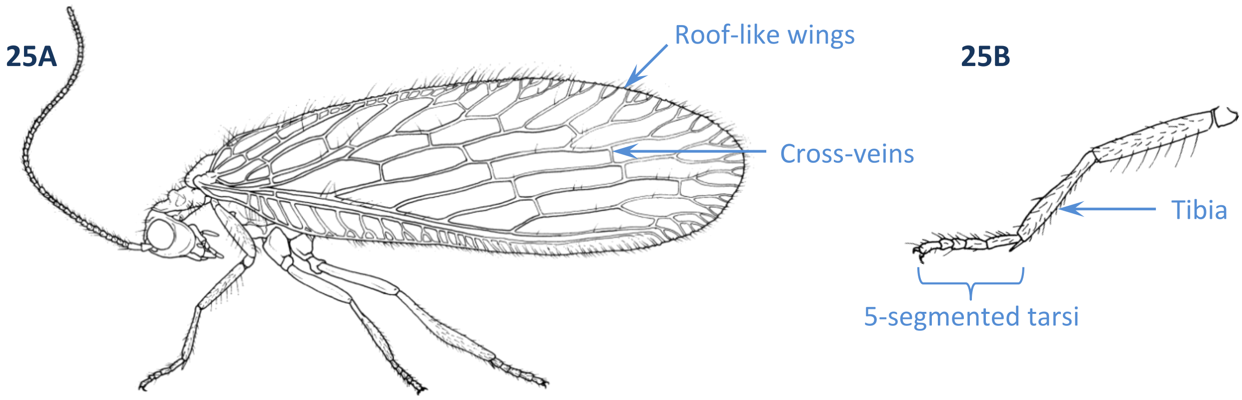


Fig. 25. NEUROPTERA

- Wings without cross-veins, without waxy surfaces **(Fig. 26C)**; short cerci present **(Fig. 26B)**; eyes small; tarsi 4-5 segmented; wings held flat over body at rest; wings often dehiscent = (partly lost) **(Fig. 26A)**.. **Blattodea: Termitoidea (some adults) (Fig. 26)**

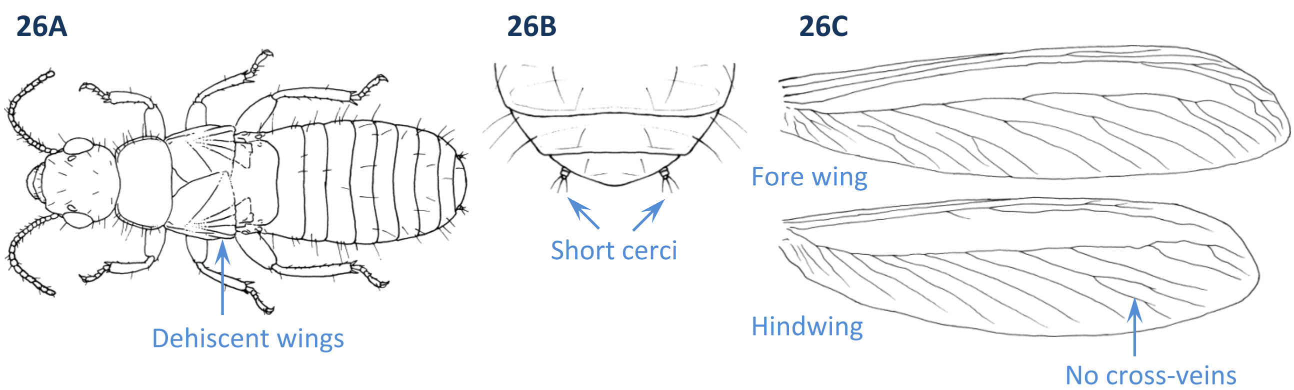


Fig. 26. BLATTODEA (TERMITOIDEA)

24(20). Size large, 20 - 150 mm body length; wings almost entirely net-like, including many regular similar sized rectangular cells **(Fig. 27A)**; wings not foldable, held rigidly laterally or along body; legs obliquely displaced, situated anterior to wings in lateral view **(Fig. 27B)**; antennae minute, appearing 2-3 segmented, with large basal scape and tiny apical flagellum **(Fig. 27B)**; mandibles large, well-developed **(Fig. 27B)** .... **Odonata (adults) (Fig. 27)**

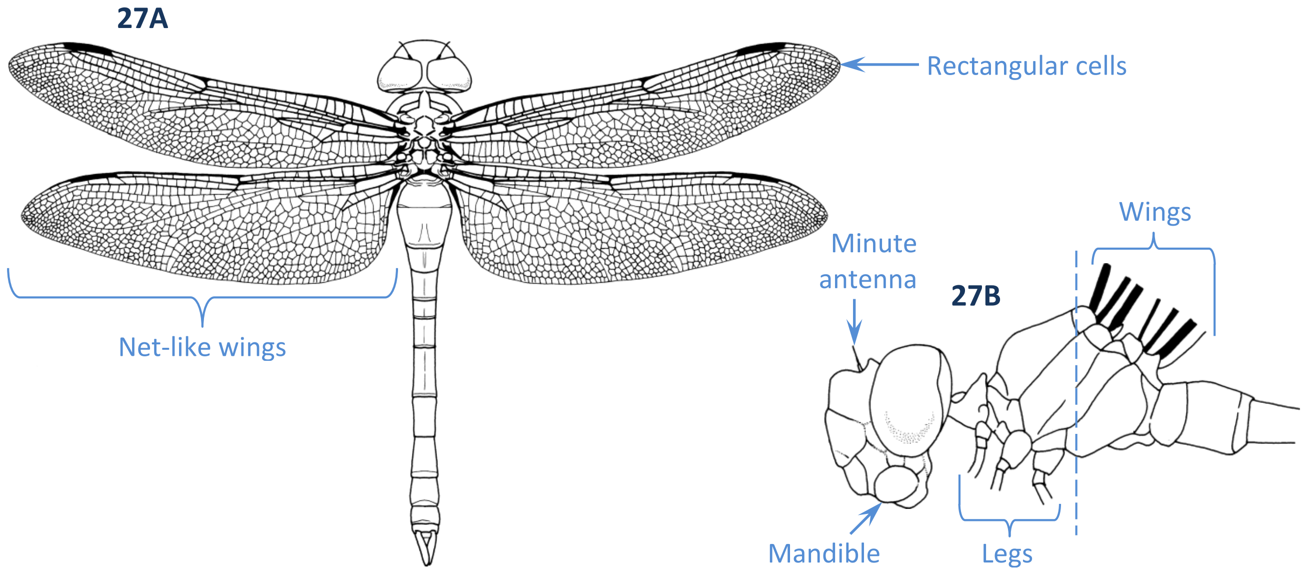


Fig. 27. ODONATA

\- Size variable, 0.5 - 55 mm body length; wings variable but wing cells if present forming irregular polygons not a regular mesh; wings often foldable in species with more numerous veins; antennae conspicuous, filiform or clavate or flabellate, often geniculate at base; mouthparts variable **25**

25(24). Body length 1 - 10 mm; face with swollen area above clypeus (postclypeus) and eyes relatively small **(Figs 28A, 28B)**; forewing venation distinct with strongly curved veins, no closed cells and no cross-veins **(Fig. 28A)**; wings at rest often held tent-like over body; antennae filiform, with numerous segments (13 or more) **(Fig. 28A)**; tarsi 2-3 segmented; abdomen sometimes constricted at junction with thorax; abdomen without protruding ovipositor; rarely metallic in colour; body soft, thin walled .... **Psocodea (some adults) (Fig. 28)**

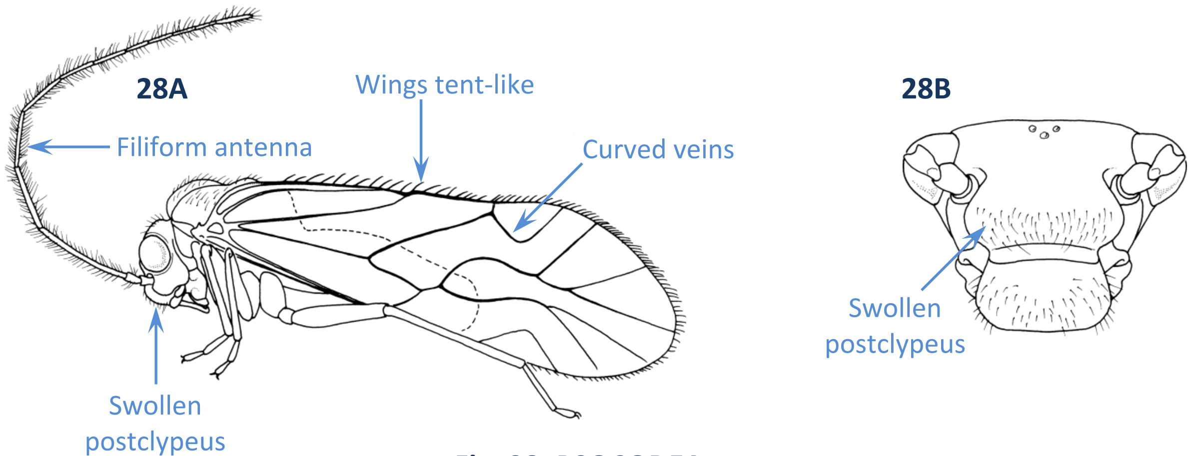


Fig. 28. PSOCODEA

- Body length 0.5 - 55 mm; face without swollen postclypeus and eyes often large; wing venation not as above, either with closed cells forming irregular polygons **(Fig. 29B)** or with a single submarginal vein **(Fig. 29C)**; wings not held tent-like/roof-like over body at rest (but may be held upright at rest); antennae either geniculate **(Fig. 29A)**, clavate or filiform or flabellate or moniliform, usually less than 14 segments; tarsi 4-5 segmented, except Trichogrammatidae (with single submarginal vein); abdomen not constricted, or constricted between first and second segments (waist-like) **(Fig. 29A)**, in which first segment fused to metathorax (determined by presence of spiracle); female often with prominent apical ovipositor; sometimes metallic; body hard, thick walled .... **Hymenoptera (most adults) (Fig. 29)**

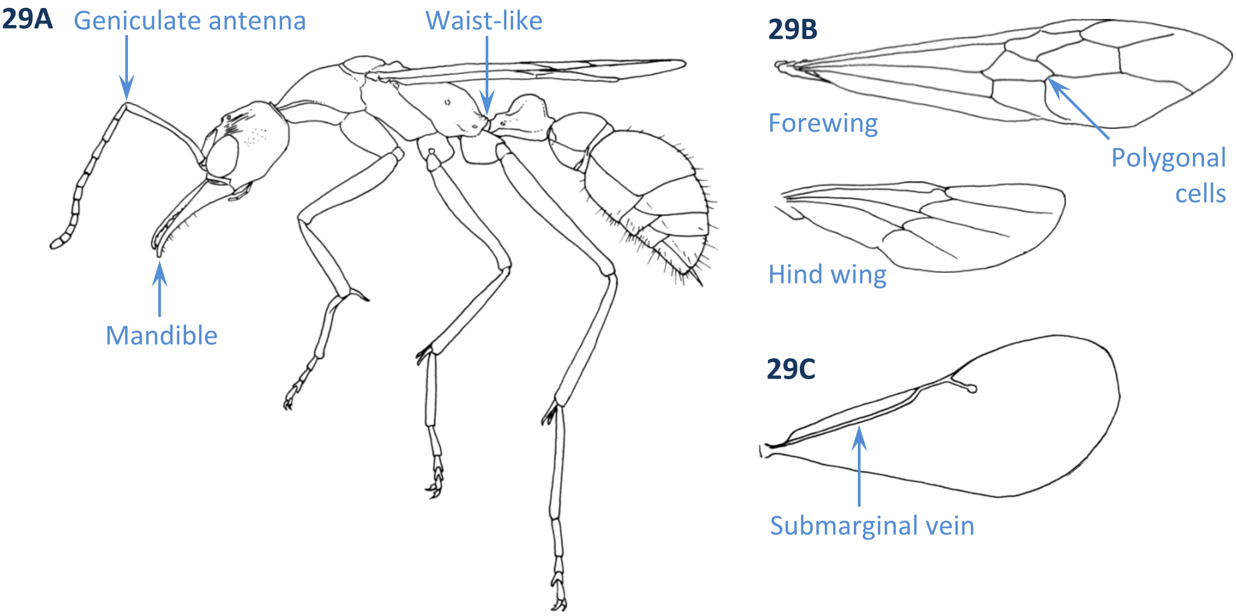


Fig. 29. HYMENOPTERA

Larvae, Nymphs or Apterous Adults

At this point the key to orders becomes much more difficult to use. Immature stages are not fully developed and therefore often lack the characters that usefully distinguish adults (genitalia, wings, sensory organs on head, body appendages). The key therefore also incorporates life history information, but only where it should be obvious (aquatic or parasitic species). It may not be possible to determine the order of some specimens.

26(1). Ventral part of mouthparts modified into a hinged flat extensible labium, with labial palps modified into sharp pincers **(Fig. 30C)**; abdomen bearing three apical filaments **(Fig. 30B)**, usually strongly flattened (damselflies), or without obvious apical appendages (dragonflies) **(Fig. 30A)**; eyes large, compound **(Figs 30A, 30C)**; length greater than 4mm; aquatic .... **Odonata (nymph) (Fig. 30)**

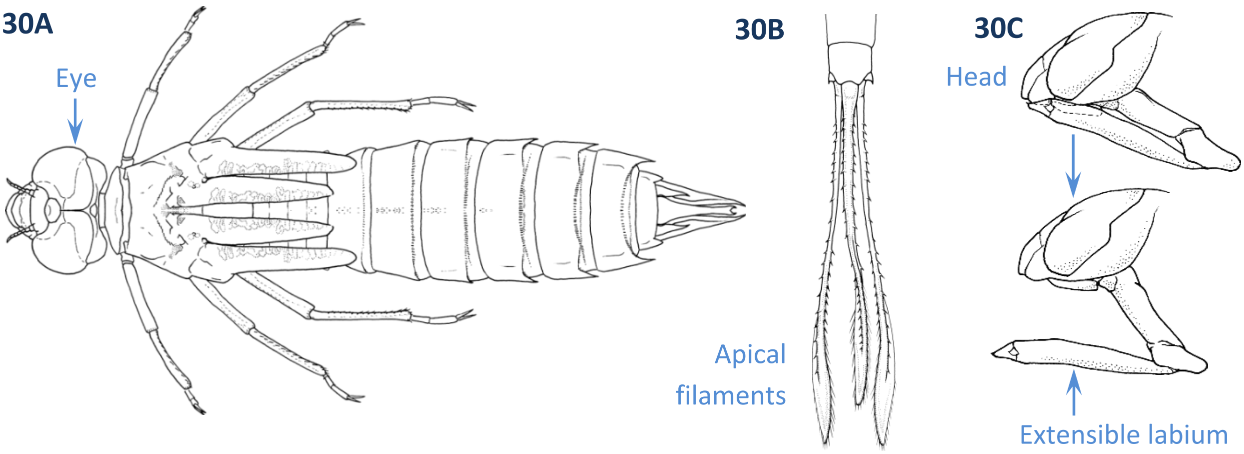


Fig. 30. ODONATA

- Mouthparts never modified as a ventral hinged extensible lobe; abdomen sometimes with 2 or 3 filiform apical filaments, never flattened; eyes and length variable **27**

27(26). Three long, multisegmented apical abdominal filaments present, median as long as or longer than lateral **28**

- At most two long multisegmented apical abdominal filaments **30**

28(27). Thoracic segments structurally differentiated from abdominal, mesonotum much longer than pronotum **(Fig. 31A)** or basal abdominal segment, flat, quadrate; abdominal segments with paired lateral gills **(Fig. 31A)**, at least on one segment; maxillary palp 1-segmented; body dorsally flat; aquatic .... **Ephemeroptera (most nymphs) (Fig. 31)**

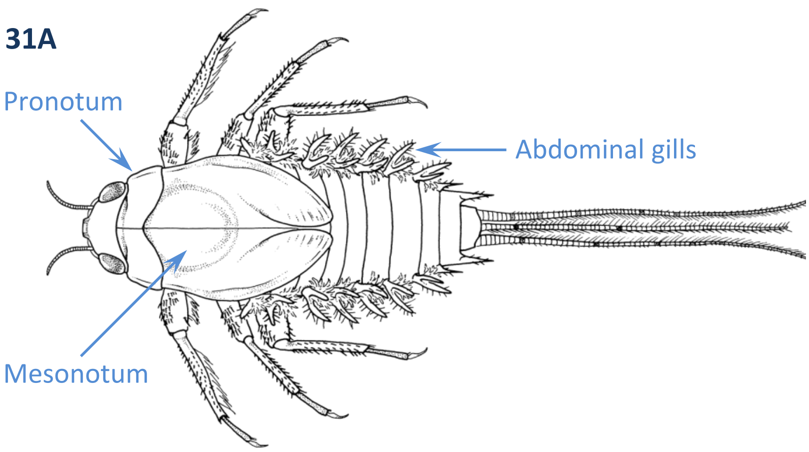


Fig. 31. EPHEMEROPTERA

- Thoracic segments similar in shape to abdominal, evenly convex; abdominal segments without gills but short ventral appendages may be present; maxillary palp 5- or 7-segmented; body dorsally convex with flat venter; not aquatic **29**

29(28). Eyes not compound, present as isolated laterally placed single lenses (= stemmata), or absent; 5-segmented maxillary palp **(Fig. 32A)** ....**Zygentoma (adults and nymphs) (Fig. 32)**

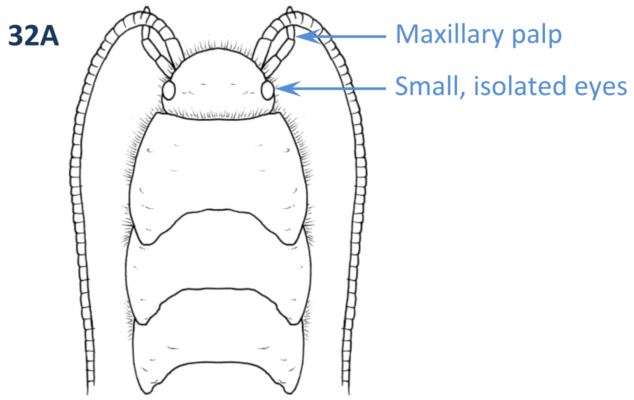


Fig. 32. ZYGENTOMA

\- Eyes compound, large and dorsally contiguous; 7-segmented maxillary palp **(Fig. 33A)** .... **Archaeognatha (adults and nymphs) (Fig. 33)**

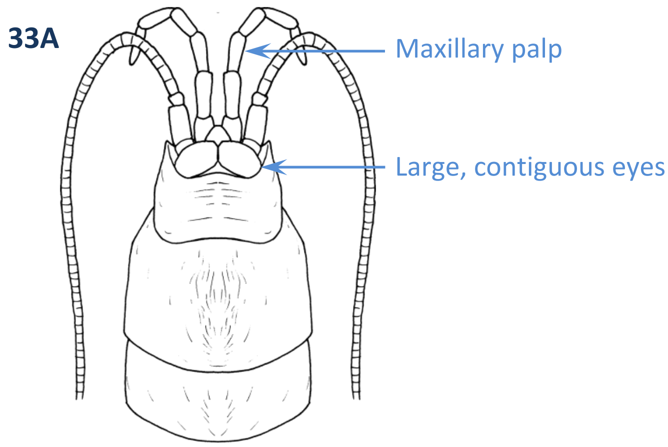


Fig. 33. ARCHAEOGNATHA

30(27). Ectoparasites on birds and mammals, rarely found away from hosts or host nests; strongly flattened dorsoventrally or laterally; compound eyes absent or not obvious/small; short piercing or mandibulate mouthparts; antennae short, with 3-5 segments; thoracic segments small, without trace of wing lobes; modified thickened legs with large apical claws and thickened setae for gripping; apical abdominal appendages absent; length less than 5mm **31**

\- Not ectoparasites on birds and mammals; or if so (Hemiptera: Cimicidae) then dorsoventrally flattened, with simple unmodified antennae & legs, long segmented piercing rostrum and distinct compound eyes...**33**

31(30). Laterally flattened/compressed body **(Fig. 34A)**; mouthparts modified into a piercing stylet **(Fig. 34B)**; apical antennal segment ovate, subdivided with 8 transverse grooves, antenna placed in a lateral hollow on head; hind legs enlarged, for jumping; legs with 5 tarsal segments **(Fig. 34A)**; on birds and mammals, and in nests ....**Siphonaptera (adults) (Fig. 34)**

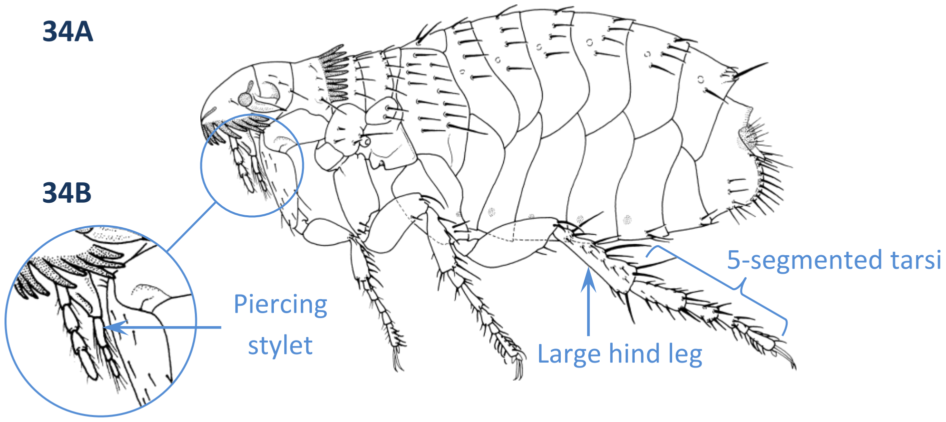


Fig. 34. SIPHONAPTERA

- Dorsoventrally flattened body; mouthparts variable or absent; antennae without ovate last segment; hind legs laterally splayed, incapable of jumping; legs with no more than 4 tarsal segments...**32**

32(31). Spider-like, with long anterodorsally flexed legs, hind leg longer than body when stretched out **(Fig. 35A)**; 4 tarsal segments **(Fig. 35A)**; head reflexed to middle of body **(Fig. 35A)**; antennae obscured; on bats .... **Diptera (adult Nycteribiidae) (Fig. 35)**

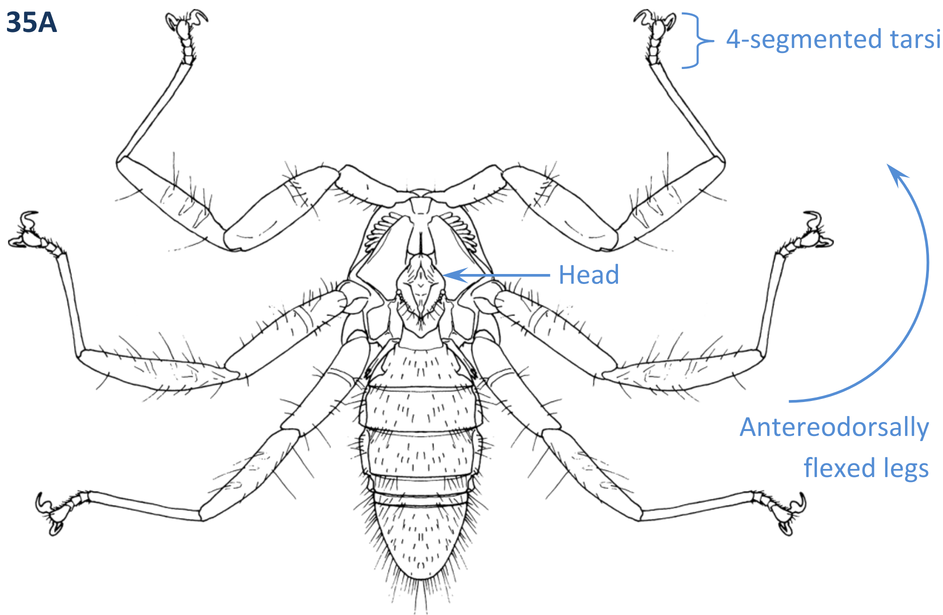


Fig. 35. DIPTERA (adult NYCTERIBIIDAE)

- Not spider-like, with short legs, not dorso-anteriorly flexed, hind legs much shorter than body length; tarsi 1-2 segmented **(Fig. 36A)**; head clearly distinguishable at anterior of body **(Fig. 36A)**; 3-5 segmented antennae usually visible **(Fig. 36A)**; on birds and mammals ....**Psocodea (suborder Phthiraptera) (Fig. 36)**

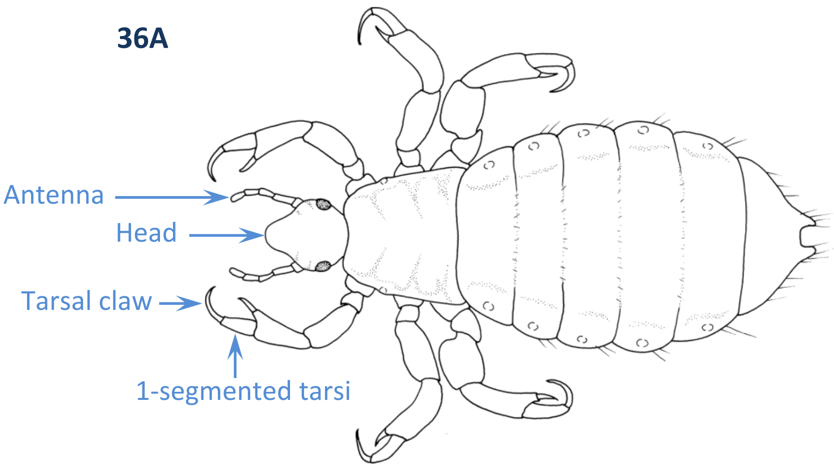


Fig. 36. PSOCODEA (PHTHIRAPTERA)

33(30). Compound eyes absent, eye replaced by 6 or less isolated stemmata, or stemmata absent; head not distinctly delimited from thorax; legs present or absent **34**

\- Compound eyes present (reduced to 3 facets in larval Thysanoptera), often also 1-3 centrally placed ocelli on dorsum of head; head distinctly delimited from thorax; legs present **49**

34(33). Endoparasitic on insects, but with apex of abdomen partly exerted from host **35**

\- Not endoparasitic in insects, or if so, body entirely within host (but spiracles may be exerted through host body wall)... **36**

35(34). Body U-shaped **(Fig. 37A)**; on Hemiptera: Auchenorrhyncha .... **Hymenoptera (Dryinidae larvae) (Fig. 37)**

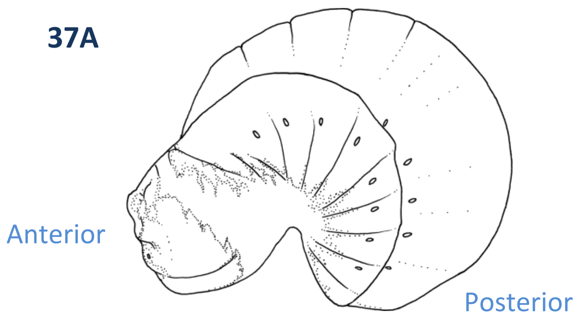


Fig. 37. HYMENOPTERA (DRYINIDAE larvae)

\- Body simply cylindrical; on Hemiptera, Blattodea, Orthoptera, Diptera, Hymenoptera .... **Strepsiptera (larvae and female adults)**

36(34). Mouthparts modified into thin segmented rostrum and stylet **(Fig. 38C)**; if head not distinguishable and stylet ventrally placed and minute animal sessile on plant surfaces, and legs usually very short, often obscured by body or absent **(Figs 38A, 38B)**; usually secreting white wax .... **Hemiptera (some adults and nymphs of Coccoidea, Aleyrodoidea, Aphidoidea) (Fig. 38)**

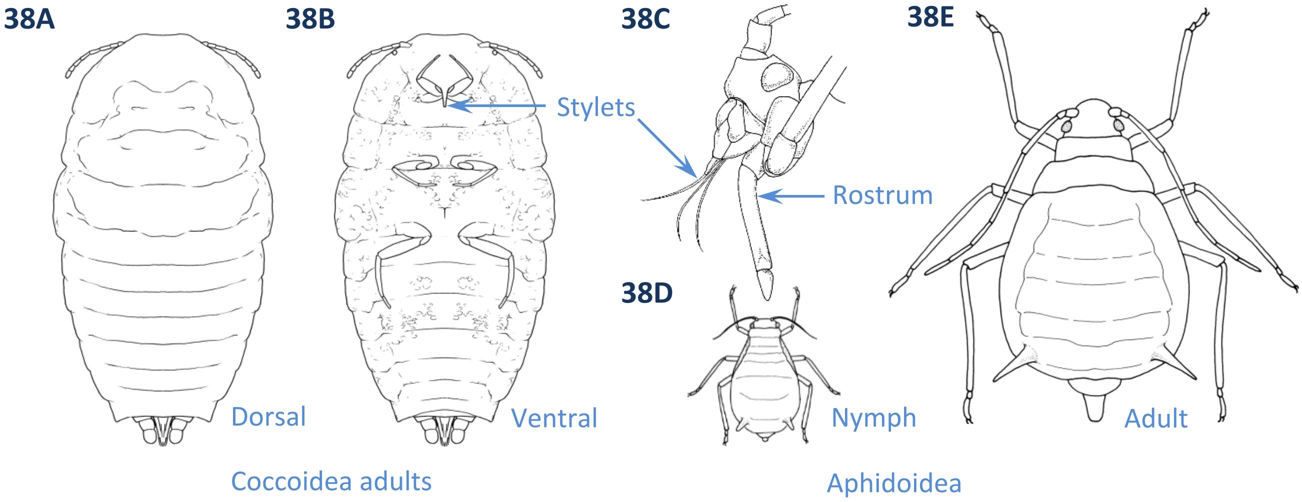


Fig. 38. HEMIPTERA

- Mouthparts not modified into segmented rostrum and stylet; if sessile on plants then with mandibulate mouthparts; if secreting white wax, then mandibulate with well-developed legs (Coleoptera: some Coccinellidae larvae) **37**

37(36). Thoracic legs absent **38**

- Thoracic legs present **40**

38(37). Distinct head absent, mouth reduced to a pair of strongly sclerotised hooks **(Figs 39A, 39B)** .... **Diptera, Cyclorrhapha larvae (typical fly maggots) (Fig. 39)**

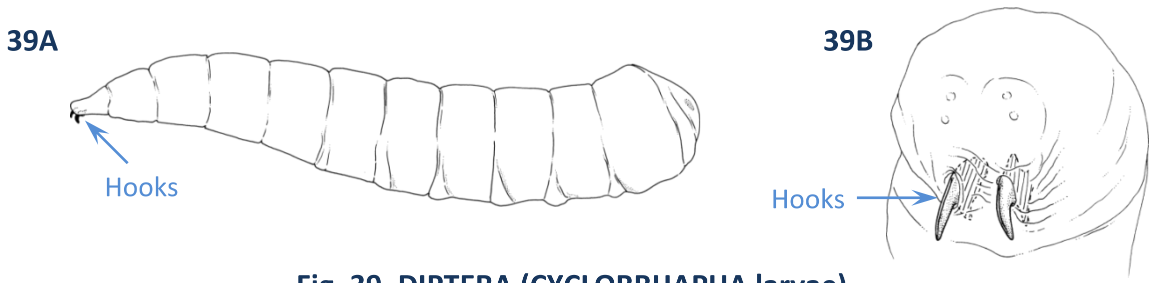


Fig. 39. DIPTERA (CYCLORRHAPHA larvae)

- Distinct head present; mouth not a pair of hooks **39**

39(38). Living in bird or mammal nests; abdominal segment 10 bearing a pair of prolegs or anal struts; body with long and stiff setae **(Fig. 40A)**; body elongate and cylindrical... .... **Siphonaptera (larvae) (Fig. 40)**

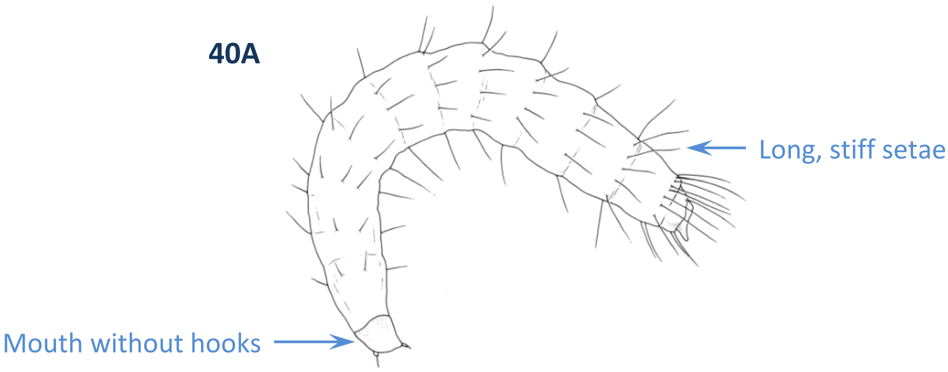


Fig. 40. SIPHONAPTERA

- Without the above combination ....

This group of legless endopterygote insect larvae is very difficult to separate into different orders. There are exceptions to all character combinations therefore habitat is also useful for diagnosis.

- Free-living, aquatic ....**Diptera** (**different nematoceran families**)
- Endoparasitic ....**few Diptera (rare Cecidomyidae), many Hymenoptera: Apocrita, few Coleoptera (rare Rhipiphoridae)**
- Leaf mining .... **some Hymenoptera: Apocrita, some Coleoptera, some Lepidoptera**
- In soil.................................. . **many Coleoptera, many Diptera, few Hymenoptera: Apocrita**
- With median labial spinneret or silk gland .... **almost all Lepidoptera, some Hymenoptera: Apocrita**
- Two pairs of thoracic spiracles .... **some Hymenoptera: Apocrita**
- With inverted Y-shaped ridge on frons (adfrontal lines)..............................**most Lepidoptera**
- Prolegs present on abdominal venter, with crotchets ....**most Lepidoptera**
- Maxillary palpi with one segment .... **most Hymenoptera: Apocrita, few Coleoptera, few Lepidoptera**
- Maxillary palpi with 3 segments.................................... **most Coleoptera, most Lepidoptera**

40(37). 5-segmented maxillary palps; 9-segmented antennae **(Fig. 41A)**; 2-segmented tarsi on well-developed walking legs; pair of small 1-segmented cerci at apex of abdomen **(Fig. 41A)**; small (<4mm long) soft bodied insects with paired claws similar to termite workers (Blattodea superfamily Termitoidea) but these have 4-5 segmented tarsi; living in rotting wood; rarely seen or collected (one locality in New Britain) ....**Zoraptera (adults and nymphs) (Fig. 41)**

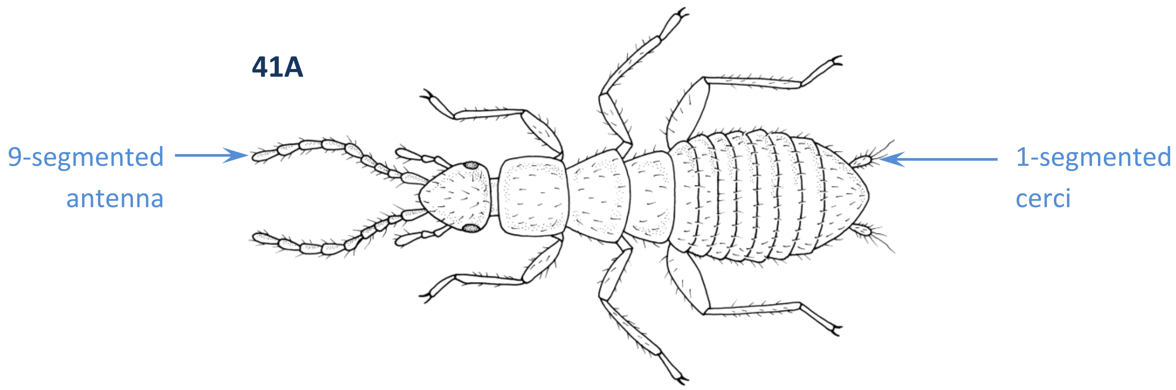


Fig. 41. ZORAPTERA

- Without above combination of characters; maxillary palpi with no more than 4 segments...........**41**

41(40). Mandibles elongated, needle-like or forceps-like, without internal tooth **(Fig. 42A)**; length of legs usually equal to or wider than thorax; antennae often with more than 3 segments, as long as or longer than head capsule; if antennae only 3-segmented and shorter, then larva ectoparasitic on spiders, head capsule without distinct sutures and legs very short (Mantispidae); maxillary palpi absent; mostly free-living terrestrial predators, but including one rarely collected aquatic group of freshwater sponge predators ....**Neuroptera (larvae) (Fig. 42)**

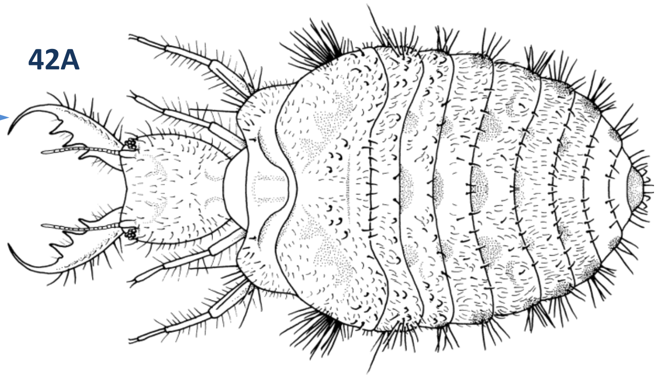


Fig. 42. NEUROPTERA

- Mandibles usually not elongate; if jaws greatly elongated (some Coleoptera larvae), then with internal tooth and maxillary palpi well-developed, with 3-4 segments **42**

42(41). 2-segmented anal prolegs at apex of abdomen (short, hooked leg-like appendages either side of anus); aquatic larvae, usually case-bearing (living in a self-constructed case) **(Fig. 43B)**; all legs long thin, 5-6 segmented, with single apical claw **(Fig. 43A)**; antenna tiny, one-segmented, thread-like, conical or absent **(Fig. 43A)**; adfrontal lines absent from frons; body segments not smoothly contiguous; silk glands present in labium .... **Trichoptera (larvae) (Fig. 43)**

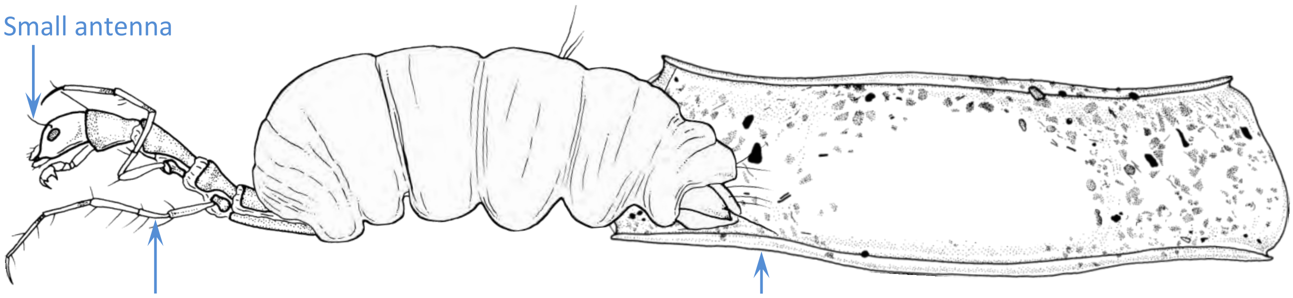


Fig. 43. TRICHOPTERA

- Without 2-segmented prolegs at apex of abdomen; aquatic or not aquatic; if aquatic and with a pair of apical hooks adjacent to anus, then hooks unsegmented, antennae 3-segmented, body smooth and cylindrical with contiguous segments and without silk glands (aquatic larvae of Coleoptera: Elmidae) **43**

43(42). 'Caterpillars' = free-living eruciform larvae with well-developed thoracic legs, usually also abdominal prolegs, chewing leaves, sometimes flowers or bark **44**

- Not eruciform larvae (not caterpillar-like)... **46**

44(43). Abdominal prolegs present **(Fig. 44A)**, at most with four pairs on segments 3-6, and one pair of prolegs on segment 10, each with small ring or band of hooks (crotchet) **(Fig. 44C)**; head with adfrontal lines (inverted Y-shaped ridge) usually present on frons **(Fig. 44B)**; median labial silk gland present .... **Lepidoptera (larvae) (Fig. 44)**

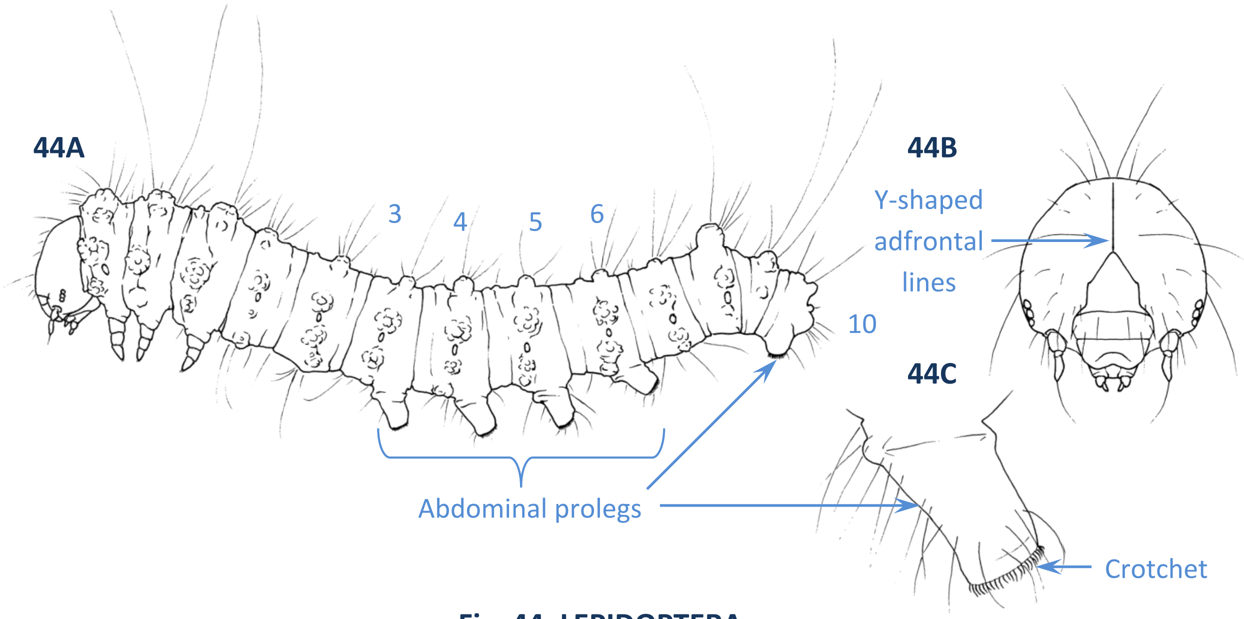


Fig. 44. LEPIDOPTERA

- If abdominal prolegs present, then without crotchets **45**

45(44). Well-developed abdominal prolegs usually present **(Fig. 45A)**, on segments 2-6, 2-7, 2-8 or 3-8, and 10, sometimes only on 10 or completely absent; if prolegs absent, only one pair of large stemmata present **(Fig. 45A)**, antennae dome-like and unsegmented, and metathoracic spiracle present .... **Hymenoptera (some Tenthridinoidea larvae) (Fig. 45)**

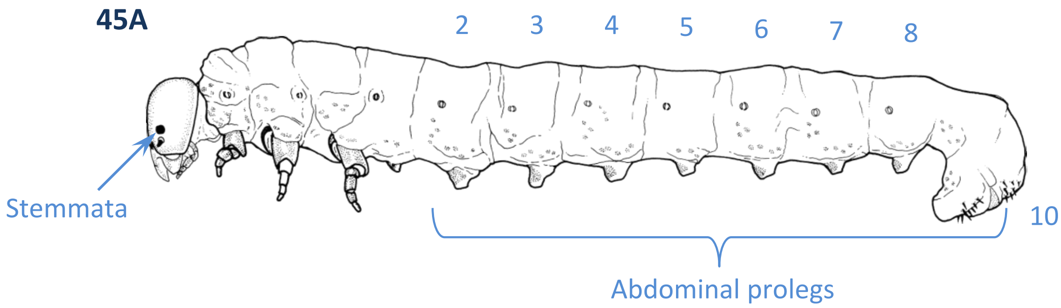


Fig. 45. HYMENOPTERA (TENTHRIDINOIDEA larvae)

- Abdominal prolegs absent, or weakly developed on segments 6-8 **(Figs 46A, 46B)**, in which case 6 stemmata present **(Fig. 46A)**; antennae never dome-like, 1-3 segmented; metathoracic spiracle absent ....**Coleoptera (some Chrysomelidae larvae) (Fig. 46)**

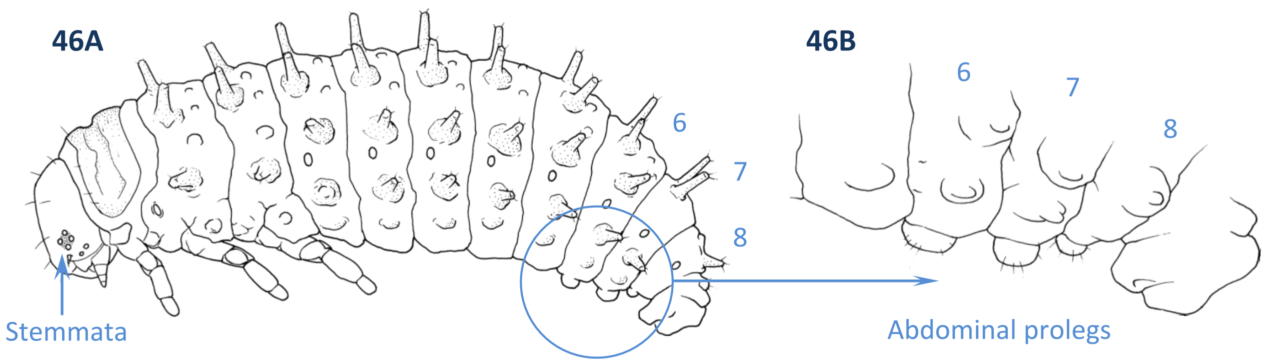


Fig. 46. COLEOPTERA (CHRYSOMELIDAE larvae)

46(43). Antennae elongate, at least as long as head, with 10-32 segments **(Fig. 47A)**; head enlarged, broader and longer than thorax **(Fig. 47A)**; pair of short 1-5 segmented cerci at apex of abdomen **(Fig. 47A)**; tarsi with 4-5 segments **(Fig. 47A)**; soft bodied terrestrial insects with long thin well-developed walking legs and usually either produced mandibles **(Fig. 47A)** or a needle-like anterior extension of the head ....**Blattodea superfamily Termitoidea (adults & nymphs) (Fig. 47)**

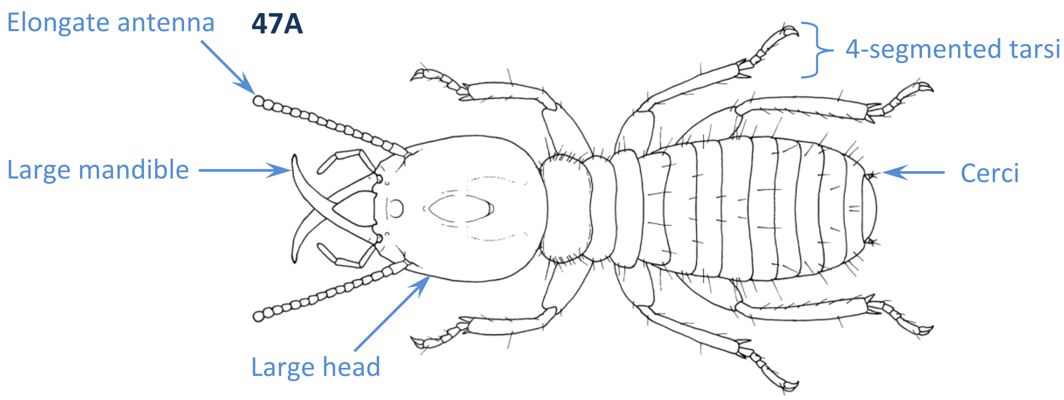


Fig. 47. BLATTODEA (TERMITOIDEA)

\- Antennae shorter than head, with 5 or less segments; if antennae with elongate 10-25 segmented antennae, then body setose, cylindrical, with short legs and 1-segmented tarsi, head smaller than prothorax, with short mandibles, and aquatic or in wet soil and wood (larvae of Coleoptera: Scirtidae) **47**

47(46). With at least one of the following features: abdominal prolegs **(Fig. 48A)**, each with small ring or band of hooks (crotchet) **(Fig. 48B)**; adfrontal lines on frons; median labial silk gland; metathorax without spiracles... **Lepidoptera (larvae) (Fig. 48)**

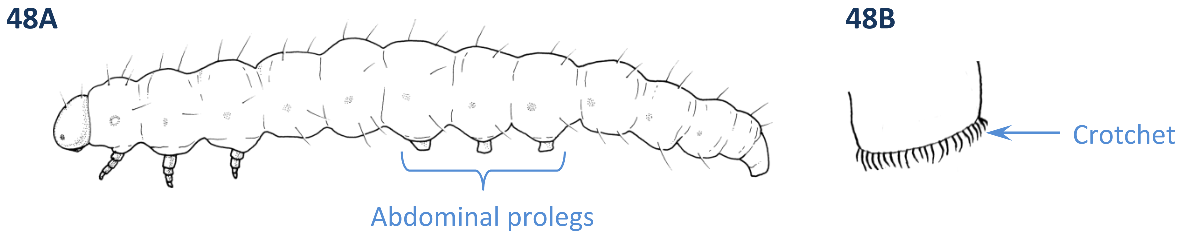


Fig. 48. LEPIDOPTERA

\- If prolegs present, without crotchets, or if crotchets present then aquatic (some larval Coleoptera: Hydrophilidae); adfrontal lines absent; metathorax with or without spiracles **48**

48(47). Combination of elongate abdominal spiracles, metathoracic spiracle present, labial silk glands; rarely seen or collected ....**Hymenoptera (leaf mining and stem boring Symphyta larvae)**

\- Without the above combination; abundant and diverse in form ....**Coleoptera (larvae)**

49(33). Pair of multisegmented filamentous cerci present at apex of abdomen; aquatic, usually with lateral abdominal gills; antennae with numerous segments, much longer than head; body slightly flattened, with legs splayed out laterally; head entirely exposed, not hidden by pronotum; forelegs not raptorial; hind legs not saltatorial (enlarged for jumping)..**50**

- Without the above combination; if aquatic, without multisegmented cerci; if pair of multisegmented abdominal cerci present, either with pronotum covering most or all of head viewed from above, or with raptorial forelegs or with saltatory hind legs **51**

50(49). Tarsi with single apical claw; metanotum much shorter than mesonotum, with wing buds overlapped by mesonotum wing buds **(Fig. 31A)**; apex of abdomen usually with long multisegmented median filament **(Fig. 31A)**.............................. **Ephemeroptera (nymphs) (Fig. 31)**

- Tarsi with pair of apical claws; metanotum of similar size to mesonotum **(Fig. 49A)**, wing buds not overlapped by mesonotum wing buds; apex of abdomen without multisegmented median filament.. **Plecoptera (nymphs) (Fig. 49)**

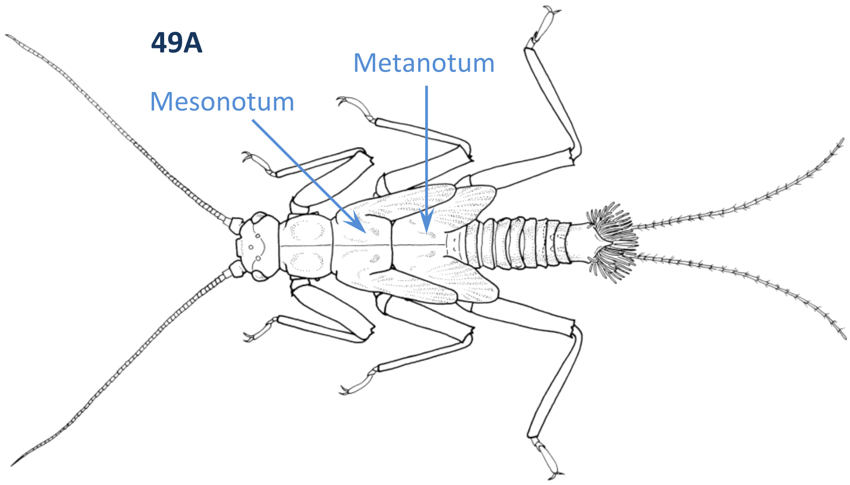


Fig. 49. PLECOPTERA

51(49). Body clothed in erect overlapping scales **(Fig 50A)**; mouthparts haustellate (short or curled unsegmented tube / proboscis) or absent **(Fig 50A)**; legs not raptorial or saltatorial; eyes large **(Fig 50A)**; rarely seen or collected................**Lepidoptera (completely wingless adult females) (Fig. 50)**

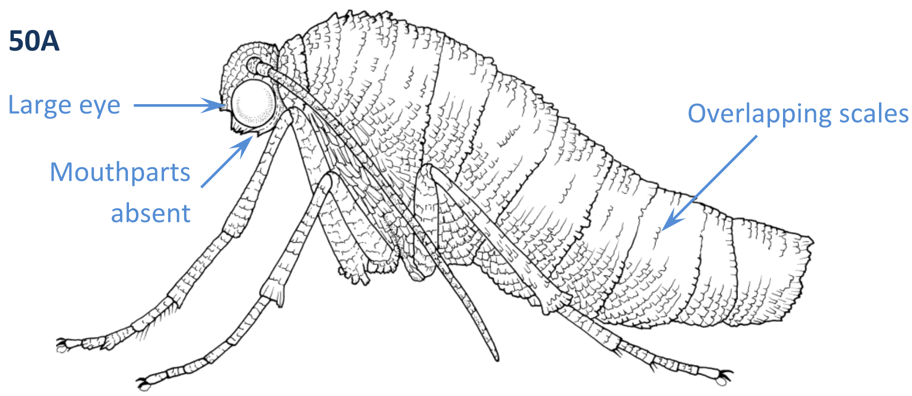


Fig. 50. LEPIDOPTERA

- Body not clothed in scales or, if present, scales flat, legs saltatorial and mouthparts mandibulate; mouthparts proboscis-like (short stylet or straight segmented rostrum) or mandibulate **52**

52(51). Tarsus 1-2 segmented with apical eversible bag (= arolium) and mouthparts postero-ventrally directed **(Fig. 51B)**, with stylets; small 0.5-12mm long soft-bodied insects with conically tapering abdominal apex; head not separated from thorax by narrow neck; legs simple, of similar size and shape **(Figs 51A, 51C)**; antennae with 4-9 segments, not geniculate .... **Thysanoptera (nymphs and wingless adults) (Fig. 51)**

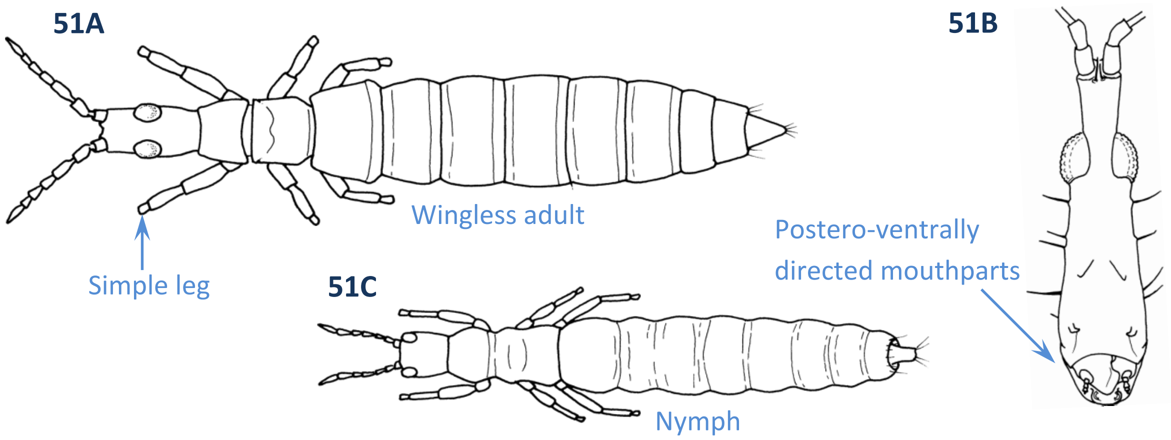


Fig. 51. THYSANOPTERA

\- Tarsus 1-5 segmented; without combination of arolium and stylet mouthparts **53**

53(52). Mouthparts modified into a straight tube-like rostrum or proboscis (only mouthparts, not head projection), ventrally positioned, oriented posteriorly, without palps, usually segmented, sometimes reduced to thin stylet **(Fig. 52B)**; without visible abdominal cerci **(Fig. 52A)**.. **Hemiptera (most nymphs, some adults) (Fig. 52)**

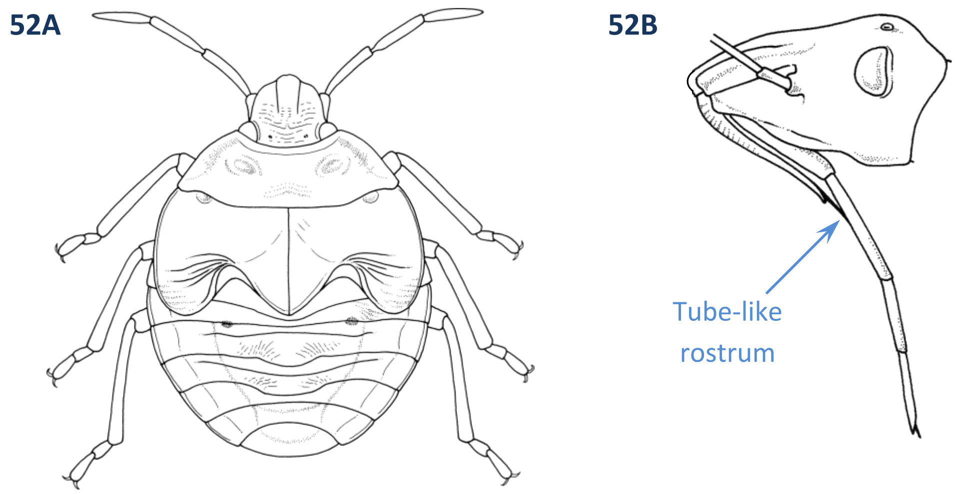


Fig. 52. HEMIPTERA

\- Mouthparts usually mandibulate (chewing), or mouthparts vestigial (reduced or not visible); with or without abdominal cerci **54**

54(53). Forelegs raptorial, enlarged compared with mid and hind legs, with large elongated forecoxae, internally spined femora, hooked tip of tibiae and long tarsi, usually held together anteriorly in characteristic flexed position **(Figs 16A, 16B)**; mid and hind legs simple, thin and without spines **(Fig. 16A)**; pronotum usually elongate and freely articulated, longer than relatively short mesothorax **(Fig. 16A)** .... **Mantodea (nymphs) (Fig. 16)**

- Forelegs not raptorial, with small forecoxae, and apex of foretibiae not hooked **55**

55(54). Paired forceps (modified single-segmented cerci) at apex of abdomen **(Figs 14A, 14B)**; head separated from thorax by a narrow neck and mouth prognathous; body relatively flattened; all legs of similar size, tarsi 3-segmented .... **Dermaptera (nymphs and wingless adults) (Fig. 14)**

- Without paired forceps at apex of abdomen **56**

56(55). Base of abdomen strongly constricted between first and second segments, first segment strongly fused to metathorax (recognised by presence of spiracle), sometimes two constrictions at base of abdomen, rarely without **(Fig. 29A)**; if without abdominal constriction, antennae geniculate **(Fig. 29A)**; foretibiae usually with an enlarged spur, (= calcar); cerci absent or 1-segmented; mandibles strongly developed **(Fig. 29A)**; hard-bodied insects, with thoracic and abdominal segments thick-walled and rigid (or soft-bodied, but living inside figs) ....
.... **Hymenoptera (wingless adults) (Fig. 29)**

- Without strong constriction between abdomen and thorax, or if present soft bodied insects with simple antennae and legs; antennae never geniculate; foretibiae without calcar **57**

57(56). Hind legs modified for jumping (= saltatorial), with femora elongated and thickened compared with middle femora **(Figs 19A, 19C)**; tibiae relatively elongated; pronotum saddle-shaped with sides projecting ventrally as descending lobes **(Figs 19B, 19C)**; tarsi 4-segmented; head generally hypognathous .... **Orthoptera (nymphs and wingless adults) (Fig. 19)**

- Hind legs not modified for jumping (not saltatorial); if hind femora greatly thickened, then pronotum flat and first tarsal segment of foreleg enlarged (Embioptera), or tarsi 5-segmented (Phasmatodea); pronotum not saddle-shaped **58**

58(57). Face with swollen area above clypeus (= postclypeus) **(Figs 28A, 28B)**; antennae filiform, with 2 broad basal segments and numerous thin apical segments **(Fig. 28A)**; tarsi 2-3 segmented; abdomen sometimes constricted at junction with thorax; abdomen without protruding ovipositor; body soft, thin walled; body length 0.5 - 6 mm; cerci absent ....
.... **Psocodea (nymphs and wingless adults) (Fig. 28)**

- Face not swollen above clypeus; only first antennal segment enlarged or all segments similar; abdomen never constricted at junction with thorax; cerci often present **59**

59(58). First tarsal segment of forelegs enlarged (elongated and thickened) **(Figs 24A, 24B)**; tarsi 3-segmented; head prognathous, mouthparts visible from above; body parallel-sided; rarely seen or collected.. **Embioptera (nymphs and wingless adults) (Fig. 24)**

- First tarsal segment not enlarged; tarsi 4-5 segmented (termite tarsal segments difficult to see); head pro- or hypognathous, sometimes hidden by pronotum; common insects **60**

60(59). Pronotum relatively large, semicircular, often covering most or all of head **(Figs 20A, 20B)**; head strongly hypognathous; body flattened **(Fig. 20B)**; legs covered in strong stiff spine-like setae ....
.... **Blattodea excluding Termitoidea (nymphs and wingless adults) (Fig. 20)**

- Pronotum not enlarged, never covering head which is entirely visible in dorsal view and usually prognathous; body rarely flattened, if so legs without obvious setae or spines **61**

61(60). Stick or leaf mimics, >10 mm long; mesothorax elongate (thinner than wide) (only slightly so in leaf-mimics) **(Figs 17A, 17B)**; femora and tibiae often spined along edges; front legs extending well beyond front of head (by several head lengths) **(Fig. 17A)** ....
.... **Phasmatodea (nymphs and wingless adults) (Fig. 17)**

- Not mimicking sticks or leaves, 2.5 - 15 mm long; mesothorax transverse (wider than long); femora and tibiae without lateral spines; front legs as long as to reach front of head or shorter (not extending past front of head) **(Fig. 26A)**...
....**Blattodea: Termitoidea (nymphs and wingless adults) (Fig. 26)**

Diagnostic Descriptions and Information on the Insect Orders of Papua New Guinea

To identify insects you can either use written identification keys, diagnoses and descriptions or compare material with accurately identified specimens. The use of identification keys requires knowledge about how keys work and morphological terminology. Keys contain what are fundamentally diagnostic characters, i.e., those characters that define a taxon in comparison to other taxa. When differentiating taxa there is often a single character that is unique to it but this is not always the case, and a user may have to examine a combination of characters.

The orders are given in alphabetical order.

Format of this section

The following section gives key information about the insect orders of Papua New Guinea. This information is structured in the following format:

1) **Scientific name** is a formal scientific name for an insect that includes synonyms (= a different scientific name for the same insect). In this section we refer mostly to the scientific name of orders, which each have a unique name. For example, the Archaeognatha is the ordinal name for those insects which are commonly called bristletails. There are rules (for animals the rules are given in the International Code of Zoological Nomenclature: http://iczn.org/code) that need to be followed in the formation of scientific names. If there are multiple scientific names for the same organism, they are synonymised and in nearly all cases the oldest name is the one that is used.

2) **Common name** is a non-scientific name that is given for a species of a group of species. For example, bristletails are the common name for the order Archaeognatha. Common names do not follow an agreed set of rules in their formation, but there is usually a consensus about what common name one should use, and for some groups of organisms there are agreed lists of common names. For many organisms there are multiple common names, and in such cases they are not synonymised, and can be used interchangeably. This can lead to confusion in communicating about organisms but common names are popular because they do not require scientific expertise to be able to communicate about organisms.

3) **Simple diagnosis** is a set of characteristics that define an organism, which could be a species or a higher taxon, like a family or order. In this manual we have introduced a simple diagnosis for each order, where we have minimised the use of technical terms. The simple diagnosis will assist the non-specialist in quickly identifying insects to orders. In some circumstances the simple diagnosis may not be detailed enough to correctly identify an insect to order. During your training you will become more familiar with the technical terms used to identify insects and you should be able to use a technical diagnosis to complement the simple diagnosis.

4) **Technical diagnosis** is more detailed and uses scientific terminology for the morphology that is diagnostic for an insect order. These scientific terms are explained in brackets after the term and in the glossary.

5) The section, **'What can they be confused with?'** is sometimes referred to as a differential diagnosis. When you are identifying insects to order you may be confused in the morphological characters used to diagnose them. This can lead to a misidentification. To avoid getting the wrong answer we have provided a comparison in morphology between insects that have a similar appearance. For this section we use more technical terms but have included definitions for them in brackets, which is also supplemented with illustrations and definitions in the glossary.

6) **Biology.** A summary of important life history features is given for each insect order, including feeding behaviour and preferences, microhabitats, life cycle and development.

7) **Diversity in Papua New Guinea.** A synopsis of the diversity of the target insect order is given.

8) **Key references.** References are provided on the taxonomy and biology of each insect order.

Glossary

This manual includes a glossary (see Appendix, pages 183-188) which will assist the user in understanding technical terms that are used in the identification keys (see previous) and the following diagnostic section.

Most morphological terms are sourced from 'The Torre-Bueno Glossary of Entomology' (1989) published by the New York Entomological Society. If you are uncertain about the meaning of words/terms please consult the Torre-Bueno glossary or your workshop demonstrator.

General references

Commonwealth Scientific and Industrial Research Organisation (CSIRO). 1991. *The Insects of Australia*. Volumes 1 and 2. Melbourne University Press.

Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2012. Australian Insect Families, accessed 7 April 2016, <http://anic.ento.csiro.au/insectfamilies>.

Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2016. Insects and their Allies accessed 7 April 2014 <http://www.ento.csiro.au/education/index.html>.

International Code for Zoological Nomenclature http://iczn.org/code

Miller, S. 2007. Insects of Papua. In: Marshall, A.J. and Beehler, B.M. (eds), *The Ecology of Papua*, pp 515-531.

Order Archaeognatha

(= Microcoryphia)

Common name: bristletails

Simple diagnosis. Bristletails are wingless insects of small to moderately large size (6 to 25 mm) with scales covering the body, large compound eyes which meet in the middle of the head, three tail filaments at the apex of the abdomen with the middle filament much longer than the lateral ones, and long threadlike antennae. They are running and jumping insects.

Technical diagnosis. Bristletails are diagnosed by the absence of wings or wing pads; presence of scales (= unicellular outgrowth of the body); more or less cylindrical, elongate body; presence of three long segmented tail filaments at the end of the abdomen, comprising two lateral cerci and a medial filament (or appendix dorsalis) which is much longer than the cerci; mandibulate chewing mouthparts with a monocondylar (= single point of articulation to the head) mandible; mouthparts with seven-segmented maxillary palps; large and contiguous (= touching) eyes; pair of ocelli; long filiform (= threadlike) antennae; and abdominal segments with styli (= leg like remnants on ventral surface of abdomen) and eversible vesicles (= sacs on the abdomen) ventrally. Bristletails are capable of jumping by sudden flexion of the abdomen. The immature stages are similar to adults, but smaller.

What can they be confused with? Bristletails can be confused with their near relatives, the Zygentoma (= silverfish); both are wingless, have long threadlike antennae, body covered with scales (= flattened tile-like structures), have three tail-like filaments at the end of the abdomen.

Silverfish differ because their eyes are reduced or absent, the maxillary palps (= finger-like appendages on the middle mouthpart region) are 5-segmented, and the lateral abdominal cerci are almost as long as the medial tail-like filament.

Biology. Bristletails are mainly nocturnal and live commonly under bark and stones in diverse conditions. Their diet consists mainly of lichen, algae detritus, and leaf litter. They have indeterminate growth and have ametabolous development (= do not undergo distinct metamorphosis, larvae and adults similar in body form).

Bristletail (Archaeognatha)

Diversity in Papua New Guinea. They are comprised of two families and about 350 species worldwide, but only the family Meinertellidae is native to the Australian region. The PNG fauna is mostly undescribed (Miller 2007).

Bristletail (Archaeognatha)

Photograph: © John Pickering 2004-2012

Key references for Papua New Guinea.

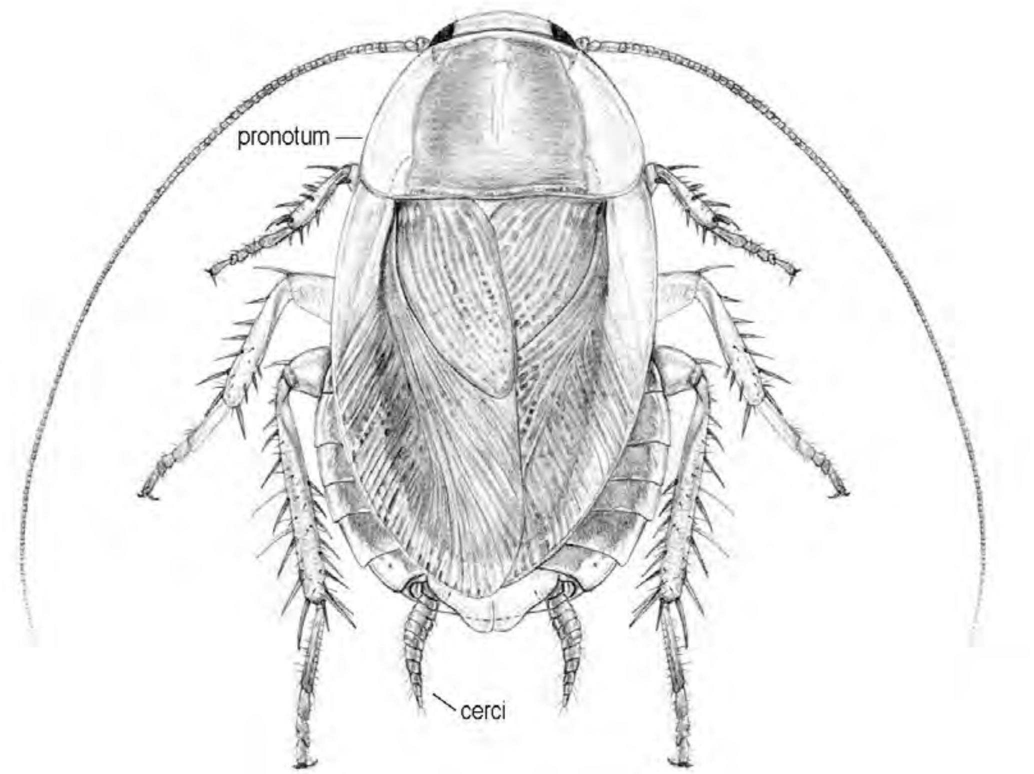
Watson & Smith 1990. Archaeognatha. *Insects of Australia Volume 1*. CSIRO Publishing, Melbourne.

Bristletail (Archaeognatha)

Photograph: © Graham Smith

Order Blattodea

(= Dictyoptera; incl. Isoptera)



Common name: roaches, cockroaches, termites

The classification of the order Blattodea has been recently revised and now includes the termites (formerly order Isoptera, now superfamily Termitoidea of Blattodea, see below for diagnosis).

ROACHES ONLY

Simple diagnosis. Blattodea have a flattened oval body with a large disc shaped pronotum often covering some or all of the head, chewing mouthparts, head and mouthparts directed vertically, antennae threadlike and multi-segmented. They always have a pair of cerci at the end of the abdomen. Roach legs often have many spines and 5-segmented tarsi. Forewings when present are leathery tegmina with many veins.

Technical diagnosis. Roaches are flattened oval insects, that have a large and semicircular pronotum, often covering the posterior part of the head; leathery forewings with distinct venation; semicircular hindwings with well-developed anal (= fanlike portion of the hindwing) lobes. Roaches also have long multi-segmented, filiform (= thread-like) antennae; a head strongly hypognathous (= head and mouthparts vertically oriented) or sometimes opisthognathous (= ventral position of the mouthparts); well-developed mandibulate (= biting and chewing) mouthparts (= biting and chewing); distinct compound eyes, which are rarely reduced; ocelli often in the shape of ocelliform (= like ocelli) spots; and un-segmented or multi-segmented cerci (= paired terminal abdominal appendages). Nymphs resemble adults, but either lack wings or possess wing buds.

What can they be confused with? Roaches are separated most easily from termites in their body shape. The body of termites is never flattened (more or less round in cross-section), the wings always membranous and never leathery, and the eyes are often reduced or absent. Termites also have more moniliform (= bead-like) antennae with 10 to 31 segments, and legs most often with 4-segmented tarsi (very rarely 5-segmented).

Roaches can be sometimes confused with some hemipterans such as plant and leaf hoppers also can have forewings that are leathery and spiny legs, but roaches always have their forewings held flat over the body, chewing mouthparts and cerci. Bristletails and silverfish also have long threadlike antennae and cerci. In contrast, roaches have short cerci and no medial filament, an oval shieldlike pronotum extending over the head and the body without scales. Some representatives of the suborder Heteroptera (Hemiptera) also have somewhat flattened and oval bodies and leathery forewings with veins, but can easily be distinguished by the piercing-sucking tubelike mouthparts.

Roaches also share some similarities with Dermaptera (earwigs), in having a flattened body, non-modified mandibulate (= biting and chewing) mouthparts, thickened forewings, hindwings with large anal region, tip of abdomen with cerci and a shield-like pronotum. However, Dermaptera differ in that the body is not oval, cerci are nearly always greatly enlarged and have forceps (= enlarged unsegmented pincer-like processes at end of abdomen), the head is prognathous (= head and mouthparts directly anteriorly), forewings are often shortened and without veins, and the tarsi are 3-segmented.

Cockroach (Blattodea)

Biology. Roaches are diurnal or nocturnal. They are most diverse in tropical regions. Some species are infamous for being pests in human dwellings. In nature they live under stones and logs, or among foliage, and are polyphagous (= varied diet) and mostly saprophagous (= eat dead or decaying vegetable matter). Some species can eat wood.

Diversity in Papua New Guinea. Roaches have a worldwide distribution, and comprise about 4000 described species. The native New Guinea fauna is poorly known (Miller 2007).

Cockroach (Blattodea)

Key references for Papua New Guinea.

Roth, LM. 1990. Blattodea. *Insects of Australia*, CSIRO Publishing, Melbourne.

Roth, LM. 2003. Systematics and phylogeny of cockroaches (Dictyoptera: Blattaria). *Oriental Insects* 37: 1-186.

Superfamily Termitoidea

(Blattodea: Superfamily Termitoidea)

Common names: termites

TERMITES ONLY

Simple diagnosis. Termites are social insects that have a soft, pale cylindrical body, with distinct thoracic segments, chewing mouthparts, the head and mouthparts project vertically, the antennae are bead-like with 10 to 32 segments, the tarsi are usually 4-segmented, and the tip of the abdomen has small limb-like (= cerci) structures.

Technical diagnosis. Termites are social insects that live in colonies and usually have castes, including reproductives, soldiers and workers. Termites are usually pale insects with an elongate body, with all thoracic segments separate, the pronotum (= shield-like sclerite on the dorsal surface of the thorax, adjacent to the head) is subrectangular and does not cover the head, the fore- and hindwings are membranous, subequal in length, and have reduced venation (= system of wing veins), without cross-veins (= small veins that connect longitudinal veins), the tarsi are often four-segmented, rarely five-segmented (only *Mastotermes*), and the tarsal segments are not swollen, the cerci are 1- to 5-segmented, the head is hypognathous (= directed ventrally), sometimes prognathous (= directed anteriorly), the mouthparts are mandibulate (= biting and chewing), and usually not modified (they can be long and exaggerated or reduced in soldier caste), the eyes are often reduced or absent, especially in workers and soldiers, and the antennae are moniliform (= bead-like) or filiform (= thread-like) with 10 to 32 round or elongate segments.

Alates (= winged caste) are small to moderately sized (= body length ranges between 6 to 18 mm). They have two pairs of membranous wings that are roughly the same size, with reduced venation (= system of wing veins) and no cross-veins or cells, and are folded flat over the body.

Alate termite (Blattodea: Termitoidea)

Apterous termites (Blattodea: Termitoidea)

Workers and soldiers are usually smaller than the reproductives (= body length ranges between 2.5 to 15 mm), wingless, have well-developed cursorial (= walking) legs, and usually lack eyes. The head of workers is more sclerotised (= robust and thickened cuticle) than the thorax and abdomen. In soldiers with reduced mandibles, the head is elongate anteriorly, forming a nasus (= anterior projection on the head).

Immature individuals of each caste usually resemble adults. The nymphs of alate forms often have wing buds.

What can they be confused with? Termites are closely related to roaches. Roaches usually live in leaf litter or foliage and are not social like termites, although some species are gregarious (= individuals aggregate together) or have limited social behaviour. Unlike termites, the body of roaches is flattened, with a shield-like pronotum covering at least the posterior part of the head, the forewings are sclerotised (= robust and thickened), the antennae are long with many segments, the eyes are well-developed and the tarsi are 5-segmented.

Like termites, ants are also social insects that have chewing mouthparts, live in colonies, and have castes with winged forms. Termites can be distinguished from ants by having bead-like or threadlike antennae about as long as the head and the antennae are not elbowed as in ants (= geniculate or elbowed antennae). Termites also have a uniformly cylindrical abdomen which attaches broadly to the base to the thorax (cf. ants which have a narrow waist), short abdominal cerci (= leg-like appendages at tip of abdomen), and forewings and hindwings that are roughly equal in size (when wings are present), which are held flat over the body. Termites also have an open venation system with no cross-veins or closed cells.

Termites are similar to the order Zoraptera. Zorapterans are known to sometimes live in termite nests. Zorapterans have winged and wingless forms, reduced wing venation (= system of wing veins), separated thoracic segments, mandibulate (= biting and chewing) mouthparts, moniliform (= bead-like) antennae, often-reduced eyes and short unsegmented cerci. Zorapterans differ from termites by having the forewings longer than the hindwings, the tarsi are 2-segmented, and the adults are very small.

Termites are similar to Embioptera (= footspinners), as they live gregariously (= aggregate together), have winged and wingless forms, similar antennae with 12-32 segments, mandibulate (= biting and chewing) mouthparts, fore- and hindwings that are roughly equal in length, and short cerci. In contrast to termites, embiopterans live in silk galleries, possess well-developed eyes, have 3-segmented tarsi, the foretarsi have a greatly swollen first segment (= for silk production), 2-segmented cerci, and the wings have cross-veins. Embioptera do not form true castes.

Termite workers can be similar externally to wingless representatives of Psocoptera (= book lice), as they both have a large head, mandibulate (= biting and chewing) mouthparts, moniliform (= bead-like) or filiform (thread-like) antennae, and often reduced eyes. Psocopterans differ in having the clypeus greatly rounded and swollen, mouthparts are modified for scraping, the antennae are filiform are usually much longer than the head, the pronotum is usually small, the tarsi are 2- or 3-segmented, and the cerci are absent.

Biology. Termites are social insects which live in colonies, and are composed of several castes and they have winged forms. Alates (= winged forms) can usually be found outside of termite mounds. After flight, alates can lose their wings, and are then move to within a colony, where they mate and form 'kings' and 'queens'. During the reproductive phase they are usually deep found inside the termite mound. The abdomens of queens can be swollen to grotesque proportions to accommodate her eggs. Soldiers protect the colony. Workers are the most numerous caste and forage for food, feed the other castes and repair the nest. Soldiers and workers do not take part in reproduction.

Termites mainly inhabit tropical and subtropical regions. They feed on cellulose found in decayed wood, fungi, grass, timber and other woody material. They can contribute greatly to the recycling of dead wood and soil formation. They are social insects that have cast systems, with winged reproductives, soldiers and workers.

Diversity in Papua New Guinea. Termites are mostly found in tropical regions of the world, and include more than 2300 species. The New Guinea fauna is poorly known (Miller 2007).

Key references for Papua New Guinea.

Watson, JAL & Gay, FJ. 1990. Isoptera. *Insects of Australia*. CSIRO Publishing, Melbourne.

Roisin, Y & Pasteels, JM. 1996. The nasute termites of Papua New Guinea. *Invertebrate Taxonomy* 10: 507-616.

Order Coleoptera

Common names: beetles, weevils, chafers, longhorns, scarabs, whirligigs, ladybirds, curl grubs, wireworms

Simple diagnosis. Beetles have thickened forewings called elytra, which meet along the midline of the body, do not overlap, and are without venation, although they often have rows of punctures. If present, the hind wings are membranous, folded 2 or 3 times from the end inwards, and held beneath the elytra at rest. Beetles have chewing mouthparts, they usually have more than 3 segmented feet (tarsi) and their antennae do not have more than 12 segments.

Technical diagnosis.

Adults. Adult beetles are diverse in shape and size (0.5-100mm long) but generally have a 3 body part appearance, with distinct head, prothorax, and forewings over the remainder of the body. The distinctive sclerotised forewings (elytra) are without venation, usually pitted (punctured, often in rows) and are not flapped in flight. The elytra do not overlap along the midline, and vary in length, but are only completely absent in rare larviform adults (adults which have larva-like bodies but fully developed genitalia). Hindwings if present are entirely covered by the elytra. The head is prognathous to hypognathous head, with compound eyes rarely absent or subdivided (4 eyes present), and usually without ocelli. The antennae vary greatly, but have 12 (very rarely) or less

Rove beetle (Coleoptera: Staphylinidae)

segments. The mouthparts are mandibulate, although in some beetles they are reduced for lapping up nectar or other secretions. The pronotum of beetles is well developed, and the meso- and metathorax are fused, forming a pterothorax. Fully winged species have a small triangular scutellum at the base of the elytra. Legs of beetles are generally robust, have short trochanters and tarsi with 3- five segments. The abdomen has 7 or fewer visible segments and lacks multisegmented appendages or cerci.

Larvae. Beetle larvae vary considerably in morphology, reflecting great diversity in life styles, but lack any evidence of wing development or genitalia. For example, predatory larvae are generally long-legged with distinguishable head, thorax and abdomen, prominent mouthparts and long abdominal urogomphi, whereas herbivorous larvae boring into plants, or parasitic larvae, may be simply cylindrical with minute mouthparts, and no legs or processes. The head is always present, prognathous or hypognathous, and sclerotised, without an adfrontal area. Mouthparts are mandibulate, usually chewing, usually with maxillary and labial palps, with the maxillary palps usually two- or three-segmented (not more than 4). The labium is without a spinneret, and the labial palps are 1-2- segmented or absent. Eyes are usually present and composed of six to zero stemmata, often organised in a row or loose cluster. Antennae are short and usually composed of 4 or fewer

Leaf beetle (Coleoptera: Chrysomelidae)

Tortoise beetle (Coleoptera: Chrysomelidae)

Straight-snouted weevil (Coleoptera: Brentidae)

segments, usually 1-3 (multisegmented in aquatic larvae of Scirtidae). Legs if present have 6 or less segments, and may be absent. The abdomen usually has 10 segments, but with the 10th not visible dorsally. Ventral swellings like prolegs may occur but these lack crotchets (hooks) except in a few aquatic Hydrophilidae. There may be paired processes on abdominal segment IX (urogomphi), and sometimes a short apical spine is present.

What can they be confused with? Adult beetles may be confused with several other orders, especially Heteroptera, Dermaptera and Blattodea.

Heteroptera (bugs), especially shield bugs or stinkbugs: these have sucking mouthparts, 3-segmented tarsi and usually part of the upper wing is membranous. Dermaptera (earwigs): only those beetles with very short elytra might be confused with earwigs, which differ by always having a pair of large forceps at the apex of the abdomen; they also have only 3-segmented tarsi. Blattodea (cockroaches): cockroaches are superficially similar to beetles but have distinct venation on the forewings and usually paired multisegmented cerci at the apex of the abdomen.

Scarab beetle (Coleoptera: Scarabaeidae)

Leaf beetle (Coleoptera: Chrysomelidae)

Scarab (Coleoptera: Scarabaeidae)

Photograph: © John Pickering 2004-2014

Coleopteran larvae vary and different forms can be confused with larvae form a number of other holometabolous orders. The active long-legged campodeiform larvae are similar to those of Neuroptera, and Trichoptera, also the non-insect adult Diplura.

Biology. Coleoptera are cosmopolitan and include more than 350,000 described species. Coleoptera is the most diverse insect order and is known worldwide, from almost any habitat, including fresh water, marine (rarely) and vegetation microhabitats. Both adults and larvae can be carnivorous, omnivorous or herbivorous.

Diversity in Papua New Guinea. Some groups (generally with large species) are well-known for New Guinea but others (generally with small species) are very poorly known.

Weevil (Coleoptera: Curculionidae)

Photograph: © Celia Symonds 2016

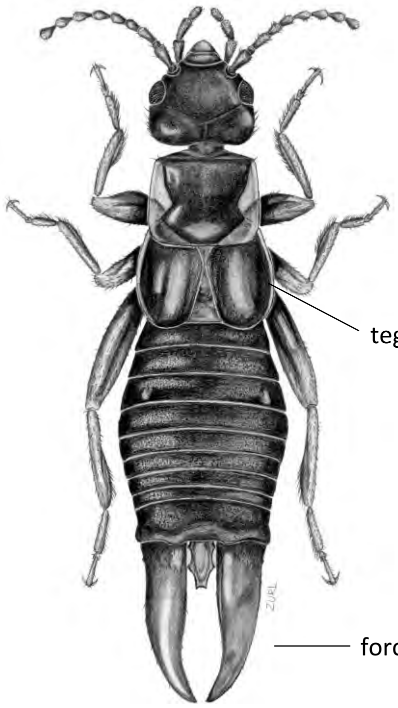
Key references for Papua New Guinea.

Gressitt, JL & Hornabrook, RW. 1977. *Handbook of common New Guinea beetles*. Handbook 2, Wau Ecology Institute, Wau.

Setliff, GP. 2007. Annotated checklist of weevils from the Papuan region (Coleoptera, Curculionoidea) *Zootaxa* 1536: 1-296

Lawrence, JL & Slipinski, SA. 2013. *Australian Beetles volume 1*. CSIRO Publishing, Melbourne.

Order Dermaptera



Common name: earwigs

Simple diagnosis. Dermaptera are elongate, flattened insects, recognised by long forceps (= enlarged pincer-like unsegmented cerci) at the end of the abdomen. The have shortened, thickened forewings (= tegmina) and membranous fan-like hindwings, with a widened anal region (= posterior region of wing). They have a prognathous (= directed forwards) head with mandibulate (= biting and chewing) mouthparts (= biting and chewing mouthparts), multi-segmented antenna (mostly threadlike, sometimes bead-like), absence of ocelli, and 3-segmented tarsi.

Technical diagnosis. The earwigs are small to large insects, and range between 4-50 mm in length. They have mandibulate (= biting and chewing) mouthparts (= biting and chewing) and have an elongate body shape, and are usually heavily sclerotised (= robust exoskeleton), and dorsoventrally (= body compressed) flattened insects. The distinctive character of this order is the presence of long unsegmented forceps-like cerci. Sometimes they can be shortened, especially in females, and in ectoparasitic (= living semi-permanently on external surface of other organisms) that live on bats the cerci can be multi-segmented. If wings present, the forewing is small and leathery and never reaches the tip of the abdomen. The hindwing is entirely membranous, large and circular, and is folded, and can be seen protruding from the tip of the forewings. Many earwigs have lost their wings. Earwigs have a prognathous (= directed forwards) head with unmodified mandibulate (= biting and chewing) mouthparts, usually with large compound eyes, lacking ocelli, the antennae are multi-segmented which are either moniliform (= beaded) or filiform (= thread-like), the pronotum is usually shield-like, the legs are short, tarsi 3-segmented with the second segment shortened. Nymphs resemble adults, but without wings or with wing buds, shorter antennae and are often paler in colouration.


Earwig (Dermaptera)

What can they be confused with? Earwigs are most easily confused with rove beetles (= superfamily Staphylinoidea) with both having short and thick forewings, without veins. At rest staphylinids do not have the hindwings protruding beyond the tip of the forewings but they may unfold when killed, giving that appearance. Earwigs and rove beetles can be easily separated by the presence in earwigs of large, unsegmented, pincer-like forceps; rove beetles lack cerci entirely.

Dermapterans are similar to Blattodea in their habits, flattened body, unmodified mandibulate (= biting and chewing) mouthparts, leathery forewings, and the hindwings have a large anal region. Roaches have a more or less oval body whereas earwigs are usually much narrower. Also, winged roaches have the forewings longer, often reaching or surpassing the apex of the abdomen, the tarsi are 5-segmented, and the cerci are never in the shape or size of the enlarged forceps of earwigs.

Dermapteran nymphs have shortened and multi-segmented forceps, and can be confused with Plecoptera (= stone flies), with both insect orders sharing mandibulate unmodified mouthparts, three-segmented tarsi, and hindwings with a large anal region. Plecopterans differ in having a hypognathous (= directed vertically) head and mouthparts (= vertically directed), two or three ocelli, the forewings are not thickened into tegmina and the body is not flattened. They are found in different habitats, with earwigs hidden in damp microhabitats (e.g., under rocks and bark) and stone flies are aquatic.

Wingless earwigs have short cerci and are similar to wingless Embioptera (= web spinners), with both have having a prognathous (= directed forwards) head and mouthparts (= directed forwards), multi-segmented antennae, no ocelli, mandibulate (= biting and chewing) mouthparts, well-defined thoracic terga (= dorsal sclerites of the thorax), and three-segmented tarsi. Unlike earwigs, embiopterans have the foretarsus greatly enlarged.

Biology. Earwigs live in damp habitats, such as leaf litter, in debris, under bark, in crevices, and a few species are ectoparasitic on bats and rodents. Earwigs are usually omnivorous, but can be herbivorous or carnivorous.

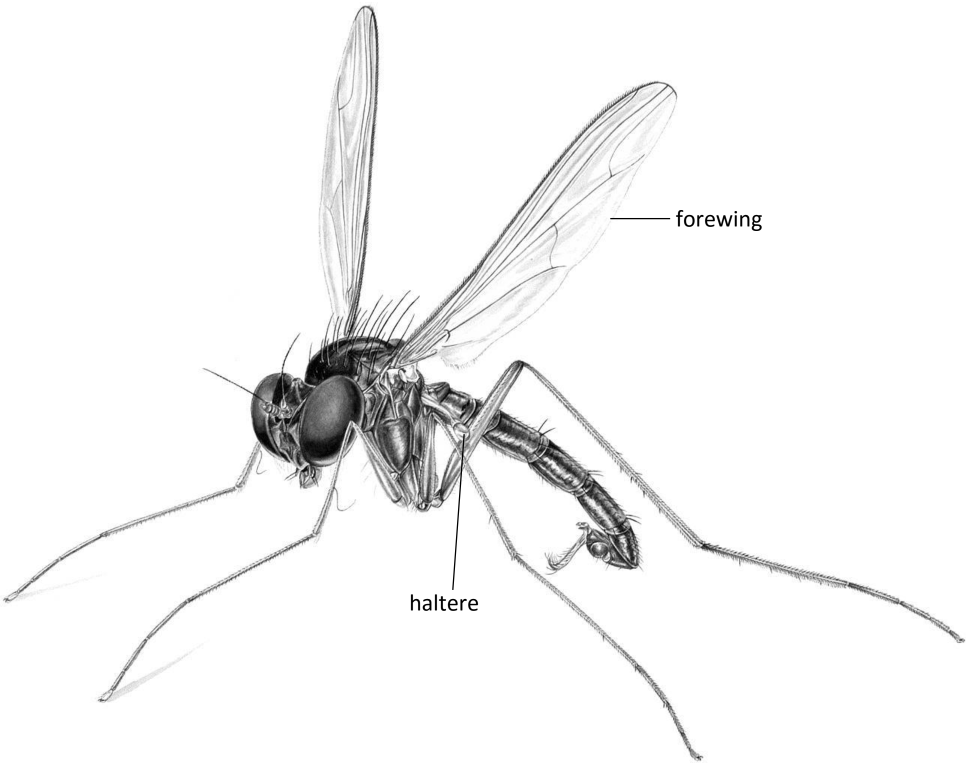
Diversity in Papua New Guinea. Earwigs are distributed worldwide, with about 1800 species. The New Guinea fauna is poorly known (Miller 2007).

Key references for Papua New Guinea.

Steinmann, H. 1989. *World catalogue of Dermaptera*. Kluwer, Dordrecht.

Rentz, DCF & Kevan, DKM. 1990. Dermaptera. *Insects of Australia*. CSIRO Publishing, Melbourne.

Order Diptera



Common names: flies, mosquitoes, horseflies, craneflies, bots, keds, midges, blackflies, fleshflies, fruitflies

Simple diagnosis. Most Diptera differ from the other orders by the structure of their wings, with the forewings well developed, and the hindwings reduced to paddle-shaped or drumstick-shaped structures called halteres. Wingless species have soft spongy mouthparts.

Taxonomic diagnosis. Adult flies are recognised by their membranous forewings with reduced venation and hindwings reduced to halteres; sometimes both pairs of wings are reduced or absent. Mouthparts are of two types or may be absent. In brachyceran flies the clypeus, labrum, maxillae, labium and hypopharynx form a rostrum often with a fleshy labellum (= sponge like structure) apically and the mandibles are reduced. In nematoceran flies (e.g., mosquitoes) the mouthparts are usually long and thin, composed of a number of stylets that are derived from the labrum, hypopharynx, mandibles and maxillae. Other important diagnostic characters are the reduced pro- and metathorax, and a swollen mesothorax, chaetotaxy (= arrangement of bristle like hairs) on the head and thorax, and the tarsi are usually five-segmented.

Other characters are rather variable, however, eyes are usually present and distinct, antennae are either aristate (= last segment with prominent bristle), moniliform (= bead-like) or filiform (thread-like). There are also highly-modified parasitic flies that are dorsoventrally flattened and have a spider-like appearance with elongate legs.

Larval Diptera can be recognised by the absence of true legs, and mandibulate mouthparts, which are usually modified forming hooks or fans. Sometimes larvae are acephalic. The abdomen is usually

Crane fly (Diptera: Tipulidae)

8 or 9 segmented, although sometimes the number of segments is reduced. The number of spiracles is also often reduced and only one or two pairs of spiracles are present on the abdomen apically. Sometimes a siphon is apically present on the abdomen.

What can they be confused with? Most adult flies can be recognised by having only one pair of membranous wings. This is very rare in other insects and occurs in the wasp family Mymarommatidae (order Hymenoptera), males of Coccoidea (Hemiptera), and males of the order Strepsiptera. Mymarommatidae can be separated by having two basally constricted abdominal segments, and the wings are fringed with long hairs. The males of Coccidae have reduced mouthparts and a fully developed pronotum. In Strepsiptera the forewings are reduced, whereas the hindwings are membranous and functional.

Wingless dipterans can be confused with wingless hymenopterans, as they both have an oval or roundish shape and a reduced pronotum. However, in Hymenoptera they have chewing mouthparts and the abdomen is constricted basally.

Stalk-eyed fly (Diptera:Platystomatidae)

Louse fly (Diptera: Hippoboscidae)

Wasp mimic (Diptera: Syrphidae)

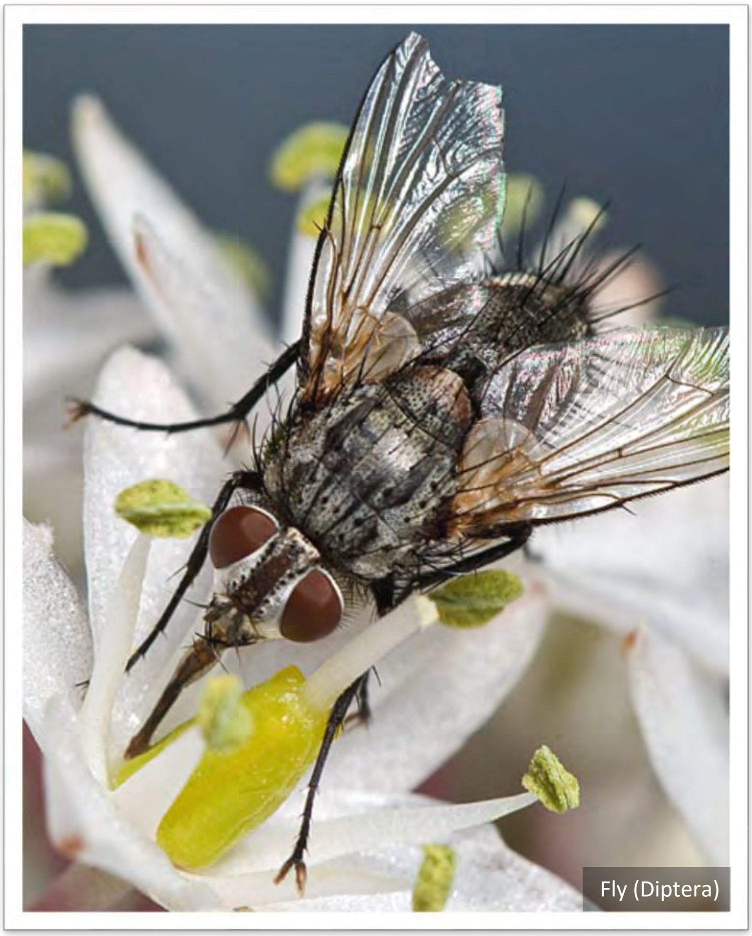
Mosquito (Diptera: Culicidae)

Wingless parasitic flies that live on vertebrates can be confused with members of the suborder Phthiraptera (lice), as they are also dorsoventrally flattened and have piercing and sucking mouthparts. However, the latter can be recognised by the short legs, two pretarsal segments, and the claws are in the shape of large hooks. Parasitic flies also can be similar to bed bugs (family Cimicidae), but the latter differ in having straight sucking mouthparts that are segmented, and the pronotum is well developed.

Larvae of Diptera are legless and are similar to legless larvae of other insect orders, which occur in Coleoptera, Siphonaptera, Strepsiptera, Lepidoptera and Hymenoptera. Females of Strepsiptera also do not have legs. All the listed orders commonly have 10 (rarely 9) abdominal segments, and with more than four pairs of abdominal spiracles. They commonly have mandibulate (= biting and chewing) mouthparts, and never with hooks or fans. The larvae and females of Strepsiptera also have 10 distinct abdominal segments, and their head and thorax are fused and distinctly sclerotised, the mouthparts are reduced. The larvae of Lepidoptera, Coleoptera and Hymenoptera are usually thick and fleshy. Lepidopteran larvae usually have a distinct labium with silk glands, used for silk production.

Biology. Diptera is one of the most diverse groups of insect orders, and flies are abundant in most ecosystems. Many larvae are aquatic. The adults feed on various liquids, including the blood of vertebrates. Larvae are often scrapers or filterers, feeding on decaying materials, fungi or other animals.

Diversity in Papua New Guinea. Flies are cosmopolitan, with more than 150,000 species estimated to occur. Many fly groups are well-known in New Guinea but many still require documentation (Miller 2007).



Photograph: Stavros Markopolous 2008; used under the Creative Commons Attribution-NonCommercial-NoDerivs License - Version 2.0

Key references for Papua New Guinea.

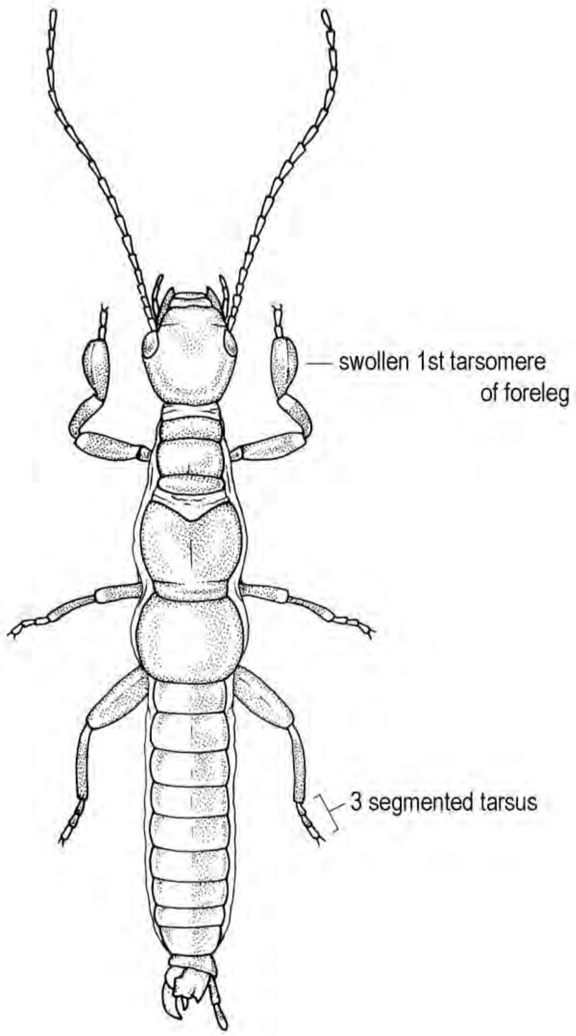
Evenhuis, NL. 1989. *Catalogue of the Diptera of the Australasian and Oceanian Regions*. EJ Brill, Leiden.

Oosterbroek, P. 1998. *The families of Diptera of the Malay Archipelago*. Brill, Leiden.

https://en.wikipedia.org/wiki/Morphology_of_Diptera

Order Embioptera

(= Embiidina)



Common name: webspinners, footspinners

Simple diagnosis. Embioptera are small, elongate insects with biting and chewing mouthparts, 3-segmented tarsi with the first tarsal segment of the leg enlarged and used for silk-production, they have a pair of short two-segmented cerci at the end of the abdomen and short legs.

Technical diagnosis. The footspinners are small winged or wingless insects. Their main diagnostic characters are three-segmented tarsi with the first tarsal segmented enlarged. The head and mouthparts are prognathous (= directed anteriorly), they have mandibulate (= biting and chewing) mouthparts, with elongate mandibles, the antennae have 12-32 segments, the compound eyes are often very small, and ocelli are absent. If both pairs of wings are present, both are about equal in length with reduced venation, with only a few cross veins (= small veins connecting longitudinal veins) present. The abdominal cerci are two-segmented. The nymphs are similar in overall morphology to adults and wing buds are present in species that have winged adults.

Webspinner (Embioptera)

What can they be confused with? Footspinners share some similarities with termites; both live in groups, have winged and wingless forms, similar antennae, with 10-32 segments, mandibulate mouth (= biting and chewing) mouthparts, unmodified antennae, the thoracic terga (= dorsal sclerites) are well-defined, fore- and hindwings are roughly equal in shape and size, with reduced venation. Termites differ from footspinners by having a hypognathous (= directed vertically) head, mostly 4-segmented tarsi, the foretarsus is never enlarged, the cerci are two-segmented and the wings lack cross veins. Termites are also social insects with a caste system.

Embiopterans can be confused with Zoraptera, as both live gregariously, and have wingless and winged forms, mandibulate (= biting and chewing) mouthparts, the eyes are usually reduced or absent, possess a well-developed prothorax, and the wing venation is reduced. Zorapterans can be distinguished by the hypognathous (= directed vertically) head, two-segmented tarsi, without enlargement, unsegmented cerci, and the hindwing is smaller than the forewing, with reduced venation but without cross veins. Zorapterans never live in silk galleries.

Wingless footspinners are also similar to wingless thrips (= order Thysanoptera), with both having an elongate body and short gressorial legs. Thrips can be separated by a hypognathous (= directed vertically) head, minute and asymmetrical mouthparts (= triangular in anterior view and mandibles in shape of stylets), antennae 5- to 9-segmented, tarsi two segmented with no enlarged tarsomeres, the apex of the abdomen is conical, and they lack cerci.

Wingless footspinners are superficially similar to small earwigs (= Dermaptera) with short cerci, and both have a prognathous (= directed forwards) head, multisegmented antennae, no ocelli, simple mandibulate (= biting and chewing) mouthparts, and all thoracic terga are well-defined and possess three-segmented tarsi. Dermapterans can be separated by the absence of an enlarged foretarsus, and most species have enlarged forceps at the tip of the abdomen.

Biology. Embiopterans are gregarious insects that live in silk-galleries, mostly on bark or rocky surfaces. They do not have true eusociality and castes. They feed on mosses, lichens, outer bark and dead leaves.

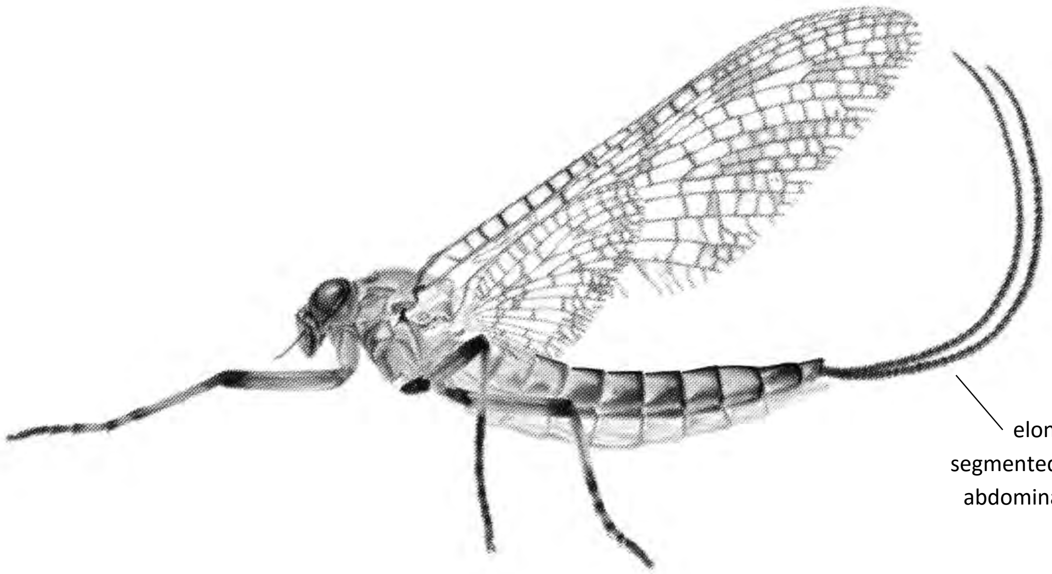
Photograph: © Ken Walker; used under a Creative Commons Attribution-NonCommercial-ShareAlike License

Diversity in Papua New Guinea. Footspinners are known from tropical and warm temperate regions. Only about 200 species are described. The New Guinea fauna includes only one recorded genus (Ross 1990; Miller 2007).

Key references for Papua New Guinea.

Ross, ES. 1990. Embioptera. *Insects of Australia*. CSIRO Publishing, Melbourne.

Order Ephemeroptera



Common name: mayflies

Simple diagnosis. Adults have one to two pairs of unfolded wings with extensive venation; the wings are held upright at rest. The hindwings are much smaller than the forewings, or are absent. Adults also have three, rarely two, long tail-like segmented filaments on their abdomen. Mouthparts are reduced or absent, eyes are large and often touching in males, and three ocelli are present. The antennae are usually shorter than the head.

Technical diagnosis. The adult (= imago) and subadult (= subimago) stages are characterised by having two pairs of unfolded wings with extensive venation, the forewings are subtriangular and the hindwings are distinctly shorter than the forewings, the wings can also be reduced or absent. They usually possess three, sometimes two, long caudal (= at tip of abdomen) segmented filaments, short and bristlelike antennae, presence of costal brace on the forewings (= thickened leading edge of the forewing), and the forelegs of males are often elongate. Adult mayflies do not feed as they lack mouthparts and there are swellings on the head where the mouthparts are normally placed.

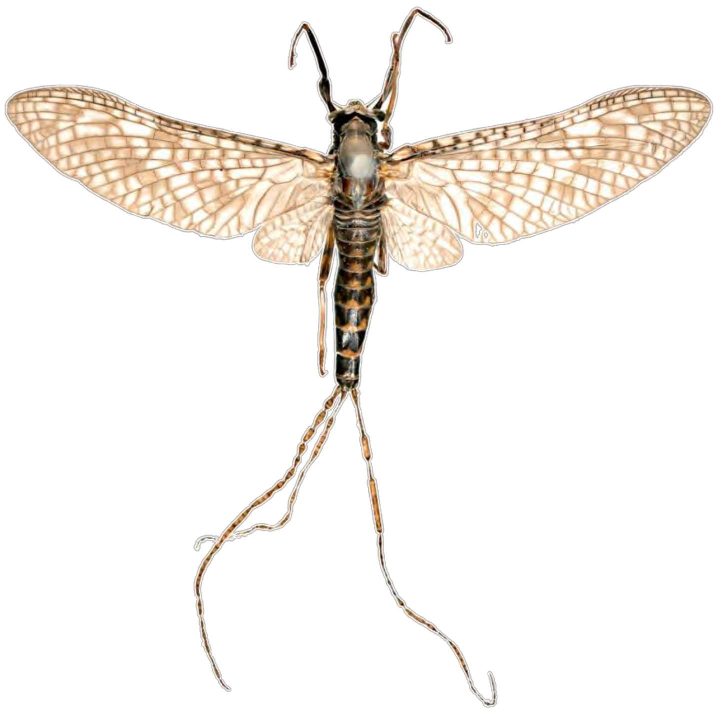
Mayfly nymphs are aquatic and differ considerably from adults. They have an elongate body, with distinct compound eyes and three ocelli, distinct mandibulate (= biting and chewing) mouthparts, long legs, and often, wing buds. They also have two or three caudal segmented filaments, a large mesonotum (= second dorsal thoracic segment) covering a shorter metanotum (= third dorsal abdominal segment), a series or one pair of abdominal gills (= respiratory organs within water), and no spiracles (= external opening of the tracheal system).

What can they be confused with? Adults are distinct and cannot be confused with other orders. Mayfly nymphs can be confused with the aquatic nymphs of the orders Odonata (= dragonflies and damselflies) and Plecoptera (= stoneflies). Odonate nymphs can be readily recognised by the mouthparts having a mask shape, the presence of three caudal lamellae (not filaments) on the abdomen, and the absence of lateral abdominal gills. Plecopteran nymphs can be distinguished by the metanotum being visible from above, and subequal or only slightly shorter than the mesonotum, and the presence of not more than two abdominal filaments, which are sometimes very short.

Biology. Adult mayflies are ephemeral, living for no more than a few days. They do not eat and their only purpose is to reproduce. Conspecific adults (= individuals of the same species) usually appear synchronously (= together) and swarm near or above aquatic habitats. These congregations can include millions of individuals. The Ephemeroptera is the only order to have a winged immature stage, the "subimago", which precedes the reproductive adult stage.

Mayfly nymphs have a distinct way of swimming, where the abdomen moves vertically, up and down. This is opposed to the nymphs of the Odonata and Plecoptera which move the abdomen from side to side when swimming. Unlike adults, ephemeropteran nymphs (= naiads) are aquatic, have functional mandibulate (= biting and chewing) mouthparts and mostly feed on small plants, fungi and/or detritus. There are a few predaceous species.

Diversity in Papua New Guinea. The order is comprised of about 3000 species and has a worldwide distribution, with the highest diversity in the temperate regions. The New Guinea fauna is poorly known (Miller 2007).



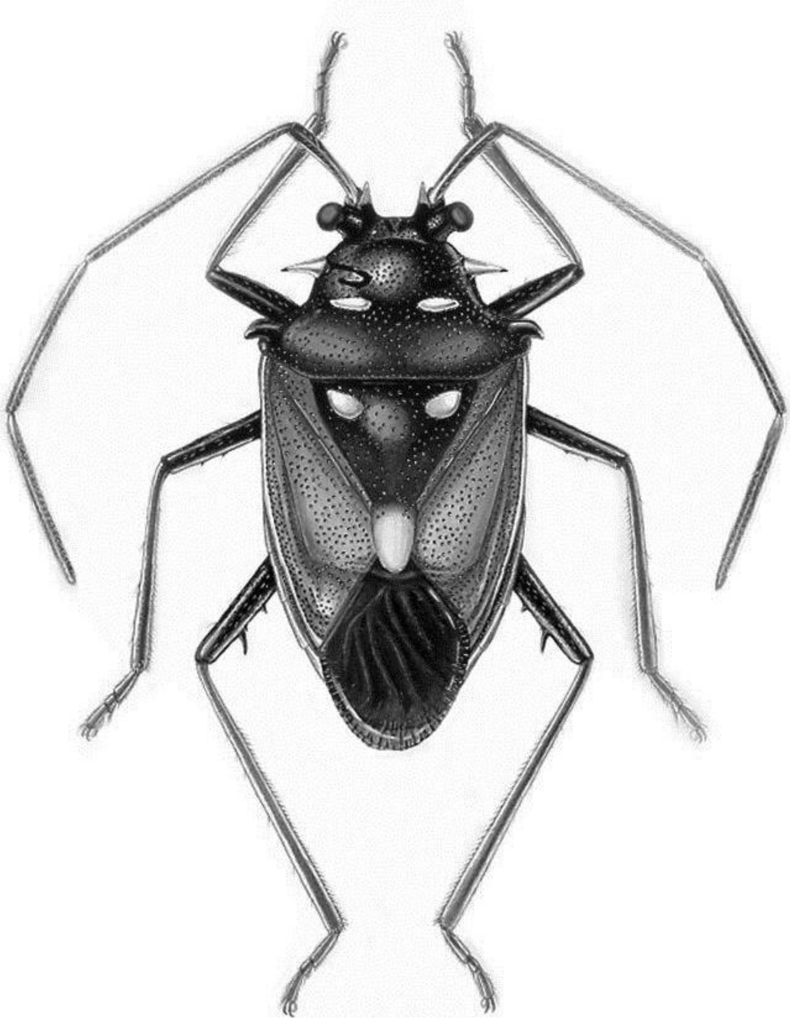
Small mayfly (Atalophlebia: Baetidae)

Mayfly (Ephemeroptera)

Key references for Papua New Guinea.

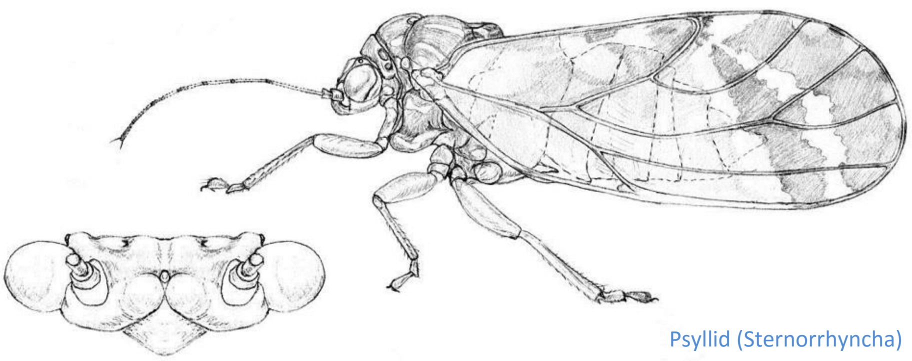
Edmunds, GF & Polhemus, DA. 1990. Zoogeographical patterns among mayflies (Ephemeroptera) in the Malay Archipelago, with special reference to Celebes. In: Knight & Hollloway*, Insects and the rain forests of southeast Asia*. Royal Entomological Society, London.

Order Hemiptera

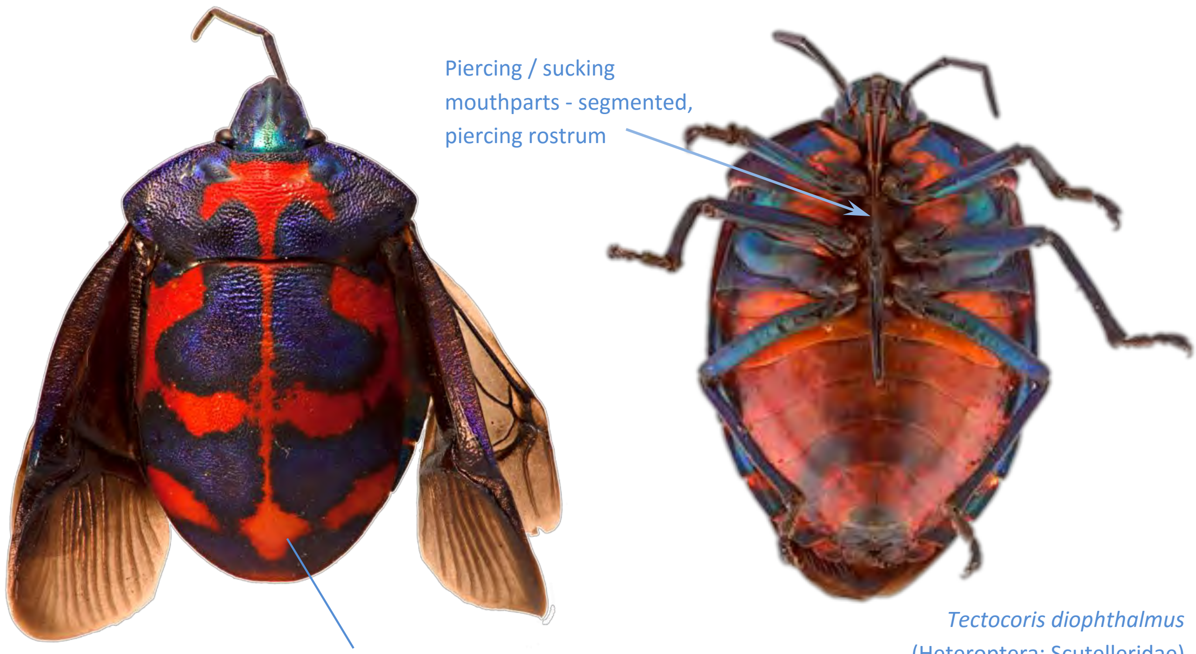


Common names: aphids, scales, whitefly, psyllids or jumping plant lice, leafhoppers, plant hoppers, treehoppers, spittlebugs or froghoppers, cicadas, true bugs, water striders, stinkbugs, seed bugs, assassin bugs, lace bugs

Simple diagnosis. Hemipterans are recognised by their piercing and sucking mouthparts, which are nearly always long and thin and in the form of a straight or weakly curved tube.



Psyllid (Sternorrhyncha)



Tectocoris diophthalmus
(Heteroptera: Scutelleridae)

Technical diagnosis. The order Hemiptera can be diagnosed by their proboscis-like mouthparts (=piercing and sucking), with the mandibles and maxillae modified into long and sharp stylets, that form two pairs of stylets that are interlocking, encased by a segmented labium. Maxillary and mandibular palps are nearly always absent. Their head is either hypognathous (= directed vertically; suborders Heteroptera, Coleorrhyncha), opisthognathous (= directed backwards; suborders Sternorrhyncha, Auchenorrhyncha), or rarely prognathous (= directed anteriorly; some Heteroptera). The pronotum is usually well-developed and the metasternum is most often concealed. The tarsi are most often three-segmented, but 1, 2 or 4 tarsomeres are known. In some taxa the tarsomere number varies between the legs (some Nepomorpha, some Dipsocoromorpha). Forewings are either membranous, part leathery or entirely leathery. The suborder Heteroptera (true bugs) can be identified by leathery flat forewings often membranous posteriorly, a 3-4 segmented labium and 4-5 segmented antennae. They most often have complex metathoracic glands between the middle and hind legs that have a mushroom-like texture on the outer surface of the body. Coleorrhyncha (moss bugs) are similar to Heteroptera, but the forewings are fully leathery, with many closed cells.

Diceropyga subapicalis

Auchenorrhyncha (cicadas, planthoppers, leafhoppers, treehoppers, spittlebugs) also may have leathery forewings, but they are held tent-like over the body, and the antennae are aristate (= bristle-like). In Sternorrhyncha (scale insects, mealybugs, whitefly, psyllids, aphids) the wings are membranous, and sometimes only the forewing is well-developed, with the hindwing reduced, and the mouthparts arise from near the junction of the head and prosternum. Abdominal cerci are absent. Some Sternorrhyncha, such as aphids, have a pair of siphunculi (= small tubes) on the apex of the abdomen in dorsal position.

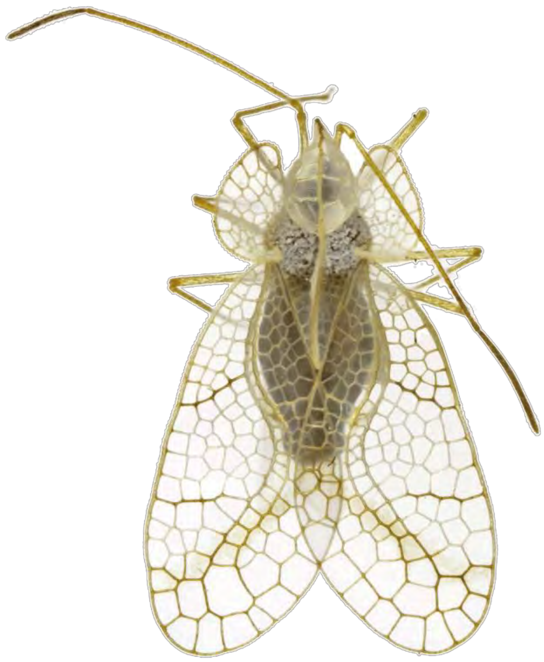
Heteropterans often exhibit a great deal of wing polymorphism, with wings often shortened to varying degrees, which can be sexually dimorphic.

Most nymphs are similar to adults and they undergo incomplete metamorphosis. The nymphs of aphids can undergo complete metamorphosis with pupal stages, sedentary and sessile nymphs. Sternorrhyncha often have the wings reduced or absent (e.g. scale insects, mealybugs, aphids). In male scale insects (family Coccidae) only the forewings are present and the hindwings are reduced to small paddle-shaped structures (= haltere-like).

What can they be confused with? Some flies like mosquitoes and bees have a long straight tube that make up their mouthparts, but hemipterans always have their wings flat or held tent-like over their bodies.

Prodromus occulatus (Heteroptera: Miridae)

Nerthra colaticollis (Heteroptera: Gelastocoridae)



Stephanitis sp. (Heteroptera: Tingidae)

Membracid planthopper
(Auchenorrhyncha: Membracidae)

Biology. Hemipterans are found in all major ecosystems, including deserts, tropical forests, and alpine regions. Some species are aquatic or semiaquatic and some live on the open ocean. The majority of hemipterans are plant feeders, predominantly of seed plants, and some species are host plant specific. There are also many omnivorous and predacious species. There are heteropterans that feed on blood of vertebrates, including humans, such as the human bed bug.

Diversity in Papua New Guinea. Hemiptera is the fifth largest insect order and are greatly diverse in morphology and habits. They are cosmopolitan in distribution, and include about 100,000 species. Many bug groups are well represented in New Guinea but are poorly documented (Miller 2007).

Cicada (Auchenorrhyncha)

Photograph: © Hannah Mathews, 2016

Key references for Papua New Guinea.

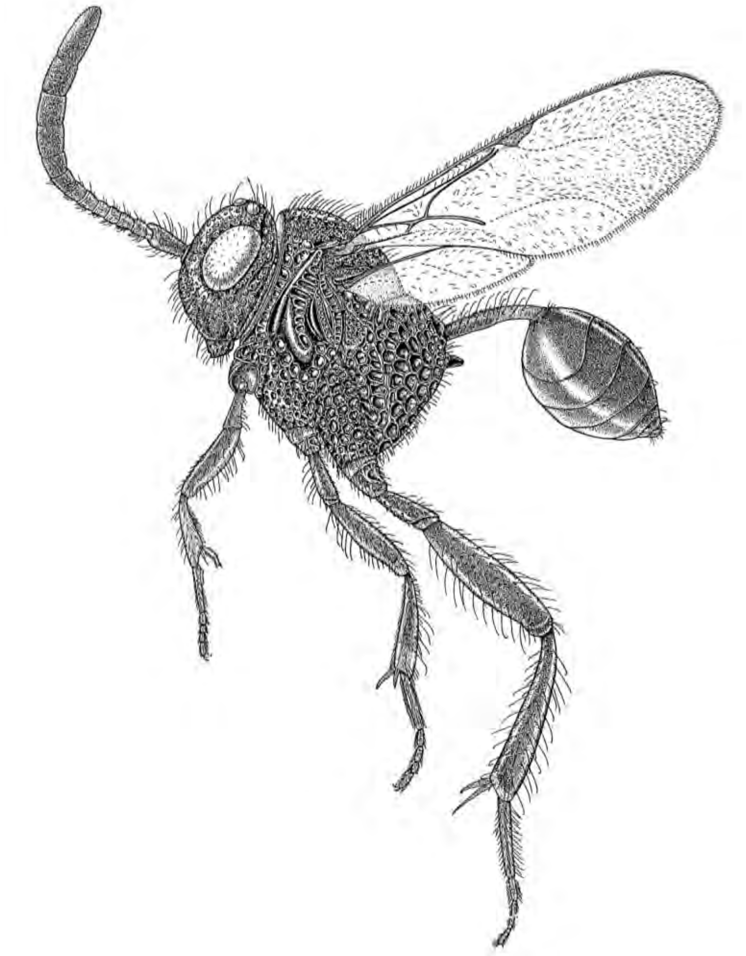
Sands, D.P.A., 1977. The biology and ecology of Leptocorisa (Hemiptera: Alydidae) in Papua New Guinea. *Research Bulletin, Department of Primary Industry, Papua New Guinea*, (18).

Carvalho, J.C.M., 1981. The Bryocorinae of Papua New Guinea (Hemiptera, Miridae). *Arq. Mus. Nac. Rio de Janerio*, 56, pp.35-89.

Polhemus, D.A. and Polhemus, J.T., 1998. Assembling New Guinea: 40 million years of island arc accretion as indicated by the distributions of aquatic Heteroptera (Insecta). *Biogeography and geological evolution of SE Asia,* pp.327-340.

Wheeler Jr, A.G., 2000. Plant bugs (Miridae) as plant pests. *Heteroptera of economic importance*. CRC Press, Boca Raton, pp.37-83

Order Hymenoptera



Common names: bees, wasps, ants, fig wasps, velvet ants, sawflies, ichneumons

Simple diagnosis. The Hymenoptera are very diverse in morphology. Adults are characterised by having mandibulate (= biting and chewing) mouthparts, although bees have tongue-like mouthparts; there are two pairs of wings that are membranous, and the tarsi are usually five segmented and the abdomen is often constricted into a one- or two-segmented petiole (= waist-like segment).

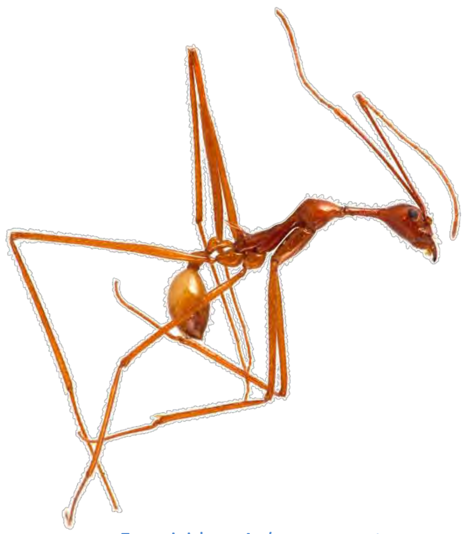
Technical diagnosis. Hymenoptera are diagnosed by two pairs of membranous wings with reduced venation, often with polygonal cells, and the anal vein of the forewing does not reach the posterior margin of the wings. The wings are often coupled with hooks (= hamuli). The hindwing is smaller than the forewing and is rarely reduced; sometimes the wings are absent. The mouthparts are mostly mandibulate (= biting and chewing), although in bees they are modified into a sucking tongue-like proboscis (= glossa). The mesothorax is well-developed, more so than the pro- and metathorax. Protibial spurs are present for cleaning the antennae. Tibial spines are usually present and the tarsi are often five-segmented. The female ovipositor is usually well-developed.

Bees (Hymenoptera: Apidae)

Larvae are mostly terrestrial, live on vegetation or in nests built by adults. They have a thick, eruciform (=caterpillar-like) body, have prolegs on segments II-VIII and X, which are sometimes absent; some larvae are apodous (= legless). The head capsule is usually thick and robust, without an adfrontal area, with mandibulate (= biting and chewing) mouthparts. The labium sometimes has a spinneret (= silk spinning organ).

What can they be confused with? The hymenopteran groups with reduced hindwings (family Mymarommatidae) can be confused with Diptera and male Coccoidea (Hemiptera); the two latter groups having two unconstricted basal abdominal segments, whereas in the family Mymarommatidae they are waist-like.

Wingless Hymenoptera can be confused with wingless Diptera, as they also have a similar body shape and the pronotum is reduced. However, wingless representatives of Hymenoptera have mandibulate (= biting and chewing) mouthparts. If their mouthparts are modified into a sucking proboscis, then they have a constricted abdomen. In contrast, representatives of Diptera that have a sucking proboscis never have constricted basal abdominal segments



Formicidae: *Aphaenognaster* sp.

Formicidae: *Polyrhachis* sp.

Formicidae (left to right): Ponerinae sp., *Camponotus* sp., *Dolichoderus* sp., *Odontognathus* sp.

Hymenopteran larvae are similar to those of Lepidoptera, and Coleoptera, as they are also usually thick, with mandibulate (= biting and chewing) mouthparts, and also can have prolegs and a 10-segmented abdomen. In Lepidoptera the prolegs are commonly placed on segments III-VI and X, having crochets, a spinneret is often present, and the head has an adfrontal area. Larvae of Coleoptera only rarely have prolegs. In other apodous larvae, the labium is segmented, whereas in apodous Hymenoptera it is usually unsegmented.

Biology. The Hymenoptera is one of the hyperdiverse orders of insects. They are ubiquitous in terrestrial habitats but do not occur in marine environments and are almost absent from water. Their feeding habits are diverse, but they are mostly herbivorous or parasitoids. Hymenoptera are known for their social systems and as pollinators, including bees and fig wasps.

Diversity in Papua New Guinea. This cosmopolitan order includes 150,000 species. Most groups are poorly known in New Guinea, but the ant fauna is well-described (Miller 2007).

Parasitic wasp (Hymenoptera: Gasteruptiidae)

Mud-dauber wasp (Hymenoptera: Sphecidae)

Vespid wasp (Hymenoptera: Vespidae)

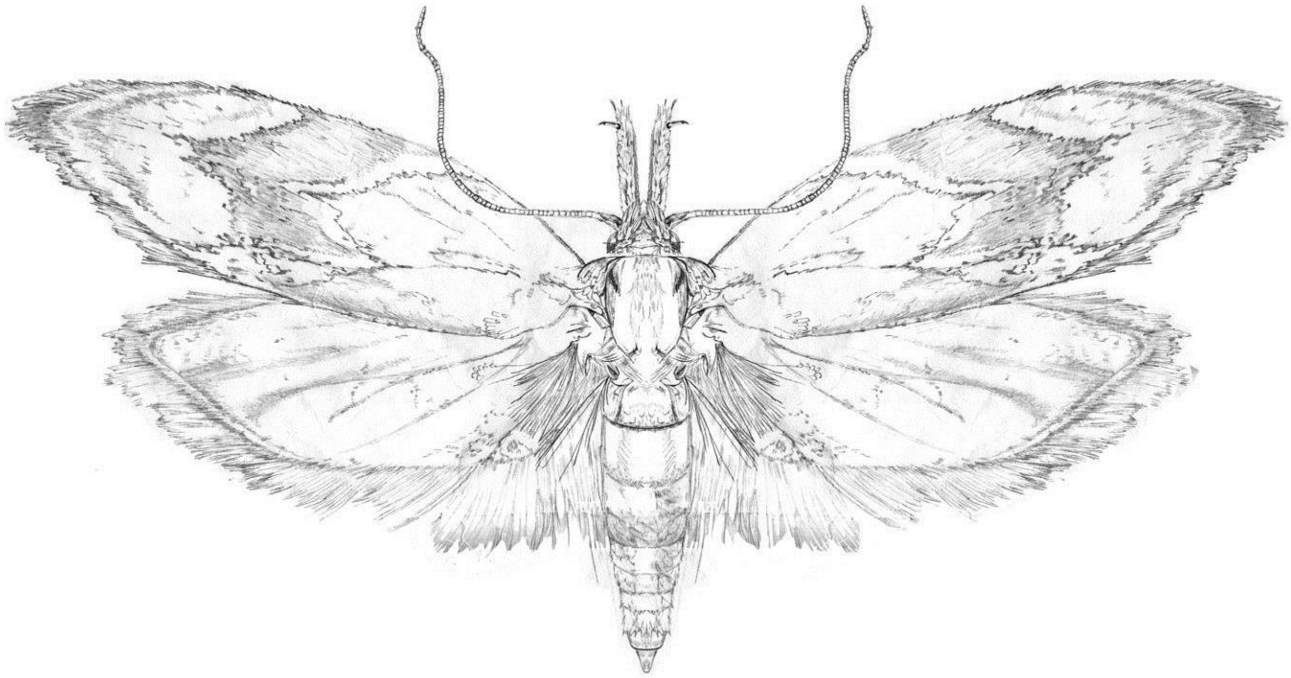
Key references for Papua New Guinea.

Goulet, H. & Huber, JT. 1993. *Hymenoptera of the world: an identification guide to families*. Agriculture Canada, Ottawa.

Bolton, B. 1994. *Identification guide to ant genera of the world*. Harvard University Press, Massachusetts.

Bee (Hymenoptera: Apoidea)

Order Lepidoptera



Common names: moths, butterflies, caterpillars, loopers, bagworms, cutworms

Simple diagnosis. Lepidoptera are recognised by having both surfaces of the wings and often other parts of the body densely covered with overlapping scales, most often with tubelike sucking mouthparts elongate and coiled at rest (= haustellate). Larvae and a few small adult moth species have mandibulate (= biting and chewing) mouthparts.

Technical diagnosis. The Lepidoptera can recognised by both surfaces of the wings and often other parts of the body being clothed with scales, often coloured, although some species have scale-less wing patches. The wings at rest can be held variously, horizontally, vertically, flat or tent-like. The hindwing can be similar to or smaller or larger than the forewing. . The forewing has a Y-shaped anal vein and with M veins having three branches. The wings can be reduced or absent (some females). The mouthparts of many lepidopterans form a unique coiled proboscis at rest (= haustellate), however, there are minute species with mandibulate (= biting and chewing) mouthparts (e.g. Micropterigidae). Other characters important for identification include: large compound eyes, ocelli paired or absent; pronotum desclerotised; prothorax usually small, mesothorax and metathorax both well-developed, with mesothorax larger; legs well-developed, cursorial, five segmented tarsi, foretibiae with a single or no spur; and abdominal cerci absent.

Larvae are usually eruciform (= caterpillar shaped), usually fleshy and thick, often having warning, aposematic or cryptic colouration. Some larvae are modified for tunnelling in wood (cylindrical with reduced appendages) or leaf-mining (flat with reduced appendages). The head is usually heavily sclerotised, with an adfrontal area, but the head capsule may be retractable; eyes are usually present in group of six stemmata or less, often forming a semicircle. The mouthparts are mandibulate, maxillae with a 2-3 segmented palp, labium often modified into silk spinneret, and

Papilio ulysses

always with two-segmented palpi. The antennae are usually short and three segmented. The legs are short, bearing a single claw, and often with less than the maximum five pairs of prolegs, bearing crochets; prolegs are commonly present on abdominal segments II-VI and X, and larvae are sometimes apodous.

What can they be confused with? Lepidopteran adults can be distinguished from all other insects by having scales on both surface of the wings and they usually proboscis-like mouthparts that are colied at rest. The moths with mandibulate (= biting and chewing) mouthparts can be confused with Trichoptera (= caddis flies), but the latter differ in having hair-like setae and not scales on the wings.

Lepidopteran larvae are similar to those of Hymenoptera, Mecoptera, and Coleoptera, in having a similar body shape, mandibulate (= biting and chewing) mouthparts, and often have prolegs. However, in the three latter orders the adfrontal area of the head is absent. In Sawfly hymenopterans the prolegs are present on segments II-VIII and X (6 or more pairs; except in pergids, where some without or with only one pair), without crochets, and a spinneret is most often absent. In Coleoptera a spinneret is absent except in a few aquatic Hydrophilidae.

Biology. Lepidoptera is one of the most diverse orders of insects and they are found in most terrestrial ecosystems of the world. Larvae are usually terrestrial. Lepidoptera mostly feed on plants, with adults usually having liquid food (nectar) and larvae feed mostly on leaves. There are a few parasitic and carnivorous species.

Diversity in Papua New Guinea. Lepidoptera are cosmopolitan, with 175,000 species. The New Guinea fauna is well-known for butterflies but poorly described in other lepidopteran groups (Miller 2007).

Aaathodes callixantha

Key references for Papua New Guinea.

Common, IFB. 1990. *Moths of Australia*. University of Melbourne Press, Melbourne.

Holloway, JD. 1986 – 2003. *The Moths of Borneo, Part 1 – 18.*

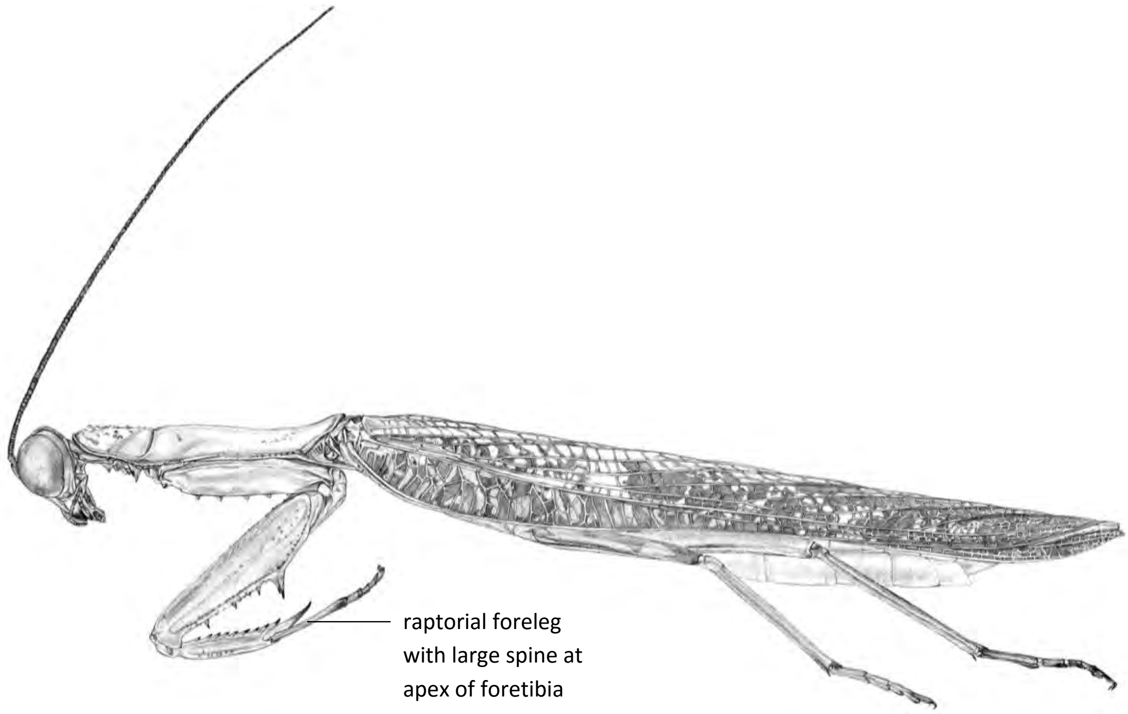
Holloway, JD, Kibby, G & Peggie, D. 2001. *The families of Malesian moths and butterflies*, Brill, Leiden.

Parsons, M. 1998. *The Butterflies of Papua New Guinea: Their systematics and biology.* Academic Press, San Diego, London, Boston, New York, Sydney, Tokyo, Toronto, 736 pp, 136 colour plates, 26 bw plates with genitalia

Robinson, GS, Tuck, KR & Shaffer, M. 1994. *A field guide to the Smaller Moths of South-East Asia.* Malaysian Nature Society, Kuala Lumpur; Natural History Museum, London.

Lepidoptera - Mouthparts unfurled for feeding

Order Mantodea



Common names: mantids, praying mantids, mantis

Simple diagnosis. Mantodea have a mobile head, with very large eyes, three ocelli, usually an elongate pronotum, elongate forecoxae and forefemora with spines. They usually have five-segmented tarsi and multisegmented cerci. Their wings have extensive venation and are held flat over the body when at rest. The forewings are leathery and the hindwings possess a well-developed anal region.

Technical diagnosis. Mantids are known for their distinctive "prayer-like" stance, and some species are either leaf-, flower- or stick-mimics. They have an elongate body with leathery forewings, with extensive venation, hindwings broader than the forewings, wings held flat over the body when at rest, which can be sometimes reduced or absent. The head is subtriangular and mobile, the eyes are prominent, three ocelli are present, and the antennae are multisegmented. The prothorax is usually elongate. The forelegs of mantids are modified for catching prey and have elongate coxae and femora, the remaining two pairs of legs are not modified, and have short coxae. The tarsi are almost always 5-segmented. Multi-segmented cerci are present. Immature stages are similar to adults, and can possess wing buds.

What can they be confused with? Mantodea can be confused with Phasmatodea (= stick insects), as they both have an elongate body, mandibulate (= biting and chewing) mouthparts, multisegmented antennae, leathery forewings and 5-segmented tarsi. However, stick insects can be differentiated in that the forelegs are never raptorial, the coxae are short, the pronotum is short and the mesothorax are usually elongate, the eyes are small and the cerci are unsegmented.

Mantid (Mantodea)

Mantodea also can be similar to some representatives of the order Neuroptera (family Mantispidae) with raptorial forelegs, they both also have subtriangular head, swollen eyes, non-modified mandibulate (= biting and chewing) mouthparts, multi-segmented antennae, elongate pronotum and five-segmented tarsi. However, the latter can be recognised by the forewings always being membranous, fore- and hindwings subequal in size and shape, and held tent-like over the body when at rest, and ocelli and cerci absent.

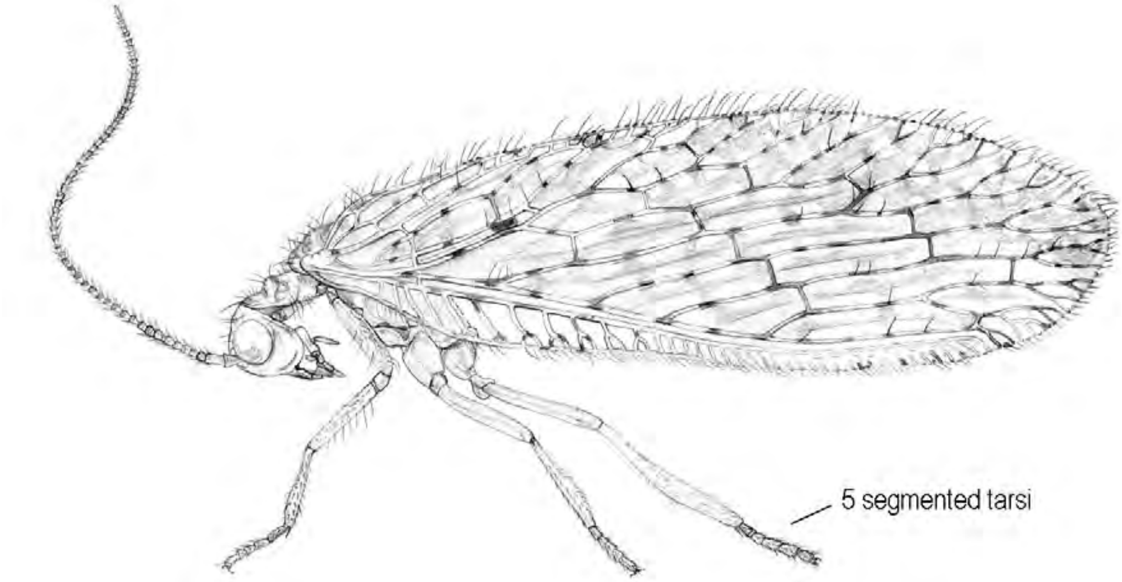
Biology. Mantids are most diverse in the topics. They are solitary and usually can be found on vegetation, from grasses to tree canopies. They are predators and regularly feed on insects, and sometimes feed on small vertebrates.

Diversity in Papua New Guinea. Mantids are found primarily in the tropical regions of the world, with a total of 1800 species. The New Guinea fauna is well-known and described (Miller 2007)

Key references for Papua New Guinea.

There are no reviews in English.

Order Neuroptera



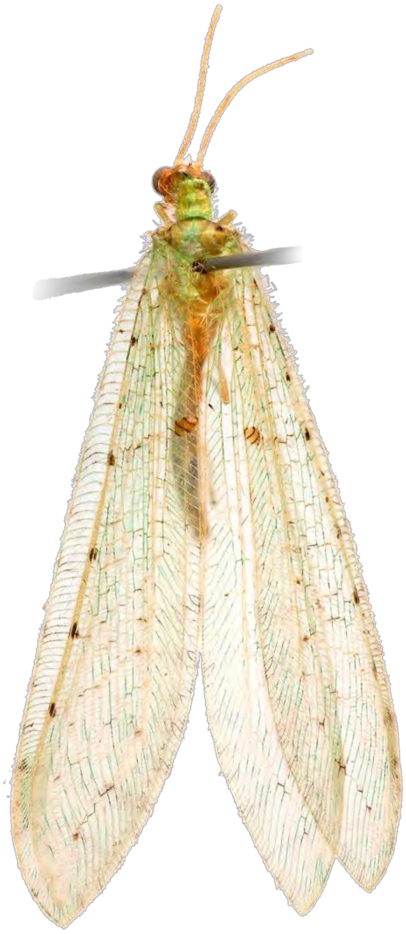
Common names: lacewings, antlions, dustywings, spongeflies, owlflies

Simple diagnosis. Neuropterans have unique larval mouthparts, with the maxillae and mandibles forming sucking and piercing tubes, and the maxillary palps absent. In adults the wings are large and membranous, with extensive venation, including cross veins, and the anal region is reduced, the ocelli are most often absent, the tarsi are five-segmented in adults and unsegmented in larvae.

Technical diagnosis. Adult Neuroptera are usually elongate and are most often large in size. The head is usually hypognathous (= directed vertically) and rarely prognathous (= directed forwards), the mouthparts are mandibulate (= biting and chewing), compound eyes are always present and ocelli usually absent. Also, the antennae are multi-segmented and usually are longer than the head, the pronotum is well-developed, sometimes elongate, and the meso- and metathorax are also well-developed. The thoracic pleura are directed upwards, but not posteriorly. Wings are membranous and large held tent-like over the body at rest, and fore- and hindwings are usually subequal in shape and length. Forewings and hindwings are never distinctly reduced, but sometimes differ in size, and one pair can be larger than the other. The anal region of the hindwings is not developed or only weakly developed. Wing venation is extensive, and veins branch distally, venation is rarely reduced, and in such species the wings have a white powdery texture. Legs are usually cursorial, but the forelegs are sometimes raptorial. The tarsi are five-segmented. Abdominal cerci are absent.

Neuropteran larvae have a well-sclerotised head, with the maxillae and mandibles forming two sucking and piercing tubes, the maxillary palps are absent, and the labial palps are three-segmented.

What can they be confused with? Small-bodied lacewings and dustywings (Coniopterygidae) can be confused with winged species of Psocoptera, with both holding their wings tent-like over the body at rest. However, in Psocoptera the wing venation is sparse, the mouthparts have the maxillae forming tubes, and the tarsi are two- or three-segmented. From Hemiptera they can be distinguished by mandibulate mouthparts.

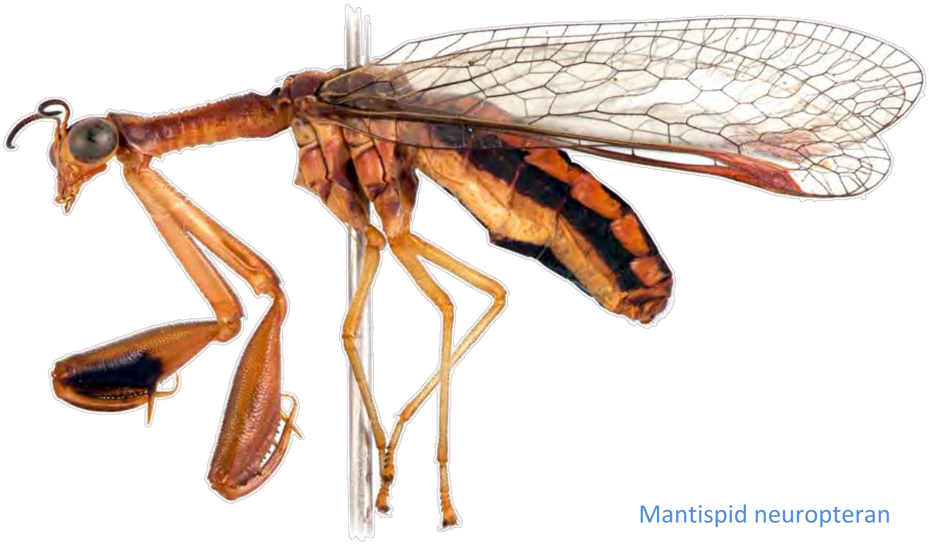


Lacewing (Neuroptera)

Large lacewing adults can be superficially mistaken for Odonata (= dragonflies and damselflies), as they also have an elongate body, mandibulate (= biting and chewing) mouthparts, and the fore- and hindwings are about equal in length, with dense venation. The Odonata can be recognised by the very short antennae, shorter than the head, thoracic pleura strongly directed posteriorly, and the wings are held upright or flat, and never tent-like over the body.

Lacewing adults can be confused with Plecoptera (= stone flies), as they also have dense wing venation, mandibulate (= biting and chewing) mouthparts, ocelli and multi-segmented antennae, but stoneflies differ in having the tarsi three-segmented and the hindwing has a distinct anal area, and the wings are held flat over the body when at rest.

The neuropteran family Mantispidae can be confused with the order Mantodea (= praying mantids), as they both have raptorial forelegs, as well as a subtriangular head, mandibulate (= biting and chewing) mouthparts, and five-segmented tarsi. However, Mantodea can be separated by the leathery forewings (if present), the hindwing has a large anal area, and the wings are held flat at rest. They also have ocelli and multisegmented cerci.



Mantispid neuropteran

The larvae of Neuroptera have very distinctive mouthparts. They can however be confused with some Coleoptera larvae, as their mouthparts can also form two long processes (families Lampyridae, Dytiscidae, Hydrophilidae). However, in the coleopteran groups the stylets are formed by the mandibles only.

Biology. Larvae are mostly terrestrial but can also live in cold streams. Adults and larvae are both predators feeding on soft-bodied insects.

Diversity in Papua New Guinea. Neuroptera inhabit all zoogeographic regions, but are most abundant in temperate regions. More than 5000 species are described worldwide. The New Guinea fauna is relatively well-known and described (Miller 2007).

Antlion (Neuropteran larva)

Key references for Papua New Guinea.

New, TR. 2003. *The Neuroptera of Malesia*. Brill, Leiden.

Order Odonata

Common name: dragonflies and damselflies

Simple diagnosis. Adults are medium to large insects (2 to 15 cm long), with a maximum wingspan of 17 cm. Their main features include two pairs of unfolded long wings that are about equal in length and held vertically or horizontally over the body. They have very large eyes, three ocelli, minute antennae, dense venation and a pterostigma (= a pigmented spot on the leading edge of the forewings).

Technical diagnosis. The Odonata are recognised by two pairs of unfolded wings, which are subequal in length without any coupling apparatus, dense quadrangular venation, minute antennae which are shorter than the head, large eyes, thoracic pleura directed posteriorly and, in males, an abdominal apex with grasping apparatus, and the genitalia are on the ventral surface of abdominal segments II and III. The nymphs are aquatic and can be recognised by mouthparts in the shape of a mask and the presence of three caudal lamellae.

The nymphs are aquatic, with a stout or elongate body, well-developed eyes and legs, and often, possess ocelli. Their characteristic mouthparts are in the shape of an elongate mask that are held below the head at rest. On the apex of the abdomen, they have three caudal lamellae composed of five short outgrowths. The nymphs do not have abdominal gills and their abdomens move from side to side during swimming.

What can they be confused with? Adults are distinct with their elongate, unfolded wings, with extensive venation, including cross-veins. They can be superficially confused with the holometabolous order Neuroptera (= lacewings), which also have an elongate body, mandibulate (= biting and chewing) mouthparts, large wings that are often subequal in length, and dense venation.

Damselfly (Odonata: Zygoptera)

Lacewings differ in that the thoracic pleura are not directed posteriorly, the antennae are usually long, and wings are held tent-like above the body when at rest.

Odonate nymphs are superficially similar to nymphs of the orders Ephemeroptera (= mayflies) and Plecoptera, (= stoneflies) but both these orders differ in that the mouthparts are simple and mandibulate, sometimes modified, but not in the shape of a mask. In addition, the abdominal filaments are present instead of lamellae and the genitalia are at the tip of the abdomen. Nymphs of Ephemeroptera can also be recognised by the presence of lateral abdominal gills.

Biology. Adults are active and diurnal, excellent flyers, and exhibit territorial behaviour, antagonistic sexual mating. They are predators and feed on aerial insects. The nymphs are voracious predators, feeding vertebrates and small aquatic vertebrates.

Diversity in Papua New Guinea. The Odonata are cosmopolitan in distribution. They comprise two suborders, the damselflies (suborder Zygoptera) and dragonflies (suborder Anisoptera), 17 families, about 600 genera and 6500 species.The New Guinea fauna is fairly well-known, with over 600 species. However, new species continue to be described, especially from more remote outer islands and inland mountainous regions (see example refs below). Some guides have recently been released. Michalski (2012) compiled the first comprehensive guide to 620 species from New Guinea and neighbouring islands with nearly half the species being endemic. Later guides have been produced separately to the dragonflies (Orr & Kalkman 2015a) and damselflies (Kalkman & Orr 2013) of New Guinea.

Photograph: © John Pickering 2004-2014

Key references for Papua New Guinea.

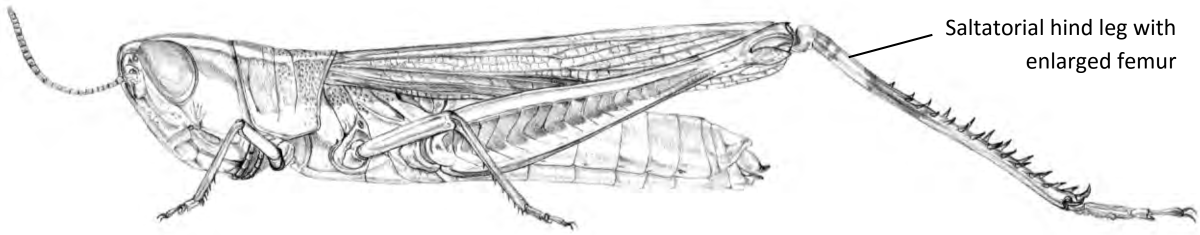
Michalski, J. 2012. *A Manual for the Identification of The Dragonflies and Damselflies of New Guinea, Maluku and the Solomon Islands.* Kanduanum Books, Morrostown, NJ, 561 pp, 8 colour pages, 1275 bw line drawings.

Orr, AG & Kalkman, VJ. 2015a. Field guide to the Dragonflies of New Guinea. *Brachytron* 17, Supplement, 3-155.

Kalkman, VJ & Orr, AG. 2013. Field Guide to the Damselflies of New Guinea. *Brachytron* 15, 3-128.

Kalkman, VJ., Theischinger, G. & Richards, SJ. 2011. Dragonflies and damselflies of the Muller Range, Papua New Guinea. In: Richards. S.J. & B.G. Gamui (ed.) 2011. Rapid Biological Assessments of the Nakanai Mountains and the Upper Strickland Basin: surveying the biodiversity of Papua New Guinea's sublime karst enviroments. *RAP Bulletin of Biological Assessment* 60. Conservation International. Arlington, VA

Order Orthoptera



Common names: grasshoppers, katydids, bush crickets, mole cricets, crickets, locusts

Simple diagnosis. Most species of Orthoptera can be recognised by the enlarged pronotum (= anterior dorsal shield of the thorax and elongate saltatorial (= jumping) hind legs, with the fore and middle legs are much smaller in size. They also have biting and chewing mouthparts and paired long rows of spines on the hind tibia, and leathery forewing with extensive venation, usually held flat over the abdomen when at rest, and the females have a well-developed ovipositor (= swordlike egg laying organ).

Technical diagnosis. Orthopterans are medium to large size insects, usually with a cylindrical body, and some species are brightly coloured, whereas other species are camouflaged. Structurally they can be recognised by the enlarged pronotum with the lateral extensions over the pleural (= lateral thoracic segments) sclerites and many species possess elongate saltatorial (= jumping) hind legs, with enlarged femora. However, both these latter two characters can be lost in burrowing forms. Orthopterans have a hypognathous (= directed vertically) head with mandibulate (= biting and chewing) mouthparts, multisegmented antennae, of varying length, ranging from very short to very long, and if so long, they are longer than the body. Also, the mesonotum and metanotum are short,

Oxya velox

Gryllotalpa africana

the eyes are well-developed and three ocelli. Are present The fore- and middle legs are usually gressorial (= walking) and smaller than the hind legs. In burrowing species, the forelegs can be fossorial (= modified for digging) or more or less raptorial (= modified for catching prey). The hind tibiae have longitudinal rows of spines on dorsal surface, tarsi 1-4 segmented. The forewings are leathery, with extensive venation, the hindwing is membranous with well-developed venation and anal region. However, wings can be distinctly shortened. Abdominal cerci are unsegmented and the female ovipositor is well-developed. The nymphs are similar to adults in overall morphology.

What can they be confused with? Some leaf-mimicking or stick-mimicking orthopteran species can be confused with stick insects (Phasmatodea). They also have: an elongate and large body, forewings leathery, and hindwings a large anal region. However, the Phasmatodea can be recognised by the shorten pronotum, that does not extend over the pleura, the elongate mesonotum, gressorial legs, not modified for jumping or digging, and the head is typically prognathous (= directed forwards).

Biology. There are both diurnal and nocturnal species. They are usually herbivorous, and some species (e.g., locusts) can cause significant damage of crops. Some species are predaceous or omnivorous. The order is well known for its sound producing behaviour (= stridulation).

Diversity in Papua New Guinea. Orthoptera are distributed all over the world, but are best represented in tropics. There are more than 20,000 species. The New Guinea fauna is poorly known except for the larger species (Miller 2007).

Key references for Papua New Guinea.

Rentz, DCF. 1990. Orthoptera. *Insects of Australia, Volume 1*. CSIRO Publishing, Melbourne.

Willemse, LPM. 2001. *Guide to the pest Orthoptera of the Indo-Malayan region*. Backhuys Publishers, Leiden.

Order Phasmatodea

Common names: stick insects, walking sticks

Simple diagnosis. Many species of Phasmatodea mimic sticks or leaves. They often have a very large body. They also can be distinguished morphologically by having a forwardly directed head often with outgrowths, small eyes, ocelli are often present the mesothorax is usually elongate, and the femora are not enlarged, wings are often reduced or absent, but if full-winged, the forewing is leathery with dense venation.

Taxonomic diagnosis. Stick insects are usually large in size, some species can exceed 30 cm in length. Many species are either stick- or leaf-mimicking, their head is usually prognathous (= directed forwards), sometimes with outgrowths, the antennae are multi-segmented, varying in length, the compound eyes are small, ocelli are usually absent, and the mouthparts are mandibulate. The prothorax in Phasmatodea is shorter than other thoracic segments, not extending to the pleura, the mesothorax is usually elongate, extending well beyond the forewing attachment. All legs are gressorial, hind femora are not enlarged, and tarsi are 4-5 segmented. The wings are often reduced or absent, but if full-winged, then the forewings are leathery with distinct venation, and hindwings have dense venation and a large anal region. The cerci are short and unsegmented. The nymphs resemble adults.

What can they be confused with? Representatives of Phasmatodea are similar to species of Orthoptera, with some species of both orders mimicking sticks or leaves. Orthoptera can be distinguished by the large pronotum, with lateral lobes extending over the pleura, the mesonotum not elongate, the greatly enlarged hind legs which are modified for jumping, large eyes and the head is strongly hypognathous (= vertically directed).

Phasmatodea are also similar to plant-mimicking Mantodea, as they also have an elongate body, leathery forewings, membranous hindwings with extensive venation. Mantodea can be distinguished by raptorial forelegs with elongate coxae, subtriangular head with large eyes and three ocelli, multi-segmented cerci and elongate pronotum.

Stick insect (Phasmatodea)

Leaf insect (Phasmatodea)

Biology. Stick insects are most diverse in tropical climates and feed on plants.

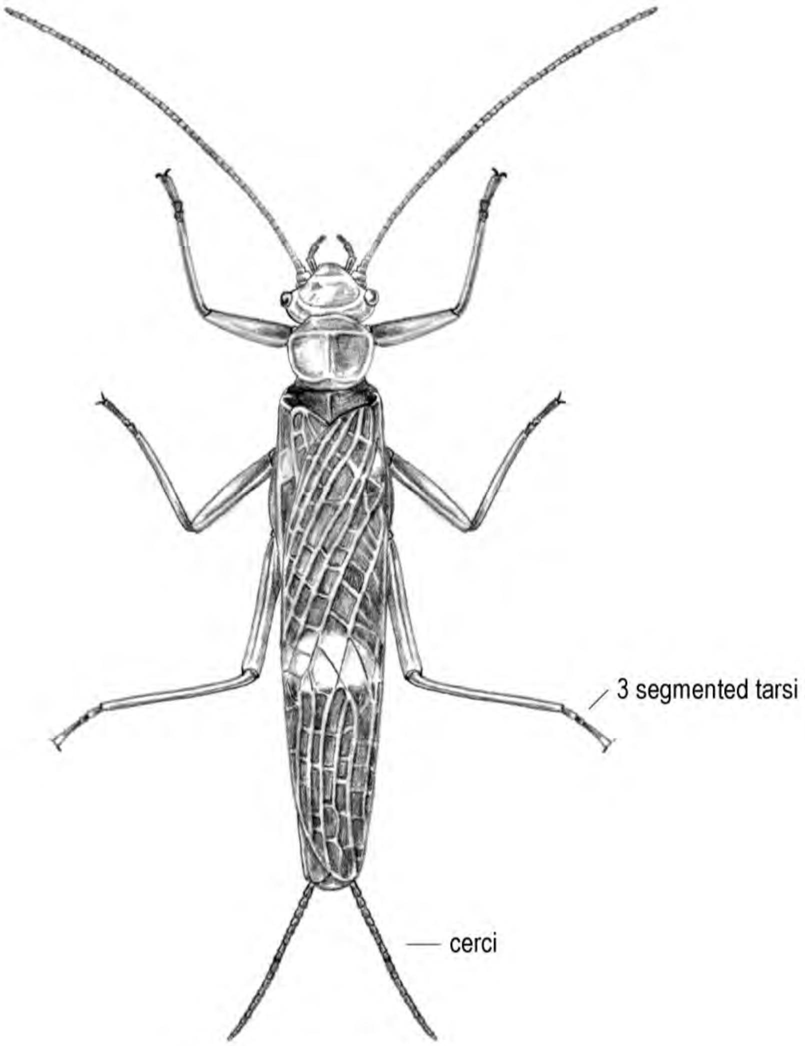
Diversity in Papua New Guinea. This order is predominantly tropical with more than 2500 species. The New Guinea fauna is well-known and mostly described (Miller 2007).

Exatostoma tiaratum , feeding

Key references for Papua New Guinea.

van Herwaarden, HCM. 1998. A guide to genera of stick- and leaf- insects of New Guinea and the surrounding islands. *Science in New Guinea* 24: 55-114.

Order Plecoptera



Common name: stoneflies

Simple diagnosis. Plecoptera can be recognised by having two pairs of membranous wings with dense venation, the hindwings are wider than the forewings, the head is vertically directed, with biting and chewing mouthparts, the antennae are long and multi-segmented, there are 2 or 3 ocelli, the cerci are multisegmented, and the tarsi are 3-segmented.

Technical diagnosis. Adults have a roughly cylindrical body, hypognathous (= directed vertically) head with mandibulate (= biting and chewing) mouthparts, well-developed eyes, two or three ocelli, long and multi-segmented antennae, separated thoracic segments, with pronotum not enlarged or shield-like, two pairs of membranous wings with dense venation, held flat over the body when at rest, and the hindwings are wider than the forewings (note, wings can be reduced), slender, well-developed legs, 3-segmented tarsi and usually elongate and multi-segmented cerci.

What can they be confused with? Adults of Plecoptera are similar to those of Neuroptera in terms of general body plan, multi-segmented antennae, simple mandibulate (= biting and chewing) mouthparts, and dense venation of wings. However, the Neuroptera differ in that the wings are

Sterniperla australis

usually held tent-like over the body when at rest, abdominal cerci are absent, and tarsi are 5-segmented. Some stonefly nymphs or wingless adults can be confused with Dermaptera (= earwigs), as they both have unmodified mandibulate (= biting and chewing) mouthparts, free thoracic segments, long cerci, and 3-segmented tarsi, but earwigs generally have a prognathous (= directed forwards) head, sclerotised and shortened (sometimes absent) forewings, no ocelli, forcep-like and unsegmented (rarely multi-segmented) cerci, and a flattened body.

The nymphs of Plecoptera are aquatic and can be confused with those of Ephemeroptera or Odonata. However, Ephemeroptera nymphs differ because the metanotum (= last thoracic dorsal segment) is small and usually not visible from above, and there are three (rarely two) caudal segmented filaments and rows of gills on the abdomen. Ephemeropteran nymphs also move their abdomen up and down when swimming. Odonata nymphs can be readily distinguished by mouthparts in the shape of an elongate mask and the presence of caudal lamellae instead of filaments (= cerci).

Biology. Adults are commonly found near water, but may hide under bark during the day. Adults live for a few days only. They are not good flyers but can run fast. They feed on plants tissues, including algae, lichen and rotten wood.

Nymphs are aquatic and usually inhabit cool, aerated water. When swimming, their abdomen moves from side to side. Some nymphs are terrestrial, but require wet conditions. Nymphs are generally similar to adults, but have wing buds instead of wings. Gills may also be present on different parts of the body. Plecoptera nymphs largely feed on detritus and plants, but some of them carnivorous or polyphagous.

Diversity in Papua New Guinea. Plecoptera is a small order of freshwater associated insects, with about 2000 species worldwide, mostly in temperate regions. Only a single species of Plecoptera is known from New Guinea (Miller 2007).

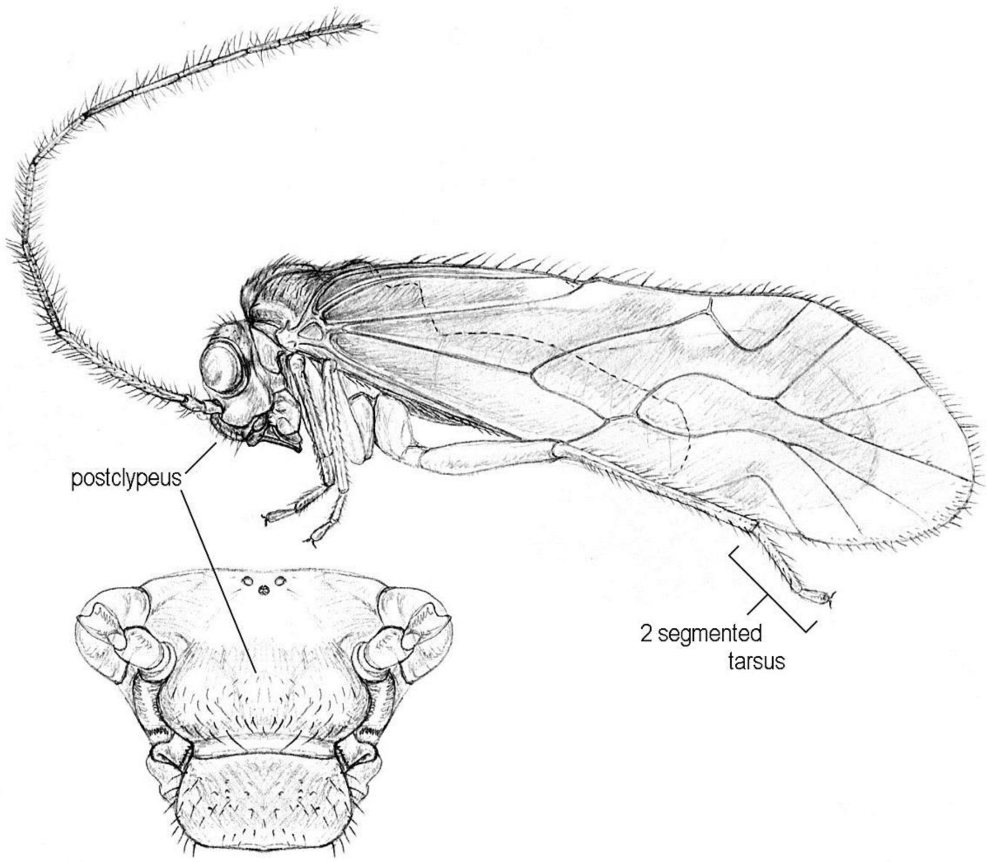
Key references for Papua New Guinea.

The single recorded species is only known from its aquatic nymphs and is undescribed.

Order Psocodea

Modern classifications include the book lice (Psocoptera) and true lice (Phthiraptera) in the same order. We provide separate diagnoses for these two groups at the subordinal level.

Suborder Psocoptera

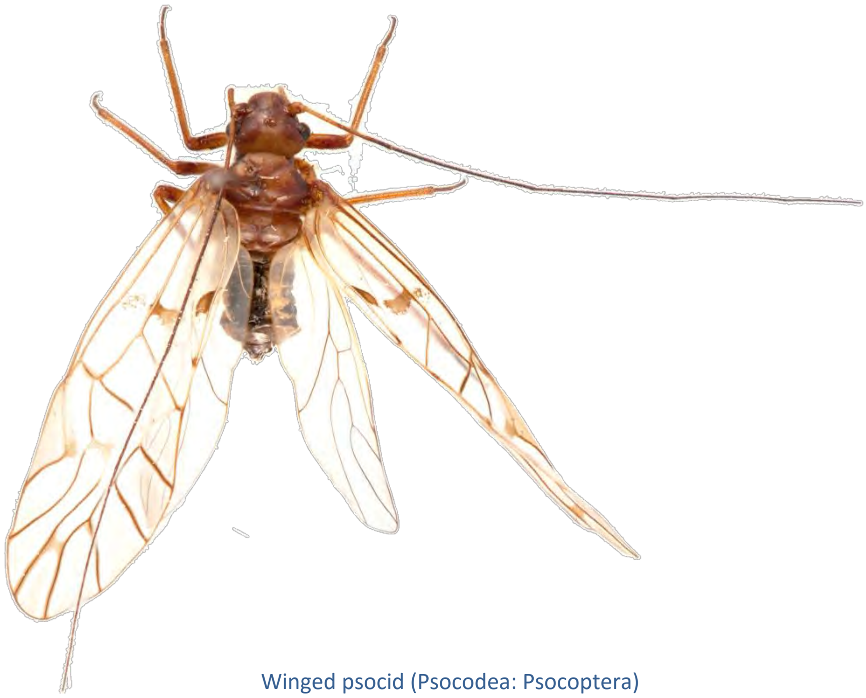


Common names: psocids, barklice, booklice

Psocids are found worldwide, with more than 3000 described species.

Simple diagnosis. The Psocoptera are defined by having a hypognathous (= directed vertically) head, mandibulate (= biting and chewing) mouthparts with elongate and pick-like lacinia (= inner lobe of the maxilla) and the wings are held tent-like over the body, hindwing short, and 2 or 3-segmented tarsi.

Technical diagnosis. Psocids are relatively small insects, 1-10 mm in length, and are either fully winged, short wings or apterous (= wings lost). They have a relatively large and mobile head, usually with large eyes, sometimes the eyes are reduced, ocelli are usually present, but are sometimes absent. Their antennae are filiform (thread-like), usually have 13 segments, but sometimes more. They have mandibulate (= biting and chewing) mouthparts with a lacinia pick-like (= inner lobe of the



Winged psocid (Psocodea: Psocoptera)

maxilla). The pronotum is usually reduced, especially in winged representatives, and the pterothorax (middle and hind thoracic segments) is enlarged. The legs are usually gressorial, the tarsi are 2 or 3-segmented which are not enlarged. The abdominal cerci are always absent. Wings, if present, are held tent-like over the body when at rest, the hindwings are shorter than the forewing, and both have reduced venation, and the forewing usually contain an open cell in the forewing (= areola postica). The nymphs resemble adults.

What can they be confused with? Winged representatives of Psocoptera are similar to some Hemiptera with tent-like wings at rest (some Auchenorrhyncha and Sternorrhyncha). The Hemiptera can be separated from psocids by having elongate tube-like mouthparts, encased by the labium and the pronotum is usually enlarged.

Winged psocids can be confused with some Neuroptera (= lacewings), as they also have tent-like wings at rest, but the latter order differs in possessing dense venation, unmodified mouthparts and five-segmented tarsi.

Wingless psocids are similar to wingless some Zoraptera, in being small, having a hypognathous (= directed vertically) head, eyes reduced and tarsi 2-segmented. However, Zoraptera differ by having 9-segmented antennae, unsegmented cerci, and the pronotum is not reduced, and is as large as the other thoracic terga.

Wingless psocids also can be confused with termite workers, as they both have a large head with a swollen clypeus, moniliform (= bead-like) antennae, and reduced eyes. Termites differ by having unmodified mouthparts, pronotum well-developed, tarsi usually 4- or rarely 5-segmented, and unsegmented cerci.

Biology. Psocids have a worldwide distribution, and most species live in cryptic (= concealed places), such as leaf litter, and under bark and stones, in caves, and nests of termites, hymenopterans or

Winged psocid (Psocodea: Psocoptera)

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mammals. They can make silk galleries. Psocids feed on lichens, algae, fungi, dead organic matter or insect eggs. They have incomplete metamorphosis and the nymphs are like the adults.

Diversity in Papua New Guinea. The New Guinea fauna is poorly known (Miller 2007).

Wingless psocid (Psocodea: Psocoptera)

Photograph: © Perry Babin; used under the Creative Commons Attribution-NonCommercial-NoDerivs License - Version 1.0. Specimen size: ~1.25 mm

Key references for Papua New Guinea.

New, TR & Lienhard, C. 2007. *The Psocoptera of tropical South-east Asia*, Brill, Leiden.

Smithers, CN & Thornton, IWB. 1981. The role of New Guinea in the evolution and biogeography of Psocopteran insects. In: Gressitt (ed) *Biogeography and Ecology of New Guinea*, Junk, The Hague.

Suborder Phthiraptera

Common names: lice

Simple diagnosis. The suborder Phthiraptera or lice comprise apterous (= wingless), dorsoventrally flattened ectoparasites (= external parasites). Their eyes are reduced or absent and the antennae are short, 3-5 segmented, the thoracic segments are partly or completely fused, the legs are short, the tarsi are 1-2 segmented, with claws forming hooks, and the abdominal cerci are absent.

Taxonomic diagnosis. Lice are obligate ectoparasites (= external parasites) living on mammals, including humans, and birds. Morphologically they can be recognised by a flattened wingless body, reduced or absent compound eyes, antennae reduced to 3-5 segments. The mouthparts are usually piercing or sucking, sometimes mandibulate (= biting and chewing), the thoracic segments can be partly or completely fused, the legs are well-developed and short, mostly used for climbing on hair or feathers, the tarsi are 1- or 2-segmented, bearing single or two claws forming a large hook, and the cerci are absent. Lice have incomplete metamorphosis and nymphs are smaller and less pigmented than adults.

What can they be confused with? Lice have highly specialised morphology associated with their parasitic life. They are sometimes confused with other unrelated ectoparasites, which can also be wingless, have a compressed body, reduced eyes and antennae, and sucking and piercing mouthparts.

Siphonaptera (fleas) differ from lice in that the body is bilaterally compressed, but never dorsoventrally compressed, and the tarsi are five-segmented. Unlike lice, they are excellent jumpers, and do not spend all their lifecycle on the same host individual.

Adult fly parasites of mammals and birds (families Hippoboscidae, Nycteribiidae, Streblidae) are also obligate ectoparasites, and spend most of their life cycle on the body of their host. However, they differ by having longer legs, usually more than two tarsal segments, typically five, and the claws are not in the shape of a large hook.

Hemipteran ectoparasitic bugs of the families Cimicidae and Polyctenidae are also dorsoventrally compressed, but differ in having long thin legs and their claws do have large hooks. Polyctenidae are permanent ectoparasites (= external parasites), living exclusively on bats. Cimicidae are temporary parasites and generally are only on their hosts to feed.

Biology. Lice are permanent ectoparasites on hosts and feed on different tissues of their hosts, including their skin, feathers or blood.

Diversity in Papua New Guinea. Lice are found worldwide, with about 3000 species described. The New Guinea fauna is poorly known (Miller 2007).

Key references for Papua New Guinea.

There are no reviews of the New Guinea fauna.

Order Siphonaptera

Common name: fleas

Simple diagnosis. Fleas are active, blood-sucking parasites, 1-10mm long, with a unique laterally compressed body and enlarged hind legs. Head, thoracic and abdominal segments are similar sized, compound eyes are absent, mouth modified into stylets for piercing and sucking, antennae short and apparently 3-segmented, wings absent, tarsi 5-segmented.

Larva legless, vermiform, with distinct head capsule, no eyes, 13-similar sized body segments, 2 short and thin unsegmented lobes on apex of abdomen.

Technical diagnosis. Siphonaptera are specialised for an active externally parasitic lifestyle. They are diagnosed by their mouthparts, which are reduced to labral, maxillary and labial elongated stylets (for piercing and sucking), without mandibles. The bilaterally flattened body is unique within insects. There are often ctenidia (combs of flat blade-like setae) on head, thorax and/or abdominal segments. The compound eyes are absent but a large lateral ocellus may be present. The antennae are short and stout with the third segment partly subdivided. Wings are absent, pro-, meso- and metanota are similar sized, and the legs are modified for jumping, with coxae larger than femora.

Larvae are white and vermiform (worm-shaped), narrow, and apodous. They have mandibulate (= biting and chewing) mouthparts but the mandibles are microscopically small, maxillary and labial segments are reduced, eyes are absent, antennae are 1-segmented but elongate and relatively conspicuous, the thoracic and abdominal segments are similar, with the abdomen 10 segmented, without prolegs. The apex of the abdomen has a pair of short unsegmented thin lobes.

Flea (Siphonaptera)

What can they be confused with? Larvae of Siphonaptera are similar to other legless larvae of the orders Diptera, Coleoptera, Lepidoptera and Hymenoptera. Diptera can be recognised by having 7-9 abdominal segments, often with modified mouthparts (hooks or fans), and prefer moist and aquatic environments. Larvae of Lepidoptera, Coleoptera and Hymenoptera have conspicuous mandibles.

Biology. Siphonaptera have a cosmopolitan distribution, feeding on mammals (including humans) and birds. Larvae usually feed on dried blood, develop in nests of birds and mammals and are free-living.

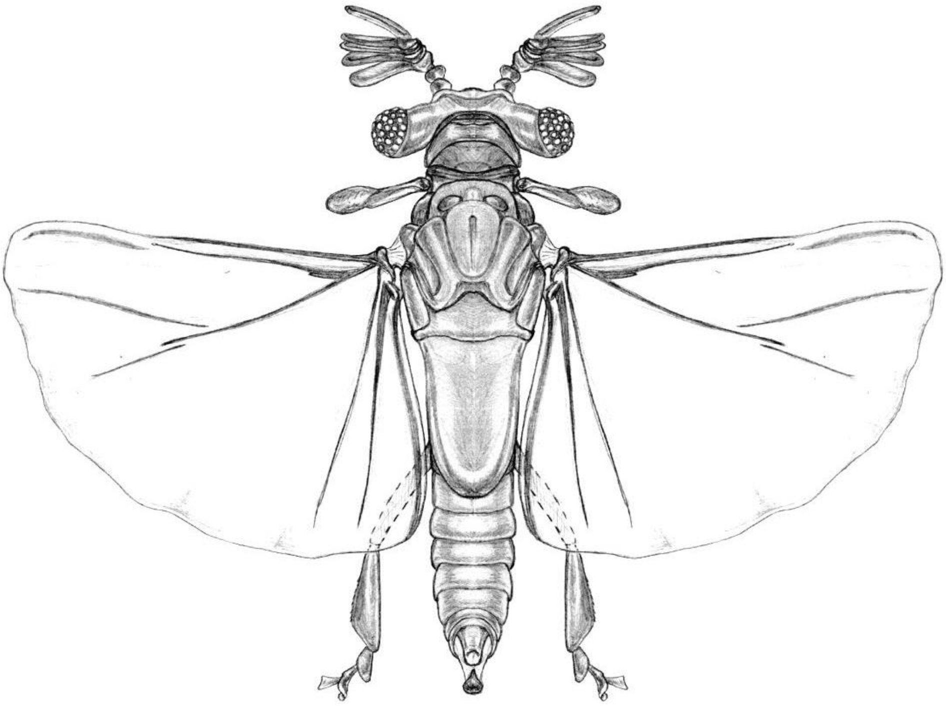
Diversity in Papua New Guinea. Siphonaptera are cosmopolitan, with about 2400 described species. The New Guinea fauna is fairly well-known, but last revised 55 years ago (Miller 2007).

Key references for Papua New Guinea.

Holland, GP 1969. Contribution towards a monograph of the flea of New Guinea. *Memoirs of the Entomological Society of Canada* 61: 1-77. The only review of the fleas of New Guinea, but out of date and in an obscure publication.

Dunnet & Mardon. 1990. *Insects of Australia*. CSIRO Publishing, Melbourne. Chapter refers to New Guinea species under descriptions of several families.

Order Strepsiptera



Common name: stylops

Simple diagnosis. Males and females are extremely different in appearance. Adult males are small slow-flying insects, with antennae like antlers (one or more segments elongately lobed), bulbous eyes, labial palpi missing, tiny paddle-like forewings, large membranous hindwings which lack crossveins, hind thorax much larger than the remainder, 10-segmented abdomen. . Adult Females are endoparasitic, partially inserted into the bodies of their hosts, with their head and thorax fused into a cephalothorax, and they lack eyes, antennae, legs and wings.

All larvae, except for the 1st and last instar, are inside the host, lacking discernible eyes, mouthparts, antennae, legs and wings. The first instar is minute (<0.3mm) and similar to a silverfish (Zygentoma) but without antennae and with 2 or 4 long apical abdominal hairs, which are unsegmented. The last instar bulges out of the integument of the host, and is like the female.

Technical diagnosis. Male Strepsiptera are small flying insects, which are rarely seen or collected. They are easily identified from their unusual morphology: antennae 4-7 segmented and shaped like antlers (one or more segments elongately lobed), eyes bulbous, labial palpi missing, tiny paddle-like forewings, large membranous hindwings which have 8 or less long veins and lack crossveins, metathorax much larger than the reduced pro- and mesothorax, 10-segmented abdomen. Other diagnostic features include: ocelli absent, reduced but mandibulate mouthparts, tarsi 2-5 segmented, with or without claws. Females are neotenic (= retain larval features) and live partly extruded from intersegmental membranes of the body of their hosts in the orders Blattodea, Diptera, Hymenoptera, Hemiptera, Mantodea and Orthoptera. Females are wingless, legless and their head and thorax forms a cephalothorax, which lacks antennae eyes and easily visible mouthparts.

The first larval instar is an active larva, similar in shape to a silverfish (Zygentoma), very small (<0.3mm), possesses eyes and legs, lacks antennae, and has 2 or 4 long caudal hairs which are unsegmented. The middle instars are similar to the female and live internally in the host body. The last larval instar is partly extruded from the host body, with either a bulbous head and pronotum (male), or a cephalothorax (female).

What can they be confused with? Males are similar to Diptera, Hymenoptera and some Hemiptera (male coccids), but are easily distinguished by antler-like antennae, bulbous eyes and reduced strap-like forewings. The female is partly extruded from the host body. The only other insect with similar biology and appearance is the partly extruded larva of Dryinidae, Hymenoptera. However these are globular, with the larva living in a shell of its shed skins.

The legless endoparasitic larvae may be confused with legless endoparasitic larvae of the orders Hymenoptera and Diptera. Most endoparasitic dipteran larvae have a pair of mouth hooks and large apical abdominal spiracles but endoparasitic hymnenopteran larvae may not be easily distinguishable from endoparasitic Strepsipteran larvae.

Biology. Strepsiptera are known from many parts of the world, with about 500 described species. Males are rarely seen or collected. They are diurnal, free-living and non-feeding, with soft fluttering flight and probably only live for a few days. Females are commonly collected when collecting other insect orders, but may not be recognised until the specimens are curated. Strepsiptera are parasites of Blattodea, Diptera, Hymenoptera, Hemiptera, Mantodea and Orthoptera. They render their hosts infertile.

Diversity in Papua New Guinea. Some New Guinean species have been described but the fauna is likely to be much larger. Most specimens are known from unidentifiable females on other insect specimens.

Key references for Papua New Guinea.

There are no detailed reviews of the New Guinea fauna.

Kathirimamby, J. 1990. Strepsiptera. *Insects of Australia volume 2*. This refers to 2 families in New Guinea and by inference 3 other families.

Order Thysanoptera

Common name: thrips

Simple diagnosis. Thrips are recognised by their narrow membranous (= translucent) wings, with the margins of the wings fringed with hairs, which are often longer than the width of the wings. They also have a small body, very small mouthparts which are conical in shape), and tarsi which are 1- or 2- segmented.

Technical diagnosis. Thrips have a small (0.5-15 mm) elongate body. They have peculiar small, piercing and sucking mouthparts, which have a cone-like appearance and are asymmetrical. The mandibles are modified and not seen externally. Thrips also have narrow membranous fringed wings with reduced venation, and the fringe can be very long and can exceed the width of the wings. The wings are sometimes reduced or absent. The legs are short and gressorial (= walking). The tarsi are 1- or 2-segmented and have an eversible bladder, and the claws are very small. Eyes are present, but vary in size. Ocelli are present in fully winged forms. Antennae are relatively short, 4- to 9-segmented. The pronotum is conspicuous and the pterothorax (meso- and metathorax) is enlarged in winged species. Abdominal cerci are absent.

Thrips (Thysanoptera)

The first and second instars resemble adults, but are smaller in size. In the later nymphal instars and 'pupal' instar, thrips are in a resting and non-feeding phase, and they sometimes reside in cocoons. During these stages reconstruction of tissues occurs through incomplete metamorphosis.

What can they be confused with? Winged thrips can be easily distinguished by their fringed wings and mouthparts with modified mandibles. Wingless thrips do no resemble other insect orders.

Wingless thrips are superficially similar to Embioptera and coleopteran rove beetles (Staphylinoidea) externally, as they have an elongate body and short gressorial legs. However, embiopterans differ in having mandibulate (= biting and chewing) mouthparts, antennae with 12-32 segments, enlarged first segment of foretarsus, and two- segmented abdominal cerci. Rove beetles can be separated by the reduced sclerotised elytra and five-segmented tarsi.

Biology. Most thrips are phytophagous, feeding on flowers or leafs. There are also few predacious species that are fungus-feeding.

Diversity in Papua New Guinea. Thrips have a worldwide distribution, with about 4500 described species. The New Guinea fauna is almost unstudied (Miller 2007; Mound 2016).

Key references for Papua New Guinea.

Mound, L. 2016. World Thysanoptera: Australasia & the Pacific. http://anic.ento.csiro.au/thrips/regions/australasia.html

Order Trichoptera

Common names: caddisflies

Simple diagnosis. Trichoptera are diagnosed by having membranous wings covered with dense hair-like setae and held tent-like when at rest; the mouthparts are reduced; antennae filiform. Larvae often build cases from sand particles and other material; they have a well-sclerotised head and pronotum, mandibulate (= biting and chewing) mouthparts, not forming a spinneret; peg-like antennae; legs and, abdomen often with tracheal gills.

Technical diagnosis. Caddisflies are elongate, moth-like insects. They can be recognized by fore- and hindwings different in shape, both covered with dense hair-like setae and held tent-like when at rest, their mouthparts are more or less reduced, adapted for taking liquids, but never forming a proboscis, they have filiform (thread-like) antennae and the thoracic tergites are equal in size. Adult caddisflies usually have large eyes and have no ocelli, the legs are slender with five-segmented tarsi, and the abdomen often has one or three pairs of finger-like processes.

Caddisfly larvae are usually aquatic and they are well known for building cases around the body from sand and other small particles, but sometimes larvae are free-living. The head is well sclerotised, usually hypognathous (= directed vertically), with eyes composed of seven or less stemmata (= ocelli like light gathering structures). The mouthparts are mandibulate (= biting and chewing), the maxillae have a 4- or 5-segmented palp and the labium has a 1 or 2-segmented palp, used to produce silk. The antennae are small, peg-like can be greatly reduced. The thoracic terga are distinct with the pronotum heavily sclerotised. The legs are strongly developed, having a single claw, and the forelegs are usually shortest. The abdomen usually has one pair of hooked prolegs on the last abdominal segment and the thread like abdominal gills are usually present.

Caddisfly (Trichoptera)

What can they be confused with? The order Trichoptera is closely related to Lepidoptera and they share some similarity in overall body shape. However, the latter differ in that the wings are have scales not hairs, and the mouthparts are usually in the shape of a proboscis, which is coiled at rest.

Larvae are distinct among those from other aquatic orders in that they build cases. They can be confused with some aquatic coleopteran larvae, but the latter often have a prognathous (= directed forwards) head and the abdomen has caudal urogomorphi.

Biology. Trichoptera is one of the most diverse groups amongst the aquatic orders of insects. Caddisflies are known worldwide, larvae can inhabit lakes or streams. Adults are predominantly nocturnal. Adults take liquid food, and usually eat little. Larvae feed on detritus or plants, they can be scrappers or gatherers, add some of them are carnivorous. Some species are polyphagous (= feeding on multiple food sources).

Diversity in Papua New Guinea. The order Trichoptera occurs worldwide and includes more than 7000 species. The New Guinea fauna is poorly described (Miller 2007).

Caddisfly (Trichoptera)

Key references for Papua New Guinea.

Neboiss, A. 1989. Additions and corrections to the Atlas of Trichoptera of the SW Pacific- Australian region. *Occasional papers from the Museum of Victoria* 4: 63-67.

Order Zoraptera

Common name: zorapterans

Simple diagnosis. Zorapterans can be recognised by the small body, 9-segmented antennae, two-segmented and slender tarsi, and unsegmented cerci. In winged forms eyes and ocelli are present, the wings are membranous (= translucent) and have very reduced venation, and the hindwing is shorter than the forewing. Wingless forms usually do not have compound eyes and ocelli.

Technical diagnosis. Zorapterans are small (= 3-4 mm long) insects, that have wingless and winged forms. Morphologically they can be recognised by their hypognathous (= vertically directed) head with unmodified mandibulate (= biting and chewing) mouthparts, moniliform (= bead-like) antennae, with 9 segments, all thoracic terga are well defined and separated, tarsi are two-segmented and not enlarged, and abdominal cerci are unsegmented. The winged forms have compound eyes and ocelli, and the wings are held flat over the body when at rest. The venation is minimal, and the hindwing is considerably smaller than the forewing. Wingless forms usually do not have eyes and ocelli. Nymphs are similar to adults.

What can they be confused with? Zorapterans are similar to Termitoidea (= termites) as they also have winged and wingless forms, reduced wing venation, thoracic segments separated, mandibulate (= biting and chewing) mouthparts, moniliform antennae, often-reduced eyes and short unsegmented cerci. However, termites have fore- and hindwings subequal in length, and the tarsi usually 4-segmented, and rarely 5-segmented.

Zorapterans can be confused with Embioptera (= foot spinners), as both of them live gregariously, although the former are not eusocial. Both orders have winged and wingless forms, mandibulate (= biting and chewing) mouthparts, eyes usually reduced or absent, thoracic terga well-developed and separated, and wings with reduced venation. However, embiopterans differs in having a

Zorapteran (Zoraptera)

prognathous (= directed forwards) head, three tarsal segments, the foretarsus enlarged, antennae with 12-32 segments, two-segmented cerci, fore- and hindwings subequal in length and with cross veins. Zorapterans live under bark or in decaying wood whereas embiopterans usually live in silk galleries.

Wingless zorapterans can be confused with wingless Psocoptera (= book lice), as both are small in size, have a hypognathous (= directed vertically) head, their eyes can be reduced or absent, and the tarsi are 2- or 3-segmented. Book lice can be separated by the antennae having 13 or more segments, swollen frons, the mouthparts with a needle-like lacinia, the pronotum is small, the pterothorax is enlarged, and the abdominal cerci are absent.

Biology. Zorapterans are gregarious and can be found under the bark or in decaying wood, and are sometimes inquilines (= living in the home of another insect and sharing its food) in termite nests. They feed on fungi and small arthropods.

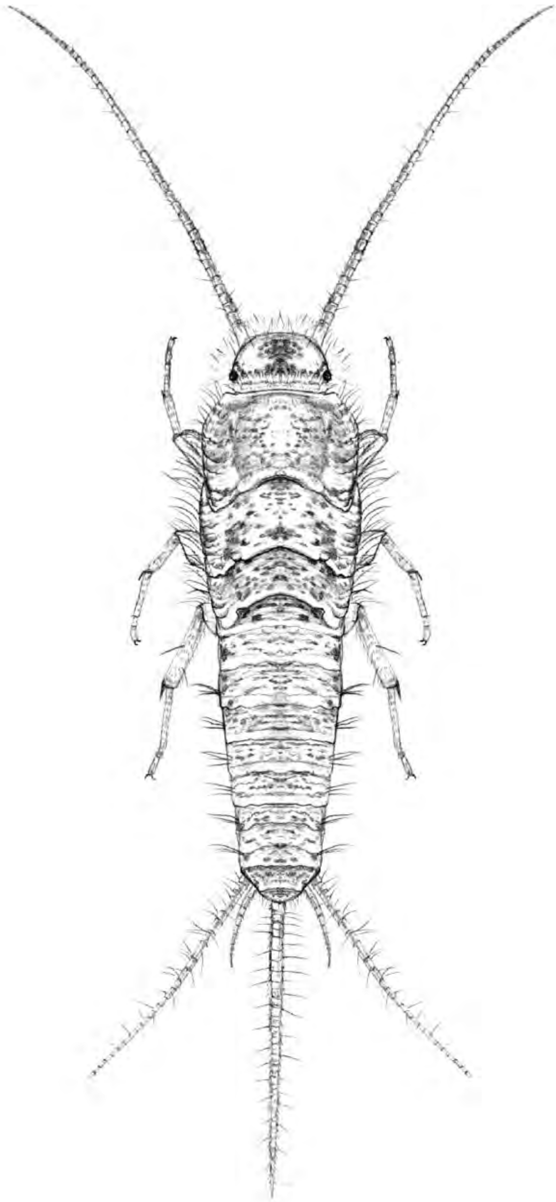
Diversity in Papua New Guinea. Zorapterans inhabit warm and temperate regions of the world (absent from Australia), but only about 40 species are known. There is a single species in New Guinea from New Britain (Terry & Whiting 2012; http://en.wikipedia.org/wiki/Zoraptera)

Key references for Papua New Guinea.

Terry, MD & Whiting, MF. 2012. *Zorotypus novobritannicus* n. sp., the first species of the order Zoraptera (Zorotypidae) from the Australasian Ecozone. *Zootaxa* 3260: 53 - 61

Order Zygentoma

(= Thysanura)



Common names: silverfish, firebrats

Simple diagnosis. Silverfish are wingless insects of moderate size (5 to 30 mm). They have an elongate and flattened body, multi-segmented antennae, reduced or absent eyes, five-segmented maxillary palps, enlarged distal segment on the labial palps, and three long caudal filaments (= tail-like cerci) at the tip of the abdomen, which are more or less equal in length.

Technical diagnosis. Adults and nymphs are diagnosed by the absence of wings or wing pads, presence of scales on the body, flattened body, presence of three long segmented filaments on the tip of the abdomen; dicondylar (= two places of articulation to head) mandibles, five-segmented maxillary palps, enlarged last segment of the labial palp, dorsoventrally flattened and enlarged coxae, and abdominal segments with styli and eversible vesicles ventrally. The immature stages are similar to adults, except early stages lack scales.

Silverfish (Zygentoma)

Photograph: © Graham Smith

What can they be confused with? Zygentoma are similar to Archaeognatha (= bristeltails) externally as both are wingless, elongate, covered with scales, and have three caudal "tails" on their abdomen. Zygentoma differ, however, in that the body is relatively flattened, the medial "tail" is slightly longer than the lateral cerci, the compound eyes are small and distant, and the maxillary palps are five-segmented.

Biology. Silverfish are mainly diurnal and omnivorous, living under bark or leaf litter, but some are subterranean and vegetarian. There are species that can survive in arid climates, like deserts, or inhabit ant nests, termite nests and mammal burrows. Some species are anthropophilic (= associated with humans). Silverfish can run fast, but are not able to jump. Like the Archaeognatha, they have indeterminate growth and have ametabolous development (= do not undergo distinct metamorphosis, nymphs and adults similar in body form). Silverfish are not capable of jumping, but can run very swiftly.

Silverfish (Zygentoma)

Photograph: © Graham Smith

Diversity in Papua New Guinea. Silverfish have a worldwide distribution, but predominantly inhabit the Southern Hemisphere. There are over 300 species worldwide, within five families. The New Guinea fauna is poorly known (Miller 2007).

Silverfish (Zygentoma)

Key references for Papua New Guinea.

Paclt, J. 1982. On some Somlomon Islands, Papua New Guinea and Sarawak Thysanura. *Annotationes Zoologicae et Botanicae* 151: 1-10.

Smith, GB & Watson, JAL. 1990. Thysanura. *Insects of Australia volume 1.* CSIRO Publishing, Melbourne.

Practical Resources for Entomology Workers

Photographing insects for identification purposes

The aim of photographing insects for diagnostic purposes is to obtain an image that is in focus and contains enough detail for someone to be able to determine the identity of the specimen.

With new camera and software technology it is becoming easier for entomology workers to efficiently obtain fully focused diagnostic shots with attached scale bars, through microscope camera systems, as in the set of images on the following page.

Basic cameras and mobile phone cameras can also be used to take photos, especially of larger specimens or of plant damage that could also assist in a diagnosis of the problem. These cameras can also take photographs down microscope eyepieces (some practise required to steady and position the camera).

The main points to remember for diagnostic photos are:

- **Lighting** - Decent lighting can make the difference between a good and bad photo. Outside daylight or beside a bright window can usually give enough light without the need for flash, otherwise use the flash. If sunny, make sure the light is behind you. In the field, try to get the species into a better lit area. You may need to have someone holding the specimen in position with their finger while the camera is set up.
- **Focus** - Try to get an image that is as sharply in focus as possible rather than trying to get too close to the specimen, in particular with digital camera or mobile phone.
- **Scale** - put a ruler or some other measure like a coin in your photo.
- **Image size** - Save the images for emailing as basic quality jpegs, around 100kB each, which can be attached easily to an email for sending to someone to get help.

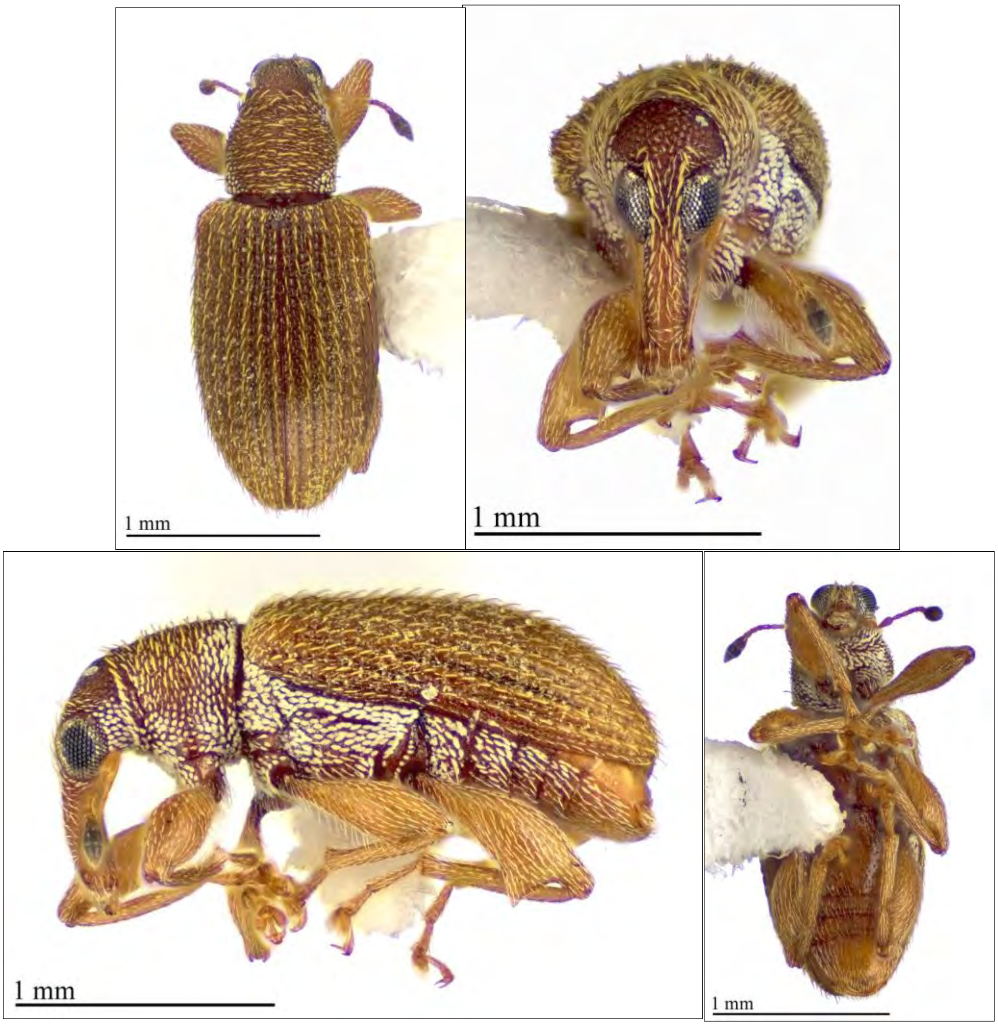
Remember to always keep your original high resolution photographs on file and copy and rename edited versions.

Digital imaging systems for insect photography

Digital imaging is an increasingly important aspect of collections management and curation with the push to get collections accessible online. As such, many museum and university entomology collections work with purpose built digital imaging systems designed for the challenges of insect photography. These are either microsystems - with a camera setup through a microscope - or macro systems - with a camera and photographic macro lens. There are five main components to these systems:

- Camera - a microscope camera or digital SLR camera body.
- Magnification - through microscope or photographic SLR macro lens.
- Moveable stage - microscope focussing stage or SLR system mounted on stand with a rail, to allow a stack of photos of the subject to be taken.
- Lighting - microscope lighting or photographic flash lighting e.g. speed light flashes.
- Computer - image capture and processing the stack of photos to create a single image with focus stacking software (e.g. Zerene Stacker, Helicon Focus).

At high magnification depth of field (the amount of the object in focus) is very small. These diagnostic photos of a small weevil (Order Coleoptera) were taken using a microscope camera imaging system where a series of photographs are taken focusing through the full range of the specimen (called a ‘stack’), by movement of the microscopes state, and then combined into a fully focused image using software. This technique is sometimes also referred to as ‘image stacking’ or ‘focus stacking’. The resulting images:



Note: a series photographs taken of this beetle in different orientations (clockwise from top left: dorsal, anterior, ventral and lateral) to show all characters of the specimen.

Editing and resizing photos

Useful editing functions which can enhance an image are the **crop, sharpen** and **rotate** tools in most basic image editing software (see details of free downloadable software at the end of this section).

Tablet and smartphones often resize images or give an option to resize an image when attaching a photo taken on the device to a text message or email. Where tablets and smartphones have internet access you can take photos and then email to a recipient direct by simply attaching the photo to an email or text message.

Cropping a photo may allow you to send a more easily visible - but still small in file size - photo through the internet. Although, particular lenses and an SLR camera are needed to get very high quality close-up insect photos in most cases, this equipment is not required for getting a satisfactory photo for general diagnostic purposes as in the example on the following page. Take photos at the highest quality possible on your camera at a distance where the subject is in focus. You can then zoom in and crop an image using editing software on the computer to view the subject more clearly.

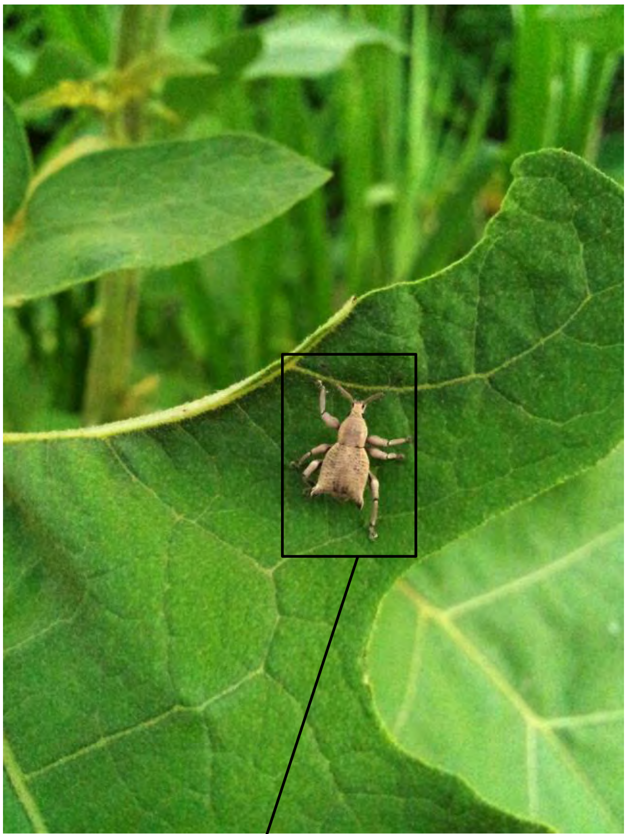


Photo of a weevil (1-1.5cm) taken with a smartphone camera at closest focusable distance to the beetle.

This high quality original photo (2.5MB with this 8 megapixel camera) gives finer detail and allows one to zoom in while maintaining adequate image resolution to see the specimen more clearly…see below.

Close up of the weevil from the photo above, cropped and then saved as a low resolution JPEG for email: 45KB.

Note: If you do not have computer editing software then send a slightly higher quality version of the original photo if possible which will allow the recipient to zoom in and see the specimen more clearly.

Free image editing software tools

Free software tools available online for editing and resizing images, which can be downloaded from links on the given websites below:

- **Picasa** (https://picasa.google.com) – **image organiser and viewer with basic editing** - primarily image file management with some editing and resizing options. Functions include: cropping, colour enhancement, image rotation, renaming and batch editing and renaming of files, reducing file size and saving for email or web upload.

- **ImageJ** (http://imagej.nih.gov/ij) – **powerful, advanced image editing, processing and analysis** - primarily for processing and analysis of images in particular, but not limited to, images taken through a microscope. High level functions include being able to assemble stacks of multiple single plane images to create a fully focussed image of an object. Image editing functions include rotate, crop, brightness and contrast enhancement, and saving files as smaller jpegs for email, sharpening, removing dust and scratches (noise), and adding text and lines to annotate an image. Analysis functions include: image measurement (incl. calibration) and adding scale bars.

  For more information on ImageJ see 'Features' - http://imagej.nih.gov/ij/features.html; and 'Documentation' - http://imagej.nih.gov/ij/docs/index.html, which has a PDF manual and further PDF and Powerpoint guides under the 'Tutorials and Examples' link, egg. Image J Basics.pdf.

Online resources for insect imaging

Compound Eye – a Scientific American science photography blog, with various articles about insect photography by an entomologist and professional insect photographer.

This article show's clearly the effect of aperture selection on depth of field in photography: http://blogs.scientificamerican.com/compound-eye/what-aperture-does-in-two-photos/

The following article details how to build a digital insect imaging system for museum standard collection imaging, using an SLR camera, macro lens, flashes and a movable stand and rail for focus stacking: http://blogs.scientificamerican.com/compound-eye/build-a-world-class-insect-imaging-system-for-under-6-000/

Guidance: Photographing specimens in natural history collections – an Atlas of Living Australia (ALA) publication outlining imaging systems and processes in three entomological collections around Australia: http://www.ala.org.au/wp-content/uploads/2011/10/BK-Guidance-on-Photographing-specimens_FINAL.pdf

Focus stacking – Cognysis: Focus stacking how to guide – Cognysis manufacture a rail for focus stacking with a digital SLR camera: https://www.cognisys-inc.com/how-to/stackshot/focus_stack_how_to.php

Focus stacking software - Zerene Stacker: http://zerenesystems.com/stacker/

Helicon Focus: http://www.heliconsoft.com/heliconsoft-products/helicon-focus/

Contacting specialists for further assistance

If specimens are unable to be identified by a collector and further assistance is required from a specialist entomologist, then either specimens or photographs could be sent on for assistance. First, contact needs to be established to check that the intended recipient will be able to accept the sample and that they will be the right person to help you out. Specialists will often be based in other countries too.

It is advisable to make contact with the National Agricultural Quarantine Inspection Authority (NAQIA) as a first port of call, as their contacts with both Australian and New Zealand Quarantine agencies may help to find an entomologist who can assist.

Sending specimens

When sending specimens to a specialist for identification, care must be taken to prevent damage to the specimens in transit, which is generally by post.

Note that you should only ever send DEAD specimens.

Specimens always need to be packed into a box or parcel and then placed inside a larger sturdy postage box filled with a light packing material such as styrofoam, bubble wrap, shredded paper or something else similar that is available (NB not organic material as this will be rejected by quarantine authorities). It is important that the specimens are secured from moving within the inner box or parcel and then that the packaging material is filled tight around the specimen box so that it is secure and will not move at all inside the postage box in transit.

Pinned insects, should be packed into a sturdy box with foam or cork glued to the base. Pins should be pressed firmly into the base and then covered so that either the lid of the box or an insulating layer of material, such as cardboard, will hold the pins down and prevent them from dislodging in transit.

Unpinned insects (dry or ethanol preserved), can be sent in polythene [i.e. not brittle plastic or glass] vials. Place the specimens at the bottom of the vial and then fill the remainder of the vial with tissue or cotton wool and then secure a lid. In the case of ethanol preserved specimens the tissue can be dampened with ethanol before the vial is sealed. For sending any ethanol preserved specimens, it is important that they are placed in a well-sealed, leak proof secondary container, which can just be a larger plastic vial with a leak proof seal. Dry vials can simply be wrapped in a package.

Note that **only very small amounts of ethanol (in excepted quantities) can be sent through the post and by airmail**, and only as long as the parcel is packed and labelled according to Dangerous Goods transportation regulations. Packing requires secondary containment of the specimen vials containing ethanol and surrounding absorbent material.

Labelling specimens and parcels clearly is very important and considerations to check before sending are as follows:

- Make sure specimens are clearly labelled.
- Ensure packages are clearly labelled with delivery address and contact details for both sender and receiver.
- Add large 'fragile' labelling to the outside of the parcel by either writing or affixing a label (preferably in red) stating 'FRAGILE' and/or 'HANDLE WITH CARE' .
- When sending specimens internationally, ensure that any required documentation is with the parcel and clearly specify the nature of the contents in customs forms, for the description of contents, stating "dead preserved insect specimens for scientific study" and "of no commercial value).

Vial of specimens in ethanol sent via post for identification – most of the ethanol was drained, vial lid taped, then vial wrapped in absorbent and protective material for posting.

Note: Specimens are well labelled with all collecting information.

Customs Declaration Form example stating contents clearly: "Dead, dried insect specimens for scientific research. No commercial value"

Note: In Australia we always have to include a nominal value (at least $1) on the customs declaration

Fragile packaging labels on posted insect specimens.

Note: You don't need special labels, just write these statements on your package in large visible lettering.

Entomological suppliers

Australian Entomological Supplies - www.entosupplies.com.au

Mail order entomological supplies specialists providing books and equipment for both the professional and amateur entomologist.

592 Coolamon Scenic Dr, Coorabell NSW 2479, Australia
Ph. +61 2 6684 7650 Fax. +61 2 6684 7188
Contact. http://www.entosupplies.com.au/contact-us

Bioquip – www.bioquip.com

Equipment, supplies and books for entomology and related sciences.

2321 Gladwick Street, Rancho Dominguez, CA 90220, USA
Ph. +1 310 667 8800 Fax. +1 310 667 8808
Email. bqinfo@bioquip.com

Watkins & Doncaster - www.watdon.co.uk

Mail order entomological supplies specialists providing books and equipment for both the professional and amateur entomologist.

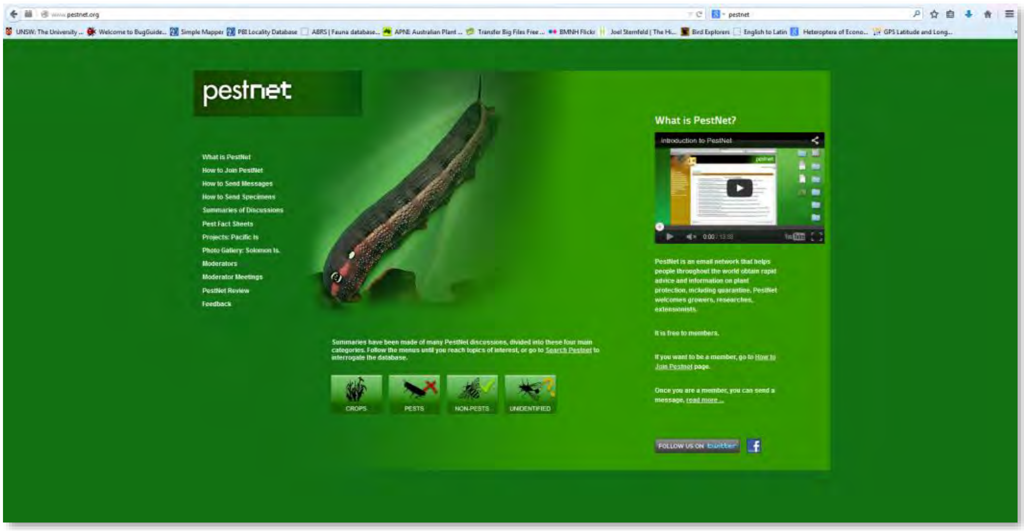
PO Box 114, Leominster, Herefordshire, HR6 6BS, UK
Ph. +44 (0)333 800 3133 or +44 (0)1568 750657 Fax. +44 (0)1568 750409
Contact: http://www.watdon.co.uk/cgi-bin/mf000088.cgi?ACTION=SHOWFORM

Insect Resources on the Web

The following webpages are a range of comprehensive resources available online for **insect identification** and **pest diagnostics** purposes. Discover Life and PestNet are partners in delivering these workshops and their online resources each cover one of these aspects.

PestNet

http://www.pestnet.org/



What is PestNet?

PestNet is an email network that helps people worldwide obtain **rapid advice and information on crop protection, including the identification and management of plant pests**. It started as a service for the Pacific in 2000, rapidly expanded to South East Asia, set up a separate service for the Caribbean in 2003, and now welcomes anyone interested in crop protection anywhere in the world as long as they have a computer and email. It's free to members.

PestNet also gives out daily alerts as these come to hand over the Internet.

Many of the email discussions are summarised under four headings: crops; pests; non-pests and unidentified. The database that has been developed can be accessed by clicking on the large button in the middle of the website. There is a search engine to help you find the information you need.

Why is there a need for PestNet?

Plant pests – insects, pathogens and weeds – are always present, damaging crops grown for home consumption, domestic markets or for export. New pests can spread from country to country and threaten agricultural production and biodiversity.

If growers and plant health professionals in the region are to manage pest problems and protect their rural industries, they need access to specialist scientific and technical advice on the identification and management of plant pests. And they need it quickly and cheaply. PestNet, with hundreds of members worldwide, can help them.

Who's it for?

PestNet has members from government and non-government organisations, universities, and the private sector, as well as farmers and students. Any organisation, group or individual can join. All they need is access to email, a question to ask, information to give, or just an interest in plant protection and being part of a worldwide network.

Topics?

Topics include pest identifications from digital images, pest outbreak alerts, pest management (biological, cultural, and chemical), and quarantine interceptions.

PestNet also contains practical information on how to sample, label and send specimens to experts for further identification (http://www.pestnet.org/HowtoSendSpecimens.aspx) as well as tips regarding sending messages and attaching photos to messages to obtain further help to identify a pest or disease: http://www.pestnet.org/HowtoSendMessages.aspx

How to Join PestNet

Send an email addressed to **PestNet-subscribe@yahoogroups.com**. Please include the following:

1. Your name;
2. Who you work for; and
3. Your country.

PestNet Factsheets and Resources

PestNet has produced a series of factsheets to enable diagnosis and management of agricultural pests and diseases, specifically to assist farmers and gardeners in the Pacific.

These factsheets are available through the PestNet website and have now also been synthesised into a portable and updateable smartphone and tablet app called Pacific Pests and Pathogens (see information about the app on page 183).

These detailed factsheets have also been summarised into small card sized mini factsheets with a quick summary of the important information for a particular pest or disease.

The factsheets and mini-factsheets can be viewed and downloaded here:

http://www.pestnet.org/PacificFactSheets.aspx

Discover Life

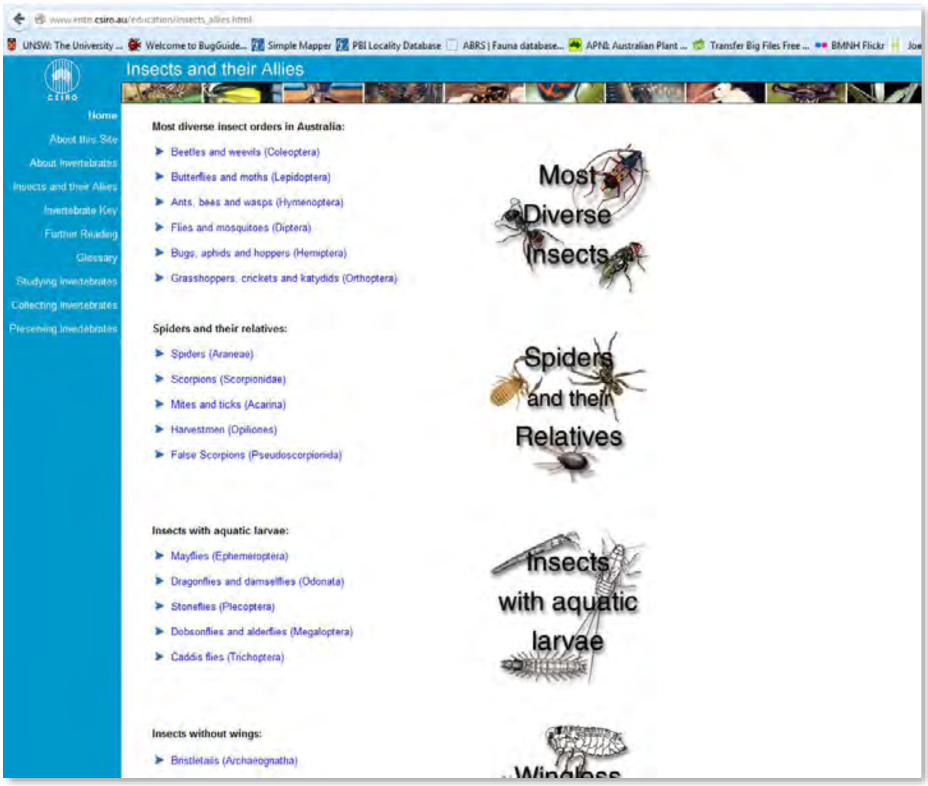
http://www.discoverlife.org/

Guide to insect orders with information and an **illustrated taxonomic key to insect orders, based on the USA fauna** (http://www.discoverlife.org/20/q?guide=Insect_orders).

CSIRO - Insects and their Allies

http://www.ento.csiro.au/education/insects_allies.html

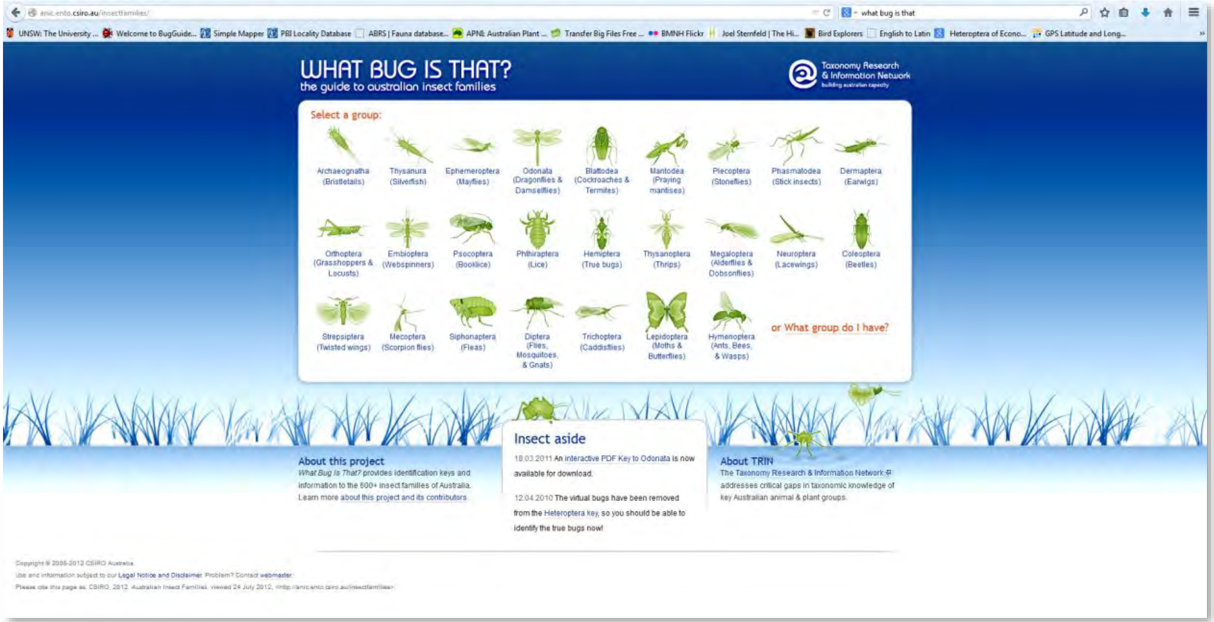
Invertebrate and insect keys to order, based on the Australian fauna, in simple format with diagrams, with good summary pages for all insect orders which includes basic diagnostic characters to help with identification. Navigate by the menu on the left side of the page.



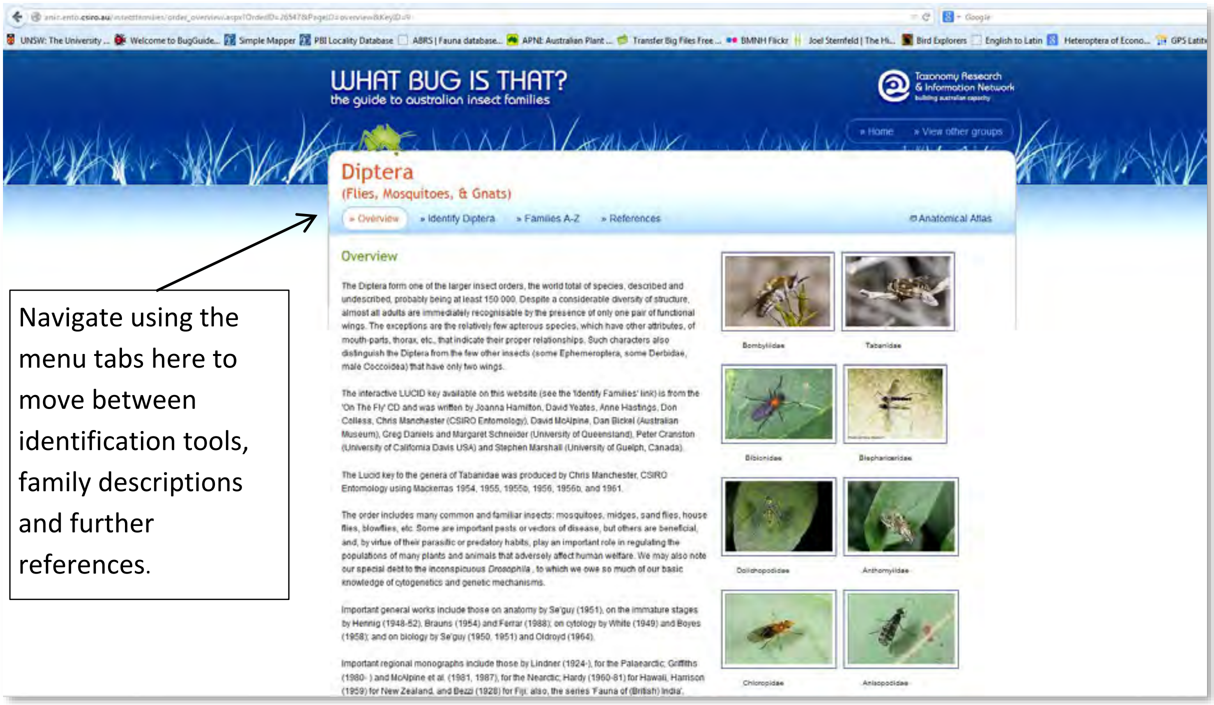
What Bug Is That? – The Guide to Australian Insect Families

http://anic.ento.csiro.au/insectfamilies/

Lucid key to insect order for adult and holometabolous larvae and within order keys for many groups to family level, for Australian insects. Also contains links to other identification tools on the web for specific groups not hosted on this site, e.g. scale insects



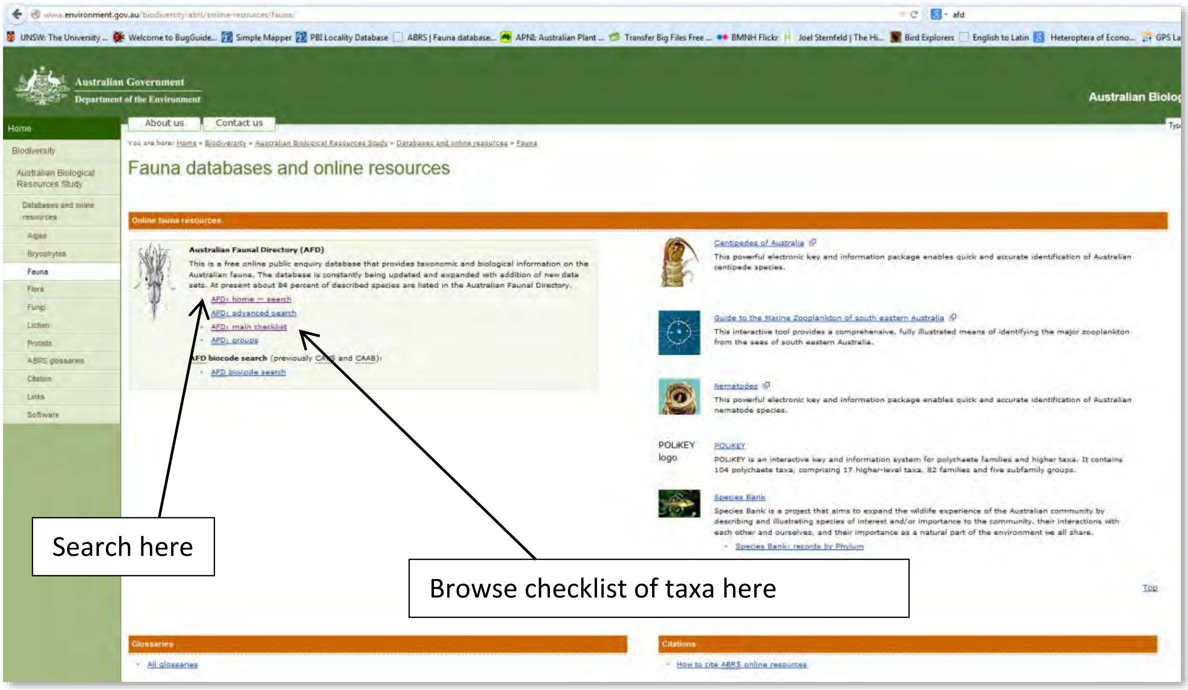
Order page example – Diptera:



Australian Faunal Directory - AFD

http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/

Australian Government online catalogue of Australian fauna. Although strictly for the Australian fauna, there are useful introductions to the different insect orders and most insect families found in PNG, covering basic literature on biology, ecology, taxonomy & systematics. On the home page (below) are links to search by taxonomic or common names, or to browse the faunal checklist.



What is a zoological catalogue?

A zoological catalogue is a database of fauna which contains taxonomic and biological knowledge of that fauna. Catalogues are generally compiled for a group or groups of fauna and are organised hierarchically according to taxonomic classification. The *Zoological Catalogue of Australia Series* (CSIRO Publishing) (accessible in the AFD online database above) contains the names of all Australian animal species. Information provided for each species includes: synonymy (previous names for that species), literature citations, depository location (insect collection) of the type material (specimens studied to describe that species), the type locality (location where the type specimen(s) were collected), geographical distribution and ecological descriptors for the species (e.g. habitat, feeding preferences, host plants if known), and important reference papers relating to that species on various aspects, including biology.

Who can benefit from the information in catalogues?

The nomenclature, taxonomy and biological information about species contained in catalogues are an essential baseline reference for taxonomists, zoogeographers, fauna survey and management authorities, ecologists, environmental consultants, agricultural authorities, quarantine authorities, public health and veterinary authorities.

LUCID Keys

Lucid is a software platform that produces interactive computer based keys which can be served on the web. Lucid keys are now also becoming available in “App” format, downloadable to smartphones and tablets. An advantage of these keys is the use of images and photographs throughout to illustrate characters.

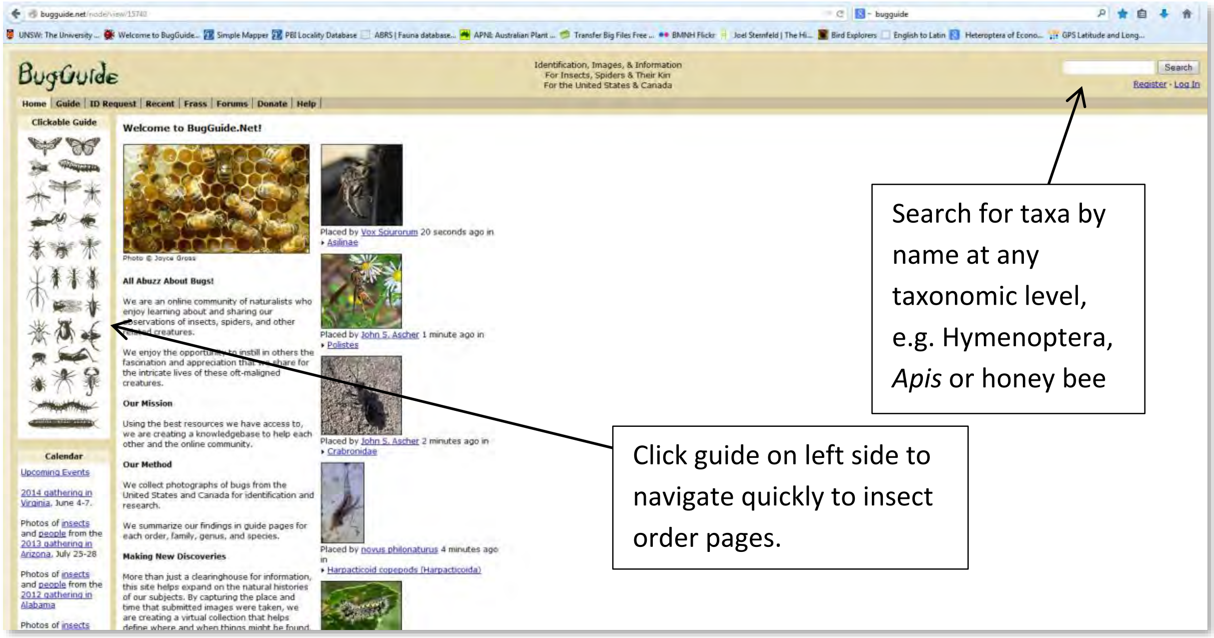
Many Lucid keys are available on the web and can be searched on the Lucid Key Server: http://keys.lucidcentral.org/key-server/keys.jsp

BugGuide.Net

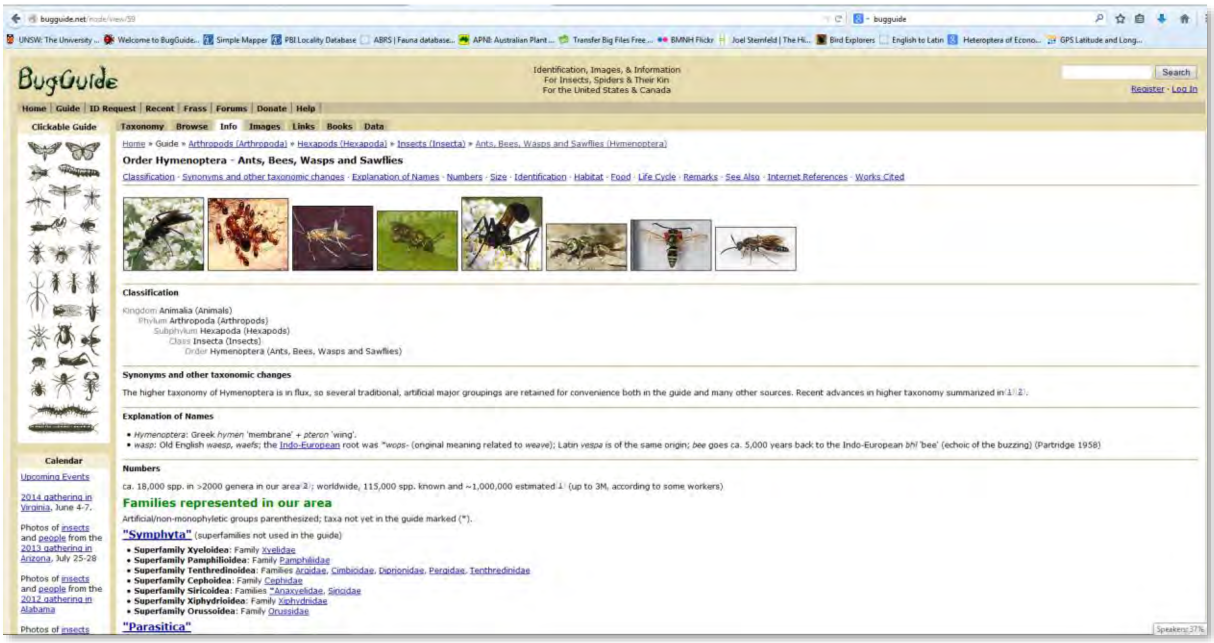
http://www.bugguide.net/

An encyclopaedia / catalogue like resource of taxonomic information and photos. Although the site is restricted to species from the US and Canada it has great overall information for orders down to families, tribes and even genera, that still relate to the rest of the world. Information is arranged taxonomically and includes diagnostic features of the groups, many images (although note these are North American taxa) and the taxonomy classification framework for the groups.

Homepage:



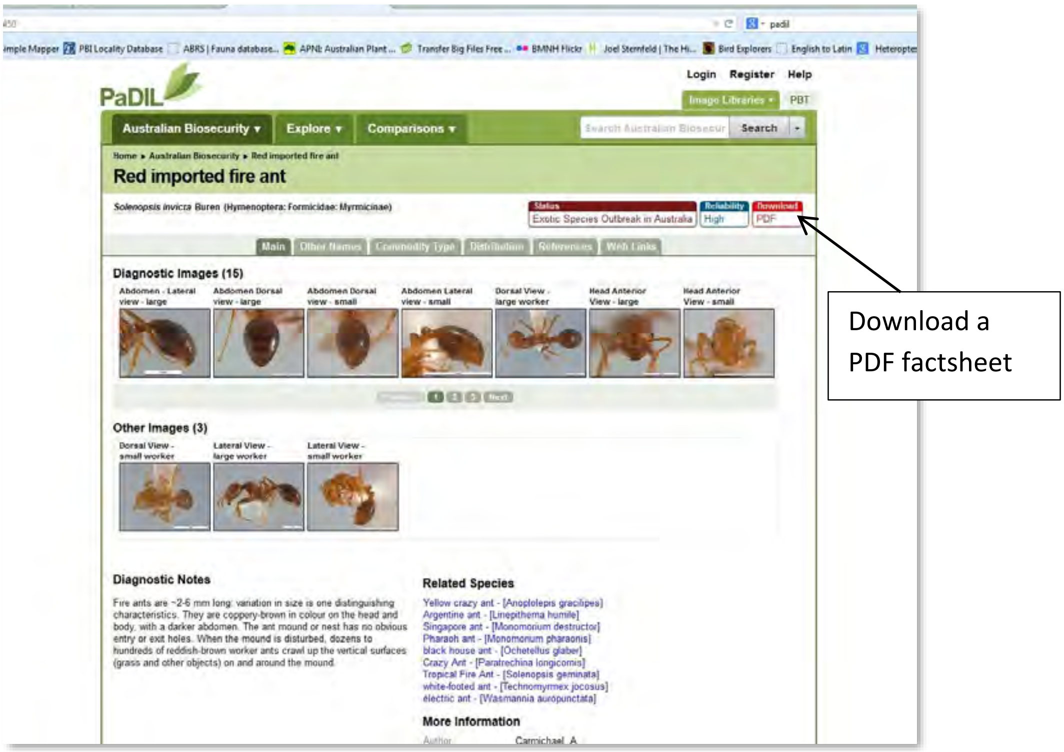
Order page example – Hymenoptera:



PaDIL

http://www.padil.gov.au/

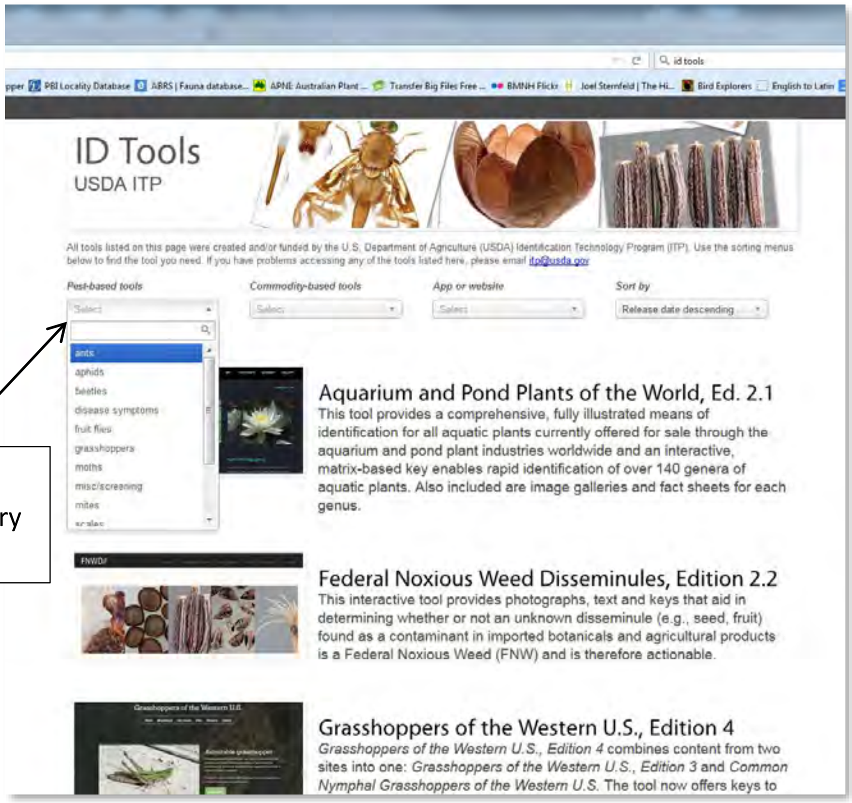
Australian government funded site primarily for biosecurity purposes to identify invasive species. The site contains high quality images and diagnostic information to identify species for both biosecurity and also biodiversity purposes. PaDIL is linked with biosecurity databases in other countries such as New Zealand and Thailand. There is also a function on each species page to create a downloadable PDF. A sample species page:



ID Tools - USDA

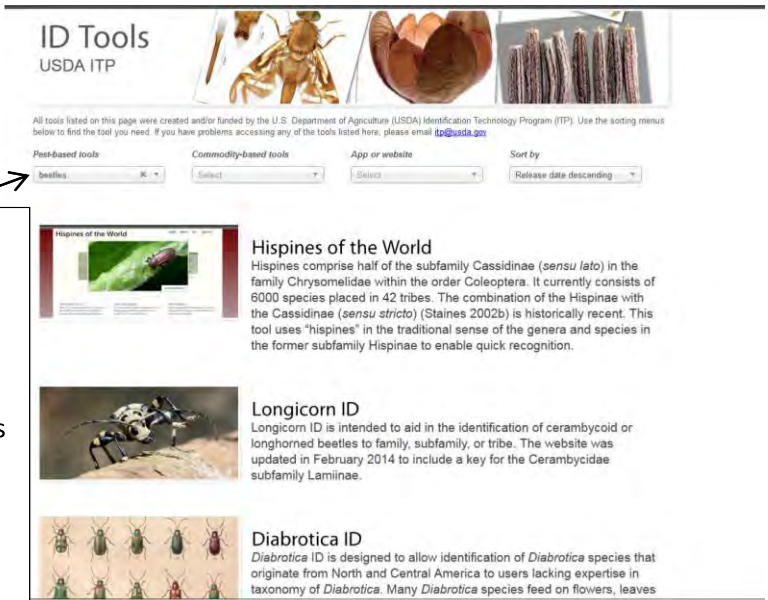
http://idtools.org

Compilation of all web-based identification tools, for pests and diseases, created or funded by the U.S. Department of Agriculture (USDA) Identification Technology Program (ITP). Some cover areas outside the USA. Search menus allow searching by pest or crop and include both websites and apps.



Search by pest category

Most of the keys are web based Lucid format keys. Search results for beetles, include keys to genera within a number of groups of economic importance, such as bark beetles and ambrosia beetles:



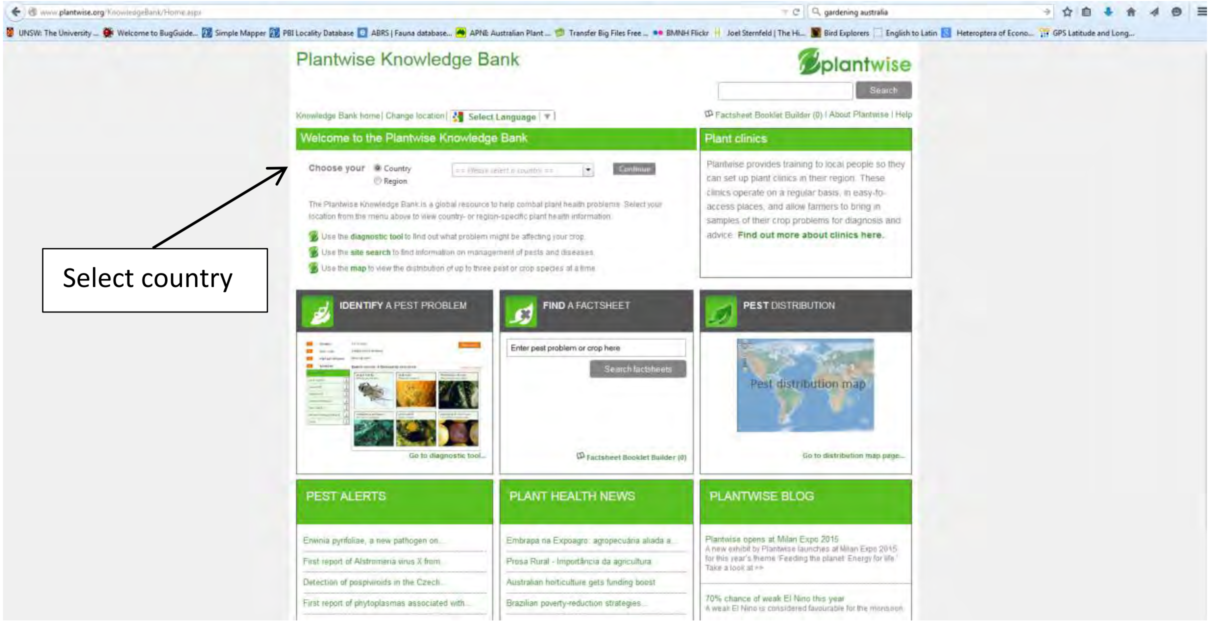
Search for "beetles" by pest category.

Ten online ID keys for various beetles e.g. "Xyleborini ambrosia beetles: an identification tool to the world"

CABI – Plantwise Knowledge Bank

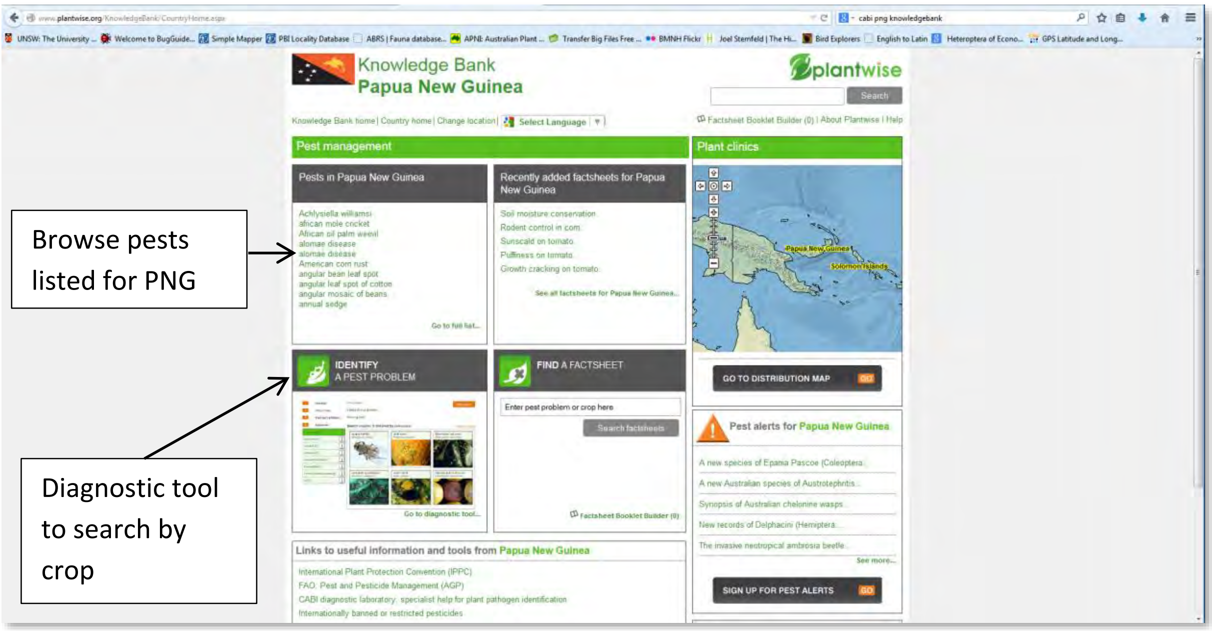
http://www.plantwise.org/KnowledgeBank/Home.aspx

Plantwise is a global knowledge bank to help combat plant health problems, worldwide. It provides country specific information (set your country location) and then filters information relevant to your selected country including news and pest alerts.

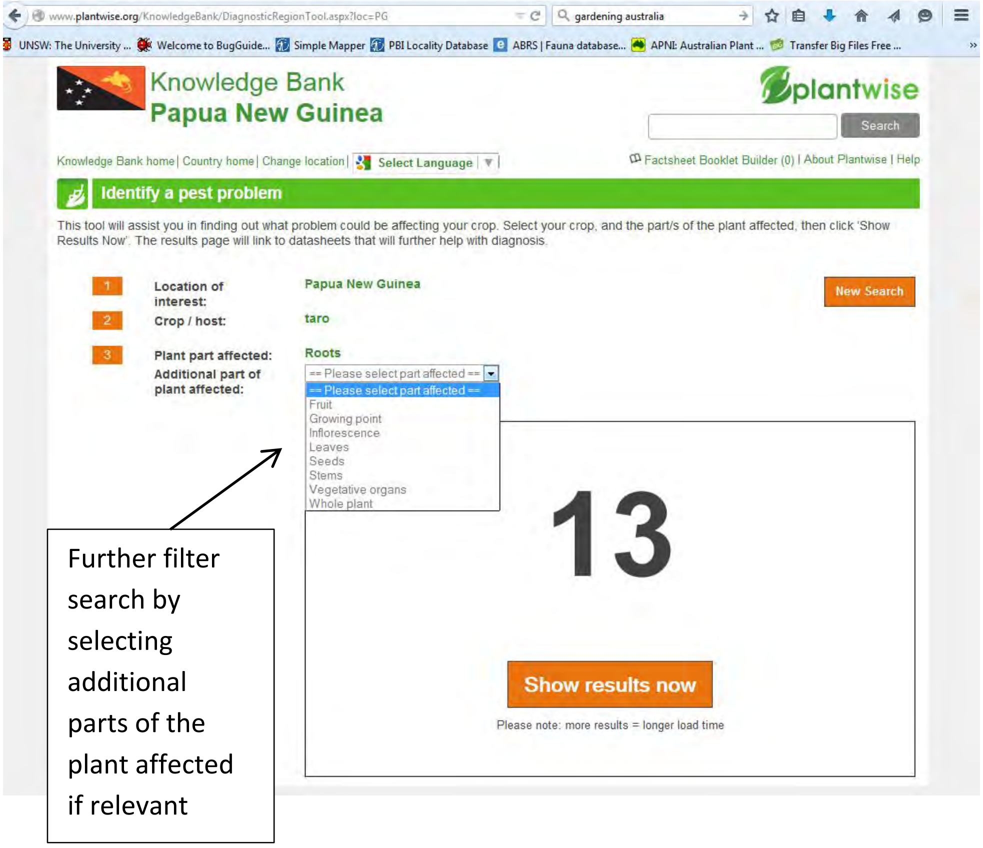


The Knowledge Bank allows you to either browse pest lists, search for factsheets on a particular pest, or identify a pest problem using the diagnostic tool searching by crop and the part of the plant affected.

PNG country page (http://www.plantwise.org/KnowledgeBank/CountryHome.aspx):



An example search using the diagnostic search tool - ***IDENTIFY A PEST PROBLEM*** - for “taro” and ”root” yields 13 possible pest or disease problems that farmers may have with taro in PNG (from the Plantwise database):



Other Insect Resources on the Web:

This bibliography will be developed into the future, however below are a selection of useful references relating to all subject areas covered in the workshop, from entomology in general, through to specific identification guides and online information for the insect fauna of Papua New Guinea.

Aquatic insect identification

Australian Aquatic Invertebrates - Lucid web keys to families of Australian aquatic insect larvae in orders – Trichoptera, Diptera, Coleoptera, Hemiptera, Megaloptera, Mecoptera, Neuroptera; and aquatic adults in the orders -Hemiptera and Coleoptera.
http://keys.lucidcentral.org/keys/lwrrdc/public/Aquatics/main.htm

Identification and ecology of Australian Freshwater Invertebrates - A comprehensive website for the identification of aquatic invertebrates. Includes insect order and family keys and information and images of all orders and families of freshwater insects. This is similar to the site above, however the keys are built into the website and in a dichotomous key format as opposed to the Lucid matrix format of the keys in the link above. Also has comprehensive guides on how to use the site and the keys and basics of how to identify aquatic invertebrates, including excellent terminology images, information about common taxonomic errors and a large glossary. Explore.
http://www.mdfrc.org.au/bugguide/

General entomology

Royal Entomological Society
Useful resource site for entomological information, but focussed on UK.
http://www.royensoc.co.uk/

Biodiversity Heritage
Online library of early (generally pre 1950) publications worldwide.
http://www.biodiversitylibrary.org

Purdue University – Department of Entomology - Large database of publications through “Extension” resources link. Covers all topics in entomology, including insect pests and agriculture, and insects in the house and garden.
https://ag.purdue.edu/entm

North Carolina State University – General Entomology - Online entomology course, with course materials and an additional resources library including Quick ID tools for orders and major families with key characters and photographs. Very comprehensive introduction to insect biology and taxonomy.
http://www.cals.ncsu.edu/course/ent425/

Insect glossaries

Amateur Entomologists' Society (UK) - comprehensive online glossary
http://www.amentsoc.org/insects/glossary/

Australian Aquatic Invertebrates – insect morphological terminology
http://keys.lucidcentral.org/keys/lwrrdc/public/Aquatics/atlept/html/insgl.htm

Insects in Papua New Guinea

The New Guinea Binatang Research Center (NGBRC) – located in Madang, their website is regularly updated and contains information on current research and training programs for PNG entomologists and other biologists at the centre, as well as links to databases for New Guinea flora and insects. The center was established and is directed by Vojtech Novotny (Institute of Entomology, Czech Academy of Sciences) and specialises in tropical rainforest biodiversity research through large international collaborative research projects and is a research and training centre for both local and international students.
http://www.entu.cas.cz/png/index.html

The Papua Insects Foundation - The insects of Papua Indonesia, taxonomic and faunistic overviews on the insect species living in Papua and West-Papua (Indonesian New Guinea) The insects of Papua Indonesia. Online resources include, calatogs of native insects for West Papua by order and includes the following orders: Dermaptera, Orthoptera, Odonata, Phasmatodea, Mantodea, Psocoptera, Hemiptera, Neuroptera, Coleoptera, Trichoptera, Lepidoptera, Hymenoptera, and Diptera. A particularly thorough reference for Lepidoptera, and also substantial entries and images of identified Odondata, and Coleoptera. The order pages include further references. The website also includes details of publications relating to (largely the taxonomy of) Papuan insects, listings of worldwide collections that contain Papuan insects, and contact information for contributing specialists.
http://www.papua-insects.nl

Pacific Insects and Pacific Insects Monographs - published by the Bishop Museum these journals contain significant taxonomic works relating to the Papuan insect fauna and many volumes are now available online.
http://hbs.bishopmuseum.org/pi/
http://hbs.bishopmuseum.org/pim/

Key To The Forest Insect Pests Of PNG – more like a checklist of pests, catalogued under the tree species. Some useful photos showing damage caused by insects on trees and simple pest information pages.
http://www.fzi.uni-freiburg.de/InsectPestKey-long%20version/page2.htm

Aquatic Insects in Papua New Guinea

Aquatic insects of a lowland rainforest in Papua New Guinea: assemblage structure in relation to habitat type – an unpublished manuscript (by Jan Klecka) from a freshwater insect survey undertaken in Wanang Conservation Area, Madang, through the New Guinea Binatang Research Center. Differing aquatic habitats and structural zones within these habitats were sampled and species / morphospecies lists compiled.
(http://biorxiv.org/content/early/2015/10/05/028423.full-text.pdf+html)

Freshwater biotas of New Guinea and nearby islands: Analysis of endemism, richness, and threats Compilation and synthesis of 10 years survey work of fish and invertebrates of New Guinea and neighbouring islands and provides an overview of biotic regions and lists of endemic taxa that define these regions, including insects in the orders Coleoptera, Heteroptera and Odonata. The report includes extensive taxonomic reference for aquatic insects in New Guinea (Polhemus et al. 2004).
http://pbs.bishopmuseum.org/pdf/ci-png.pdf

Photos of freshwater invertebrates from Papua New Guinea – very good photos taken during surveys of waterways in West New Britain and Oro Province (date unknown) and hosted by Landcare Research, New Zealand. Images include adults and larvae of aquatic insects including dragonflies, damselflies, caddisflies, mayflies, flies, beetles and bugs. http://www.landcareresearch.co.nz/resources/identification/animals/analysis-of-asiapacific-freshwater-invertebrates/papua-new-guinea

Insect pest guides

These are a combination of resources for identification of both insect pests and beneficials developed for primary industries in Australia by the Queensland (DAFF) and New South Wales Governments (DPI). The sites contain images and factsheets of pests as well as many links to online resources for management of pests in agriculture.

Insect pests in Horticulture and Field crops – NSW DPI
http://www.dpi.nsw.gov.au/agriculture/pests-weeds/insects

A-Z insect pest list – for northern NSW and QLD by DAFF QLD
http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list

A-Z list of predators, parasites and pathogens – for northern NSW and QLD by DAFF QLD
https://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-of-predators,-parasites-and-pathogens

The Beatsheet - Insect pest management for Australia's northern region, incl. links to other sites and publications and PDF guides of beneficial insects (under "Links").
http://thebeatsheet.com.au/about/

Taxon specific identification tools including some specific to PNG fauna

Although not comprehensive as yet for all taxa, below are some links to identification tools and taxonomic information for specific groups, with some sites specific to PNG and others of use for general identification purposes or for identification of insects of economic importance.

Ants

Ants of New Guinea – An online database to the New Guinea ant fauna which includes specimen records, images and information and photos about current ant research in New Guinea, plus links to the New Guinea fauna in AntWeb (worldwide online ant database).
http://www.newguineants.org/

The Pacific Invasive Ant Key (PIAkey) - An interactive and well-illustrated and photographed online key to the commonly found pest invasive ant species in the Pacific. Easy to follow and with useful links e.g. to Antweb and Australian Ants Online.
http://itp.lucidcentral.org/id/ant/pia/index.html

Ants Down Under – contains an identification key to subfamilies of Australian Formicidae, which may be helpful for PNG.
http://anic.ento.csiro.au/ants/ants_in_australia.aspx

Wasps

Universal Chalcidoidea Database – hosted by BMNH, very detailed reference website for this superfamily, includes key to families and description notes of all families, images, collection and preservation techniques and detailed morphology and terminology. Database also available on CD.
http://www.nhm.ac.uk/research-curation/research/projects/chalcidoids/

Coleoptera

Xyleborini ambrosia beetles of New Guinea - A taxonomic monograph with on-line keys and images.
http://www.ambrosiasymbiosis.org/PNG_Xyleborini/

Annotated checklist of weevils from the Papuan region (Coleoptera, Curculionoidea) – An open access pdf is available online for this publication (link below). This includes an introduction to the weevil fauna, taxonomic history and major workers and include 2,955 species-group names and 553 genus-group names of weevils for the Papuan region (Setliff 2007).
http://www.mapress.com/zootaxa/2007f/zt01536p296.pdf

Numerous Australian beetle guides here with some relevance to the PNG fauna:
http://www.csiro.au/en/Research/Collections/ANIC/ID-Resources

Lepidoptera

Australian Moths Online – image gallery organized by family. Australian pest species can be found by running a search for 'pest'.
http://www1.ala.org.au/gallery2/main.php

LepIntercept - An identification resource for intercepted Lepidoptera larvae.
Specifically designed for larval interceptions (in particular moth larvae) at ports in the US but could also be useful in other parts of the world for entomologists identifying pest larval species at ports etc. Excellent photos and description of Lepidopteran larval morphology.
http://idtools.org/id/leps/lepintercept/index.html

CATS - Caterpillars feeding on New Guinea plants – online database to New Guinea butterflies and moths recorded from ecological research by Scott Miller and Vojtech Novotny and their collaborators, through the New Guinea Binatang Research Centre. The database contains host plant and distribution records and images of adults and larvae of Lepidoptera species recorded and is limited largely to the lowland tropical forest and coastal northern region of Papua New Guinea (Madang, East Sepik and Sandaun Provinces) and highland areas around Mt Wilhelm (Simbu Province) (Miller et al. 2007).
https://www.entu.cas.cz/png/caterpillars/

Butterflies of the Wanang Conservation Area – species list of 200 butterflies recorded by researchers from the New Guinea Binatang Research Centre. Wanang Conservation is a 10000 ha protected area of intact lowland rainforest in Madang Province, established by the villagers and landowners. There is also a list for ants here on the Wanang Conservation website:
http://www.entu.cas.cz/png/wanang/species-lists

Hemiptera – Auchenorrhyncha

Auchenorrhyncha keys - online identification keys and checklists for the leafhoppers, planthoppers and their relatives occurring in Australia and neighbouring areas by Murray J. Fletcher (NSW Department of Primary Industries, Orange Agricultural Institute, Australia).
http://www1.dpi.nsw.gov.au/keys/auch/

Auchenorrhyncha species list for Indonesia/New Guinea - a checklist
http://www1.dpi.nsw.gov.au/keys/auch/splistindong/splista.htm

Scale Insects

ScaleNet – a worldwide database for scale insects. Navigate using the menu on the left side of the page. Follow "Queries" and "Scales in a Region" to find which families and species are recorded from PNG. In the menu on the left of the home page "Keys to Scale Insects (2014)" links to the USDA *Scale Insects Identification Tool for Species of Quarantine Significance* (see below for details).
http://www.sel.barc.usda.gov/scalenet/scalenet.htm

Scale Insects - Identification Tool for Species of Quarantine Significance, Edition 2 Contains keys, images and factsheets on quarantine pests. There are four interactive Lucid keys. The first is to identify a scale to the taxonomic level of family. There are three keys to species for the different families: Mealybugs and Mealybug-like Scales (including Pseudococcidae, Putoidae and Rhizoecidae), Soft Scales (Coccidae), and Other Scales. The latter contains pest species in various families.
http://www.idtools.org/id/scales/ - The direct link to the homepage for these keys and factsheets.

Diptera

Pacific Fruit Fly Project - Profiles of all Pacific countries, listing species known from that country and fruits affected by different species. Factsheets available on all Pacific fruit fly species.
http://www.spc.int/lrd/pacific-fruit-fly
http://www.spc.int/lrd/country-profiles/papua-new-guinea - **Papua New Guinea**

Smartphone and Tablet Apps

Applications or 'apps' downloaded and installed on devices such as tablets and smartphones are an emerging resource for entomology and crop diagnostics. Government and NGOs are developing apps often based on existing extension resources available on the internet, in published manuals or field guides. Apps are a very convenient way to access insect diagnostic information.

The advantage of smartphone and tablet apps are that they:

- may be updated as new information becomes available,
- can conveniently display images that can be enlarged
- once downloaded they may be used offline, and
- are a convenient form of information for taking into the field.

Disadvantages may be the initial cost of the mobile device, risk of theft, and the need for Internet access to download and update the app.

Apps are available for download from the Google Play (for Android) or Apple App (for iPhone) stores accessible online for smartphone and tablet devices. A variety of apps are currently available that relate to insect identification, for example:

- **Pacific Pests and Pathogens** (Lucid Mobile)
  Developed by PestNet for Pacific agricultural research and extension workers and lead farmers, the app contains 270 factsheets, 87 on insects. Information can be obtained by browsing the fact sheets by crop, or by symptoms. Each fact sheet is illustrated and has notes on pest distribution, hosts, biology and life cycle, impact, detection and inspection and management. The app will be updated to include mini-factsheets with a single image and key summary points in less than 100 words, and software to take photos and send them to Pestnet from either a smartphone or tablet. The factsheets (full and mini) are also available to view and download from the PestNet website: http://www.pestnet.org.
- **Insect Orders** (Lucid Mobile)
  A key is available to identify common adult insects to order; it was designed for the Australian fauna, but will work for insects in PNG, too. The key is 'simple' and does not allow for many exceptions and, as such, may not always lead to the correct identification! However, it is useful, not least for its illustrations of morphological characters, the descriptions of the orders and photographs. This key is also available online at these two locations: http://anic.ento.csiro.au/insectfamilies/key.aspx?OrderID=0&PageID=group&KeyID=5 http://keyserver.lucidcentral.org/key-server/player.jsp?keyId=1.
- **Insect ID: The Ute Guide** (Grains Research and Development Corporation)
  Designed for the identification of common insect pests affecting broad acre crops in Australia, so it has limited applicability to PNG but may provide some useful information. It is also available online: https://grdc.com.au/Resources/Ute-Guides/Insects.
- **PlantVillage** (Marcel Salathe)
  A worldwide forum where users can post questions and pictures and seek help with growing food. There are information resources on food crops in a plant library arranged by plant type so easily searchable. The forum and information is also available online: https://www.plantvillage.org/root

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The majority of these have been used extensively for the identification key and diagnoses. Other references relate to New Guinea insect fauna and taxonomy.

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Appendix

Microscope care, setup and eyepiece calibration

Microscopes need to be cared for, to ensure their longevity of use, especially in the tropics. Microscopes need to be setup correctly for use, to avoid back, neck or eye strain, or fatigue. During prolonged microscope use, it is important to take regular breaks to rest the body and eyes. The user should relax, move around, stretch, rest the eyes and focus their eyes on distant objects.

Microscope care

Cover microscopes with dust covers when not in use. Microscopes should be kept in a temperature and humidity controlled (i.e. air-conditioned) environment where possible, especially in humid tropical climates. For field use or storage outside air-conditions rooms, microscopes should be protected in sealed cases with a quantity of silica gel which is checked and changed regularly as needed as indicated by a change in colour.

Eye pieces and lenses should only be cleaned very carefully so as not to scratch or damage the glass. First blow away any dust particles and then gently clean with lens tissue or a clean soft cloth. Absolute ethanol may be used as a cleaning fluid if required.

Ergonomic setup

The microscope should be placed at the front of the desk or workbench so that the arms and shoulders are not stretching forwards, and at the right height so that back and neck are as straight as possible and relaxed. The eyepieces should be positioned so that the head is neither tucked down with bent neck nor stretched upwards. To see through the eyepieces the upper body should be kept straight by bending forward from the lower back. During prolonged use remember to have a break – relax, change position or get up, focus on distant objects.

Lighting

To protect the eyes, ensure electronic light sources are not used at too high an intensity (no greater than 75% is a good guide). A transmitted light base should be used only at low to medium intensity. Before turning lights on check that the light intensity dials are turned right down. Always turn light source dials down before switching off. This will preserve the life of the lights. Small battery powered LED light sources or LED desk lights are easily available and make good substitutes for expensive electronic lighting.

Eyepiece calibration

The eyepieces on a microscope should be calibrated before commencing work, especially if the microscope is shared. But even single users are likely to have slightly different eyes so eyepieces need to be adjusted so that each eye sees the object in focus.

One eyepiece on a microscope will be adjustable (or focusable) and this will have ruler-like graduated markings on the dial around its edges.

To calibrate the eyepieces follow these steps:

- Ensure that the eye pieces are the correct distance apart for your eyes by looking at the white base or a sheet of paper. The view should be one circular disc of light without any shadows.

- Identify the fixed eyepiece without graduated markings. With one eye looking through the fixed eyepiece and the other eye closed or covered, focus sharply on the subject using the focussing dial of the microscope.

- Close or cover the eye using the fixed eyepiece and use the other eye to look through the adjustable eyepiece.

- Make this eye sharply focus on the object using adjustable eyepiece focus. Check that this is now in focus with both eyes. Note the mark on the graduation. This is the mark appropriate for your eyes.

Preservation methods of different insect orders

For immature stages, mostly being soft bodied, wet preservation is required for the most part. However some nymphs of hemimetabolous groups such as Hemiptera and Orthoptera have a hard exoskeleton and may be dry preserved and pinned or point mounted.

For adults the following killing/preservation techniques are used:

Archaeognatha [bristletails]	Ethanol
Blattodea [roaches, termites]	Dry or Ethanol
Coleoptera [beetles]	Dry or Ethanol
Dermaptera [earwigs]	Ethanol
Diptera [flies]	Dry or Ethanol
Embioptera [footspinners]	Ethanol
Ephemeroptera [mayflies]	Ethanol
Hemiptera [aphids, psyllids, scales, cicadas, true bugs]	Dry or Ethanol
Hymenoptera [bees, sawflies, wasps and ants]	Dry or Ethanol
Lepidoptera [butterflies and moths]	Dry
Mantodea [mantids]	Dry or Ethanol
Neuroptera [lacewings]	Ethanol
Odonata [dragonflies and damselflies]	Dry
Orthoptera [crickets, grasshoppers]	Dry
Phasmatodea [walking sticks]	Dry
Plecoptera [stoneflies]	Ethanol
Psocodea [book lice, lice]	Ethanol
Siphonaptera [fleas]	Ethanol
Strepsiptera	Ethanol
Thysanoptera [thrips]	Ethanol
Trichoptera [caddisflies]	Ethanol
Zoraptera [zorapterans]	Ethanol
Zygentoma (= Thysanura) [silverfish]	Ethanol

Glossary

abdominal prolegs see prolegs

adfrontal area Y-shaped area marked by sutures on the anterior of the head in Lepidoptera larvae

adfrontal lines see adfrontal area

ametabolous simple lifecycle development type in primitive (apterygote) insects where nymphs hatch from the eggs resembling adults and get successively bigger through moulting stages to adulthood, e.g. silverfish and bristletails

anal prolegs prolegs on the terminal abdominal segment, at the apex of the abdomen in some insect larvae e.g. Trichoptera, Lepidoptera (modified and hooklike); see prolegs

anal struts see anal prolegs

antennae paired sensory appendages on the head of an insect above the mouthparts, usually associated with the eye and often with the base arising in antero-ventral positions to the eye

anterior the front or head end, referring to the position on the body

apex tip of a structure away from the body; also see apical

apical at the tip or end of a structure, referring to the position on the body

apical abdominal filaments filaments arising from the last (terminal) segment of the abdomen, the tail end

appendage limbs or other structures projecting from the body which generally have a particular function

apterygote primitively wingless insects

aquatic living in or on water

aristate antennal type found in higher flies (Diptera: Brachycera), with a bristle-like structure or arista arising from the apical antennal segment which is usually lobe-like

arolium pad-like structure of the pretasus, distal to the tip of the tarsus, between the base of the claws

asymmetrical where the two sides of a structure, when divided down the middle, are different, e.g. cerci of male Embioptera (web spinners)

basal positioned closest to the body; usually referring to the base of structure that articulates to the body

calcar large, movable, tibial spur or spine; often also with a comb of teeth

campodeiform insect larvae that are relatively flattened, elongate and active, with long legs, e.g. Heteroptera, Auchenorrhyncha, some Coleoptera, Neuroptera

caterpillar an eruciform type of larva, which possesses thoracic legs, usually also abdominal prolegs, and a distinct head; thoracic and abdominal body segments not easily distinguishable

caudal tail, tail end or posterior end, referring to position on the body

cerci apical or terminal abdominal appendages; always paired

clypeus anterior part of the head capsule, immediately posterior to the mouthparts; in many insects (e.g. many beetles) fused with the frons to form the frontoclypeus

compound eye an eye composed of many individual cells or lenses, called ommatidia, which appear hexagonal in shape.

constricted abdomen waisted, with basal segments of the abdomen greatly reduced in width, narrowly joining the metathorax; see also waist

coxa the most basal visible segment of the leg, an oval or thickened joint articulating the leg in the thorax

crotchets hooks on the prolegs of insect larvae, often organised in a ring, e.g. in most Leipdopteran larvae

dehiscent shedding, referring to the wings of termites (Termitoidea) which drop off

distal most distant, referring to position of parts of appendages relative to the body (opposite of proximal)

dorsal top or upperside, referring to position on the body

dorsum the topside of the body

ectoparasite a parasite living on the outside of its host e.g. fleas, lice, bedbugs, some flies - Nycteribiidae

elateriform a type of insect larva; elongate and cylindrical worm-like (vermiform) larvae but with small anteriorly clustered articulated legs (= "wireworms")

elytra hardened forewing of beetles (Coleoptera), which meet along the midline of the body and do not overlap; without any visible venation although sometimes highly punctured or textured; these may be fused along the midline forming a single inflexible covering in some flightless beetles.

endoparasite a parasite living inside its host, e.g. many wasp and fly larvae

endopterygote insects with wing development inside the body in immature stages; also known as holometabolous insects with complete metamorphosis

epiphysis a lobe or pad-like structure on the inner surface of the foretibia in Lepidoptera

eruciform caterpillar-like larvae, e.g. Lepidoptera, and sawflies

eversible vesicle sac-like structures can be everted or turned inside out, found on the abdomen of bristletails; see also vesicle

exopterygote insects with wing development on the outside of the body; seen as wing pads in immature stages; e.g. hemimetabolous insects with incomplete metamorphosis; also called nymphs

filament feather or hair-like projections from the body, e.g. at end of abdomen in bristletails, silverfish and Ephemeroptera - which usually possess a medial filament between paired cerci; sometimes cerci are also referred to as filaments in these groups

filiform thread-like, usually referring to antennal structure in insects

forceps modified single segmented cerci at apex of abdomen, pincer-like, usually significantly longer than apical abdominal segment, thickened and robust; found in Dermaptera

fore- first or front, often referred to first pair of legs, i.e. forelegs, foretibia etc.

frons an area of the head capsule bounded by the eyes and the clypeus

fused referring to the junction of two plates or segments so that there is no independent movement of each, often represented by loss of the division between them

genitalia sexually reproductive organs, usually located in the terminal abdominal segment or segments, at the posterior end of the abdomen.

gills respiratory (breathing) organs of aquatic nymphs, usually on abdominal segments e.g. caudal gills of Odonata and lateral abdominal gills of Ephemeroptera

glabrous hairless, smooth

haltere reduced club-like hind wing of true flies (Diptera)

haustellate coiled sucking mouthparts found in Lepidoptera, uncoiled in feeding

hemimetabolous incomplete metamorphosis lifecycle development, in which eggs hatch to wingless and non-reproductive nymphs which gradually develop wing pads and genitalia through stages as they moult, developing fully articulated wings and mature genitalia in the final moult to adulthood; in many insect orders, e.g. Hemiptera, Ephemeroptera, Odonata, Orthoptera

hemelytra the basally hardened forewings of true bugs (Hemiptera: Heteroptera); half hardened and half membranous structure, although the form varies greatly

herbivorous feeding on living plant tissue or plant fluids

holometabolous complete metamorphosis lifecycle development, in which eggs hatch to larvae which pass through a pupal resting phase (reorganising body organs) from which the adult emerges; e.g. Lepidoptera, Coleoptera, Diptera

hypognathous head vertical, mouthparts projected downwards or positioned ventrally

labial palps 1-3 segmented paired structures arising from the labium

labial spinneret a silk gland structure found in Lepidoptera larvae, positioned medially on the labium, between the labial palps; also see silk gland

labium the most ventral or posterior section of the mouthparts or 'lower lip' which usually includes paired appendages (labial palpi) and the plate to which they are attached (mentum); often modified into a greatly elongate sucking tube e.g. bugs (Hemiptera) and some flies (Diptera)

labrum most anterior or dorsal mouthpart, the upper lip of the mouth, sometimes absent (e.g. fused to head capsule)

larva the immature stage of an insect, usually only applied to the immature stage of holometabolous insects between egg and pupa; in general bears no resemblance to the adult form

larviform adults which have larva-like bodies but fully developed genitalia; also neonate

lateral on the side, referring to position on the body

mandible one of paired and opposed mouthpart structures situated immediately behind labrum, surrounded the oral cavity

mandibulate mouthparts with a pair of chewing and/or biting mandibles, usually distinguished by being thick, well-sclerotised and with internal teeth

maxillae paired structures of the mouthparts, located posterior to the mandibles, including the maxillary palp, galea and lacinia

maxillary palp paired and usually multisegmented (up to 7) projections of the mouthparts arising from the outer edge of the maxilla, often resembling miniature antennae

medial in the middle, towards the midline

membranous thin, more or less transparent, pliable

mesial inside or the inner surface of a structure

mesonotum the notum or dorsal sclerite of the mesothorax

mesothorax middle or second of the three segments of the thorax; bears the forewings and midlegs

metathoracic spiracle a spiracle on the last (third) segment of the thorax, usually positioned laterally

metathorax posterior of the three segments of the thorax; adjoins the abdomen; bears the hindwings and hindlegs

mimic to imitate, mimicry in all forms (visual, chemical, behavioural) is common in the insect world, and has a selective advantage for insects primarily in avoiding predation

morphology physical structure and associated terminology of insects

multisegmented comprising more than one segment, often referring to structures such as cerci or antennae

notum the dorsal surface or sclerite of a segment, referring to the thorax in insects, e.g. pronotum, mesonotum, metanotum

nymph a term for the immature stage of ametabolous and hemimetabolous insects (i.e. those lacking pupa); may or may not bear resemblance to the adult form

ocelli a simple single-lensed eye in adult insects; 1-3 situated at posterior dorsal part of head, but often absent

ocelliform spots spots that appear to imitate eyes, e.g. on the wings of Lepidoptera

opaque a surface that does not allow light to pass through. Such an object or surface is neither transparent nor translucent

opisthognathous head with the mouthparts directed posteriorly, articulated on the ventral surface of the head, e.g. cockroaches, hemipterans

ovipositor egg-laying structure of the female genitalia, sword-like structure on the ventral surface of the abdomen; may be folded along or hidden inside the abdomen, or greatly elongated and projecting posteriorly (e.g. Orthoptera)

parasitic living on or within another animal called the host; the host is required for part or all of the lifecycle to be completed

piercing mouthparts tube-like mouthparts that are inserted into the food source; feeding is by a sucking mechanism (e.g. mosquito proboscis or bug labium)

postclypeus the dorsal part of the clypeus which is greatly swollen in some insects, e.g. booklice (Psocodea), cicadas and some other groups of sucking insects (Hemiptera)

posterior the back or tail end, referring to the position on the body

predatory preying on other animals for food

proboscis beak-like or extended sucking mouthparts; generally referring to the coiled tube of moths and butterflies (Lepidoptera) or the elongate mandible of bees (Hymenoptera: Apocrita)

prognathous mouthparts at front of head and projecting forward

prolegs fleshy appendages on the abdominal venter (rarely also dorsum); functioning as legs but without segmentation

pronotum the dorsal part (notum) of the prothorax, often forming a dorsal shield on the thorax anterior to the wings (e.g. earwigs, cockroaches, beetles, bugs) but often greatly reduced (e.g. dragonflies).

prothorax anterior segment of the 3 thoracic segments; the first thoracic segment adjoining the head; bears the forelegs and lacks wings

proximal most basal, referring to position of parts of appendages relative to the body (opposite of distal)

pterothorax fused meso- and metathorax; present in some beetles (Coleoptera), flies (Diptera) and in all dragonflies and damselflies (Odonata)

rostrum a narrow projection of head anterior to eyes, with mouthparts at apex; in Hemiptera: mouthparts modified into an elongate tube for piercing and sucking.

Scales flattened setae; unicellular outgrowths of the body

scape first antennal segment

scarabaeiform white C-shaped larvae with a well developed head and thoracic legs (e.g. Coleoptera - scarabs)

sclerotised hardened or thickened

scutellum the posterior sclerite of a thoracic notum; a triangular sclerite on the mesonotum, usually positioned posterior to the pronotum and often visible between the forewings in many bugs and beetles

scutum the middle sclerite of a thoracic notum, e.g. the mesoscutum which is anterior to the scutellum (e.g. Heteroptera)

sessile immobile without a means of locomotion, usually attached or fixed in one place

setae hair-like outgrowths of the body wall, with a ringlike articulation at its base

silk gland structure for silk production and can be found in labium of Lepidoptera, Trichoptera, some Hymenoptera (Apocrita); also see labial spinneret

single lens eyes see stemmata

spiracle breathing hole or pore, opening of the insect tracheal (breathing) system; spiracles are often visible laterally on the thorax and abdomen

stemmata unicellular or single lens eyes of insect larvae, located laterally on the head.

sternite the ventral sclerite of an abdominal segment

stylet a piercing needle-like structure; part of piercing sucking mouthparts; in bugs two pairs of structures, each pair of mandible and maxillary origins respectively

stylus a short pointed process; plural is styli; e.g. on the abdominal sternites of silverfish

sucking mouthparts mouthparts for feeding on liquid food; variously modified to either pierce and then suck liquid from within the food source, or sponge-feed externally on liquid, or greatly elongate to access nectaries of flowers to feed on this sugary liquid

symmetrical where the two sides of something, divided down the midline are the same

tarsal segments see tarsomere

tarsi see tarsus

tarsomere a segment of the tarsus

tarsus apical major leg segment, usually subdivided, with 1 to 5 tarsal segments which are called tarsomeres; usually with one or two terminal claws; plural is tarsi

tegmina toughened leathery forewings

tergite the dorsal plate of an abdominal segment

terminal end of body or tail end; see caudal

tibia a medial leg segment, between the femur and tarsus; the long shank of the leg

translucent allowing light through but without clear visibility of objects

transparent see through and allowing all light to pass through; also see membranous

transverse wider than long

trochanter the segment of the leg which joins the femur to the coxa, usually much shorter than the femur

urogomphi paired cerci-like dorsal processes on the ninth abdominal segment of beetle larvae

venation the arrangement and structure of veins on the wings

venter the underside of the body

ventral the underside, referring to position on the body

vermiform worm-like, describing larvae of Siphonaptera, some Diptera

vesicle a cavity, sac or bladder, often below the surface, often containing liquid

vestigial weakly developed, usually non-functional

waist a constriction where the abdomen joins the thorax in most Hymenoptera (except sawflies); see constricted abdomen