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Contents

Insect Science	0
Welcome and Introduction	vi
Acknowledgment of Country	viii
1. Insect Diversity	0
<i>Where did insects come from?</i>	0
<i>Just how many insects are there</i>	0
<i>Evolutionary success</i>	0
<i>Ecological and geographical success</i>	0
<i>Diversity of Feeding Strategies</i>	0
<i>Detrimental and Beneficial Insects</i>	0
2. Insect Phylogeny and Classification	10
<i>Phylogeny and Classification</i>	11
<i>Phylum Arthropoda</i>	15
<i>Superclass Hexapoda</i>	16
3. Diversification of the Groundplan	20
<i>The Body Plan</i>	21
<i>Head</i>	22
<i>Thorax</i>	27
<i>Abdomen</i>	30
<i>Activities</i>	31
4. Insect Life Histories	32
<i>Introduction</i>	33
<i>Insect Life Histories</i>	34
<i>Sociality in Insects</i>	41
<i>Activities</i>	42
5. Insect Cuticle	43
<i>Structure of the cuticle</i>	44
<i>Functions of the cuticle/exoskeleton</i>	45
<i>Modifications of Cuticle</i>	46
<i>Respiratory System (The Internal Cuticle)</i>	51
<i>Activities</i>	54

6.	The Challenge of Moulting	56
	<i>The Process of Moulting (Ecdysis)</i>	58
	<i>Hormones Involved in Moulting</i>	59
	<i>Rates of Development</i>	60
	<i>Activities</i>	61
7.	Sensory and Motor Systems	63
	<i>Sensori-Motor Systems</i>	64
	<i>Central Nervous System (CNS)</i>	65
	<i>Vision</i>	66
	<i>Sensilla (= Sense Organs)</i>	68
	<i>The Motor System</i>	71
	<i>Activities</i>	72
8.	The Contented Insect: Feeding and Nutrition	73
	<i>Mouthparts and Feeding</i>	74
	<i>Excretory System</i>	77
	<i>Nutrition</i>	78
	<i>Insect Feeding: Its Impact on Humans</i>	79
	<i>Insects as Food</i>	79
	<i>Activities</i>	80
9.	Reproduction	82
	<i>Reproductive Systems of Male and Female</i>	83
	<i>Insemination</i>	85
	<i>Spermathecae</i>	86
	<i>The Spermatophore</i>	86
	<i>Reproduction and Nutrition</i>	86
	<i>Finding Mates</i>	87
	<i>Copulation</i>	87
	<i>Fertilisation</i>	88
	<i>Sex Determination</i>	89
	<i>Egg-laying or Live-bearing</i>	89
	<i>Activities</i>	90
10.	Semiochemicals	93
	<i>Overview of Semiochemicals</i>	94
	<i>Pheromones</i>	94
	<i>Kairomones</i>	95
	<i>Allomones</i>	95
	<i>Sex Pheromones</i>	95
	<i>Pheromones: Use in Pest Control</i>	98

11.	Living with Water	100
	<i>Return to Water</i>	102
	<i>Breathing Under Water</i>	102
	<i>Reproduction in Aquatic Insects</i>	106
	<i>Activities</i>	106
12.	Orders of Insects: Introduction	107
13.	The Orders of Insects: Non-insect Hexapods	108
	<i>Order Protura (Class Entognatha)</i>	109
	<i>Class Collembola</i>	110
	<i>Order Diplura (Class Entognatha)</i>	112
	<i>Activity</i>	113
14.	The Orders of Insects: Archaeognatha and Zygentoma	114
	<i>Order Archaeognatha</i>	115
	<i>Order Zygentoma (Thysanura)</i>	116
15.	The Orders of Insects: Ephemeroptera	118
	<i>Order Ephemeroptera</i>	119
	<i>The Subimago: A Unique Feature of Ephemeroptera</i>	120
16.	The Orders of Insects: Odonata	122
	<i>Order Odonata: Dragonflies and Damselflies</i>	123
17.	Orders of Insects: Plecoptera	127
	<i>Order Plecoptera</i>	128
18.	Order of Insects: Dermaptera	130
	<i>Order Dermaptera</i>	131
	<i>Activities</i>	132
19.	Orders of Insects: Zoraptera	134
	<i>Order Zoraptera</i>	135
20.	Orders of Insects: Orthoptera	137
	<i>Order Orthoptera</i>	138
21.	Orders of Insects: Embioptera	142
	<i>Order Embioptera</i>	143
22.	Orders of Insects: Phasmatodea	145
	<i>Order Phasmatodea</i>	146
23.	Orders of Insects: Grylloblattodea	149
	<i>Grylloblattodea</i>	150
24.	Orders of Insects: Mantophasmatodea	152
	<i>Order Mantophasmatodea</i>	153
25.	Orders of Insects: Mantodea	155
	<i>Order Mantodea: Praying mantis</i>	156

26.	Orders of Insects: Blattodea	159
	<i>Order Blattodea: Cockroaches and termites</i>	160
27.	Orders of Insects: Blattodea (Termitoidae)	164
	<i>Higher Taxon Termitoidae (termites)</i>	165
28.	Orders of Insects: Psocodea	169
	<i>Order Psocodea: Barklice, booklice, and body lice</i>	169
29.	Orders of Insects: Thysanoptera	174
	<i>Order Thysanoptera (Thrips)</i>	175
30.	Orders of Insects: Hemiptera	177
	<i>Order Hemiptera: Bugs, Leafhoppers, Cicadas, Aphids, Scale Insects</i>	179
31.	Orders of Insects: Raphidioptera	186
	<i>Order Raphidioptera: Snakeflies</i>	187
32.	Orders of Insects: Megaloptera	189
	<i>Order Megaloptera: alderflies and dobsonflies, fishflies</i>	190
33.	Orders of Insects: Neuroptera	193
	<i>Order Neuroptera: Lacewings</i>	194
34.	Orders of Insects: Coleoptera	199
	<i>Order Coleoptera: Beetles</i>	200
35.	Orders of Insects: Strepsiptera	204
	<i>Order Strepsiptera</i>	205
36.	Orders of Insects: Diptera	208
	<i>Order Diptera: Flies</i>	209
37.	Orders of Insects: Mecoptera	215
	<i>Order Mecoptera: Scorpion flies, hanging flies</i>	216
38.	Orders of Insects: Siphonaptera	218
	<i>Order Siphonaptera: Fleas</i>	219
	<i>Transmission of Disease</i>	220
39.	Orders of Insects: Trichoptera	223
	<i>Order Trichoptera: Caddisflies</i>	224
40.	Orders of Insects: Lepidoptera	227
	<i>Order Lepidoptera: Moths and Butterflies</i>	228
	<i>Economic importance</i>	230
	<i>Diversity of feeding habits</i>	231
	<i>Avoidance of predation</i>	231
41.	Orders of Insects: Hymenoptera	234
	<i>Order Hymenoptera: Wasps, bees, ants and sawflies</i>	236

Welcome and Introduction

They left the water, conquered the land, and took to the skies. They can be friends: providing invaluable pollination and nutrient recycling ecosystem services, but they can be foes: pest species can sometimes reach plague proportions. Some are masters of disguise, while others flaunt their spectacular beauty. Insects are undoubtedly the most successful animal group, in diversity, geography and ecology. They are also a rich part of our environment, economy and culture.

[THRD0023 001 \(YouTube, 2m 41s\)](#):



One or more interactive elements has been excluded from this version of the text. You can view them online here:

<https://uq.pressbooks.pub/insect-science/?p=52#oembed-1>

Welcome to Insect Science! This open-access textbook is an introductory guide to entomology, and forms the main resource for students enrolled in [BIOL2205 Insect Science](#) at The University of Queensland. This is a course for the budding entomologist and will train you in professional entomological skills: (1) insect identification, (2) specimen preparation, (3) advanced microscopy, and (4) communication.

For our students, by the end of the course you should be able to:

- **Understand** the significance of insects in environmental, economic, and social contexts
- **Characterise** (identify) an insect specimen to the Order and Sub-Order taxonomic level
- **Prepare** insect specimens for the purposes of insect identification to a professional standard
- **Read** and **appraise** entomological literature critically

The course is delivered by the authors of this textbook.



Dr Gurion Ang

My curiosity for insects did not begin until university, where I learnt about the weird and whimsical diversity of insects and plants. My PhD was dedicated to better understanding the tritrophic interaction between the diamondback moth *Plutella xylostella* and small cabbage white butterfly *Pieris rapae*, specialist herbivores of cabbage plants, and their parasitic natural enemies including the wasps *Diadegma semiclausum* and *Cotesia glomerata*.

**Dr Kathryn (Kathy) Ebert**

I've always been passionate about natural history and sharing that passion with others. Insects provide a never ending source of amazement with their incredible diversity of behaviours and forms! For my PhD, I focussed on Australian native dung beetles, in particular, the unusual behaviour, diet and microbiome of the rainforest dung beetle, *Cephalodesmus*.

The success of Insect Science builds on the legacy and passion of phenomenal entomologists. We acknowledge their contributions.

- Gordon Gordh
- Margaret Schneider
- Bronwen Cribb
- David Merritt

We would also like to acknowledge the following people for sharing their fantastic insect photos, all of whom are past students of the course or have been a keen supporter of UQ entomology in some way:

- Will Arnold
- Lyn Cook
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- Anthony O'Toole
- Jessa Thurman
- James Tweed

Acknowledgment of Country

[THRD0023 002 \(YouTube, 2m 51s\):](#)



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We acknowledge the Traditional Owners and their custodianship of the lands on which this project originated. We pay our respects to their Ancestors and their descendants, who continue cultural and spiritual connections to Country. We recognise their valuable contributions to Australian and global society.



A Guidance Through Time by Casey Coolwell and Kyra Mancktelow © The University of Queensland

ABOUT THE ARTWORK

Quandamooka artists Casey Coolwell and Kyra Mancktelow have produced an artwork that recognises the three major campuses, while also championing the creation of a strong sense of belonging and truth-telling about Aboriginal and Torres Strait Islander histories, and ongoing connections with Country, knowledges, culture and kin. Although created as a single artwork, the piece can be read in three sections, starting with the blue/greys of the Herston campus, the purple of St Lucia and the orange/golds of Gatton.

The graphic elements overlaying the coloured background symbolise the five UQ values:

- The Brisbane River and its patterns represent our Pursuit of excellence. Within the River are tools used by Aboriginal people to teach, gather, hunt, and protect.
- Creativity and independent thinking is depicted through the spirit guardian, Jarjum (Child in Yugambeh language), and the kangaroo
- The jacaranda tree, bora ring, animal prints, footprints and stars collectively represent honesty and accountability, mutual respect and diversity and supporting our people.

Learn more about [The University of Queensland's Reconciliation Action Plan](#).

CHAPTER 2

Insect Phylogeny and Classification



A collection of insects classified by Order. [Photo:K.Ebert]

In this chapter, we become familiar with the naming system for insects and explore the evolutionary relationships of the orders of insects. Because insects are so widespread, many species have not yet been named and identified: insects are the majority of new species being named and published in journals such as *Zootaxa*. The classification system for insects is not completely settled, even at the level of Orders. Application and refinement of DNA sequence-based studies, along with new discoveries has prompted recent re-evaluations of the accepted taxonomy.

Learning Objectives

- Understand the Linnean approach to classifying insects
- Be able to explain the binomial system of naming animals
- Know the members of the Superclass Hexapoda
- Identify characters that distinguish the major subdivisions of the Hexapoda

PHYLOGENY AND CLASSIFICATION

Before we discuss the characteristics of the major insect groups, we need to consider how insects are classified and named in order to gain an understanding of the terminology used by taxonomists and to appreciate the international codes governing the process of naming animals, including insects.

Important terms

Taxonomy and systematics are terms that are often confused.

- **Systematics** is the study of the diversity of organisms and how they are inter-related. It has two components: taxonomy and phylogenetics.
- **Taxonomy** is the science and practice of classifying organisms. It involves recognising, describing and naming species, and classifying them into a ranked and named system.
- **Phylogenetics** is the study of the evolutionary relatedness of organisms. It provides information useful for constructing an evolutionary ("natural") classification system, for understanding the evolution of traits, and for understanding how and why organisms are distributed as they are.

Humans like to name and categorise things, and are typically good at using small differences to distinguish among categories. Think of everyday groupings such as cups, mugs, chairs and plates. There can be lot of variety in each of these, but most of the time we can easily differentiate between them, even a cup and a mug.

Current classifications of insects (and other animals) are based on a combination of ideas for how to recognise the rank and relationships of groups, with most orders being based on groups (taxa) with distinctive morphology. Other data, such as DNA sequences, and behavioural, ecological and physiological characters, are also used by taxonomists (scientists who recognise, describe, name and classify organisms). Taxonomists group similar individuals into species, and similar species are grouped into genera, genera are grouped into families etc. Thus, the classification system for organisms is hierarchical, with classification levels nested one inside the other.

In summary, the hierarchy of major classification levels for animals, including insects, from more inclusive groups down to less inclusive groups is shown in the following table.

The practice of modern taxonomy was developed by the Swedish biologist Carolus Linnaeus in the late 1700's. The rules proposed by him still form the basis for modern taxonomy. Linnaeus proposed that all species

should have a double name, which is called a scientific **binomen**, and the use of binomial nomenclature is still generally adopted and standardised globally. Recommendations for naming and classifying animals are outlined in "[The International Code of Zoological Nomenclature](#)" (ICZN), which is administered by the [International Commission on Zoological Nomenclature](#).

The ICZN code "regulates" (it can really only recommend because there is no international "law") names in the species, genus and other major classification levels up to Superfamily. The standard use of a binomen for each species allows people everywhere in the world to communicate with little confusion over which species is being discussed.

All animals	Insects
Kingdom	Animalia
Phylum	Arthropoda
Class	Insecta
Order	27 Orders
Family	1000s of families
Genus	many 1000's of genera (plural of genus)
Species	more than 1.5 million described species

Scientific binomens are typically in Latin or latinised Greek roots and are unique to an organism under the code; no species of animal can have the same name as another. However, because plants and animals have different codes, an insect might have the same name as a plant. Examples of genus names shared across codes are:

Agathis: a coniferous plant and also a parasitic wasp

Kingia: a grass tree and a mosquito

The scientific binomen of an organism provides the key to finding information in the scientific literature. The scientific binomen for a species is the same no matter what country the species occurs. On the other hand, a common name for a particular species may vary from country to country. Care should be taken in referring to a species by a common name for this reason.

The scientific name of the beautiful iridescent Botany Bay weevil might also be written as *Chrysolopus spectabilis* (Fabricius, 1775). This indicates that the person who first described this species had the family name (surname) of Fabricius and he described the species in 1775. Sometimes a taxonomist later studies the same species and its relatives and might decide that the species belongs in a different genus. In this case, the original describer's (author's) name is placed in parentheses.



Botany Bay weevil, *Chrysolopus spectabilis* (Fabricius, 1775). [Photo: T.Hudson, [CC BY-SA 2.5, Wikimedia Commons](#)].

So, *Chrysolopus spectabilis* (Fabricius) is now in a different genus from that in which Fabricius first described it; we know this because Fabricius is in parentheses. When an insect species is recognised for the first time and a new scientific name published, the Code specifies that it be accompanied by a description of the appropriate life stages (almost always including the adult) in sufficient detail that the species can be distinguished from its close relatives. Features diagnostic of the newly recognised species must be explained and any variations in appearance or habits described or discussed.

Keen to know more?

If you want to know more about how species are described, you can read about some newly described species in the open access *Australian Journal of Taxonomy*:

- [a new species of parasitoid wasp from South Australia](#)
- [a new species of resin-using assassin bug](#)
- [a new species of dung beetle from Central Queensland](#)

A summary of the classification hierarchy, and the levels that are regulated by the ICZN Code, are indicated in the table below. The classification of the Botany Bay weevil is used as an example for each category.

Classification Level	ICZN Code	Example
Phylum		Arthropoda
Class		Insecta
Infraclass		Pterygota
Order		Coleoptera
Suborder		Polyphaga
Superfamily	names end in 'oidea'	Curculionoidea
Family	names in in 'idae'	Curculionidae
Subfamily	names end in 'inae'	Aterpinae
Tribe	names end in 'ini'	
Genus	names begin with a capital letter and are italicised	<i>Chrysolopus</i>
Species	names are binomial; they contain a genus name AND a species epithet that begins with a small letter and italicised	<i>Chrysolopus spectabilis</i>

The implementation and upholding of the ICZN Code is mostly done via peer review – if an author has not followed the ICZN Code, a manuscript might not be accepted by reviewers or editors until the it is followed. However, the Code is not an enforceable law and alternative systems have been proposed. One of these – PhyloCode – has been adopted by some authors and their peers, but it is not as universally accepted as the ICZN Code. PhyloCode has mainly been applied at classification levels above species.

The biological classification of the insects is an on-going process, with many hundreds of thousands of species still undescribed and waiting to be classified. Agreement on classifications is often difficult to achieve because of the great diversity of morphology and because molecular data do not resolve all relationships. As more data become available, classifications can, and do, change. Even the number of insect orders remains debatable, even though most orders are reasonably well-defined by morphological characters. We are presenting 28 orders of insects. Recent changes include the incorporation of termites into Blattodea, fleas into Mecoptera, and grouping parasitic, chewing and bark lice into Psocodea. For this text, we have examined the fleas (Siphonaptera) and hanging flies (Mecoptera) separately.

Insect Order	Common name/s
Archaeognatha	bristletails
Zygentoma	silverfish
Ephemeroptera	mayflies
Odonata	dragonflies, damselflies
Plecoptera	stone flies
Dermaptera	earwigs
Zoraptera	zorapterans
Orthoptera	grasshoppers, crickets, katydids
Embioptera	web spinners
Phasmatodea	stick & leaf insects, phasmids, walking sticks
Grylloblattodea	ice walkers, rock crawlers
Mantophasmatodea	heel walkers
Mantodea	praying mantis, mantids
Blattodea	cockroaches, termites
Psocodea	bark lice, chewing lice, sucking lice
Thysanoptera	thrips
Hemiptera	bugs, cicadas, leafhoppers
Raphidioptera	snakeflies
Megaloptera	alderflies, dobsonflies, fishflies
Neuroptera	lacewings, antlions
Coleoptera	beetles, weevils
Strepsiptera	strepsipterans
Diptera	flies
Mecoptera	scorpionflies, hanging flies, snow fleas
Siphonaptera	fleas
Trichoptera	caddisflies
Lepidoptera	moths, butterflies
Hymenoptera	ants, bees, wasps, sawflies, wood wasps

PHYLUM ARTHROPODA

(arthro = joint, poda = foot)

Insects belong to the phylum Arthropoda – the joint-legged animals. To understand the evolution of insects, it is helpful to have an overview of the evolution of arthropods in general. As a good introduction to this topic, watch “[The arthropod story](#)” from UC Berkeley. It takes you on a tour through the amazing evolutionary history of arthropods. Along the way, you’ll get a healthy dose of taxonomy, palaeontology, natural history and principles of evolution. You can be assessed on your knowledge of the story, particularly in relation to the topics mentioned in this course.

Traditionally, hexapods were thought to be most closely related to myriapods (millipedes and centipedes). Current evidence suggests that Crustacea are the closest relatives of Hexapoda. This latter relationship is supported by DNA sequences and developmental and morphological data, particularly those of the compound eye and nervous system. However, it is unclear whether the whole of Crustacea is sister to hexapods, or

whether it is just the Malacostrata (crabs, crayfish etc), or just the Branchiopoda (fairy shrimps, tadpole shrimps and water fleas).

Major subgroups of arthropods	common names
Chelicerata	spiders, mites, ticks, scorpions, etc.
Myriapoda	millipedes, centipedes
Crustacea	crabs, prawns, slaters, land shrimp, etc.
Hexapoda	arthropods with six legs (such as insects, springtails,

SUPERCLASS HEXAPODA

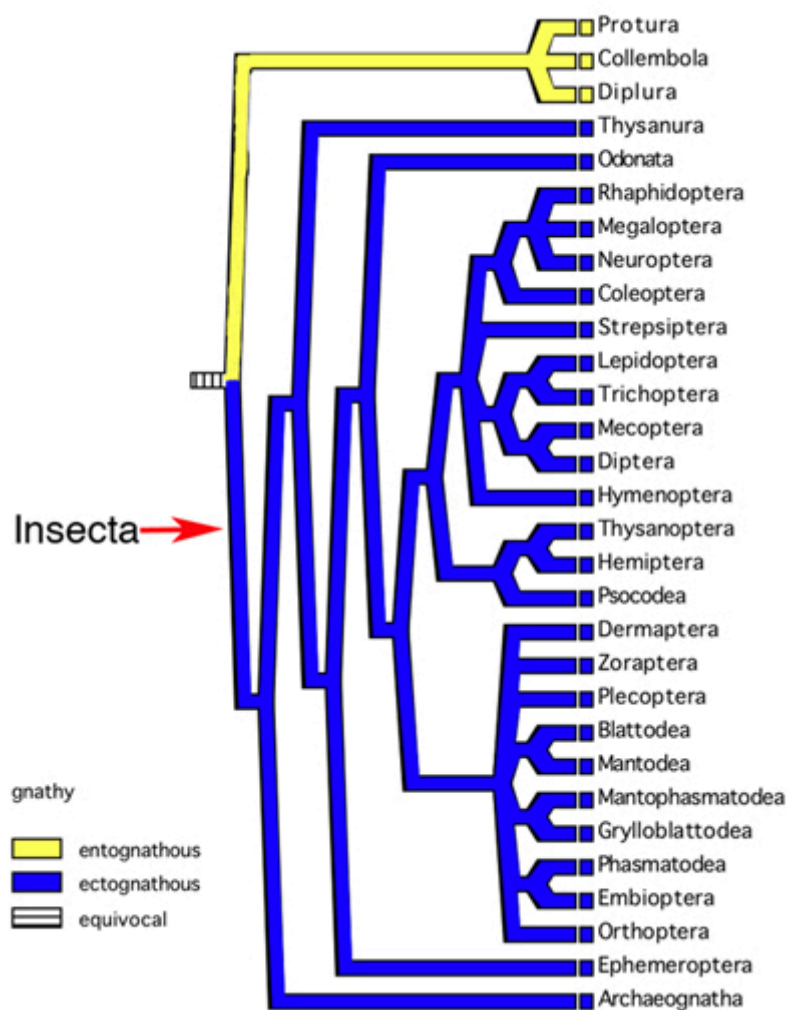
Hexapods can be classified according to different evolutionarily significant features, primarily the mouthparts and the wings.

MOUThPARTS

Entognathous: mandibles are concealed when not in use (Protura, Collembola and Diplura). There is some evidence that these three groups are each other's closest relatives and the latest edition of Gullan & Cranston's "The Insects" treats them as a Class called Entognatha. Together, they are sister to the insects.

Ectognathous: mandibles remain exposed and are not extensible (Insecta).

The relationships amongst the hexapods are shown in the phylograms below. Each taxon has been coded as to whether it has entognathous or ectognathous mouthparts (see legend; small box next to each taxon shows the state in that taxon). The origin of the insects is indicated with an arrow, indicating that all insects derived from that branch had wings as an ancestral state. Remember, though, that insects can often lose their wings as a secondary trait. The character reconstruction (coloured branches as per legend) shows that the ancestor to all insects had ectognathous mouthparts.



This figure shows the relationships amongst the hexapods. Each taxon has been coded as to whether it has entognathous or ectognathous mouthparts (the small coloured box next to each taxon shows the state in that taxon). The origin of the insects is indicated with an arrow. The character reconstruction (coloured branches) shows that the ancestor to all insects had ectognathous mouthparts. There are some minor differences to the standard phylogram.

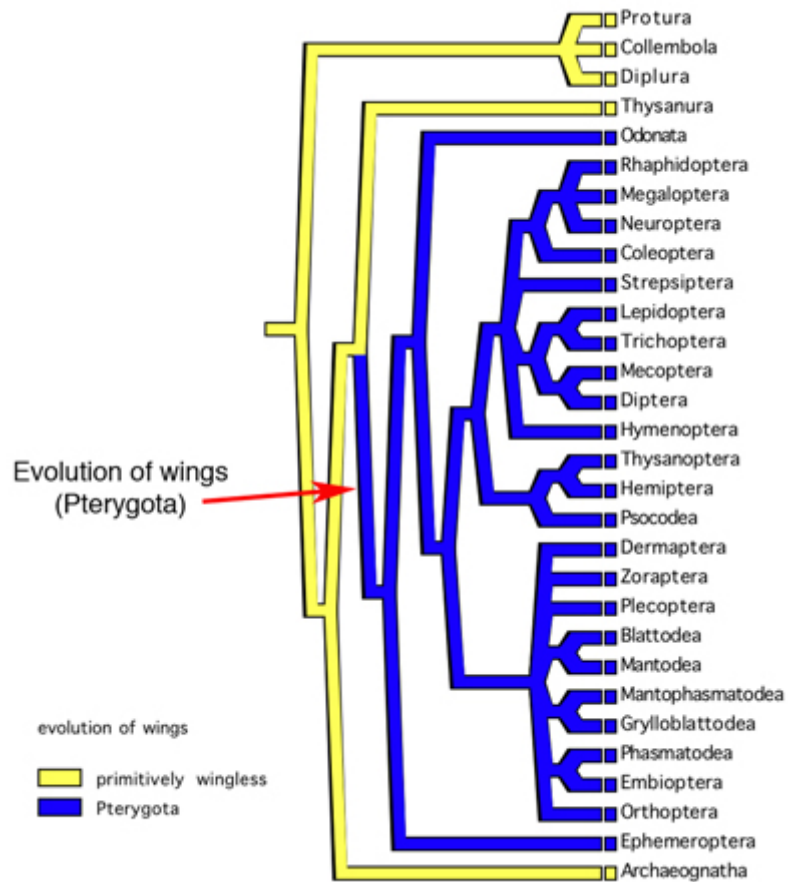
WINGS

Two orders of insects are primitively wingless: Zygentoma (Thysanura) and Archaeognatha – their ancestors did not have wings. Wings evolved in the common ancestor of the pterygote insects. Pterygota (commonly treated as an infraclass) are the winged or secondarily wingless (apterous) insects, with thoracic segments of adults usually large and with the meso- and metathorax variably united to form a pterothorax. The sharing of a common origin of wings helps define the Pterygota as a monophyletic (natural) group.

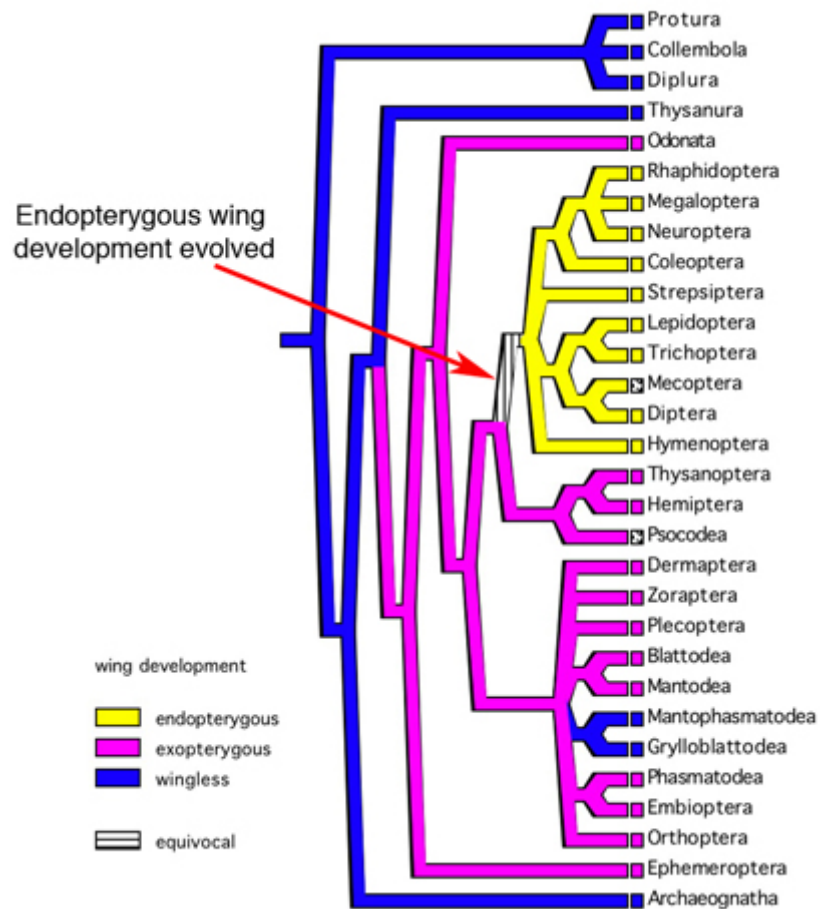
The pterygote insects can be further classified according to the mode of development of the wings. Most orders of pterygotes have wing buds that develop externally (exopterygous). This appears to be the ancestral state for pterygotes, and therefore does not help to define a group of insects. In contrast, some insects have wings and genitalia that are internalised in the pre-adult stages. This derived trait defines the group called Endopterygota. This group used to be called Holometabola because it was thought to be defined by holometabolous development, but similar development also occurs in some of the other insects.

exopterygous (= outside wings) – wing buds develop externally

endopterygous (= inside wings) – wings buds develop internally (Endopterygota)



This figure shows a reconstruction for the evolution of wings. The arrow points to the branch along which wings evolved. This branch represents the most recent common ancestor of the Pterygota.



The character reconstruction shows that the common ancestor to the Pterygota had exopterygous wing development. Endopterygous wing development evolved in the common ancestor to the Endopterygota (indicated by the arrow). The reconstruction also shows that the common ancestor to two orders, Mantophasmatodea and Grylloblattodea, lost wings. These two orders are wingless and they share a common ancestor.

Topic Review

Do you know...?

- how insects are classified?
- the various levels of classification
- the common and scientific names of the major insect orders
- The logic applied to inferring ancestral states in the phylograms of insect evolution?
- Understand the logic by which phylogenetic trees are used to make inferences about ancestral states

CHAPTER 3

Diversification of the Groundplan



King Cricket, Anostostoma australasiae (Orthoptera:Ensifera) [Photograph by Jessa Thurman. Used with permission].

We identify the basic arrangement, or groundplan, of the insect body and use a few examples to explore how evolution has modified the structures of the body. One of the elements of insect biology where they show high diversity is in the feeding structures, or mouthparts. They have become adapted to take advantage of many different types of food, from sucking or lapping liquids to chewing on hard foods.

Remember, the success of insects can be attributed to the factors listed here.

- their small size
- a simple, efficient and evolutionarily flexible body plan
- a sophisticated sensory-motor system
- the ability of adults to fly

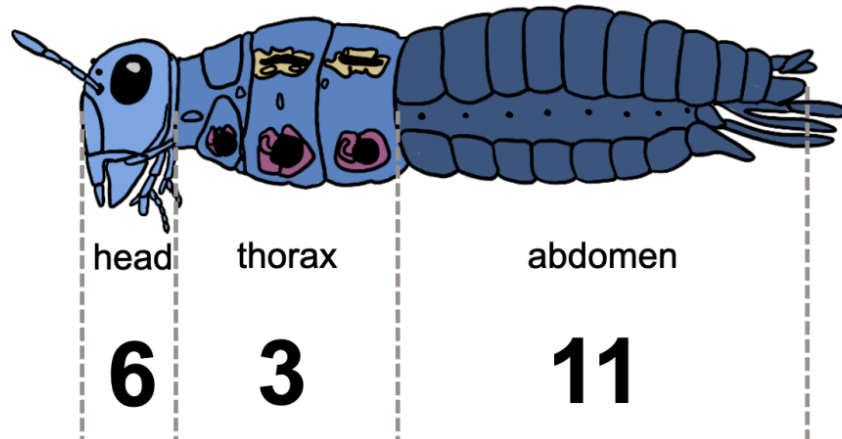
We would expect the basic body plan to show adaptations that reflect these attributes.

Learning Objectives

- Be familiar with the structure of the insect body groundplan
- Know the names of the insect body parts and their components
- Appreciate how evolution has changed the groundplan
- Realise that each order has a variation of the groundplan

THE BODY PLAN

In biology a generalised body plan is called a *groundplan*. Insects have a basic body plan made up of three **tagmata**; a **head** which actually comprises 6 segments, three segments forming a **thorax**, and 11 segments that make up the **abdomen**.



The three tagmata of the generalised insect body.

The segments that comprise the tagmata can resemble each other, e.g. the middle abdominal segments are similar in morphology. The head segments, though, are hard to recognise as individual segments. Developmental and genetic studies have contributed to understanding the segmental origins of the tagmata.

[THRD0023 007 \(YouTube, 3m 41s\):](#)



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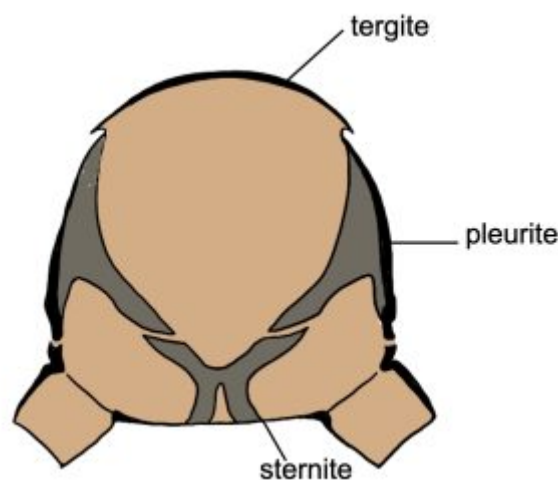
The insect groundplan is based upon three tagmata, each with specialisations according to their function.

Tagmata	Component parts	Some functions
Head	mouthparts, pair of antennae, eyes and/or ocelli, brain	feeding, seeing, detecting chemicals and odours
Thorax	3 pairs of segmented legs, 1 or 2 pairs of wings (adults)	walking, flying, jumping, sound production
Abdomen	reproductive components and genitalia (adults), prolegs (larvae)	reproduction, digestion

Often the juvenile insect looks very different from the adult but the basic components (tagmata) of head, thorax and abdomen are present.

The body plates of insects are described according to their position around the body. Each segment consists of three basic body plates:

- dorsal plates are called **tergites**
- ventral plates are called **sternites**
- side plates are called the **pleurites**



The three types of body plates in insects.

HEAD

MOUTHPARTS

Insect mouthparts are a series of cuticular appendages that have been modified to become involved in feeding. The design of the mouthparts depend primarily on two factors, (1) the taxonomic group, and (2) the

type of feeding habit. Each Order of insects has a basic plan of the mouthparts, but if there is a variety of feeding habits within the order then frequently the mouthparts become modified to suit the food type.

The major types of mouthparts found in insects are:

- chewing mouthparts, e.g. grasshopper (Orthoptera) or beetles (Coleoptera)
- piercing and sucking mouthparts, e.g. mosquitoes (Diptera), bugs (Hemiptera), fleas (Siphonaptera)
- non-piercing, sucking mouthparts, e.g. butterflies (Lepidoptera)
- chewing-sucking or chewing-lapping mouthparts, e.g. honeybee (Hymenoptera)

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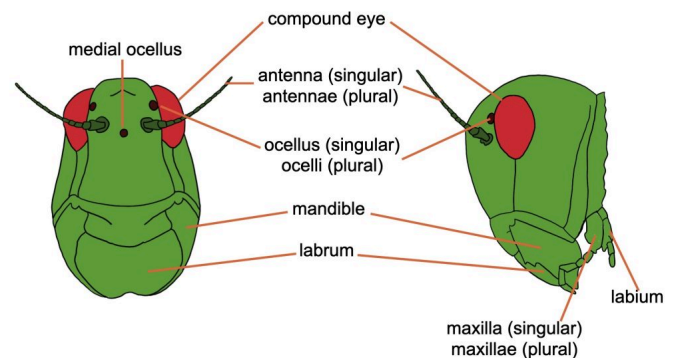
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The chewing mouthparts found in the Orthoptera and Blattodea could be considered as close to the groundplan of pterygote insect mouthparts as they are plant-feeding or omnivorous.

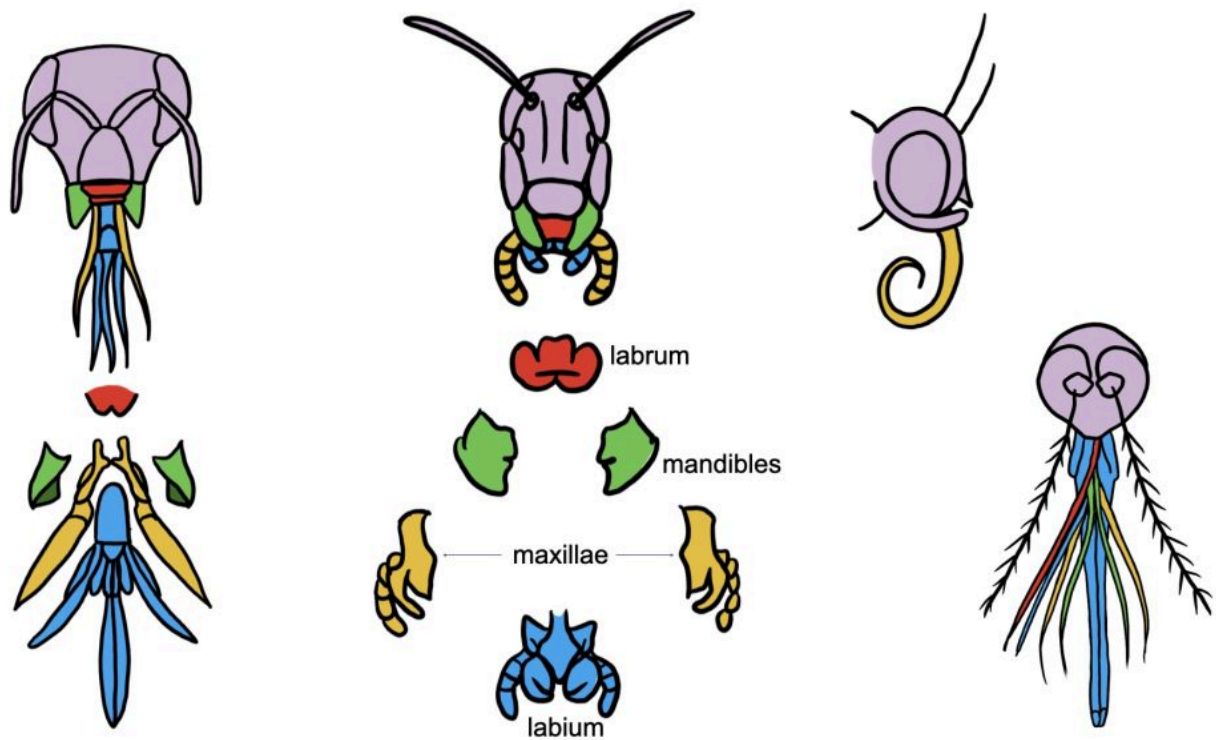
The main components of insect mouthparts are:

- labrum, or 'upper lip' (inner surface is called epipharynx)
- mandibles, or jaws
- maxillae, paired, singular 'maxilla'
- labium, or 'lower lip'

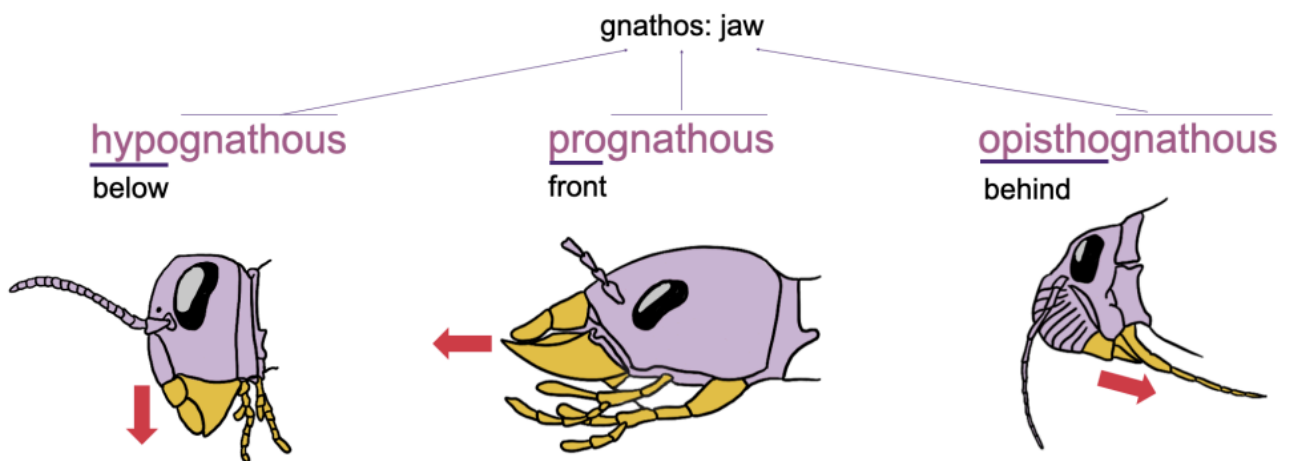


Generalised insect head and mouthparts

In the evolutionary transitions, some components are lost and others are extensively modified. Once an evolutionary step has taken place, it is difficult to go back to the groundplan. Rather, evolution modifies what is already present. For example, some moths and butterflies have become fruit-piercers or blood-feeders. They modified the sucking proboscis to enable it to become a piercing tool.



Different types of mouthparts The evolution of insect mouthparts from the primitive chewing mouthparts (centre, e.g. grasshopper) to the lapping type (left, e.g. honeybee) and the siphoning type (right, e.g. mosquito). Colours correspond to the same mouthpart with different morphology. Shared under a [CC BY-SA 4.0](https://creativecommons.org/licenses/by-sa/4.0/) licence. [Image adapted from: [Xavier Vázquez](#), [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/), Wikimedia Commons].



Three different types of mouthpart orientation in insects.

ANTENNAE

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The groundplan insect antenna has three regions:

- scape
- pedicel
- flagellum, consisting of flagellomeres

Insect antennae serve two main functions:

- they are the site of a concentration of olfactory sensilla
- they are the site of auditory perception in many insects.

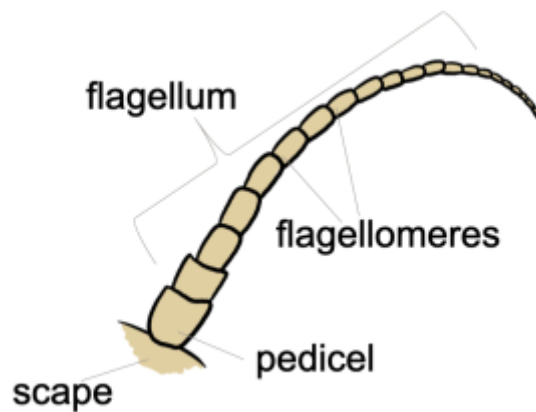
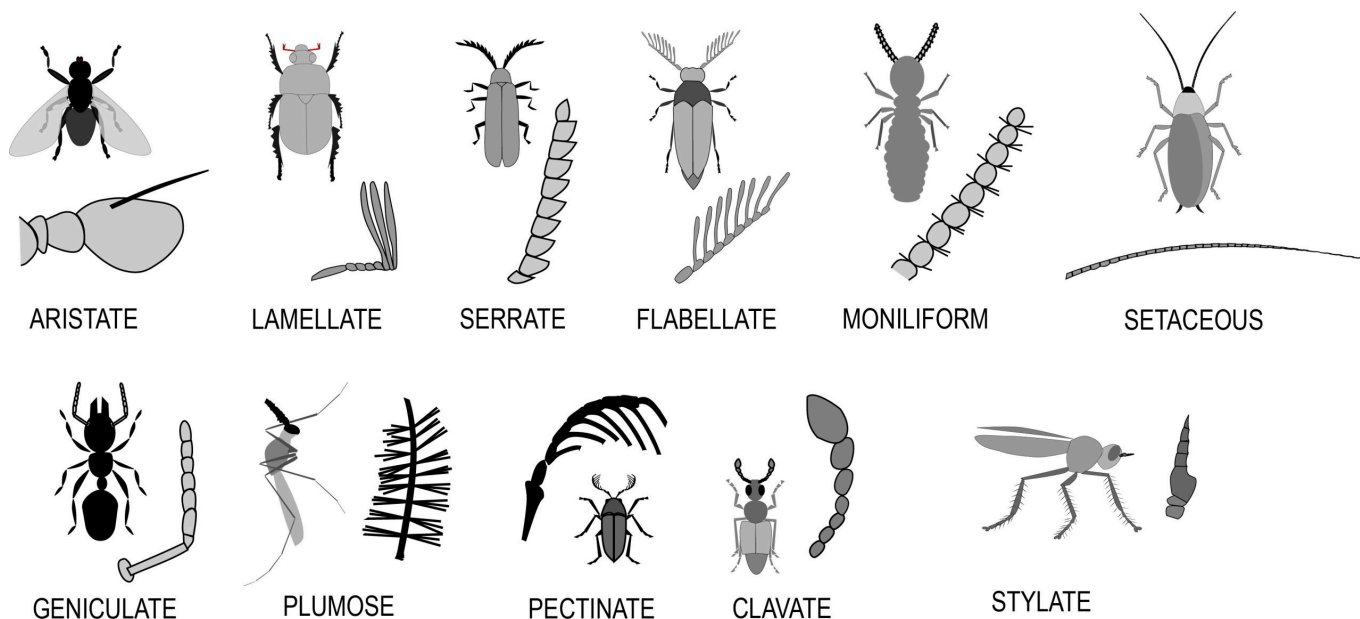


Diagram of the ground plan insect antenna.

In a similar way to the mouthparts, the design of the antennae depends primarily on the taxonomic group.



Variations of insect antennae, depicted in their many forms and sizes specific to different groups. [Image: [L. Shyamal](#), CC BY-SA 2.5, Wikimedia Commons].

Antennal shape	Description
Moniliform	like a string of beads
Filiform	thread-like
Aristate or stylate	first flagellomere is large; the remaining flagellomeres are modified to form an arista or a stylus; the arista is long, flexible and usually arises from the dorsal surface of the 1st flagellomere. The stylus is of variable length, inflexible and apical.
Geniculate	elbowed
Clavate or capitate	clubbed
Plumose	bearing whorls of long setae; feathery
Serrate	saw-like
Setaceous	bristle-like
Pectinate	comb-like
Flabellate	fan-shaped
Lamellate	arranged like plate stacked on top of each other

There can be major differences in antennal morphology between males and females, especially in Lepidoptera where some male moths have much larger antennae than females, due to a concentration of pheromone-detecting sense organs.

Like the mouthparts, antennae are evolutionarily derived from appendages. This is dramatically shown in some *Drosophila* mutants, in which changes in the regulatory region of a gene called *antennapedia* cause the antennae to become transformed into recognisable, but distorted, legs. This is evidence for homology between legs and antennae.



Bipectinate antennae of a male Antheraea sp.
(Lepidoptera) [Photo: [Yathumon M.A](#), CC BY-SA 4.0,
Wikimedia Commons].

THORAX

The groundplan insect has three thoracic segments (pro-, meso- and metathorax) with two pairs of wings: a pair on the mesothorax and a pair on the metathorax, plus three pairs of legs located on the **prothorax**, **mesothorax** and **metathorax**.

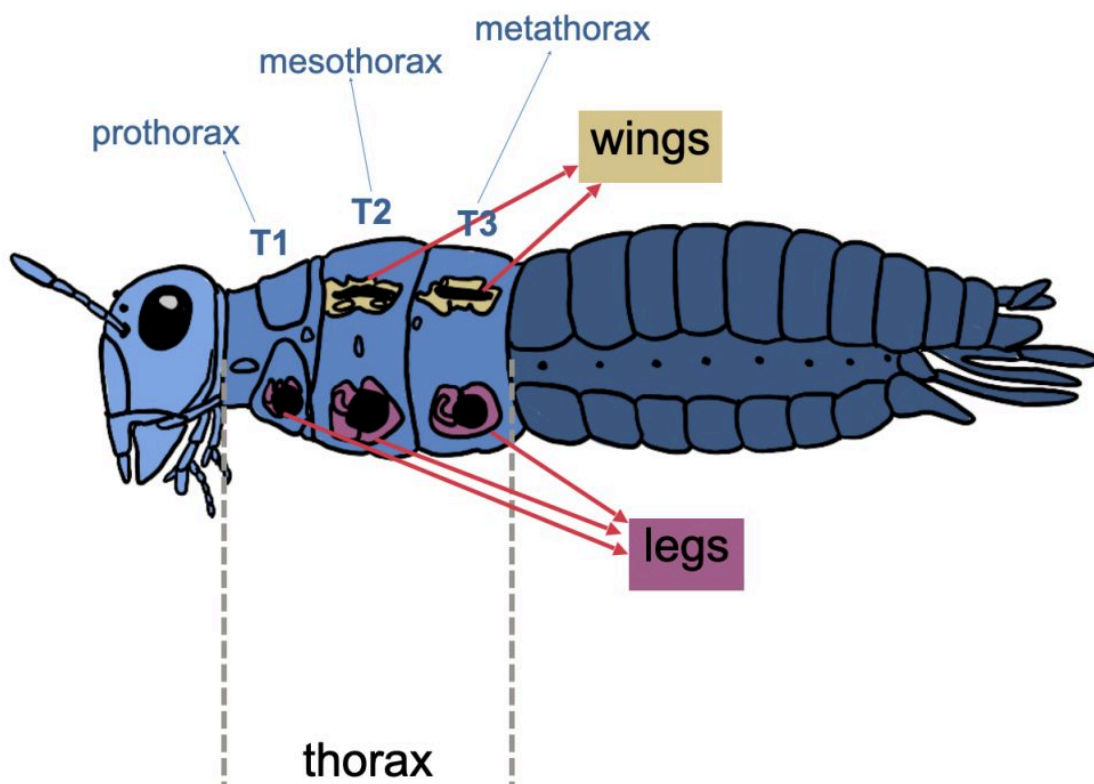


Diagram of generalised insect thorax

The wings are flattened cuticular sheets with very flattened epidermal cells between the upper and lower layers. Wings are living tissue, hence the wing veins provide haemolymph circulation (haemolymph is the insect equivalent of blood). Surprisingly, the wings are often covered with sense organs. The sensory axons run from the sense organ along the wing veins into the CNS.

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MODIFICATIONS OF WINGS

The wings can be highly modified. Once again, the modifications may be fundamental features of an order such as the elytra of beetles (Coleoptera) or the halteres of flies (Diptera). Or single species or species groups can modify the basic wing structure. For example some Diptera have evolved the loss of wings altogether in response to particular environmental features. The forewings have become modified in a number of taxa to lose their role in flight and become covers for the hindwings that take on the flight function.

Some modifications of the forewings are:

- forewings as protection for hindwings
 - **tegmina**, e.g. grasshoppers (Orthoptera), cockroaches (Blattodea)
 - **hemelytra**, e.g. bugs (Hemiptera)
 - **elytra**, e.g. beetles (Coleoptera)
- forewings as organs of equilibrium
 - **halteres**, e.g. Strepsiptera

Modifications of the hindwings are:

- hindwings as organs of equilibrium
 - **halteres**, e.g. flies (Diptera)
- some insects have lost the hind wings, e.g. female mountain cricket (Orthoptera)

Wings can be positioned in different ways in relation to the body axis: flat over the body (e.g. Cockroach), tent-like over the abdomen (e.g. Psocoptera) or at a right angle to the body (e.g. Odonata).

Some groups have become completely wingless. The fleas (Siphonaptera) dispensed with wings as they took on the parasitic lifestyle. In fact, a number of parasites have become flightless because they can transfer from host to host during host roosting, host reproductive activity and the bearing of young. The most likely reason is that the wings can get in the way when moving among fur and feathers and the dispersal ability afforded by flight became unnecessary when they could move from host to host during contact between hosts.

LEGS

The groundplan insect has 3 pairs of legs. The segments of the leg are:

- coxa
- trochanter

- femur
- tibia
- tarsus
- pretarsus

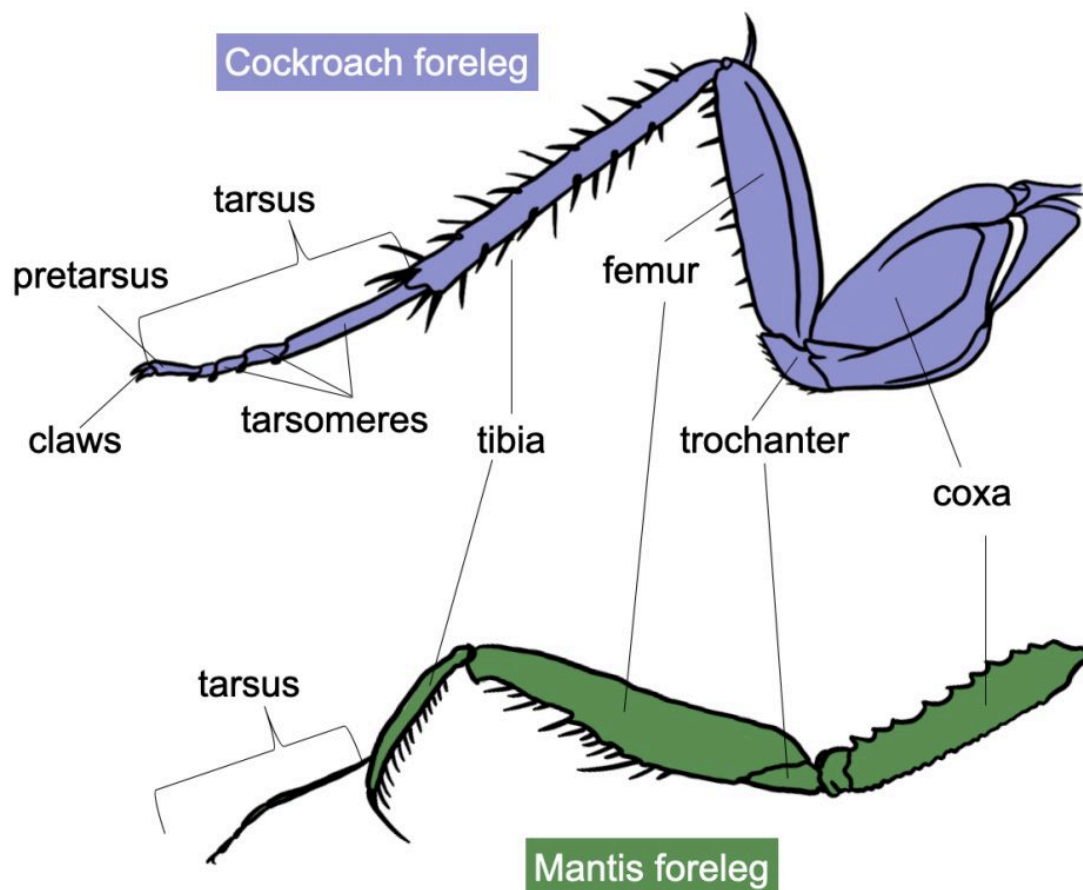


Diagram of the insect leg parts.

The leg segments are tubular structures with articulation points between segments. Internally, muscles and apodemes are present.

The legs are covered with **sensilla**, including

- proprioceptors
- touch receptors
- taste receptors

Leg type	Examples
Jumping (Saltatorial)	Grasshopper hind legs
Grasping (Raptorial)	praying mantis forelegs
Digging (Fossorial)	mole cricket forelegs
Swimming (Natatorial)	water beetles
Walking (Gressorial)	ants, terrestrial bugs
Running (Cursorial)	cockroach, tiger beetle
Climbing or clinging (Scansorial)	parasitic lice

ABDOMEN

The groundplan abdomen has 11-segments. Abdominal segments are usually more alike than, say, the thoracic segments. However, the terminal segments are usually modified for reproduction and sensing.

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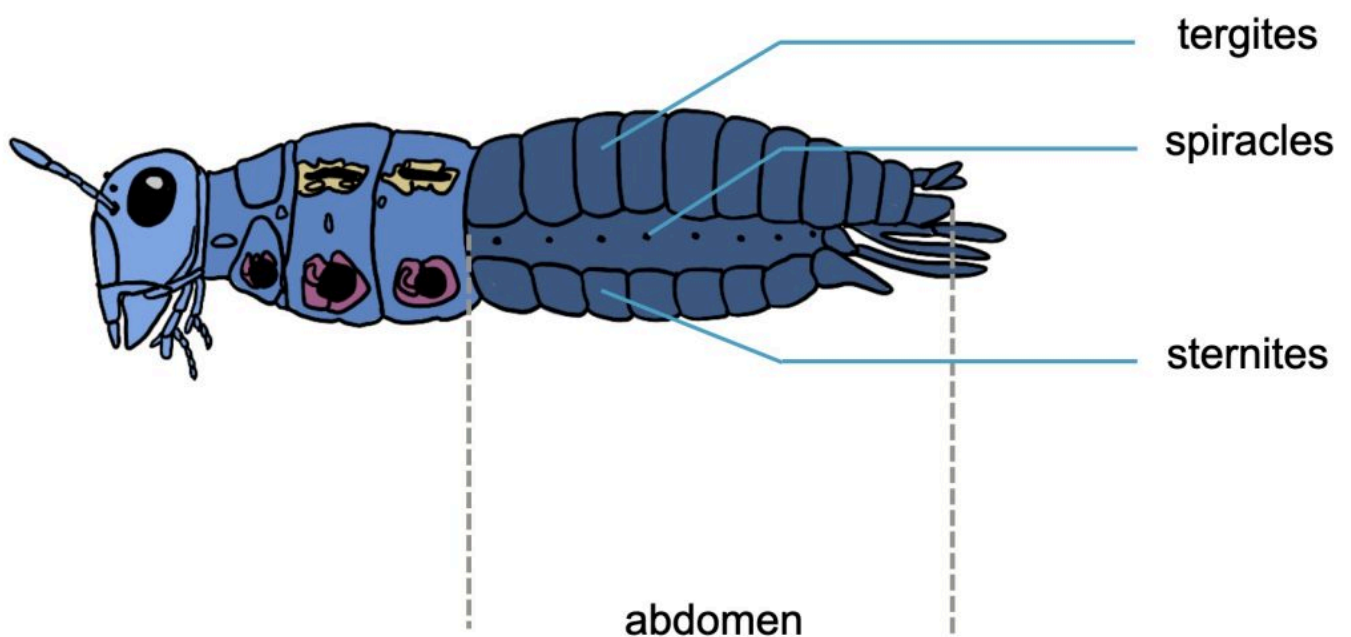


Diagram of a generalised insect abdomen.

ABDOMINAL APPENDAGES

Appendages (=terminalia) are located on the posterior segments. The genital appendages are on segments 8 and 9. A pair of appendages called cerci are often present on segment 11. Segment 11 bears a median appendage (appendix dorsalis) in some insects.

The external genitalia comprises the organs and appendages concerned with mating and egg laying that are located on the terminal abdominal segments. In females, the egg-laying tube is called the **ovipositor**. In males, the intromittent organ (penis) is frequently called the **aedeagus**. The word, **terminalia**, is often used for the sensory and mating related terminal abdominal structures.

ACTIVITIES

Activity 3.1: Determine some other sensory functions of insect antennae other than smell and sound mentioned here.

Activity 3.2: Describe how the wings of beetles and flies are modified from the insect ground plan and name the modified structures.

Topic Review

Do you know...?

- the make-up of the insect groundplan
- the names of the groundplan tagmata
- the names of the leg segments
- The names in anterior to posterior order of the thoracic segments?
- the names of the different types of antenna and legs?

Can you...?

- match the different types of antennae and legs to diagrams of the structures?
- List reasons why some mammalian parasites have lost the ability to fly?

CHAPTER 4

Insect Life Histories

A female tesseratomid bug guarding her eggs and nymphs [Photograph by Jessa Thurman. Used with permission].

We continue the theme of Chapter 3 but rather than identifying modifications of the groundplan, we identify modifications in the development of insects; their life histories (or ontogeny).

[THRD0023 012 \(YouTube, 2m 34s\):](#)



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Adult insects are (usually) the only stage that possess fully functional wings: the transition from an immature wingless stage to a mature adult is called metamorphosis. A fundamental division among insects is whether they are holometabolous or hemimetabolous. These different developmental approaches have impacted greatly on the way insects interact with their environment.

Learning Objectives

- Know the main types of metamorphosis

INTRODUCTION

One of the reasons for the success of insects is that they can fly. However, not all stages can fly, only the adult. Consequently the transition between the sub-adult and adult stage involves considerable growth and rearrangement of the body to accommodate the formation of the wings. This transition is called **metamorphosis**.

Remember from Chapter 2 that many orders of insects are within the infraclass **Pterygota**: they are winged. The pterygote insects can be further classified according to the mode of development of the wings. Most orders of pterygotes have wing buds that develop externally (**Exopterygota**). This appears to be the ancestral state for pterygotes, and therefore does not help to define a group of insects. In contrast, some insects have wings and genitalia that are internalised in the pre-adult stages. This derived trait defines the group called **Endopterygota**. This group used to be called Holometabola because it was thought to be defined by holometabolous development, but similar development also occurs in some of the other insects.

Holometaboly is undoubtedly a successful life strategy; it has been estimated that four orders of insects—the Hymenoptera, Coleoptera, Lepidoptera, and Diptera—include more than 45% of all known animal species.

- exopterygote (= outside wings) – wing buds develop externally
- endopterygote (= inside wings) – wings buds develop internally.

The **instar** is the name of the growth stage between moults. For example, midges have four larval instars as shown in the diagram below. It is important that we understand the terms for describing the life stages. The **stadium** is the period of time between moults. Immature stages are called nymphs or larvae. Usually “**nymph**” is used to refer to an immature hemimetabolous insect and “**larva**” refers to an immature holometabolous insect. In holometabolous insects, the quiescent phase is called the **pupa**. Common names include chrysalis (when referring to butterflies) and cocoon (refers to the protective structure surrounding the pupa; in moths, the caterpillar constructs it using silk excreted by glands).

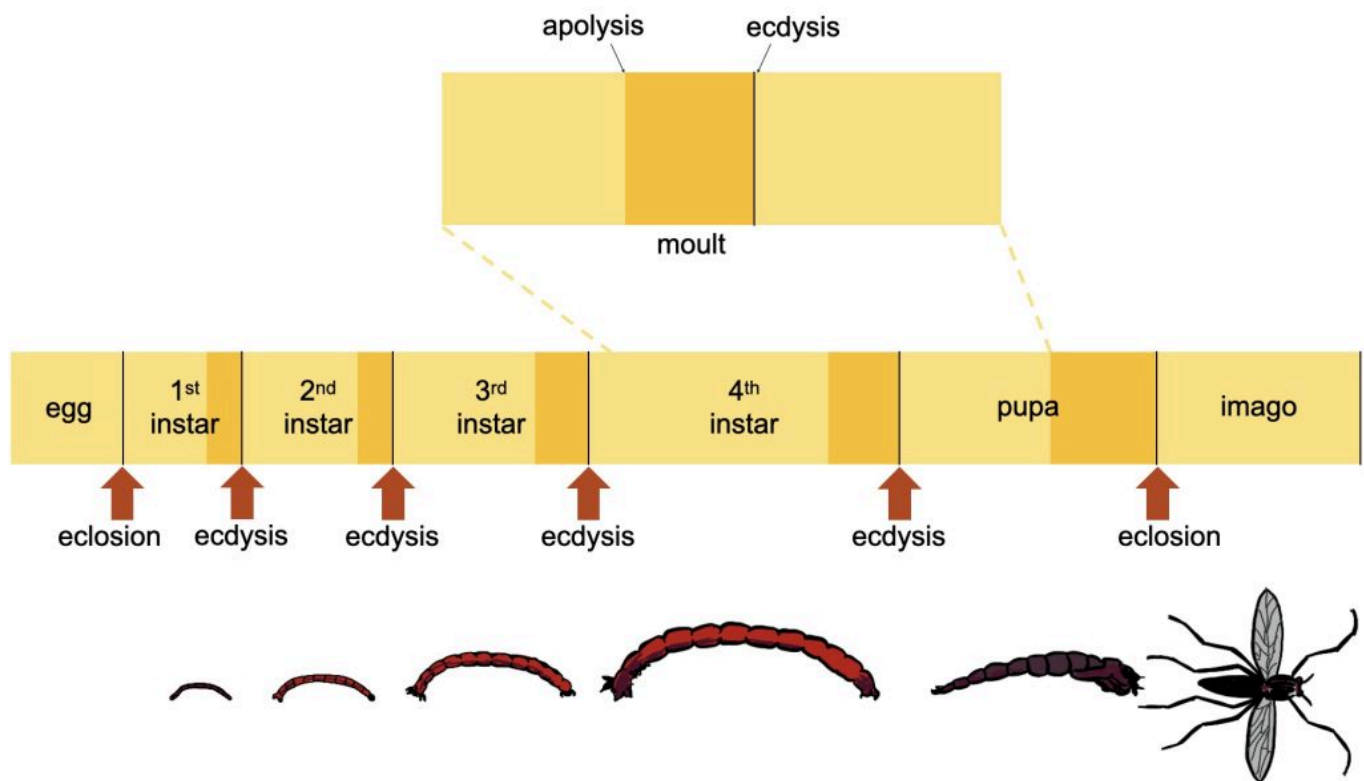


Diagram of a typical life cycle of a holometabolous insect, in this case a midge (Diptera: Chironomidae).

INSECT LIFE HISTORIES

AMETABOLY AND PROMETABOLY

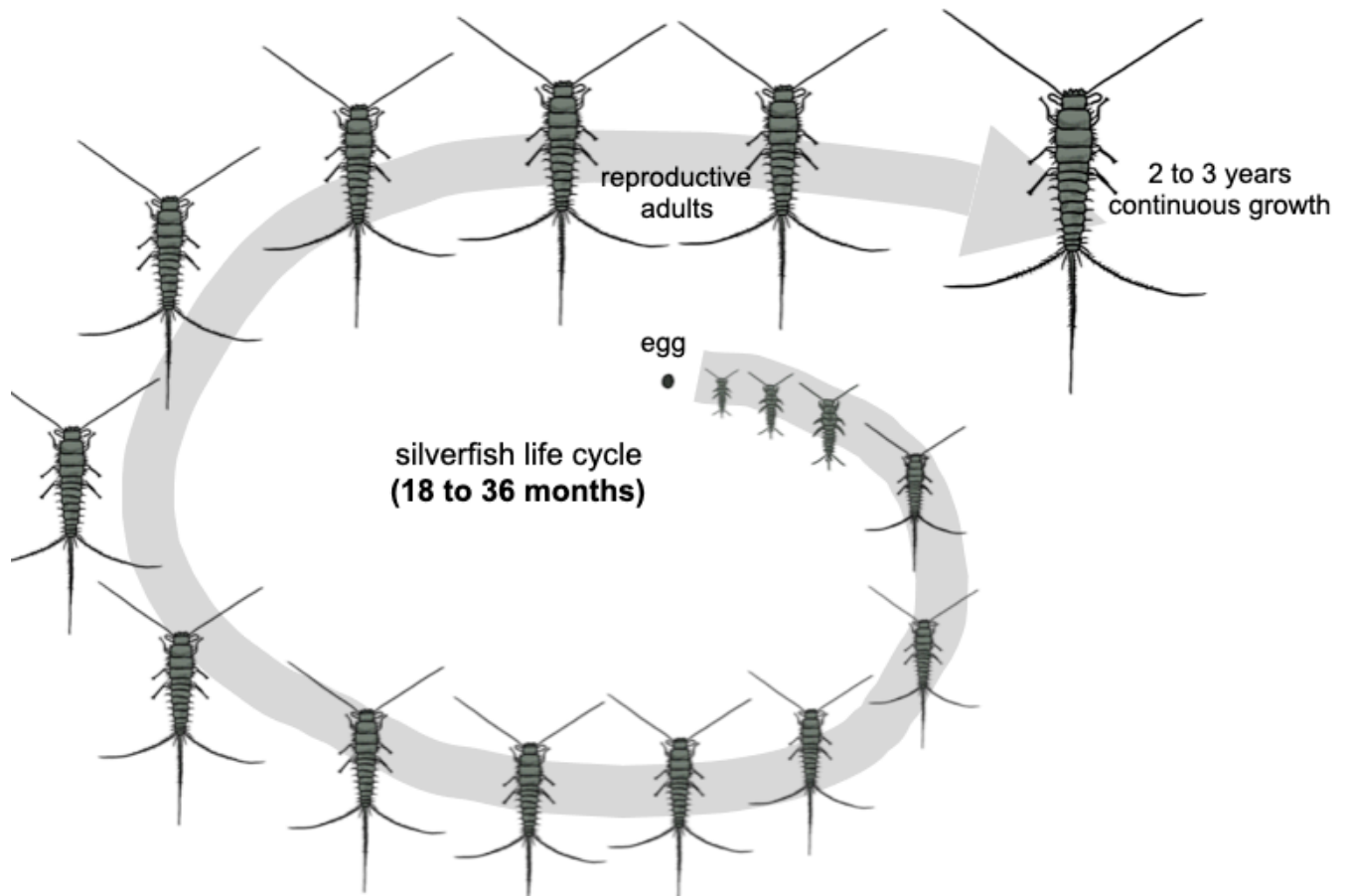
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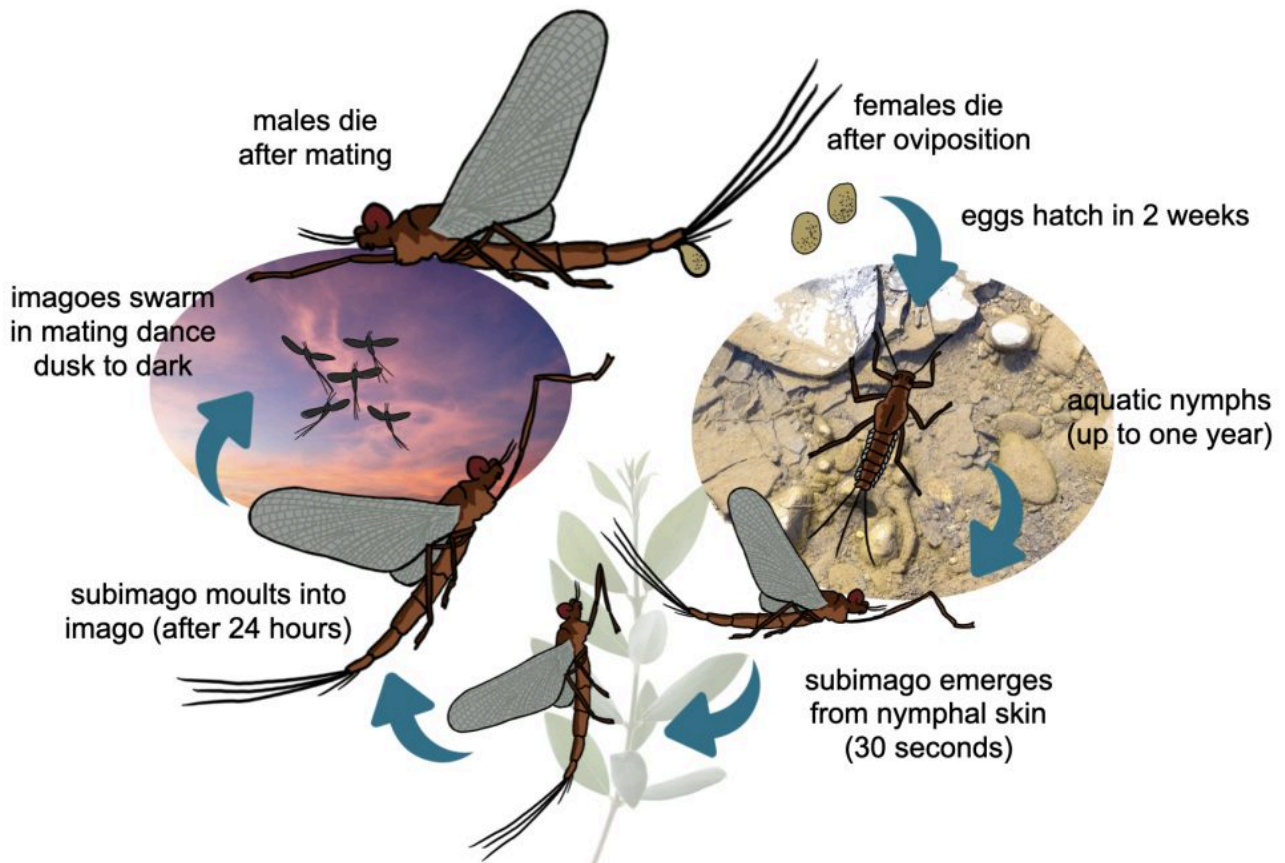
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The ancestral life-cycle. The hatchling resembles the adult. This condition is found in apterygote (wingless) insects, the silverfish (*Zygentoma*) and bristletails (*Archaeognatha*). The adults continue to moult after sexual maturity, making them different to the hemi- and holometabolous insects.



*Ametabolous life cycle in the silverfish (*Zygentoma*)*

Prometabolous development is found only in the mayflies (Ephemeroptera). This unusual condition involves two winged stages, the adult and the penultimate instar, termed the subimago.



Prometabolous life cycle of the mayfly (Ephemeroptera).

HEMIMETABOLY & HOLOMETABOLY

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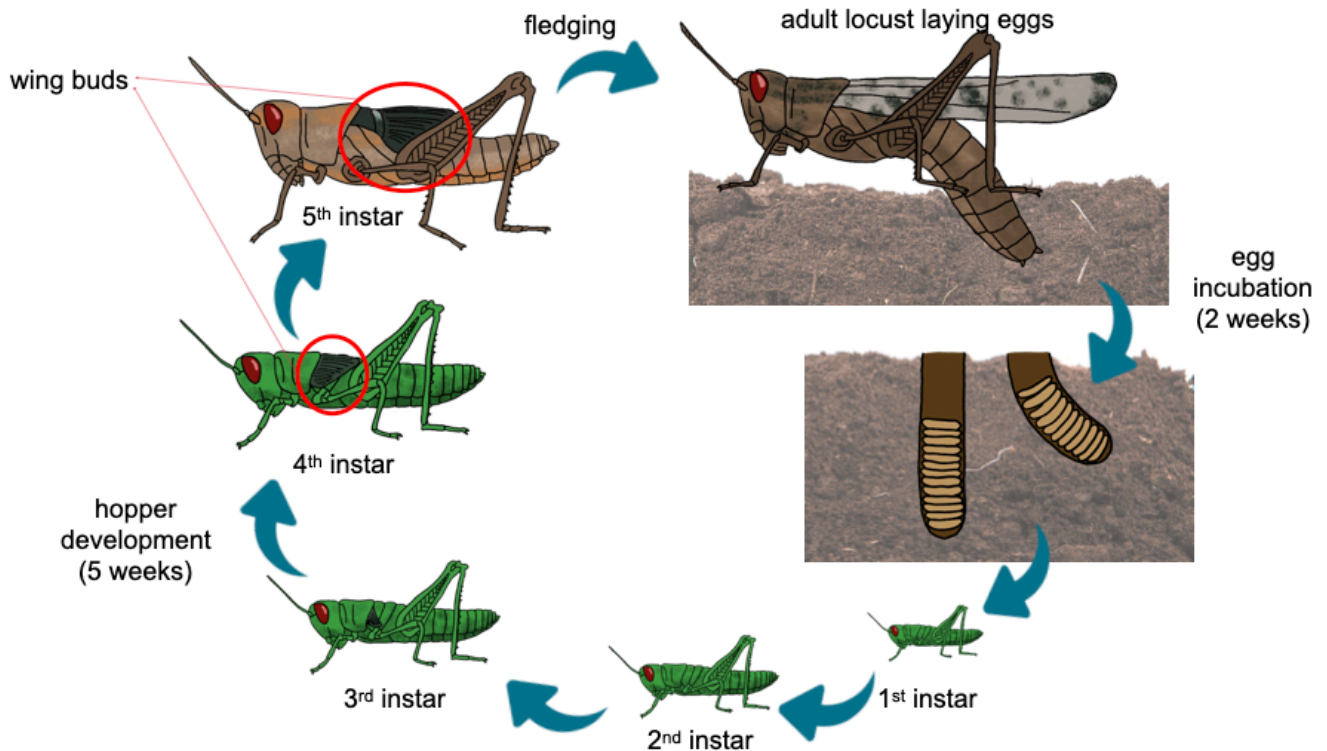
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In hemimetabolous insects, wings develop gradually as external wing buds. They become fully-formed at the adult stage (in the imago). The immature stages are called nymphs.

There are two types of **hemimetabolous** development:

1. Adults and immatures (nymphs) have different lifestyles and different habitats, e.g. adults are terrestrial; immatures are aquatic. Therefore adults and nymphs often look quite different and may possess different structures e.g. nymphs have gills. Examples include dragonflies (Odonata), mayflies (Ephemeroptera), stoneflies (Plecoptera).
2. Adults and immatures (nymphs) have similar lifestyles and habits and are terrestrial. Adults and nymphs look similar. Examples include the true bugs (Hemiptera), cockroaches (Blattodea),

grasshoppers (Orthoptera) and preying mantids (Mantodea).



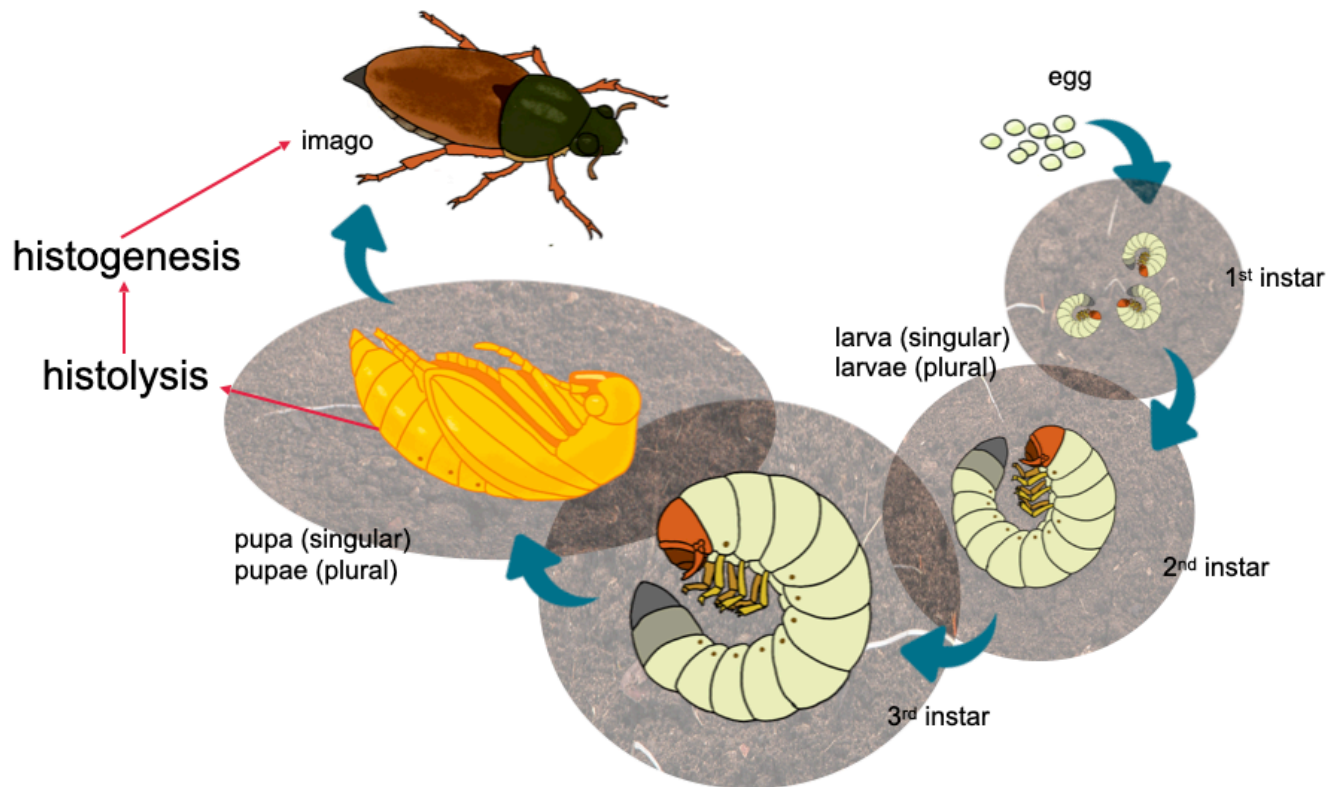
Hemimetabolous life cycle in grasshoppers (Orthoptera)

The most important difference between hemi- and holometabolous development is that holometabolous insects have a quiescent stage called the pupa. In the pupa the body form of the larva changes radically and the wings develop.

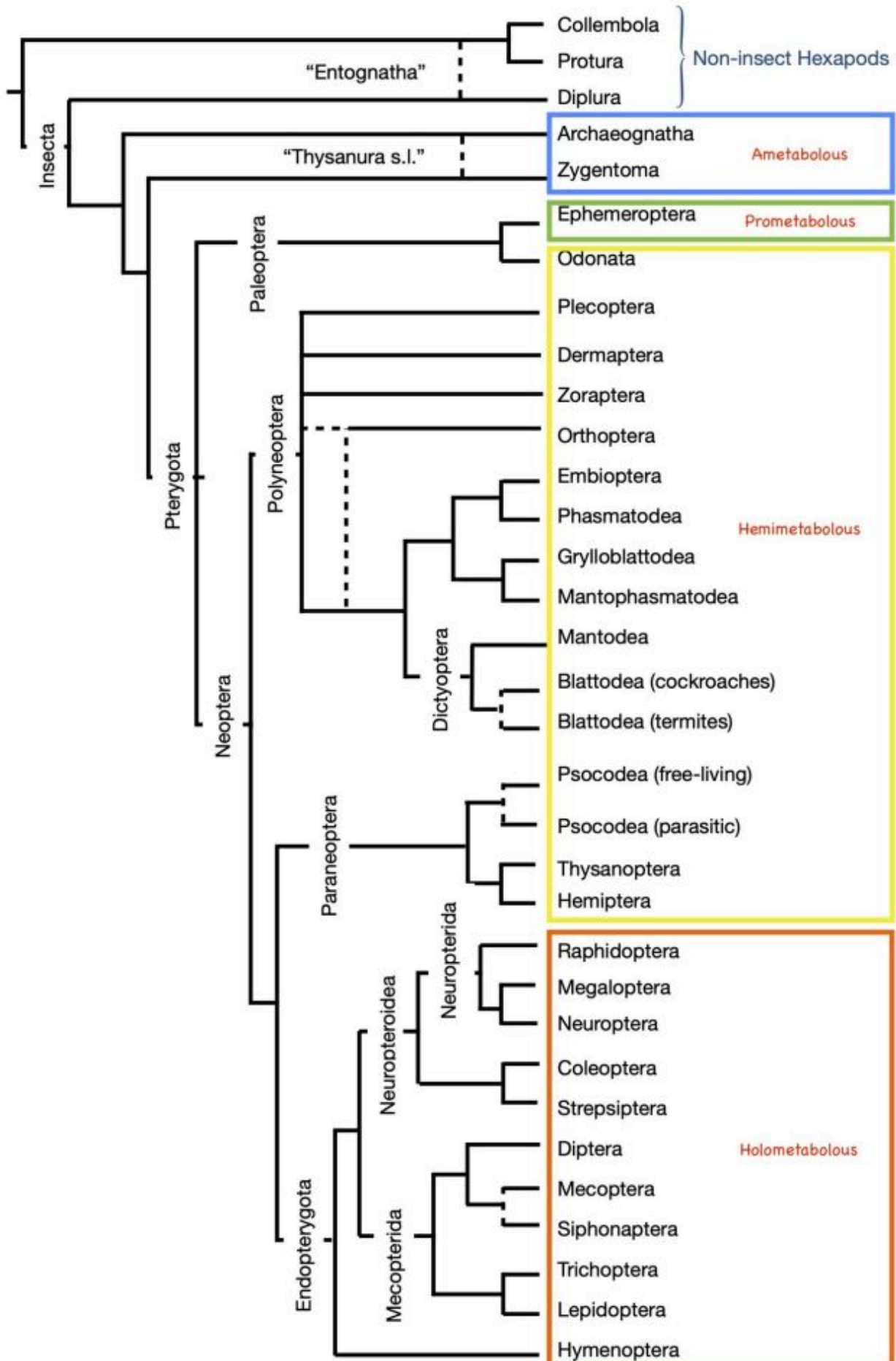
Three stages are present after the egg; the larval instars, the pupa and the adult.

1. The **larva** grows from instar to instar. Primarily, only size changes between moults. Importantly, no external wing buds are seen in the larva. They grow internally in the form of imaginal disks.
2. The **pupa** (penultimate instar) is generally inactive and concealed. Internally, histolysis of some larval tissues occurs and the new adult organs such as reproductive- and flight-related structures are developing internally.
3. The **adult** (final instar) possesses functional wings (usually), and functional reproductive organs such as mature eggs or sperm.

Examples of holometabolous insects include lacewings (Neuroptera), butterflies, moths (both are Order Lepidoptera), wasps (Hymenoptera), beetles (Coleoptera), and flies (Diptera).



A holometabolous life cycle in beetles (Coleoptera)



An evolutionary examination of life-histories in insects, with the most derived and modified orders being holometabolous. [Adapted from Gullan, P. J., & Cranston, P. S. (2009). The insects: an outline of entomology, 3rd edition (3rd ed.). Wiley].

Within the Holometabola, the most basic form of pupation is seen in the group Neuropterida, which includes the orders Neuroptera, Raphidioptera and Megaloptera. The pupa is not entirely inert and it doesn't have the same mummy-like appearance as pupae you might be more familiar with such as in the Diptera and Lepidoptera.

The pupa in Neuropterida is **exarate** and **decticous**. Exarate means the appendages are free of the body, not stuck to it, so in some cases the pupa is mobile. Decticous means the pupal mandibles are articulated, so they can move and chew. The **pharate adult**, i.e. the late-stage pupa, is mobile and, in many species, it breaks out of a cocoon and wanders to find an appropriate surface to eclose into the adult. This amazing capability of a pupa to walk and orient belies our concept of pupae as a mummy-like, completely inert stage. The early-stage pupa is inert as it undergoes histolysis and formation of adult structures; the late-stage pupa has the adult structures in place internally and it is able to move around.



Exarate pupa of a mantispid lacewing (Neuroptera)
[Photo: [James Dorey Photography](#), Used with permission.
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Past BIOL2205 student [James Dorey](#) discovered mass emergences of Mantispidae (Neuroptera) on a family *Macadamia* orchard in northern New South Wales. He recorded and photographed pharate adults emerging from underground and climbing tree trunks to undergo eclosion. He made a beautiful time-lapse movie of adult eclosion (see Chapter 6). Read the [complete paper](#).



An eclosing mantispid lacewing adult (Neuroptera: Mantispidae) [Photo: [James Dorey Photography](#), Used with permission. Shared under a [CC BY-NC 4.0](#) licence].

EVOLUTION OF LIFE HISTORIES

It is likely that early in insects' evolution, the immature stages resembled the adults, i.e. they were ametabolous. Read this [article](#) in *Scientific American* — it summarises a possible scenario for the evolution of holometabolous instars from the “pronymph” and gives a bit of interesting history about metamorphosis.

SOCIALITY IN INSECTS

In Chapter 1, we discussed different aspects of the biology of insects that could be used to indicate that they are a successful group. The sheer number of individuals and species, their ecological breadth and geographic distribution are all characteristics that indicate successful invasion of land (terrestrialisation).

The social insects are some of most successful groups of insects; they are present in large numbers, they are present in many ecosystems and they are widely distributed across the globe. Some social insects such as termites are very important pests and, conversely, others such as bees are among the most valuable commercial species.

First, let's define what we mean by sociality. Insects that show cooperative behaviours are regarded as being social. **Eusocial** insects (meaning *truly* social) show cooperative behaviours, partitioning of roles and concentration of reproductive effort on a subset of individuals. They are also referred to as colonial insects. The Hymenoptera have many eusocial groups; ants, bees and wasps. The termites, group Isoptera within order Blattodea, are also eusocial.



Brood comb and honey pots inside a native bee hive, Tetragonula sp. (Hymenoptera: Apocrita) [Photo: K. Ebert].

The specific traits of eusocial insects are:

1. a **caste system**, meaning different individuals have different roles;
2. **cooperation in reproduction**, meaning that individuals other than the parents help rear the young,
3. **overlapping generations** in the colony.

Subsociality is more difficult to define. It is present in a wider range of taxa and has arisen independently in many groups. Examples of subsociality include insects that aggregate and communicate with one another and insects that show parental care.

ACTIVITIES

Activity 4.1: Definitions of metamorphosis: Using dictionaries and other resources see if you can find two alternative definitions for metamorphosis. What other animal groups experience metamorphosis?

Activity 4.2: Differences in metamorphosis: Looking at the diagrams in the text, what differences can you see between hemimetabolous and holometabolous metamorphoses?

Activity 4.3: Wingless orders: Some orders of insects are wingless. Identify these orders and give reasons why you think they have become wingless.

Activity 4.4: Wing buds: Carry out a Google image search for cockroach. Some images will show adults, others nymphs. Can you distinguish between them? Can you see the wing buds of nymphs? Do the same search for jewel bugs. The adults might be harder to identify based on the presence of wings. Why?

Topic Review

Do you know...?

- The difference between a stadium and an instar?
- Reasons for the success of holometabolous insects How the circulatory system can interact with the respiratory system?
- Four types of metamorphosis
- The names of the juvenile and quiescent stages of insects
- A possible evolutionary scenario for the transition from hemi- to holo-metaboly?
- What eusociality means and the characteristics of eusocial insects.

CHAPTER 5

Insect Cuticle

A spiny forest katydid nymph, Phricta sp. (Orthoptera: Ensifera) [Photograph by Will Arnold. Used with permission].

The possession of a cuticular exoskeleton has a major impact on all aspects of insect biology. We take a closer look at the structure of cuticle and explore ways in which cuticle is modified to provide colours, camouflage, jumping ability and outright strength. Insects breathe by taking air into the body through internal tubes that are lined with cuticle.

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<https://uq.pressbooks.pub/insect-science/?p=132#oembed-1>

Learning Objectives

- Describe the structure and function of the insect integument
- Describe the types and functions of variations in cuticle composition and form
- Know the structure and function of trachea

STRUCTURE OF THE CUTICLE

The exoskeleton of insects is usually called the cuticle. The integument is a collective term that incorporates the single layer of cells below the cuticle called the epidermis plus the cuticle (cuticle + epidermis = integument). The cells of the epidermis secrete the cuticle.

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The cuticle has different zones (from the outside to the epidermis) which vary in chemistry and function. The procuticle may be differentiated into an endo- and an exocuticle. **Procuticle** is overlaid by an **epicuticle**. Dermal glands and wax filaments extend upwards through the cuticle.

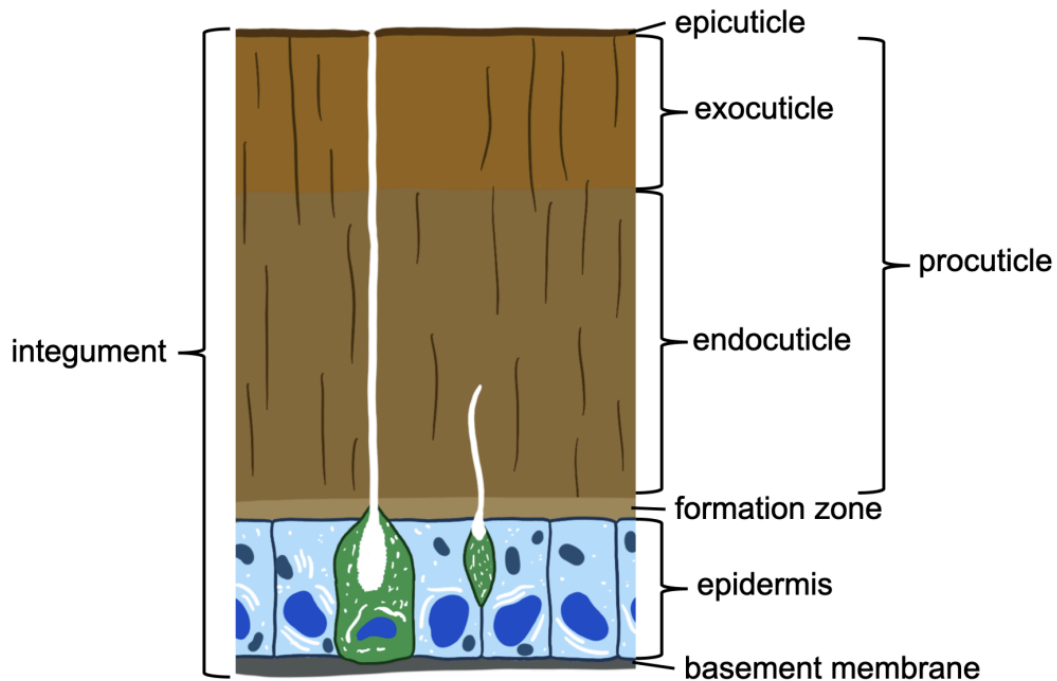


*Diagram of the insect cuticle: Epidermal cells are coloured light blue with dark blue. nuclei. Dermal gland cells are coloured green. [Adapted from Gullan, PJ & Cranston PS (2009). *The Insects: an outline of entomology* (3rd ed.) Wiley.*

The cuticle itself is made up of chitin microfibrils. **Chitin** is an unbranched amino-sugar polysaccharide. The chitin molecules form long fibrils which are embedded in and linked by a protein matrix.

The most common arrangement of the microfibrils is for them to be parallel to one another in sheets, with each sheet differing slightly in its orientation from the previous. This arrangement provides strength and retards fracturing.

FUNCTIONS OF THE CUTICLE/EXOSKELETON

The cuticle has a number of general functions. It can:

- provide a tough protective covering
- provide flexibility where needed
- reduce water loss through the presence of a waxy layer
- provide antibiotic properties and a barrier to invasion by microorganisms
- provide a rigid skeleton for attachment of muscles
- act as 'tools' for processes such as cutting (mandibles), grasping (claws), sticking to surfaces (pads at the tips of the tarsi), piercing (mouthparts), embedding (hooks on mouthparts).
- allow perception of the environment through the sensory system that transmits signals through the cuticle or through minute pores in the cuticle (the taste receptors)
- provide insulation through production of scales or hairs such as the many hairs seen on a bee.
- provide colour through surface sculpting such as the finely detailed architecture of the scales of iridescent butterfly scales

INTERNALISED CUTICLE

Parts of the gut, the internal respiratory system and the internal reproductive system are lined with cuticle. This cuticle is usually thin and unsclerotised. The structure of the gut is covered in another section.

MODIFICATIONS OF CUTICLE

Insect cuticle provides a model for artificial materials in an area of research called biomimetics. Biomimetic materials are artificial products that mimic the attributes of natural products, from plants or animals including types of insect cuticle. Some examples include:

- making flexible cuticle in the laboratory by first producing artificial versions of cuticle proteins and then cross-linking them to make a rubber-like material
- copying the structure of cuticular surface sculpting that produces the brilliant “interference” colours
- copying the cuticular structure of individual hairs that make up the “foot pads” (pulvilli) between the tarsal claws that allows flies to walk on the ceiling.

Keen to learn more?

Read about:

- [Antibacterial properties of nanopillars on cicada wings](#)
- [Using structure of black butterfly wing scales to improve solar panels](#)
- [University of Adelaide researchers using dragonflies as models for drone tracking](#)

SCLEROTISATION

Tanning, or **sclerotisation** as it is called, is an irreversible process involving proteins that darkens the cuticle. Protein chains become linked by phenolic bridges (quinone tanning). Water is excluded and the cuticle dries. The proteins in the cuticle become water-insoluble. Only exocuticle becomes sclerotised. The dark cuticle of an adult jewel beetle (Coleoptera) probably contains melanin whereas the lighter larval cuticle would not.

The black pigment, **melanin**, is often formed during sclerotisation. It is made from excess dopamine involved in the chemical process. Melanin, as well as contributing to sclerotisation and blackening of the cuticle, is useful in photon shielding (UV light protection) and as an antibiotic for insects.

Unsclerotised or poorly sclerotised cuticle is found in some larval insects and in intersegmental regions in adults where it can allow for bending and stretching. This is seen, for example, in honey pot ants (Hymenoptera) (Watch this David Attenborough [video](#) of honeypot ants in Australia!); scale insects (Hemiptera); abdomens of mosquitoes (Diptera) and other blood feeders; and in grub-like larvae that feed on plants.

Soft cuticle has about 50% each of chitin and protein where as stiffer cuticles have about 30% chitin and 70% protein.



Honey pot ants (Hymenoptera: *Myrmecocystus* sp.) with swollen abdomens full of nectar. [Photo: [Greg Hume](#), [CC BY 2.5](#), [Wikimedia Commons](#)].

ADDITIVES FOR STRENGTH AND FLEXIBILITY

Cuticle forms the anchor points for muscles. Cuticle can also be hardened and stiffened to perform specific functions such as the hardening of mandibles, claw tips and drilling ovipositors. Metals such as zinc, manganese and sometimes, iron can be incorporated into these specialised areas of cuticle. The transition metals always co-occur with halogens such as chlorine or bromine. It is thought that these metals and halogens are incorporated into proteins that help make the cuticle especially hard. For example, some termites with zinc in their mandibles have cutting edges 20% harder than termites without the metals. Leafcutter ants incorporate zinc into their mandibles and only start cutting leaves when the full complement of metal has been reached.



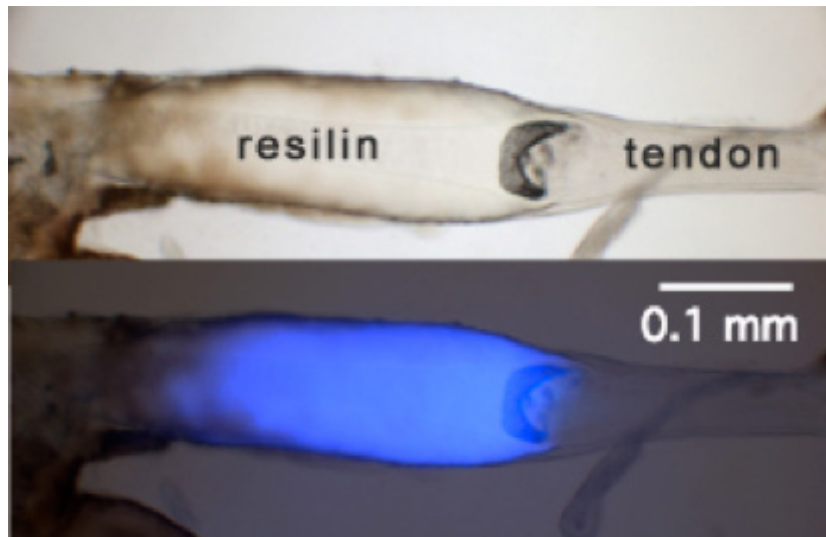
A leaf cutter ant (Hymenoptera: *Acromyrmex octospinosus*) [Photo: [ccpccp](#), [CC BY 3.0](#), [Wikimedia Commons](#)].

Insects also show true mineralization of the cuticle. Muscid flies (*Musca domestica* and *Musca autumnalis*) have a pupal case armoured with calcium. This appears to reduce parasitism presumably because wasps cannot easily drill through the outer casing to lay eggs within. Calcium has also been found in the cutting edges of some parasitic wasp ovipositors, as crystals of calcium carbonate in the body cuticle of some beetles and as amorphous calcium phosphate in the cuticle of the soil-burrowing predatory larvae of the primitive fly, *Exeretonevra angustifrons*. These are examples of true mineralization, similar in nature to the crab carapace.

THE ELASTIC CUTICLE PROTEIN, RESILIN

One form of insect cuticle is made up entirely of a protein called resilin. Resilin protein is highly hydrated which means it contains water. It has been isolated and manufactured in the laboratory and is the most efficient elastic protein known to mankind.

Resilin is found in and associated with joints and tendons of insects and in specialised patches that undergo repeated compression and stretching; it is the equivalent of an insect spring. The material can be bent and stretched for the life of the insect without wearing out. Because it shows a bright blue fluorescence under UV light it is easy to find. Patches are seen under the wings of dragonflies and in the legs of fleas and leafhoppers.



A resilin cord attaches a flight muscle tendon of a dragonfly to the cuticle of the thorax. It is viewed under the microscope illuminated with natural white light (top) and with ultraviolet light that produces blue fluorescence (bottom). [Image: D. Merritt © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

COLOURS AND CAMOUFLAGE

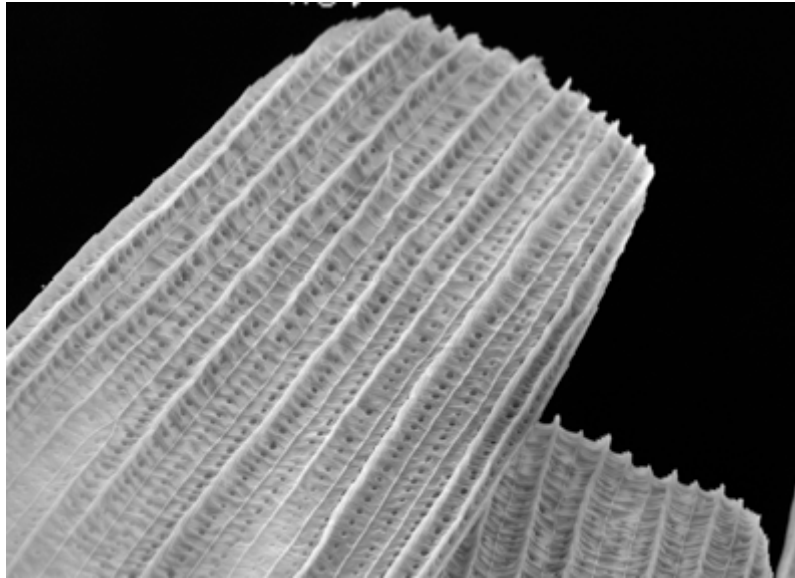
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The cuticle of insects is often brown or black but can be a range of colours as seen in butterflies, moths, lady beetles and the reds and golds of some jewel beetles. Colour is achieved through a number of mechanisms. Light waves can interfere with one another as they bounce off cuticle that has a grating or fine striation. Such colours are called **interference colours** and produce iridescence and ultraviolet colours. Butterfly and moth scales have such patterns.



Moth scales under the scanning electron microscope. The fine pits and grooves produce interference colours. [Images: BW Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/) licence].



A museum display of blue iridescent butterflies [Photo K. Ebert].

Colours can also be produced by **light scattering** that relies on the degree of cuticular roughness relative to the wavelength of impinging light. Whites are produced by structures larger than the wavelength of light whereas blues require irregularities that reflect only short wavelengths.

Another mechanism for producing colour is **pigment**-based. Chemicals with colour can be found in secretions onto the cuticle, within the cuticle, or in the epidermal cells or fat body. A range of chemicals are involved: carotenoids and flavonoids can produce yellows, tetrapyrroles provide reds, blues and greens, melanins produce blacks.



A well-camouflaged moth [Photo: K. Ebert].

RESPIRATORY SYSTEM (THE INTERNAL CUTICLE)

All insects must exchange gases with the environment, obtaining oxygen and releasing carbon dioxide. The insects' respiratory system is not based on lungs but on passage of air through cuticle-lined tubes. At the finest branches of this tubular system the cells harvest the oxygen. The respiratory system of insects is a discrete system known as the **tracheal system**. The trachea are cuticle-lined tubes that ramify within the insects body, carrying oxygen and carbon dioxide inside the tubes. They link to the atmosphere via spiracles.

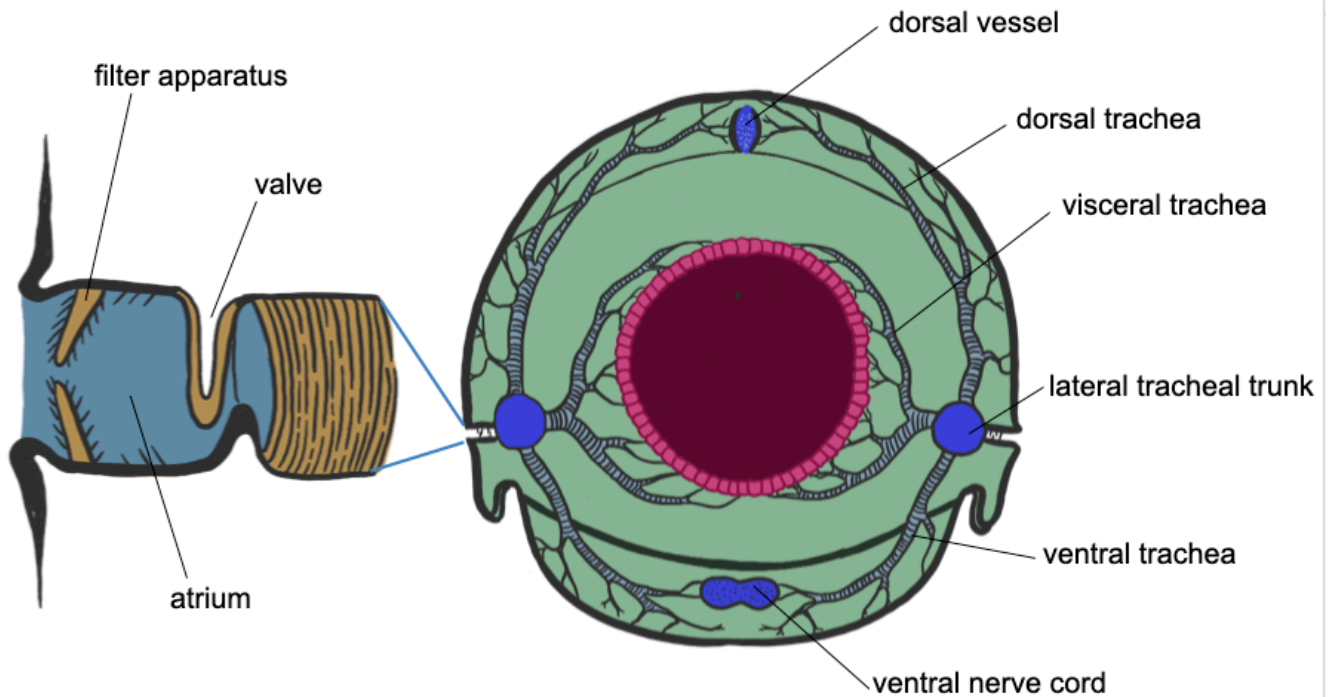
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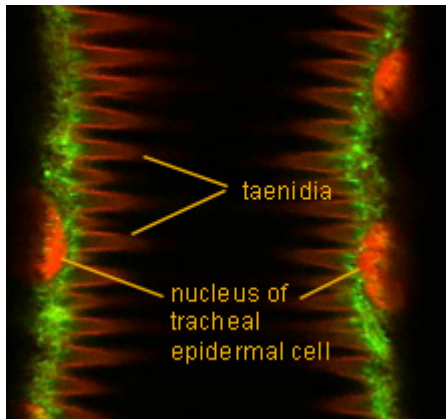
Body movements help flush air through the tubular system (convective ventilation); however, passive diffusion over a concentration gradient is the mechanism for removing CO₂ and supplying O₂ near the cells.



*A cross-section of a typical insect segment showing the arrangement of trachea. The main lateral tracheal trunks are present on each side. Branches run to the major organ systems. [Adapted from Gullan, PJ & Cranston PS (2009). *The Insects: an outline of entomology* (3rd ed.) Wiley.*

The trachea open through ports in the exoskeleton called spiracles. Spiracles of some insects are able to be opened and closed to allow water conservation and to create a directional flow through the tracheal system. Some spiracles may be surrounded by cuticular modifications such as valves and they sometimes have an atrium just inside the opening.

The longitudinal tracheal trunks are the main components of the ventilation system, connecting each segment and sending off branches into the tissues and organs of each segment.



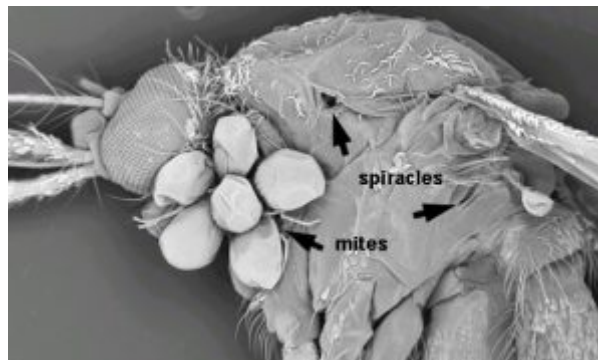
Confocal microscope image of an insect trachea. The taenidia jut into the inner air-filled lumen of the trachea. The cells that secrete the cuticular lining are highly flattened, surrounding the tracheal tube. The nuclei are stained red in this image [Image: D. Merritt © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

Spiracles are the holes in the body wall that allow gaseous exchange with the external environment. Primitively, each main thoracic and abdominal segment has a pair of spiracles but this plan is modified in more derived groups; many insects have fewer than ten spiracles. Spiracles are rarely as simple in structure as a pore or hole. They may have opening and closing mechanisms and may have complex structures that prevent entry of dust and tiny mites. Spiracles allow for gaseous exchange but can also allow water loss or the opposite, drowning. Survival strategies on land involve regulation of opening to the minimum time needed for oxygen exchange. To see how aquatic insects deal with respiration, go to Chapter 11.

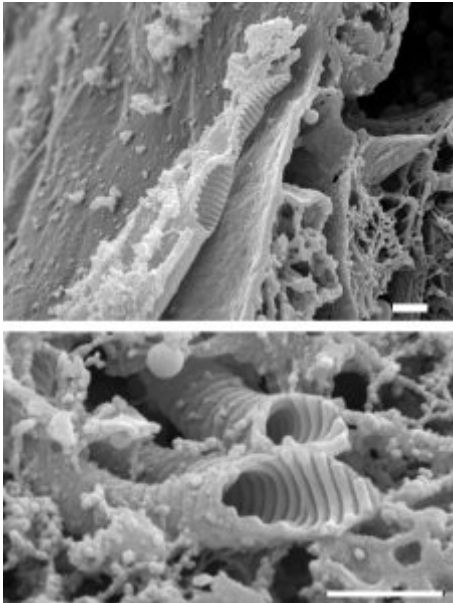
While **trachea** are the main air tubes, the **tracheoles** are fine branches of trachea that spread into contact with individual cells.

Taenidia are spiral ridges or thickenings of cuticular lining of tracheae. They provide flexibility and resist collapse, similar to the function of the rings in a vacuum cleaner hose.

Air sacs are dilations of trachea that have a whitish appearance within the body cavity. They are most developed in the most active insects, e.g. fast fliers, where muscle activity compresses and expands the sacs, leading to active ventilation



Mosquito spiracles. Arrows point to the large openings (spiracles). This mosquito was imaged under the scanning electron microscope to investigate the cluster of mites attached around its neck region. [Image: B. Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].



Scanning electron micrographs of tissue that has been frozen and cut to reveal the trachea and taenidia on their inner surface. The scale bars are 1 μm . [Image: B.Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

ACTIVITIES

Activity 5.1

What are the advantages of being able to seal off the tracheal system from the outside environment?

Activity 5.2

Look up the meaning of **apneustic** in reference to some insect respiratory systems. What characteristics of the cuticle would apneustic insects have?

Activity 5.3

The table below lists terms for standard insect spiracle patterns. Look up the meaning of each one, make a note of the pattern it describes and give an example insect with that pattern.

Spiracle pattern	Thoracic spiracles	Abdominal spiracles	example insect with this pattern
polypneustic			
holopneustic			
hemipneustic			
amphipneustic			
propneustic			
peripneustic			

Activity 5.4

Watch [Next Level Camouflage \(YouTube, 1m 04s\)](#) showing an extreme form of insect camouflage: a Lichen Katydid (*Markia hystrix*, Family: Tettigoniidae), from Costa Rica.

Topic Review

Do you know...?

- the effect of protein additives on cuticle mechanical attributes
- the function of the trachea
- the difference between a trachea, a tracheole and a spiracle
- Can you draw a diagram of the integument, naming the main types of cuticle?

CHAPTER 6

The Challenge of Moulting



A newly moulted cicada (Hemiptera: Auchenorrhyncha) [Photo: K.Ebert].

To grow, insects must moult. Moulting imposes major restrictions on insects: a new cuticle has to be formed under the old before it is cast off, and insects are immobile for a while after each moult and exposed to predation. We examine the complex hormonal processes involved in moulting and through the use of videos, we look at how insects moult.

Learning Objectives

- know the terms used to describe the moulting process
- be able to describe the basic cuticular and hormonal events associated with moulting
- understand the relevance of moulting to the success of insects
- be aware of how the developmental rate of insects varies with temperature

THE PROCESS OF MOULTING (ECDYSIS)

The life histories of insects are many and varied, however they all reflect the need to moult to grow. Insects grow in discrete steps. In some insects the cuticle is rigid while in others—the soft-bodied insects—it can stretch.

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The majority of insects cannot grow in between moults because the cuticle doesn't allow for expansion, especially in the head and thorax. It is relatively easy to determine what stage a nymph is at from its overall size. On the other hand, larvae of holometabolous insects can be harder to "age" because the cuticle can be softer and the body might expand through the instar. However, the size of the head capsule is a useful indicator of instar because it is sclerotised and does not change in size through an instar.

Hormones control the timing of the moult cycle and the progression through the life-history phases.

The moult cycle is a continuous, ongoing process that terminates only after adulthood is reached. It involves the following steps, progressing clockwise in the diagram:

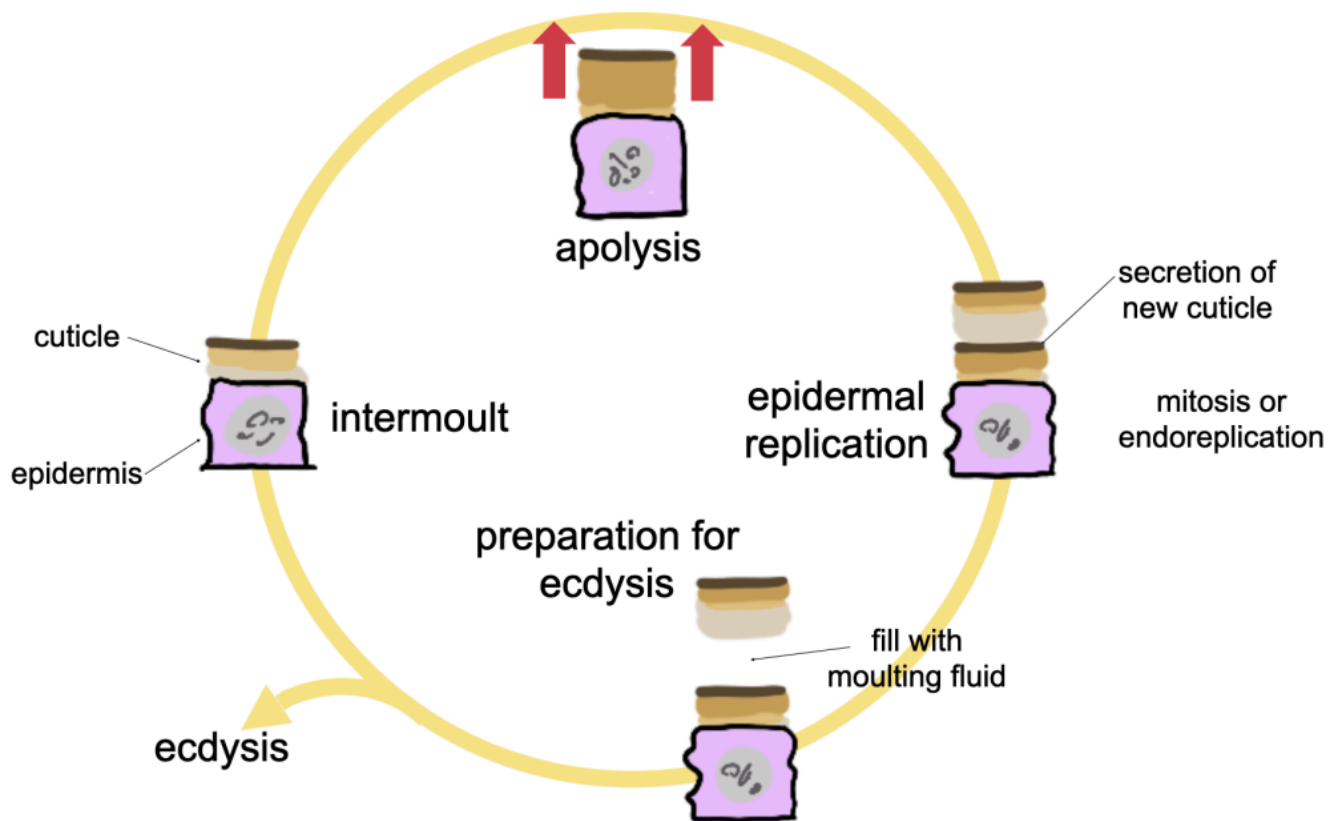


Diagram of the moulting cycle.

- **Apolysis** – The old cuticle separates from the new cuticle so the insect has two cuticular layers. Often we are not aware that an insect is at this stage (called the pharate stage, for example a 2nd instar larva that has undergone apolysis is called a pharate 3rd instar: think of pharate as meaning “in hiding”). Caterpillars undergo a stage called head slip that indicates they are pharate.
- Epidermis **replication** by mitosis. This is the stage at which the number of cells increases.
- Secretion of **moulting fluid** and digestion of the inner layer of cuticle. Digestion allows recycling of nutrients.
- **Secretion** of new cuticle
- **Ecdysis** is the physical removal of the old cuticle. It is the most visible part of the moult cycle. Immediately after ecdysis an insect is at a vulnerable stage as locomotion is compromised and the body is soft and flexible. On eclosion, the wing epidermal cells change shape from cuboid (rounded) to squamate (flattened). The wings appear to inflate. Stereotyped behavioural steps are needed to release old cuticle, split the old cuticle along lines of weakness (called sutures) and extract the legs and abdomen. Shivering and pulsating muscular activity is often seen. Usually, a dorsal midline split in the thorax is the main point of emergence from the old cuticle. The adult ecdysis is the most challenging because the wings have to be extracted from the wing buds and allowed to expand and harden. The cast-off cuticle is called an **exuvium**. The tracheal linings are extracted as well. The intermoult period is the longest duration component of the moult cycle.

HORMONES INVOLVED IN MOULTING

[THRD0023 020 \(YouTube, 5m 12s\):](#)



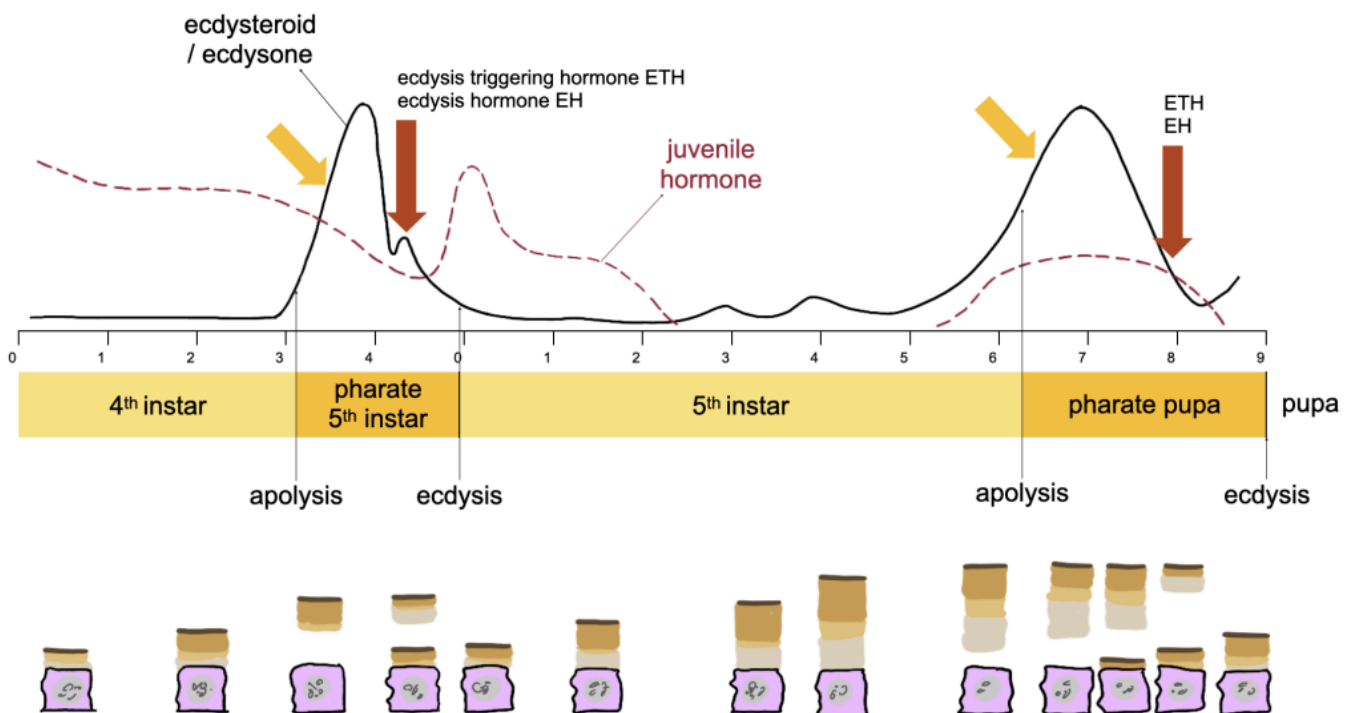
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Hormones control the timing of the moult cycle and the progression through the life-history phases. One of the hormones involved in moulting is juvenile hormone (JH). The level of JH dictates the stage identity at the next moult. Lack of JH at the last moult results in an adult. JH is secreted by neurosecretory cells of the brain, located in a section called the **corpora allata**.

Eclosion hormone (EH) and ecdysis-triggering hormone (ETH) are the two main **ecdysteroid hormones** involved in regulation of moulting.

Prothoracicotropic hormone (PTTH) is released by the activity of neurosecretory cells in the brain. This hormone acts on the prothoracic gland, causing it to produce a pro-hormone, ecdysone, that is then changed into the active eclosion hormone, 20-hydroxyecdysone.



Levels of moulting-associated hormones and the progression through apolysis and ecdysis in the tobacco hornworm caterpillar.

[Adapted from Gullan, PJ & Cranston PS (2009). The insects: an outline of entomology, (3rd ed.) Wiley.]

RATES OF DEVELOPMENT

As poikilotherms, the developmental rate of insects depends on temperature. It is important in pest monitoring to be able to predict future pest problems based on the temperatures experienced over the preceding days. It is important in forensic entomology to estimate the time at which eggs were laid on a corpse

derived from the stage of the maggots collected and the temperatures experienced since oviposition. Each species has a minimum and a maximum threshold temperature below and above which development ceases.

The method used to determine developmental rates is called a day-degree method. It is based on estimating the accumulation of “heat units”. In the laboratory, the species under investigation is reared at a range of constant temperatures. The upper and lower temperature thresholds are then estimated. Temperatures recorded at the site itself are then used to estimate the accumulated heat units and relate to the expected rate of development of the insects.

Interesting Facts

- Insecticides have been developed that target the moulting hormones: they are non-toxic to vertebrates as we don't moult! They are called insect growth regulators (IGRs). Methoprene is a common IGR used for flea control.
- What instar caterpillar? Measurement of head width is generally used as a reliable indicator because the head capsule cuticle is hardened whereas the body is relatively flexible. Read more in [Morphology and Morphometry of *Aedes aegypti* Adult Mosquito](#).
- To maintain sensitivity of the sensory system between apolysis and ecdysis, the neurons of the sense organs run through the moulting fluid space.

ACTIVITIES

Activity 6.1

Watch this [time-lapse video of mantispid lacewing \(YouTube, 1m\)](#) (Neuroptera) eclosion. The video was taken by Dr [James Dorey](#), a former BIOL2205 student! Note the position of the wings once they have become fully expanded.

Activity 6.2

Look up the meaning of the cuticular structures called “acarinarium” and “mycangium”. What are their functions?

Activity 6.3

Here are more videos that illustrate and further explain the moulting process:

- Watch these moulting videos from Texas A&M university:
 - [Insect integument: structure and moulting \(YouTube, 8m 53s\)](#)
 - [Cuticle degradation & reformation during insect moulting \(YouTube, 2m 58s\)](#)
- Watch a stick insect moult: [\(Questacon video, 55s\)](#)

Topic Review

Do you know...?

- The names of the main hormones that regulate moulting
- The stages of the moult cycle?
- The difference between apolysis and ecdysis?
- Why insects are vulnerable around the time of moulting?
- The locations of the glands that release juvenile hormone and prothoracicotropic hormone?

CHAPTER 7

Sensory and Motor Systems



Australian native cockroach, *Polyzosteria mitchelli* (Blattodea) [Photo: Fred and Jean Hort, [CC BY 2.0](#), Wikimedia Commons].

For relatively simple organisms, insects can carry out some incredibly complex flight manoeuvres. We begin to explore the way insects regulate such complex behaviours. First, we see how insects sense external stimuli through the cuticle, then we examine the organisation of the central nervous system. Finally we touch on some of the complexities of insect locomotion.

Learning Objectives

- the diversity of sense organs possessed by insects
- the role of the central nervous system in integrating sensory input and regulating motor output
- how insects have evolved an auditory sense based on the ability of chordotonal organs to detect vibration

SENSORI-MOTOR SYSTEMS

[THRD0023 021 \(YouTube, 3m 41s\):](#)



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A key to success of insects, mentioned in topic 1, is the ability to fly and the possession of a sophisticated sensori-motor system. Here we will explore the diversity of insect senses, the structure of the sense organs and the way sensory and musculature systems combine to permit sophisticated flight and walking control.

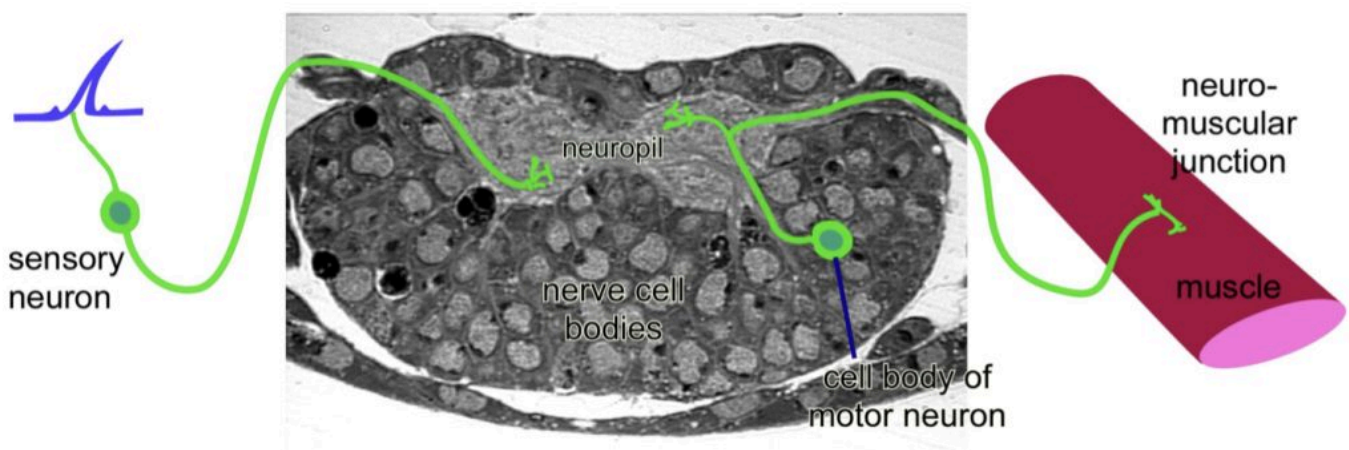


Diagram of a sensory neuron and motor neuron. Sensory integration occurs in the neuropil where synapses are present. [Image: D. Merritt © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

Insect sense organs tend to be concentrated into areas that specialise in sensory perception. The head with the eyes, antennae and mouthparts is one such area. Other sense organs can be found concentrated on the legs, wings and general body surface. Sense organs are usually situated on the cuticle because this is where the stimuli are encountered. The cell bodies of sensory neurons sit immediately under the sense organ itself and their axons run along nerves into the central nervous system (CNS).

CENTRAL NERVOUS SYSTEM (CNS)

The insect central nervous system is composed of a string of segmental units called ganglia. The brain is a fusion of multiple ganglia, located in the head.

The original pattern of ganglia in the ancestral state was probably one ganglion per segment with an ancient fusion of ganglia to form the brain. Commonly in insects, the thoracic ganglia are fused, probably to speed up neural signalling over shorter distances allowing the complex integration of sensory and motor information needed for the regulation of flight and walking. There are different degrees of fusion of ganglia in different groups, indicating that there is a groundplan for each group. In the Diptera, each family seems to have the same degree and type of fusion.

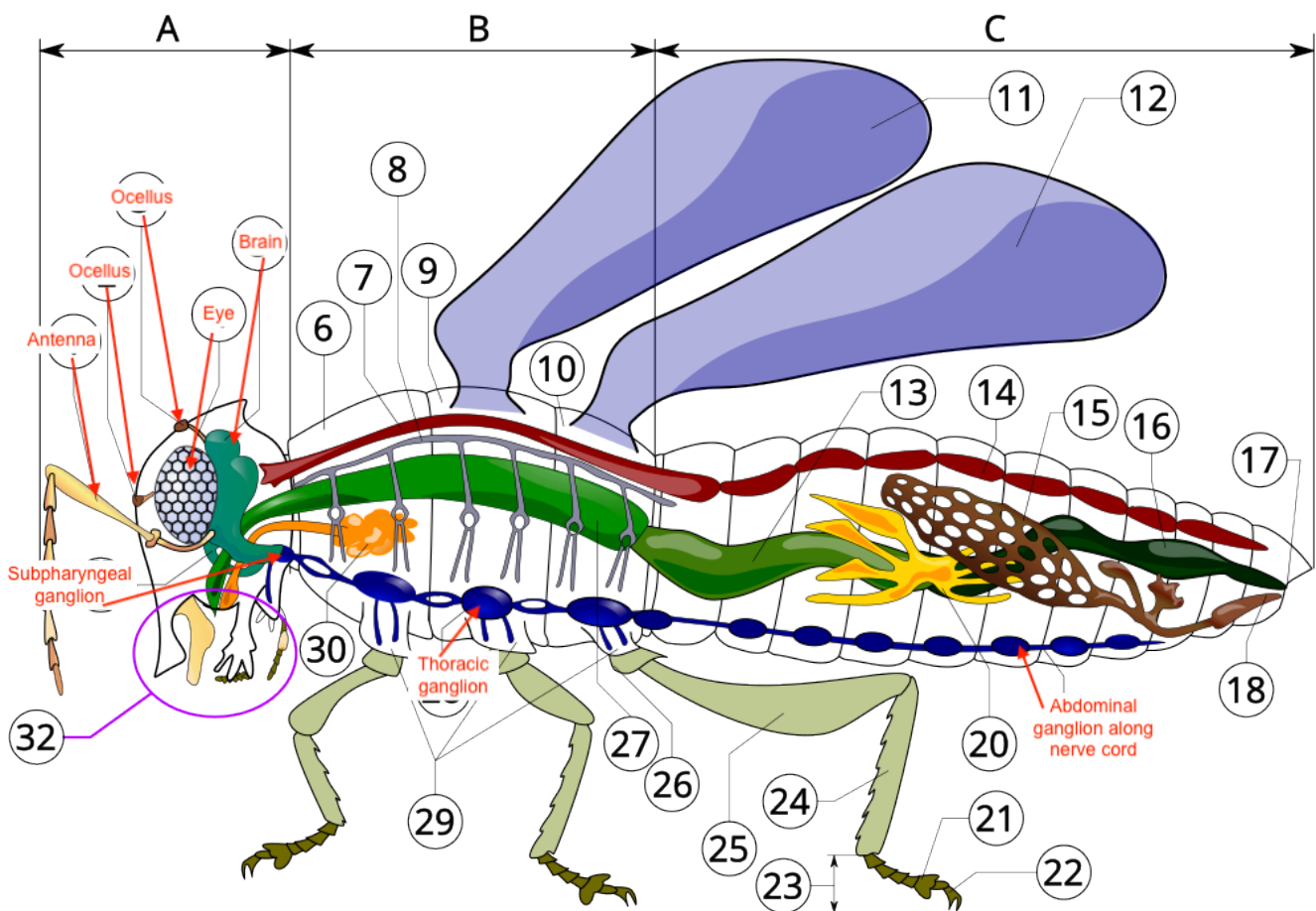


Diagram of an insect with elements of the central nervous system (CNS) or sensory system labelled (red). Shared under a [CC BY-SA 4.0](#) licence. [Image adapted from: [Insect anatomy diagram](#) by Piotr Jaworski, [CC BY-SA 3.0](#), Wikimedia Commons].

Much of the brain is taken up with neuropil associated with integration of sensory information: the optic lobes (vision) and the olfactory glomeruli (olfaction).

Types of senses	sense organs	location
vision	eyes, ommatidia, stemmata, ocelli	head
touch	tactile hairs, campaniform sensilla	all over the body; concentrated on legs
taste	gustatory hairs and pegs	mouthparts, wings, ovipositor
smell	olfactory sensilla	antennae
hearing	chordotonal organs	Johnston's organ, other locations
nociception (injurious stimuli)	multidendritic neurons	side of body wall
heat and cold	various hair-like sensilla and some internal multidendritic neurons	antennae

VISION

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Note that flying insects usually have sophisticated vision. The **compound eyes** are made up of many individual ommatidia, clustered together in a highly structured hexagonal matrix. The outermost cuticle is transparent, allowing light to penetrate inward into the light-receiving (photoreceptive) cells, called retinular cells or photoreceptor cells. Each ommatidium has 7 of these sensory neurons.

Compound eyes are found in adults and nymphs. They are the major organs of sight. They focus light and consequently form images.

Ocelli are found in adults and nymphs. Most adult insects have a cluster of ocelli between the compound eyes. They do not focus light and cannot form images; however, they are very sensitive to changes in light intensity.

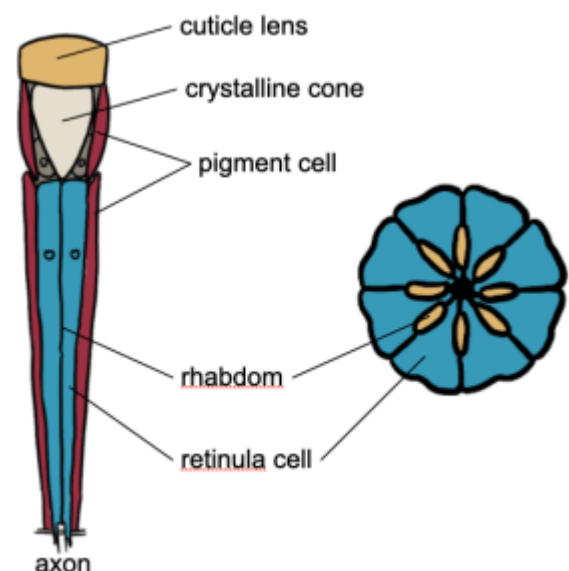
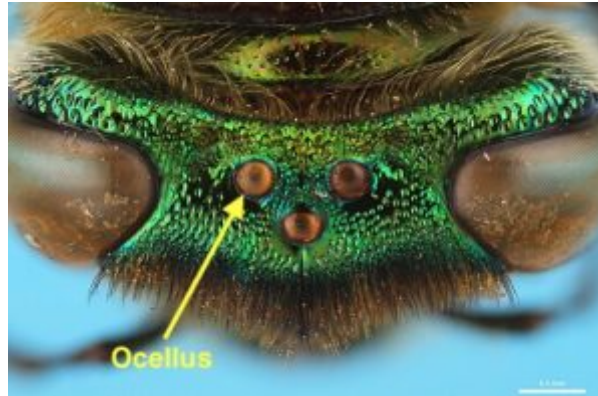


Diagram of an ommatidium. [Adapted from Gullan, PJ & Cranston PS (2009). *The insects: an outline of entomology*. (Fig. 4.10, 3rd ed.) Wiley.



Eyes and ocelli of an orchid bee (Hymenoptera: Apidae, *Euglossa hansonii*) with one ocellus highlighted [Adapted from *Insects Unlocked*, [CC0](#), Wikimedia Commons].

Stemmata are common in holometabolous larvae, e.g. caterpillars.



The stemmata on the side of the head capsule of a caterpillar (Lepidoptera) [Image: B. Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

COLOUR

The colour range sensitivity of insects is shifted to shorter wavelengths than in humans. Most insects don't see red very well at all and most insects are sensitive to ultraviolet light.

The general inability of insects to see red can be used to our advantage. If you wanted to do experiments on insects, for example, watch their behaviour at night, you can illuminate the experiment with dim, red light and the insects behave as if they are in total darkness, while an observer can see what is going on. The trouble is, a few insects have been shown to be red-sensitive, so you cannot assume all insects are red-blind.

One way around this is to use the fact that many video cameras are sensitive to near infra-red (NIR) light. Neither we nor insects can see near infra-red, but if you illuminate a scene with NIR (NIR LED illuminators are readily available) a video camera registers a near-normal, grey-scale image.

SENSILLA (= SENSE ORGANS)

A functional classification of sensilla is not coincident with a classification based on anatomy of the receptors. Functionally, sensilla of various morphological types have been shown to respond to different categories of stimuli.

Sensilla are broadly classed as:

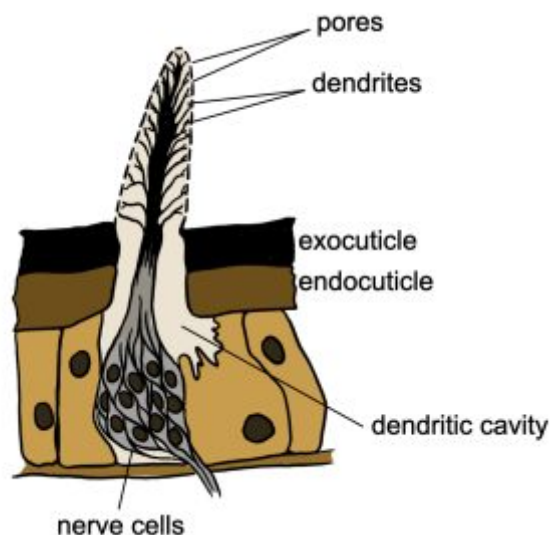
- chemoreceptors (taste and olfaction)
- thermoreceptors
- mechanoreceptors.

Each sensillum has from one to many sensory neurons associated with it. The nerve cell body sends an axon into the CNS. Opposite to the axon, a sensory dendrite emerges from the nerve cell body. It is associated with the cuticle of the sensillum. The dendrite may be branched (especially olfactory sensilla) or unbranched (taste receptors and mechano-receptors).

Antennae are probably the most important sensory structures in the majority of insects in terms of variety and functions of sensory receptors. Antenna are usually covered with thousands of individual olfactory sensilla. Taste receptors are often present as well, especially in insects with long antennae that are used to tap the substrate. Antennal olfactory receptors are used in tracking odour plumes, for example, a blowfly attracted to carrion, or a male moth tracking the pheromone plume released by a female.

OLFACTION

Olfactory sensilla have many pores in the wall of the sense organ. The sense organs can vary in external appearance from long hairs, to short pegs, to flattened domes. The olfactory dendrites are finely branched to increase surface area. The walls of the cuticular peg or hair have many fine pores allowing molecules to enter and access the walls of the dendrites.



An olfactory sense organ: the dendrites of the sensory neurons are branched.

TOUCH

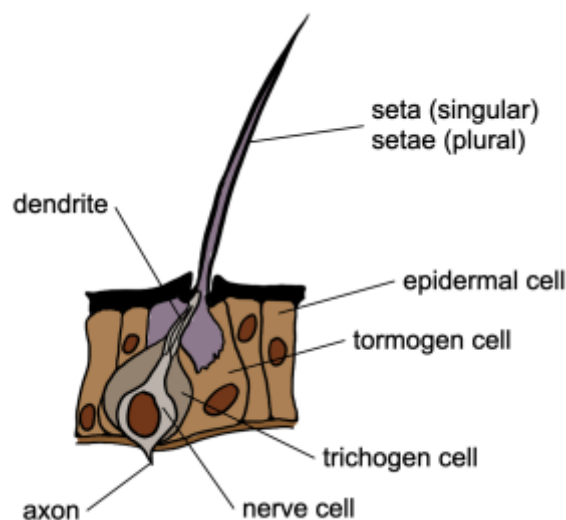
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Touch receptors are spread all over the body. They inform the insect when it is touching something and provide feedback on limb position; for example, during grooming. Sensory receptors within the limbs also provide feedback on the relative positions of the leg segments during walking. They are concentrated near the joints and are termed proprioceptors. The key attributes are that touch-receptors have a single neuron per sense organ. The single neuron has a single dendrite whose tip is compressed as hair moves, firing an electrical signal that runs along the axon into the CNS.

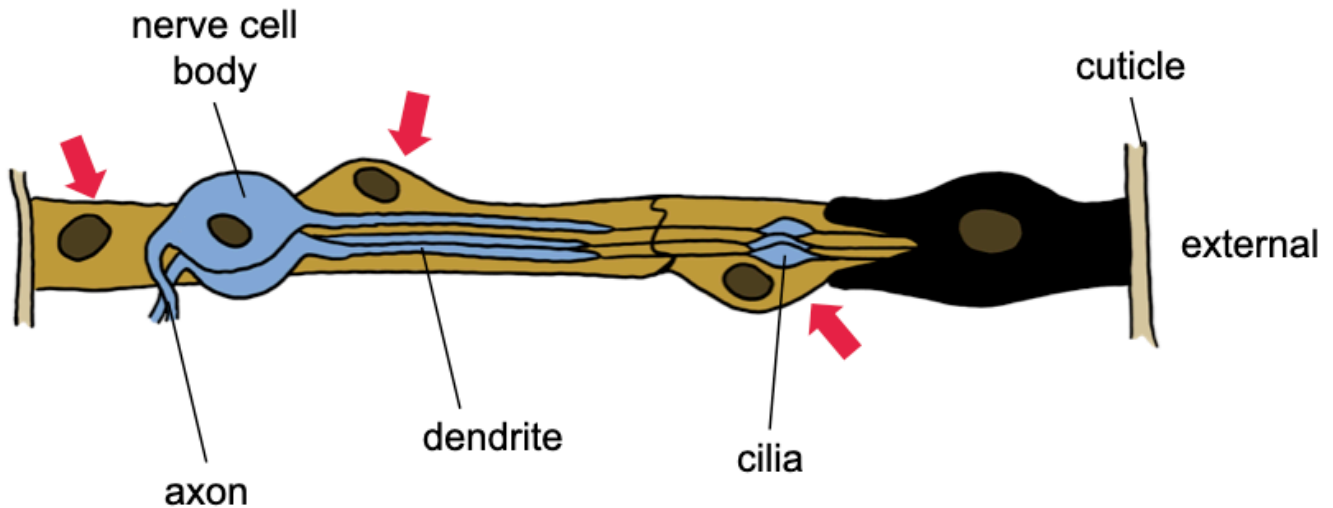


A touch sense organ has a single sensory neuron with an unbranched dendrite.

HEARING

Insects hear by detecting the vibration of parts of their body in reaction to sound. There is no one type of ear common to all insects. Auditory sensitivity has evolved many times separately, usually based around a site where there is a concentration of a type of proprioceptor called a chordotonal sensillum. The most common type of ear is located in the Johnston's organ in the pedicel of the antennae. In simple terms, the sound causes the antenna to vibrate which is detected by the chordotonal organs in the pedicel.

Key attributes of chordotonal organs are that they are capable of detecting subtle movements. The movement detection can be proprioceptive (giving feedback on position) or auditory (detecting vibration). Clusters of many chordotonal sense organs provide range sensitivity. The dendrite tip is kept under tension by surrounding cells.



Chordotonal sense organ

Other examples

- Johnston's organ as an auditory receptor.
 - A circle of chordotonal organs lie in the pedicel of many insects' antennae. The **flagellomeres** (elements of the flagellum) vibrate in response to sound. The ring of chordotonal organs detects the vibration and transmits its characteristics into the brain via the sensory axons.
- Tympanum-based auditory perception in Orthoptera (see activity)
- Tympanum-based auditory perception in parasitoid flies.

Keen to know more? Check out: [caterpillars sensing parasitoid wasps via "electroreception"](#)

TASTE RECEPTORS

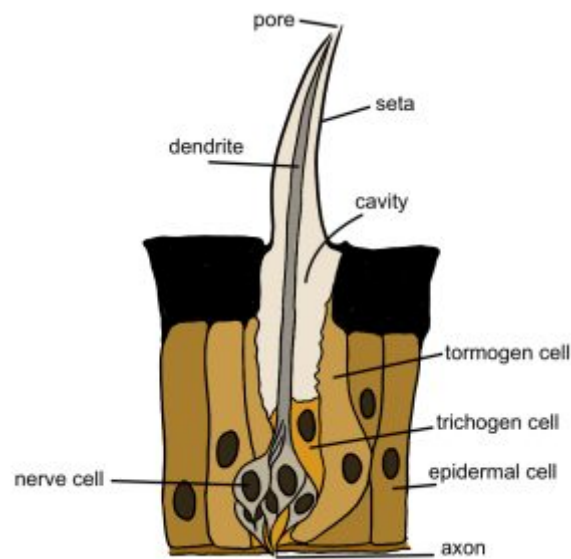
[THRD0023 024 \(YouTube, 2m 50s\):](#)



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<https://uq.pressbooks.pub/insect-science/?p=174#oembed-4>

Gustatory sensilla are located in large numbers on the mouthparts. They are also concentrated on the tarsi and, in some insects, on the wings. A characteristic of gustatory sensilla is that they usually have multiple sensory neurons per sensillum and each sensory neuron responds to a different suite of stimuli. The stimuli reach the dendrites via a pore at the tip of the hair or peg.



A gustatory (taste) sense organ.

THE MOTOR SYSTEM

The muscles of insects are elongated and multicellular. They tend to be pinkish in colour. Motor neurons synapse onto the muscles at sites called neuromuscular junctions.

The big difference between vertebrates and arthropods is that in arthropods the muscles involved in locomotion and movement insert on the inside of the cuticle. They have special muscle attachment sites, called tonofibrillae. Frequently the cuticle grows inwards at the site of muscle attachment to form an apodeme or apophysis.

- apodeme: an inner, cuticular ridge
- apophysis: an elongate inward cuticular extension

The biggest muscle blocks are in the thorax in the form of the flight muscles.

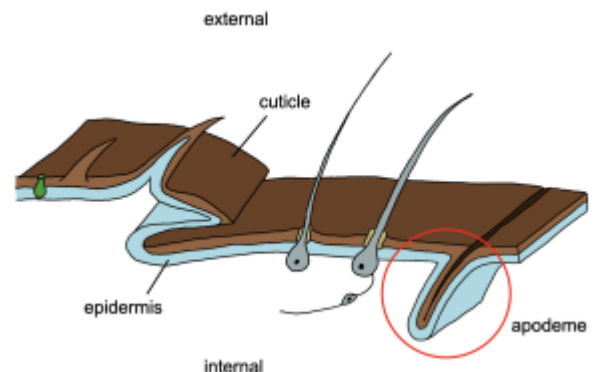


Diagram of the cuticle with an apodeme labelled.

INSECTS FLYING

One role of the eyes in flight control is to provide feedback on flight speed. The rate of movement of the visual field across the compound eye tells the insect how fast it is moving. Flight stability relies on inputs from the eyes and from sensory receptors that detect airflow.

In flies, the halteres act as gyroscopes, oscillating at the same frequency as the wings but out-of-phase. Removal of the halteres causes flies to crash!

In butterflies and moths, the chordotonal organs at the base of the antenna (Johnston's organ) have the same role.

INSECTS WALKING

Insects use a stable gait based on usually having 3 legs on the surface at any one time, while the other 3 legs are off the ground and moving. A central pattern generator controls this basic walking gait. Robotics researchers have studied the sensory and motor control of walking in insects in the hope of applying the same principles to guiding six-legged robots.

ACTIVITIES

Activity 7-1

Name the sense organ that an insect would use:

- to detect a person's footsteps?
- to detect the wind blowing its antenna?
- to detect a weight was on its back?
- to be able to move away from light?

Activity 7-2

Carry out a search of the scientific literature and read about the structure of tympanum-based auditory perception in parasitoid flies and Orthoptera.

Activity 7-3

Go to the external site "[How Insects Fly](#)" and become familiar with the content. It takes you on a tour of wing structures, flapping flight, the role of the compound eye in maintaining flight stability and the way insect flight muscles can act directly or indirectly to flap the wings. Read about the indirect and direct flight muscles and how they regulate wing-beat frequency.

Topic Review

Do you know...?

- The names of the main sensillum types and how they differ morphologically?
- The names of the different types of eyes and the stages of insects where they are found in?

Can you...?

- Draw and describe the differences between indirect and direct flight muscle activity?
- Describe what is meant by a tripod gait?

CHAPTER 8

The Contented Insect: Feeding and Nutrition



A spiny leaf insect (Phasmatodea) feeds on Eucalyptus leaves [Photo: S. Fraser-Smith, [CC0](#), [Flickr](#)].

One of the reasons insects are so important to humans is that they can be major pests or important beneficial species. These roles pivot around insects' feeding habits. We identify the diversity of feeding strategies used by insects and take a closer look at chewing insects.

[THRD0023 025 \(YouTube, 4m 50s\)](#):



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<https://uq.pressbooks.pub/insect-science/?p=177#oembed-1>

Learning Objectives

- explain how the diversity of food types impacts on the structure of the mouthparts and the gut
- appreciate the role of plant-derived chemicals in initiating and deterring feeding by insects

MOUTHPARTS AND FEEDING

As a general rule, insects' mouthparts possess adaptations that are appropriate for their feeding strategy. The obvious examples are the possession of stout mandibles in plant feeders or siphon-like mouthparts in sap-sucking bugs. However, there are evolutionary constraints on the diversity of feeding habits within each order. Let's compare three widespread and successful orders as an example. Flies have a characteristic groundplan for the mouthparts, as do beetles and bugs. Each groundplan is different to the others. The fly groundplan is based on nectar or liquid feeding, the beetle groundplan on chewing and the bug groundplan on plant-sucking. Each of these orders has diversified, producing many different species that have explored different foods but they must each evolve from their own peculiar groundplan.

The adults of Diptera are pre-adapted for feeding on liquids. It is perhaps not surprising that a number of families have settled on blood-feeding as a successful strategy; blood provides protein as well as carbohydrates. To draw blood, the fly needs to be able to pierce the skin so we see adaptations of the mouthpart appendages such as serrations or hooks to enable them to pierce the epidermis and hold the mouthparts in place. Mosquitoes, biting midges and tabanids (horse or march flies) have all independently modified the dipteran groundplan to enable them to exploit blood-sucking.



Images above: Scanning electron micrographs of (left) a female biting midge: a bloodsucker (Diptera: Forcipomyia (*Lasiohelea townsvillensis*). Note the blade-like mouthparts with serrated edges for cutting into skin (right) [Images: BW Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/) licence].

Plants are thought to have developed strategies to discourage feeding by herbivores over evolutionary time by producing feeding deterrents. However insects counter this by evolving tolerance and in some cases specialising on certain plant types. They can even metabolically neutralise the plant's compounds and turn the table on the plant by using the anti-feedant chemicals to help find the plant. As an example, milkweed is the food plant of the Monarch (or Wanderer) butterfly (*Danaus plexippus*). Milkweed is named for its milky juice, which contains alkaloids, latex, and other compounds including toxic cardenolides. Latex is a physical barrier to feeding while the cardenolides are chemical deterrents/toxins. Monarch caterpillars are specialized to feed on milkweed despite the chemical defences present. The caterpillars have developed strategies to deal with the plant toxins. In fact, both larva and adults incorporate the cardiac glycosides into their tissue. These then protect it against predation. Birds learn to associate the distaste with the aposematic colouration of the caterpillars and thereafter avoid feeding on the caterpillars.

In this video, the milky sap can be seen oozing from the plant as the caterpillar begins feeding. (Video: Myron Zalucki © University of Queensland, shared under a [CC BY-NC SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/) licence):



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<https://uq.pressbooks.pub/insect-science/?p=177#video-177-1>

Different foods require different processing systems. Insects' food varies from liquid to solid, and plant-derived to animal-derived. The structure of the mouthparts and the gut frequently reflect adaptations that facilitate consumption of their the particular food type.

[THRD0023 026 \(YouTube, 3m 22s\):](https://www.youtube.com/watch?v=THRD0023026)



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<https://uq.pressbooks.pub/insect-science/?p=177#oembed-2>

SOLID DIETS

Insects ingesting solid food with low nutrient value typically have a straight, wide gut so that they can process a large volume over a short period. Strong grinding or cutting mandibles are required to macerate the food.

VERY WATERY DIETS (SAP, BLOOD)

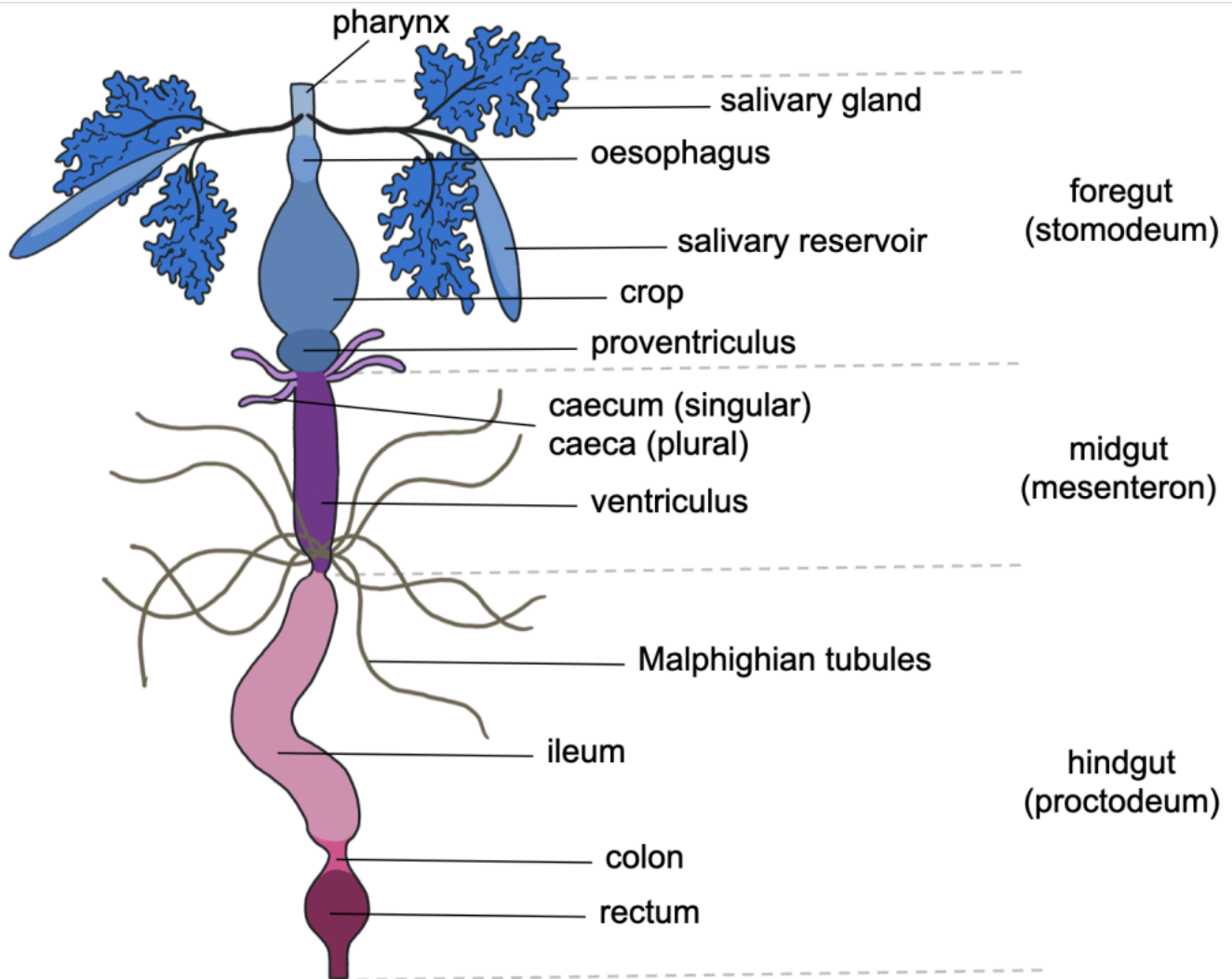
Such insects are faced with the challenge of extracting nutrient and getting rid of the excess water. The gut of bugs (Hemiptera) is highly convoluted, wrapping around itself to create a “filter chamber” that allows direct extraction of liquid into the hindgut for excretion. Blood-sucking insects have extremely specialised diets that require rapid elimination of excess water.

CELLULOSE

Some insects use symbionts to provide enzymes to break down ingested food e.g. termites cannot digest cellulose in wood without gut symbionts.

GUT MORPHOLOGY

The gut, also called alimentary canal, is divided into three parts the foregut, midgut and hindgut. The fore- and hindguts are cuticle-lined.



The gut, or alimentary canal, is divided into three parts: 1) the foregut, 2) the midgut and 3) the hindgut.

Sections of the gut	components	functions
foregut	pharynx, oesophagus, salivary glands & ducts, crop, proventriculus	ingestion, storage, grinding, transport
midgut	caeca, ventriculus, peritrophic membrane	digestion (enzymes), absorption of digested products, sieving out small food molecules ready for absorption
hindgut	malpighian tubules, ileum, colon, rectum	absorptions of water, salts and other valuable neocules

EXCRETORY SYSTEM

Excretion is linked to food intake and digestion. The main excretory system of insects is the Malpighian tubules.

They are found at the junction of midgut and hindgut. The distal portion removes nitrogenous waste (usually uric acid), salts and water from blood (more correctly called haemolymph) and deposits them in the hindgut.

The hindgut then voids solid waste (insect faecal pellets are called frass), excess salt and water.

The proximal part of malpighian tubules and the hindgut both resorb the proper amount of salt and water required to maintain proper osmolarity of blood. Often insects have structures called rectal papillae that specialise in extracting moisture from the faeces.

Primarily liquid feeders are faced with the challenge of eliminating liquid and separating out the protein and salts, while solid feeders are often faced with the opposite challenge of retaining as much water as possible.

NUTRITION

Insects require protein, carbohydrate, lipid and micronutrients just as we do. They have taste and smell receptors (chemoreceptors) which monitor the environment around and in the mouth. Feeding choices are made on the basis of hunger, and quantity of feeding stimulants present versus repellants or substances which inhibit feeding.

A few generalisations can be made:

- Sucrose and fructose are particularly effective in stimulating feeding (there are species differences). The higher the concentration, the bigger the meal taken. Sugars are primarily important in determining the duration of a meal. It appears that insects cannot taste protein but they can taste amino acids.
- Inorganic salts (e.g. sodium chloride: salt), in high enough concentrations, are deterrent but in lower concentrations usually have no effect. For blood feeders, higher concentrations are tolerated.

Sometimes specific substances— called phagostimulants—need to be present along with nutrients to achieve feeding. They may not have a high nutritional value themselves but they are indicators of the correct foodstuff. An example is the flavonoid Morin (found in mulberry leaves) which is a phagostimulant (feeding stimulant) for *Bombyx mori* (the silkworm larva).



[Silkworm caterpillars](#) (Lepidoptera) feeding on mulberry leaves [Photo: Fastily, [CC BY-SA 3.0](#), Wikimedia Commons].

Plants have evolved chemicals to protect themselves from insect feeding. These chemicals are often contained in glandular trichomes, hairlike structures present on plant surfaces. Many plant chemicals such as menthol (mint) are thought to have evolved as a form of plant defense.

INSECT FEEDING: ITS IMPACT ON HUMANS

To survive, grow and reproduce, insects need to feed. They compete with us for many of the resources we use: agricultural products, building products and clothes. Some insects feed on our livestock and even on us. However, there are examples where insects' feeding habits are advantageous to us: for example, insects can prey on one another which can help us. Some recycle our waste products while others pollinate plants.



*Larva of *Helicoverpa armigera* on a tomato leaf. Note the glandular hairs on the leaf. The larvae swing their heads away from these sources of odour when they make contact [Photo: BW Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].*



Larvae of the diamond back moth feeding on a cabbage leaf. Cabbage contains the chemical sinigrin, which is repellant to many insects but acts as a feeding cue to those that specialise on plants from the cabbage group [Photo: BW Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

INSECTS AS FOOD

We eat food prepared by insects, e.g. honey. In African cultures roasted locusts and termites are eaten, and in South East Asia, giant water bugs and other insects are treated as delicacies.



[*Roasted Bombyx mori silkworm pupae*](#)

[Photo: Bondarev.gal, [CC0](#), Wikimedia Commons].

There is a push to use insects as waste-converters, turning waste such as discarded food or agricultural by-products such as animal manure into protein via insects. The black soldier fly *Hermetia illucens* is spread throughout the world. Its larvae are leathery maggots that efficiently turn waste into protein and lipid. The last instar larva is rich in both these nutrient types and is self-harvesting because, upon maturity, they climb out of the medium they have been feeding on so that they can pupate in the ground. Rearing containers take advantage of this fact to collect mature larvae.

Want to know more about insects as food? Read this [report](#) from the Food and Agricultural Organisation of the United Nations (FAO).

And for the keen chefs, here's some really fun insect food ideas from [Brooklyn Bugs!](#)

ACTIVITIES

Activity 8.1

Watch these videos to see examples of different feeding styles in insects:

- [Macro-videos \(YouTube, 4m 30s\)](#) of different insect feeding behaviours
- [Leaf insect feeding \(YouTube, 2m 43s\)](#)
- [Mosquito feeding \(YouTube, 3m 17s\)](#)
- [Assassin bug feeding \(YouTube, 2m 31s\)](#)
- [Butterfly proboscis structure \(YouTube, 3m 23s\)](#)
- [Butterfly proboscis \(YouTube, 1m 31s\)](#): feeding and puddling

Topic Review

Do you know...?

- the names of the different components of the typical insect gut
- the importance of phagostimulants and feeding deterrents in determining whether or not an insect will feed
- The diversity of feeding habits and the types of adaptations of the gut that suit insects to their food type?

Can you...?

- Draw and label the main components of the insect digestive system?

CHAPTER 9

Reproduction



Mating seed bugs (Hemiptera: Lygaeidae). [Photo: K. Ebert]

Insects' reproductive methods are diverse. We examine the internal morphology of male and female reproductive systems. A feature of insects is that the females store sperm so that they can fertilise their eggs "on demand" without a male being in the vicinity. Insects can be live-bearers or egg-layers.

Learning Objectives

- Be familiar with the structure of the ground-plan male and female reproductive systems
- Be familiar with the variety of mating strategies used by insects

- Understand how egg fertilisation occurs and know the main sex determination mechanisms
- Know the difference between oviparity, ovoviviparity and viviparity

REPRODUCTIVE SYSTEMS OF MALE AND FEMALE

[THRD0023 027 \(YouTube, 2m 39s\):](#)



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<https://uq.pressbooks.pub/insect-science/?p=179#oembed-1>

MALE REPRODUCTIVE SYSTEM

The significant components are the testes, vas deferens, male accessory glands, seminal vesicles, ejaculatory duct and intromittent organ, also known as aedeagus or penis.

The paired testes are bilateral, sometimes fused at the midline. The germ cells are maintained in the testes and they divide many times to produce sperm. Active sperm are stored in the vas deferens. In some cases, the males have a sperm pump that helps force sperm into the female during mating. Spermatozoan morphology is diverse across the insects and has been used as a phylogenetic character, i.e. telling us which taxa are related.

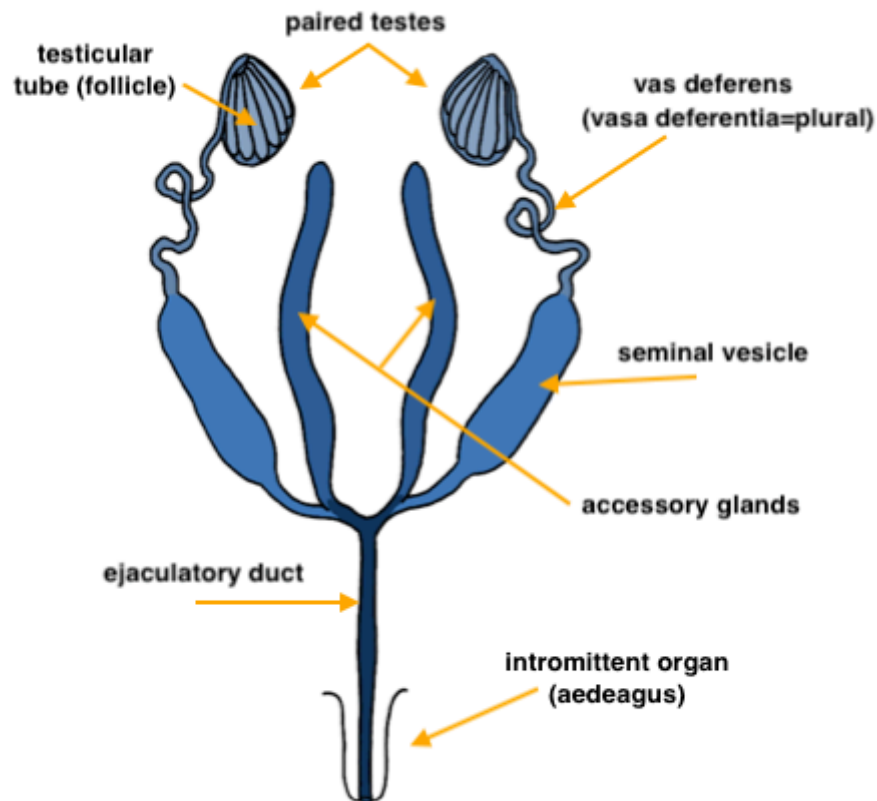


Diagram of male reproductive system. [Adapted from Gullan, P. J., & Cranston, P. S. (2009). The insects: an outline of entomology, 3rd edition (3rd ed.). Wiley].

FEMALE REPRODUCTIVE SYSTEM

The significant components are the ovarioles, lateral oviducts, common oviduct, female accessory glands, spermathecae and their associated glands, and vagina (bursa copulatrix).

The ovaries are paired, located in the posterior abdomen. In some insects, the ovaries can occupy a large volume of the abdomen in gravid (ready to oviposit) females. Each ovary is composed of many ovarioles, the units that each produce an egg. A single lateral oviduct runs from each ovary and joins a common muscle-lined oviduct. Frequently it has a muscular expansion called the bursa copulatrix. The bursa copulatrix can have a role in mating—receiving the aedeagus and secretions from the male (spermatophore, spermatozoa, accessory gland secretions)—and/or a role in oviposition; it is the site of egg fertilisation and coating the eggs with female accessory gland secretions.

Generally, one or more pairs of accessory glands open into the bursa copulatrix or common oviduct. The accessory glands often secrete an adhesive which coats the eggs to stick them together or to the substrate. Glands with this function are called colleterial glands. In cockroaches and mantids, the accessory gland secretion forms a hard coat around the egg batch. Mantids create a froth from the secretion that hardens around the eggs. In these cases the eggs are said to be contained within an ootheca (=egg case). In tsetse flies the accessory glands form milk glands that produce a nutritive secretion for the larva that is developing in the uterus.

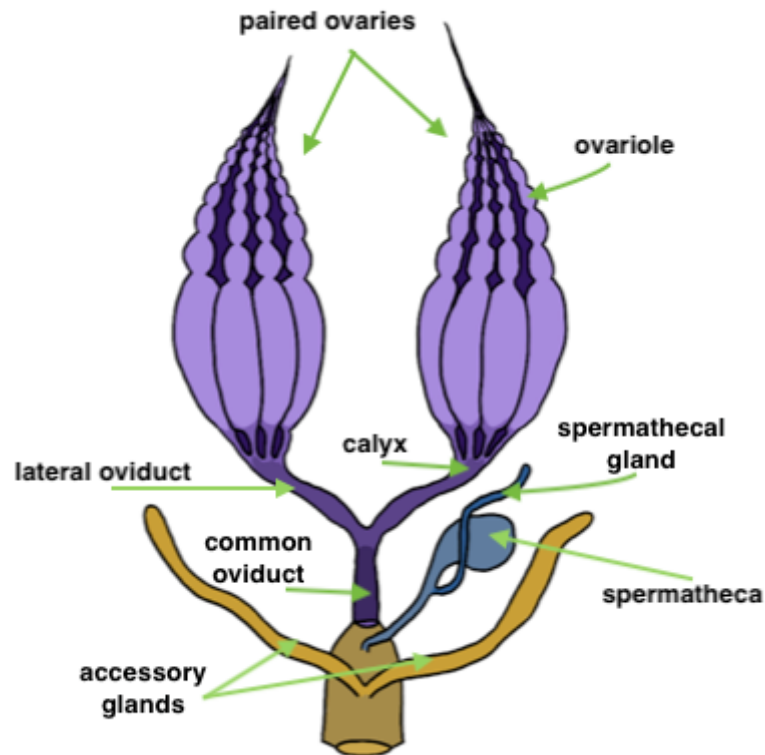


Diagram of the female reproductive tract.[Adapted from Gullan, P. J., & Cranston, P. S. (2009). *The insects: an outline of entomology*, 3rd edition (3rd ed.). Wiley].

INSEMINATION

[THRD0023 028 \(YouTube, 4m 56s\):](#)



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<https://uq.pressbooks.pub/insect-science/?p=179#oembed-2>

Some species inject sperm directly during the act of copulation. Others produce a spermatophore, a package of sperm that is deposited on the external environment, or on the female's external genitalia (Mormon cricket) or into the female's bursa. It is regarded as an ancestral condition. It is used in myriapods, collembolan and silverfish, perhaps related to terrestrialisation because it may be the first step in transitioning from fertilisation in an aquatic environment to a terrestrial environment.

SPERMATHECAE

Spermathecae are the sperm storage organs within the female. Females generally have 1-3 spermathecae. Sperm can remain viable for years. In some cases such as queen bees, sperm storage creates the interesting scenario where long-dead males can keep producing progeny.

Spermathecae are frequently lined with sclerotised cuticle, perhaps to protect sperm from UV radiation. Spermathecae are often surrounded by dermal glands or have an adjacent spermathecal gland. It is most likely that the dermal gland products provide nutrient for the sperm, although they may play a role in aiding spermathecal filling.

The spermathecal ducts are often very narrow, and the spermathecae are bulbous. The number of spermathecae varies among insects. View this [video \(YouTube, 09s\)](#) of fluorescently tagged sperm moving within the female reproductive tract of *Drosophila*.

THE SPERMATOPHORE

The spermatophore (Greek, sperma = seed; pherein = to carry) is a container that protects, envelops and transfers spermatozoa from the male to the female.

The male silverfish deposits a spermatophore surrounded by silk lines and leads the female to it. She contacts the silk thread and takes the spermatophore into her genital chamber. In some cases, the spermatophore provides nourishment to the female, i.e. it is a nuptial gift. The male thereby increases the likelihood that the progeny will survive.

REPRODUCTION AND NUTRITION

Females need protein to develop eggs. In some insects, the eggs have already developed on reaching adult stage. The juveniles have stored sufficient lipid, protein and carbohydrate for the eggs to fully develop. In others, the female seeks a special diet, often protein-rich to allow egg development, for example, in mosquito females. In some fly species the males wrap a prey item with silk as a 'nuptial gift', providing an additional protein source for the female.



Dance Flies (Diptera: Empididae) mating—one holds the 'nuptial gift'
 [Photograph by Anthony Toole. Used with permission].

Keen to learn more?

In some species of Dance Flies (Diptera: Empididae), the males usually capture a small insect, then wrap it up in silk to present to the female as a protein-rich nuptial gift. To learn more about the behaviour and the interesting silk glands of these insects:

Young, J.H. & Merritt, D.J. 2003. [The ultrastructure and function of the silk-producing basitarsus in the Hilarini \(Diptera: Empididae\)](#). *Arthropod Structure & Development* **32**: 157-165

FINDING MATES

Swarming is a behavioural trait that is usually associated with mate selection. It is common in Ephemeroptera, midges (Diptera) and some Lepidoptera. Some fireflies accumulate in trees and the males flash in synchrony to attract females.

Lekking is a behaviour where males hold territories, e.g. some fruit-flies create leks.

Hill-topping is a behaviour that is common in higher flies where males and females accumulate at the tops of hills. Mating at oviposition or feeding sites is common in higher flies. The sensory signals that are used to find feeding or oviposition sites also serve to bring the two sexes together.

COPULATION

[THRD0023 029 \(YouTube, 4m 18s\)](#):



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It is to the male's advantage to prevent females copulating afterwards so there is much evidence of "arms races" between males and females: males attempting to ensure their parenthood and females attempting to ensure the quality of the male.

In *Drosophila*, a "sex peptide" produced in the male accessory glands binds to sperm tails and is carried into the female to increase egg-lay and decrease receptivity. The carriage of the sex peptide on the sperm is the suggested reason for extra-ordinarily long sperm tails in some *Drosophila* spp (a 3 mm long male of *Drosophila bifurca* has sperm tail length of 58 mm).

Male dragonflies have barbed structures on the aedeagus whose role is to withdraw foregoing males' sperm from within the female.

In *Lucilia cuprina* (the Australian sheep blowfly), males have evolved structures on the aedeagus to deliver accessory gland fluid (AF) into receptacles in the female bursa copulatrix. The AF causes the female to become unreceptive to any further mating attempts for a long period. Paired barbs on either side of terminal opening tear into the cuticle lining the internal female tract and release accessory gland fluid.

FERTILISATION

Eggs are fertilised as they pass through the oviduct and vagina. Frequently the egg rests momentarily in the bursa copulatrix near the spermathecal duct opening into the bursa. Sperm are released from spermathecae or other storage organs and enter the egg through the micropyles: microscopic holes in the egg.

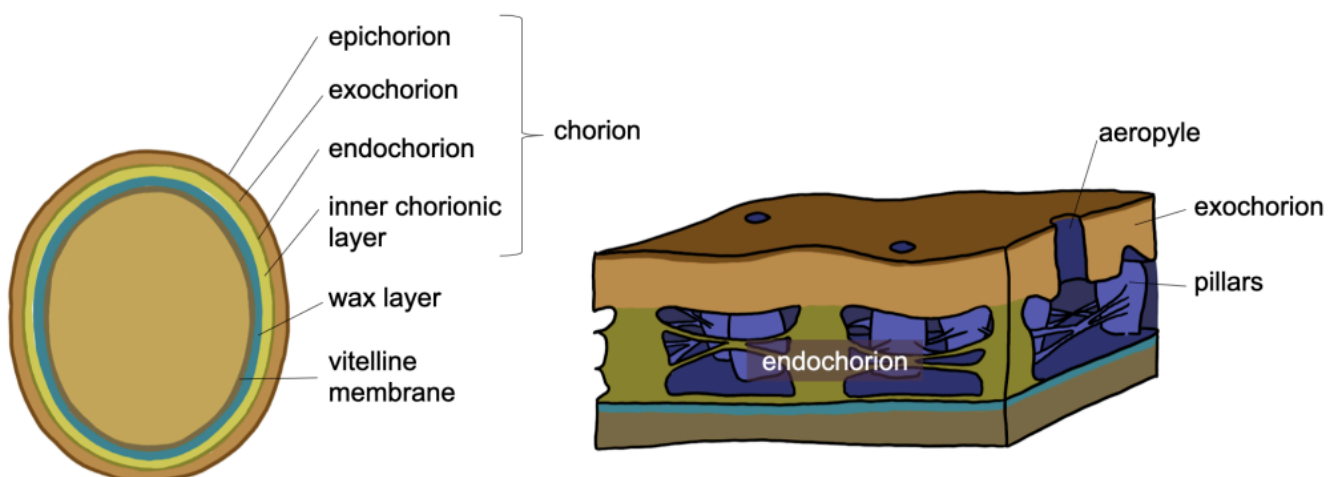


Diagram of an insect egg detailing the outer layers: oxygen enters through the aeropyles.

Keen to know a bit more detail about the insect egg? Check out this [website](#).

SEX DETERMINATION

In most insects, both sexes are diploid. In *Drosophila*, males are X/Y and females are X/X, just like humans. There is a variety of sex chromosome mechanisms, based on diploidy.

HAPLODIPLOIDY

In haplodiploid sex determination, males have one set of chromosomes. One way is for the female not to fertilise the egg to make males (arrhenotoky). Consequently females are derived from fertilised eggs and males from unfertilised eggs. This is common in Hymenoptera. In honeybees, all workers are female as they are derived from fertilised eggs. Just a few males (drones) are produced from unfertilised eggs

In some insects, the paternal genome is eliminated from males after fertilisation occurs. This occurs in scale insects.

EGG-LAYING OR LIVE-BEARING

[THRD0023 030 \(YouTube, 4m 33s\):](#)



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<https://uq.pressbooks.pub/insect-science/?p=179#oembed-4>

OVIPARITY

Most insects are oviparous, i.e. they lay eggs (oviposit). Among insects there is an extraordinary array of strategies of oviposition. The female is frequently very choosy in where to lay eggs because of the risks associated with web predation and parasitism by wasps.

Eggs can be laid singly or in batches. Eggs can be stuck together through coating from colleterial glands (accessory glands). Some insects protect the eggs through guarding by the female. This is frequently seen in bugs (Hemiptera) where the female sits atop the egg batch. Often, females lay eggs in, on or near suitable food. For close up videos of insect oviposition and egg-protection behaviour go to the UQ library catalog to find close-ups of insect behaviour [videorecordings] at this link: [Insect Oviposition](#).

A honeybee, *Apis mellifera* queen produces about 220,000 eggs during a 12 month period i.e. 602 eggs per day, 25 eggs per hour. The termite *Kaloterms flavicollis* is estimated to lay 10 million eggs per year, an incredible 27,400 eggs per day. The embryonic development period varies greatly among insects, for example, embryos may develop quickly and eggs may hatch soon (<24 h in blowflies) to utilise ephemeral resources (e.g. fruit, carrion). At the other extreme, stick insect eggs are cast off by the female to fall into the leaf litter. They take many months to hatch.



Female tesseraatomid bug (Hemiptera) guarding her eggs
[Photo: K. Ebert].

OVIVIVIPARITY

In this situation, fertilized eggs are held within female and the eggs hatch immediately on being deposited. It occurs in some flies, cockroaches, aphids and scale insects.

VIVIPARITY

Viviparity means live-bearing. Embryonic development is completed within the female so that the larvae are active as soon as they are deposited. Various forms:

In the most extreme cases, larvae feed on secretions within female tract and pupate immediately after being deposited. The complete larval phase occurs within the female. Obviously, females can produce only a few offspring in their lifetime using this approach. It is found in tsetse flies and batflies among others.

ACTIVITIES

Activity 9.1

Watch these 3 videos on oviposition or larva position:

- [tsetse fly birth \(YouTube, 4m 55s\)](#)
- [Fly laying eggs \(YouTube, 6m 54s\)](#)
- [Cockroach eggs hatching \(YouTube, 4m 15s\)](#)

Activity 9.2

Which of the following terms in the table apply to the male or female reproductive systems and what is the function of the structure?

Term	M	F	Function
Ovaries			
Vas deferens			
Seminal vesicle			
Bursa copulatrix			
Accessory glands			
Oviduct			
Spermatheca			
Gonopore			
Testes			

Activity 9.3

Suggest a reason why: (1) eggs are stalked and (2) eggs are laid in clusters.



Antlion larvae (Neuroptera) hatching from eggs on stalks [Photo: K. Ebert].

Topic Review

Do you know...?

- The structure of the generalised male and female reproductive systems
- The function of spermatophores and spermathecae
- The mechanism of sex determination in the Hymenoptera
- The difference between oviparity, ovoviviparity and viviparity.

Can you...?

- Draw and label the main components of the male and female reproductive systems?

CHAPTER 10

Semiochemicals



Bipectinate antennae of a male Antheraea sp. (Lepidoptera: Saturniidae) [Photo: Yathumon M A, [CC BY-SA 4.0](#), Wikimedia Commons]

Semiochemicals are signalling chemicals. Insects produce them to communicate with members of their own species. They produce them to interact with other insect species. Insects react to chemicals produced by plants, using them for orientation to hosts or away from deterrent compounds.

Learning Objectives

- Know the main types of signalling interactions within and between species

- Appreciate the diversity of signals and their different functions
- Understand how egg fertilization occurs and know the main sex determination mechanisms
- Be familiar with the important roles of sex pheromones in insect biology

OVERVIEW OF SEMIOCHEMICALS

Semiochemicals are chemicals used as signals: after they are detected, they alter the behaviour or physiology of the receiver. Semiochemicals encompass a significant part of the spectrum of sensory modalities that can be received by insects. Semiochemicals can be detected by olfaction, taste and internal sensory receptors but by their definition cannot include tactile and visual signals.

Semiochemicals do not encompass chemical signals from abiotic aspects of the environment.

Feeding and mating are the major behaviours that utilise semiochemicals. Semiochemicals can be intraspecific or interspecific (intra=within, inter=between). Interspecific chemicals can be signals that originate from a plant and affect an animal, or they can originate from one animal or plant species and affect another.

Interspecific signals are divided into two categories: **allomones** and **kairomones**, based on the direction of the signalling.

The obvious existence of coevolution in the use and purpose of signals makes them relevant to:

- evolutionary studies
- ecology
- sexual selection
- pest control

Types of Semiochemicals

- Pheromones – intraspecific signalling
- Kairomones – interspecific signalling; the responder benefits
- Allomones – interspecific signalling; the sender benefits

PHEROMONES

Pheromones elicit a reaction from members of the sender's species. Examples include the use of odours to attract or find members of the opposite sex and the use of the sense of taste in many flies where sex pheromones are distributed in the waxes of the cuticle and are detected by taste on contact.

Some specific types of pheromones include:

- sex pheromones

- aggregation pheromones, e.g. swarms, group attack on a plant resource, oviposition
- spacing pheromones, e.g. oviposition-deterrent pheromone in fruit flies
- trail-marking pheromones, e.g. ant trails
- alarm pheromones, e.g. bees

KAIROMONES

Kairomones elicit a behavioural or physiological reaction that is favourable to the receiver. For example, exploiters are attracted to chemicals produced by potential food or oviposition sites.

Some examples:

- Brassica plants produce **sinigrin** that probably originally evolved as an antifeedent (an allomone). The sinigrin attracts *Pieris rapae* (cabbage white) butterflies to lay their eggs.
- Lactic acid produced as a component of sweat is an attractant for mosquitoes.
- Predators or parasites home in on odours from the host.

ALLOMONES

Allomones elicit a behavioural or physiological reaction that is favourable to the sender. An easy way to remember the name is to associate it with “alarm”. Any chemical that repels predators or parasites is an allomone. Allomone emission is often associated with aposematic colouration, i.e. bright colours, often yellow and black or red and black, that make the subject conspicuous. Examples include repellent odours and tastes such as the toxic cardiac glycosides of wanderer caterpillars mentioned in the chapter on feeding.

Venoms are allomones because they elicit a reaction favourable to the sender. Venoms can function as prey immobilisation chemicals and/or nest defense chemicals. Wasps use their venom for both functions, whereas honeybees use them only for defence. Some allomones are designed solely to repel vertebrates, such as the repugnatorial substance released by stink bugs.

For example, the bronze-orange bug thrives on citrus. Brushing against the bush or disturbing the insects results in them releasing a pungent-smelling liquid from gland reservoirs in their metathorax.

Bombardier beetles spray benzoquinones in an explosive burst. The fluid reaches high temperatures and can be aimed toward the direction of a potential predator. Specialised glands produce secretions separately: when mixed, the temperature rises, gas forms, and causes explosive ejection of hot caustic fluid.

Check out this [video](#) of a bombardier beetle ejecting its “stink bomb”!



Bronze orange bugs have glands on the underside of their thorax that produce a pungent-smelling liquid, hence the common name: stink bugs (Hemiptera: Tesseratomidae) [Photo: K.Ebert].

SEX PHEROMONES

Finding mates can be difficult for some insects, especially if the population is widely dispersed. A sensitivity

to odours allows upwind tracking in flight. Some insects can detect very low concentrations of odour allowing them to detect mates from far away. These long distance attractants are perhaps the best known examples. They are especially common in Lepidoptera and Coleoptera. Most often, the female releases the pheromone. Courtship pheromones are pheromonal signals that constitute a part of the mating process: places both partners in the appropriate behavioural and physiological state.

SEX PHEROMONES OF FLIES

In Diptera, sex pheromones are commonly derived from cuticular hydrocarbons. They do not have a high vapour pressure so are not effective at long distances. Rather, they serve at close-range or are contact-only because they are not highly volatile. They appear to be derived from the cuticular lipids of insects whose primary function is water-proofing.

Some Diptera secrete volatile pheromones. For example, female sandflies (Psychodidae: *Lutzomyia*) in South America transmit leishmaniasis: a disease where a protozoan parasite causes dermal lesions in humans. Males secrete terpenes acting as an attractant over several metres, attracting both males and females to **leks** (mating swarms). More specifically, it could be called an aggregation pheromone. Note: that these “real” sandflies are not related to what we commonly call sandflies in Australia which are better termed ‘biting midges’ (Diptera: Ceratopogonidae).

Fruitflies (Tephritidae) are noted for their complex mating behaviours. Males produce a secretion in anal pouches that are extruded and contents sprayed into the air using wings or legs. It has a nice fruity smell!

Blowflies (Australian sheep blowfly) have an oviposition pheromone: females cluster together at an oviposition site and all contribute to an extra-large batch of eggs that will hatch at the same time.

GLAND LOCATIONS

Glands that produce semiochemicals can be found at almost any epidermal location. Commonly, specialised structures such as a specific gland with a reservoir release the semiochemicals. Sometimes they are associated with dispersal structures such as cuticular hairs with large surface area or even scales that are designed to be cast off to disperse the chemicals.

In female Lepidoptera, the sex pheromone glands are frequently in the terminal abdominal region, often in the soft intersegmental membrane between terminal abdominal segments. By arching the abdomen, they can control pheromone release. “Calling” is elicited by either (a) eversion of cuticle: females evert the sac and “call” at a particular time of night or (b) depressing tip of abdomen to reveal intersegmental membrane.

Some male Lepidoptera have “hair pencils” kept internalised in the abdomen. Glands open out at the base of the hairs. The hair pencils or the inverted sacs they sit on are everted during calling.



Male Crow butterfly showing the hair pencils everted at the end of the abdomen [Photo: [R. Kasambe, CC BY-SA 4.0, Wikimedia Commons](#)].

In Lepidoptera, the pheromone comprises blends of aliphatic straight-chain hydrocarbons, alcohols, acetates, aldehydes, and ketones. Some components are common to a genus but the specific blends and minor components differ.

Milkweed butterflies (Danainae, e.g. *Danaus plexippus* is the famous Monarch butterfly) males can release pheromone-carrying particles from gland-containing pockets on the wings. Others have special scales (androconia), often on the wings that break up and are released and dispersed. The androconia are lepidopteran scales that are specialised to carry scent. They have a large surface area at the tips.



Androconia: special scales on butterfly wings that produce sex pheromones [Photo: [G. San Martin, CC BY-SA 2.0, Wikimedia Commons](#)].

In Diptera, the oenocytes, single-celled glands sitting under the cuticle, produce the pheromones.

MALE ACCESSORY GLANDS

Chemicals deposited into female during mating are technically pheromones. The secretions aid in transfer of sperm to spermathecae by producing oviduct contractions, as studied in the blood-sucking bug, *Rhodnius*.

In some cases, the male accessory gland secretions produce oviposition enhancement, shown in mosquitoes by implantation of male accessory gland in female abdomen.

Oocyte production and maturation can be accelerated in some insects after the act of mating, induced by male-derived chemicals.

Substances in the male accessory gland fluid terminate receptivity in female mosquitoes, *Drosophila*, houseflies, blowflies, as well as representatives from other orders. Return to receptivity occurs with time, or after multiple oviposition events, or after sperm depletion. In some cases, receptivity inhibition is due to the presence of sperm, while in others sperm don't play a role. It is not known where they act, but they enter the haemolymph rapidly and presumably bind to receptor sites in the CNS.

Peptides with this function have been isolated in *Drosophila* and mosquitoes (called matrone in mosquitoes)—studied because of their potential uses in regulating pest insect reproduction. The problem is that peptides are notoriously difficult to manipulate into insects:

- Usually broken down in gut if digested
- Don't penetrate cuticle
- Break down rapidly in environment
- Could possibly use engineered carrier viruses or transposable elements

PHEROMONES: USE IN PEST CONTROL

Advantages:

- Selective (no effect on beneficials)
- Non-toxic (delayed onset of resistance)
- Short-lived and non-polluting

MONITORING

The most extensive use of pheromones to date has been in monitoring for pest incursions. For example: quarantine and biosecurity officers check for presence/absence of pests, most often at ports. Pheromone traps give indications of pest density used for decision-making on when to spray or use other controls, i.e. to determine population density.

For the codling moth *Cydia pomonella*, sticky traps baited with pheromone are commonly used and placed in fruit trees at 1-4 per hectare. Traps attract males but there are problems with migration into trapping orchard from untreated, abandoned orchards.

MASS TRAPPING

Aim is to reduce insect populations by attracting and killing insects, usually with insecticides or sticky traps.

SEX ATTRACTANTS

Not very useful as they only attract one sex: usually males in Lepidoptera, and typically only a few males are needed to fertilise many females.

AGGREGATION PHEROMONES

- Useful in control of Spruce bark beetle in USA.
- Potential "lure and kill" for mosquitos: synthetic oviposition pheromone combined with growth regulator insecticide. Affects females which are the blood-feeding sex.

MATING DISRUPTION

Permeating the atmosphere with sex attractant can cause sensory fatigue or compete with natural sources, or camouflage natural plumes. This technique has been successfully used in control of pink bollworm, oriental fruit moth, grape berry moth and artichoke plume moth.

The best use of mating disruption pheromones occurs when the insect has a short life span, a synchronised mating period and a short mating period.

Problems:

- Migration of mated individuals into treated area (growers' groups and area-wide efforts are an advantage)
- Fecundity: in species producing many eggs, the small proportion that manage to mate may still produce sufficient progeny to cause pest problems

Would be better if the males attracted the females, then females could be trapped, removing them from the population. Otherwise escaping males can inseminate multiple females. This is almost the rule in Lepidoptera and many other insects.

REPELLENTS

Using pheromones as repellents has limited commercial use. Trials have been done to repel beneficial insects from insecticide-treated areas, e.g. bees as pollinators are often killed, but can be repelled by treating the area with bee alarm pheromone.

Topic Review

Do you know...?

- Definitions of pheromones, allomones and kairomones
- Examples of the use of pheromones in insect pest control, including the advantages and drawbacks of their use
- Can you name at least 3 different types of insect pheromones and give examples of their use and the groups that use them
- What structural adaptations are present in Lepidoptera males and females that are associated with pheromone signalling and reception

CHAPTER 11

Living with Water



A male giant water bug (Hemiptera: Belostomatidae) carrying eggs on its back [Photo: [Greg Hume](#), CC BY-SA 3.0, Wikimedia Commons].

In this chapter we will take a look at insects that have returned to water. The topics we have covered so far feature adaptations to the life on land: aquatic insects had to re-adapt their forebearers' terrestrial adaptations

to a water-dwelling lifestyle. We examine the unique problems faced by insects in the aquatic environment; the prime challenge being able to breathe when their respiratory system was pre-adapted to a terrestrial habitat.

Learning Objectives

- Be aware of the adaptations that aquatic insects have evolved to allow them to breathe underwater
- Recognise that the aquatic lifestyle may have evolved from a terrestrial lifestyle in insects

RETURN TO WATER

Most insects are terrestrial; however, some, over evolutionary time, have gone back to the water either as immatures or as adults. All insects that have a juvenile aquatic stage appear to have adapted to water secondarily from terrestrial ancestors. Consequently, the respiratory system of aquatic insects is derived from that of their terrestrial cousins. Refer back to the chapter on Insect Cuticle for a description of the terrestrial insects' tracheal system.

Common name (Order)	Life stage
Dragonflies & damselflies (Odonota)	juvenile
Stoneflies (Plecoptera)	juvenile
Caddisflies (Trichoptera)	juvenile
Alderflies, dobsonflies (Megaloptera)	juvenile
Mayflies (Ephemeroptera)	juvenile
Water bugs, water boatmen (Hemiptera)	juvenile & adult
Diving Beetles, whirligig beetles (Coleoptera)	juvenile & adult
Mosquitoes, midges, rat-tailed maggots (Diptera)	juvenile

Note: Aquatic nymphs of Ephemeroptera, Odonata and Plecoptera are often called **naiads**.

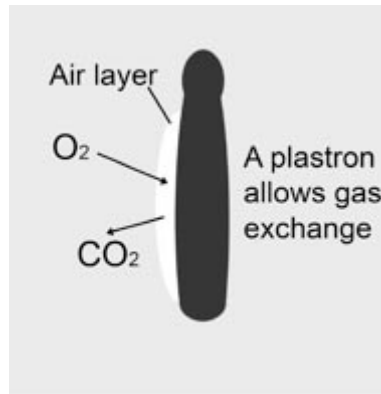
BREATHING UNDER WATER

Possession of an aquatic life stage places demands on the terrestrial body form, in particular the ability to breathe underwater. Insects achieve respiration underwater using multiple methods. First, by surface breathing. The prime example is where hydrophobic hairs allow access to air at the water surface; for example, the siphons on abdomen of a mosquito larvae has hydrophobic hairs that open out when the surface tension is breached, allowing the respiratory system to directly access the atmosphere.

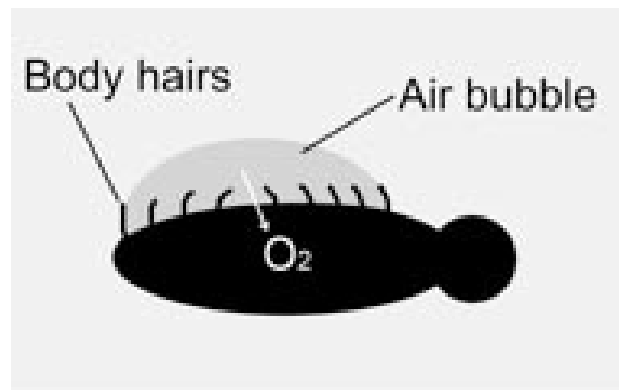
A number of insects (and spiders) are bubble carriers: they drag an air bubble with them as they dive below the surface. The air bubble overlies the spiracles so the normal terrestrial breathing pattern can continue underwater. Some adult beetles use this approach. The bubble may be held under the elytra. The bubble can exchange oxygen and carbon dioxide with the water due to the diffusion gradient generated by the insect. In this case the bubble acts as a "physical gill". However, the bubble tends to shrink in size over time so it must be replenished by regular visits to the surface.

Some aquatic insects such as the water boatmen (Hemiptera) are carriers of a thin film of air, termed a

plastron. Hydrophobic hairs trap a film of air against the body. The plastron acts as a physical gill—just like an air bubble—but it does not need the regular replenishment required of air bubbles. The reason is that the volume of the air layer is kept constant by the entrapping hairs, meaning that the diffusion of gases continues indefinitely.



A thin film of air forming a plastron.



Hydrophobic hairs trap the air against the insect body.

[Images: B.Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

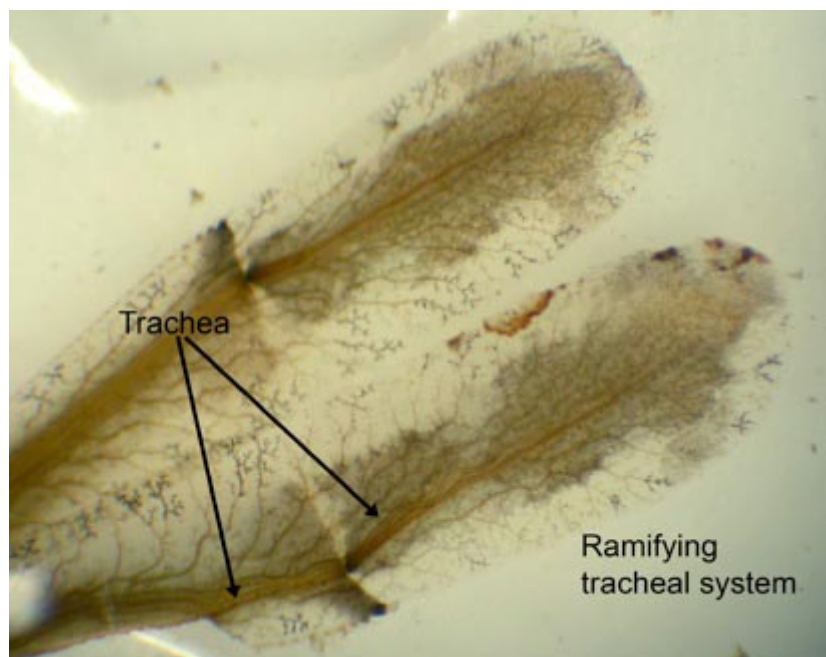
These physical gills allow exchange of oxygen and carbon dioxide with the water. Oxygen, comprising 20% of the atmosphere) is water soluble, as is carbon dioxide. Nitrogen is relatively insoluble in water.

Other insects cope with water by possessing a closed tracheal system with no spiracles that would allow entry of water into the tracheal system. They maintain an air-filled tracheal system without any direct access to the external atmosphere. They utilise cutaneous respiration that allows diffusion of gases across the cuticle. Obviously, the cuticle must be thin and permeable.

Tracheal gills such as those found in damselfly naiads are a further specialisation of the closed tracheal system. Portions of body wall (often outgrowths) that are very rich in trachea are the sites where gas exchange occurs. The cuticle is extremely thin, allowing oxygen to diffuse from the water to the trachea within the gills. While vertebrates utilise haemoglobin to store oxygen in solution, this approach is rare in insects. Only one group, some chironomids (midges, order Diptera) possess haemoglobin in the haemolymph to store and release oxygen in the body. It is believed they have this capability because they frequent water that is rich in decaying organic matter, which is frequently anaerobic in nature.



Damselfly nymph: note the body cuticle is all but invisible as are many of the internal tissues. Only the tracheal system shows clearly. [Images: B.Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/) licence].



Enlargement of lamellate gills of damselfly: note the thin body cuticle is invisible so the ramifying tracheal system shows through. The oxygen exchange occurs through the fine branches. [Images: B.Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/) licence].



A chironomid midge larvae, also called a blood worm (Diptera: Chironomidae) [Images: B.Cribb © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

Examples of methods used to breathe underwater

- Water boatmen (Order Hemiptera, Family Corixidae) use a plastron to breathe underwater. Cuticular hairs on the body wall capture a thin layer of air. The plastron allows oxygen and carbon dioxide to diffuse according to their concentration gradients.
- Water beetles (Order Coleoptera) hold a bubble of air on the body with hairs or under the elytra. The air bubble is replenished when the insect moves to the surface. Insects that use and deplete a bubble of air need to regularly move to the surface to replenish.
- Damselfly nymphs have leaf-like appendages at the end of the abdomen; they are closed gills. These work because they have thin cuticle and a bed of ramifying trachea which collect air across the thin cuticle and feed it back into the main airways of the body.
- Chironomids (Diptera: Chironomidae) are usually the most abundant group of stream macroinvertebrates both in numbers of species and as individuals, in freshwater aquatic habitats. As adults, they are delicate mosquito-like flies and are grub-like as a larva. Often they are called bloodworms because they can have bright red haemoglobin in the body to take up and store oxygen; beneficial in sludgy environments low in oxygen.

REPRODUCTION IN AQUATIC INSECTS

Eggs can be embedded in a jelly-like, hygroscopic matrix produced by the female. In other groups, eggs can be glued to the substrata such as a plant or rock, to prevent them being washed away.

They can be inserted into plants either stems near the surface or into algal mats. They can be broadcast on the water surface, either singly or in clusters. Some eggs are sticky and attach to plants or other objects in the environment either singly or in clusters. Mosquitoes deposit eggs in floating rafts.

Water bugs (Belostomatidae) oviposit eggs onto the male's back and the male carries the eggs until they hatch (see image at the beginning of this chapter!)

ACTIVITIES

Activity 11.1:

Go to this [website](#) and read the pages on the [water strider](#), the [dragonflies](#) (Odonata), and the [water beetles](#) (Coleoptera: Dytiscidae) and gather reasons why these groups may or may not be useful for monitoring water quality.

Activity 11.2: Ever wondered how water striders float? Check this out this [video \(YouTube, 3m 33s\)!](#)

Activity 11.3: Watch this [video on aquatic beetles. \(YouTube, 3m 06s\).](#)

Topic Review

Do you know...?

- the ways that insects cope with gas exchange in the aquatic environment
- the attributes of freshwater insects that make them useful for monitoring water quality.

CHAPTER 12

Orders of Insects: Introduction



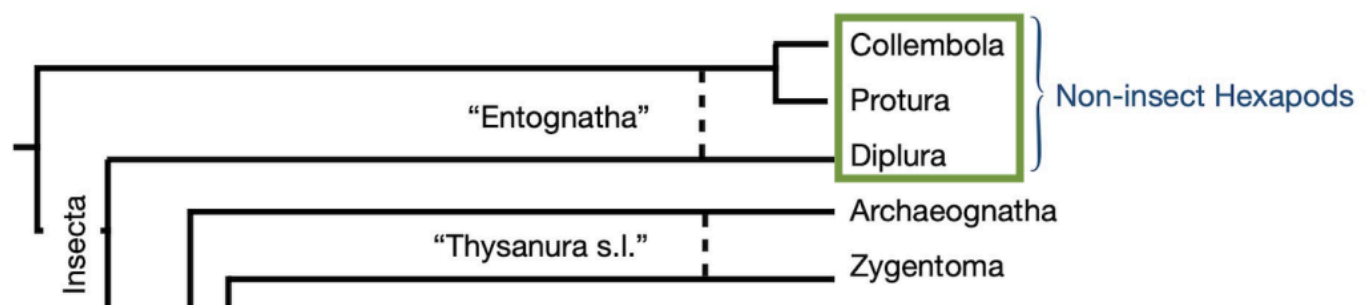
Photo of a student insect collection [K. Ebert].

The following chapters first present the three classes of non-insect hexapods, followed by the Class Insecta and all of its Orders. The chapters are in approximate order from those that retain the most ancestral features to those that show the most modifications of the ancestral state. Each chapter lists characteristics of each order of insects (or class of hexapods), both as adult and immature.

CHAPTER 13

The Orders of Insects: Non-insect Hexapods

Collembola diversity [Photo: AJ Cann, [CC BY-SA 2.5](#), Wikimedia Commons].



Cladogram highlighting the non-insect hexapods. Adapted from Gullan, P. J., & Cranston, P. S. (2014). *The insects: an outline of entomology* (5th ed.). Wiley-Blackwell.

ORDER PROTURA (CLASS ENTOGNATHA)

Order Protura

- no common name
- Greek, protos = first; oura = tail
- 500 species worldwide, about 30 species in Australia
- unknown until early 1900s
- worldwide distribution
- inhabit loose, moist soil, leaf litter; under bark, in thick moss, in decomposing logs, especially rich in humus
- observed feeding on fungal hyphae



Protura [Photo: D. Maddison, [CC BY-SA 3.0](#), Wikimedia Commons].

Characteristics of Protura

Adults

- Very small (<2mm), elongate, cylindrical body, usually without much pigmentation
- Head conical, no eyes or antennae
- **Entognathous:** mouthparts are enclosed within folds of the head, except when feeding
- Wingless
- Fore legs held forward; not used for walking but for sensory functions in the absence of antennae
- Abdomen has 12-segments; no cerci

Immatures

- resemble adults but with fewer abdominal segments

CLASS COLLEMBOLA

Class Collembola

- common name: springtails (refers to jumping mechanism on abdominal sterna 3 & 4, however a few Collembola lack this device)
- scientific name refers to tubular appendage on the first abdominal sternum which secretes a sticky substance – (Greek, kolla = glue; embolon = peg).
- worldwide distribution of about 9000 species; estimated that Australia has about 2000 species but only 1630 described
- very abundant in leaf litter and soil
- most species feed in moist habitats primarily on micro-organisms such as fungi, bacteria, algae, yeasts and pollen
- found in various habitats e.g. soil and leaf litter, marine littoral zone, surface of snow and water, termite colonies



Collembola [Photo: [Springtails](#) by AJC1, [CC BY-SA 2.0](#), [Wikimedia Commons](#)].

Characteristics of Collembola

Adults

- Small, soft-bodied, usually <3mm but some species up to 10mm; different body shapes; come in a variety of colours
- simple eyes made up of ocelli; mouthparts entognathous; antennae moniliform
- wingless; thoracic segments like those of abdomen, legs four-segmented
- abdomen six-segmented with sucker-like ventral tube (collophore) that has eversible sac-like vesicles for absorbing water from the substrate, in some species it has an adhesive function; without cerci
- forked tail-like springing structure (furca) held under the abdomen aids with jumping in many species

Immatures

- Resemble small adults, with constant segment number

Functions of the collophore:

- osmoregulation in some species
- adhesion after jumping in other species
- plays a role in ion transport, excretion, respiration
- may provide legs with a lubricant for grooming
- plays a role in uptake of water from substrate



Orchesella cincta (Collembola)–arrow points to collophore [Photo: D. Hobern, [CC BY 2.0](#), Wikimedia Commons].

ORDER DIPLURA (CLASS ENTOGNATHA)

Order Diplura

- no common name
- Greek, diploos = two; oura = tail
- consisting of about 1000 species worldwide; about 30 species described from Australia
- found under leaves, stones, etc. or in loose, moist soil in wetter forests and locations
- little known about their biology but sometimes found in small groups; a few records associate diplurans with ants and termites
- generally omnivorous feeding on soil micro-organisms, but some predacious (those with modified cerci)



Diplura [Photo: A. Murray, [CC BY-SA 2.0](#), Wikimedia Commons].

Characters of Diplura

Adults

- Most are small <5mm, but some get quite large up to 50mm; narrow-bodied
- No eyes, entognathous; antennae are moniliform
- wingless, thoracic segments like those of abdomen, legs five-segmented
- abdomen 10 segmented, sometimes with small protrusions
- two abdominal cerci often long & filiform, but sometimes more sclerotised & forceps-like, used for grasping

prey

Immatures

- Resemble small adult, with constant segment number

ACTIVITY

Watch this [video on Collembola locomotion](#).

Topic Review

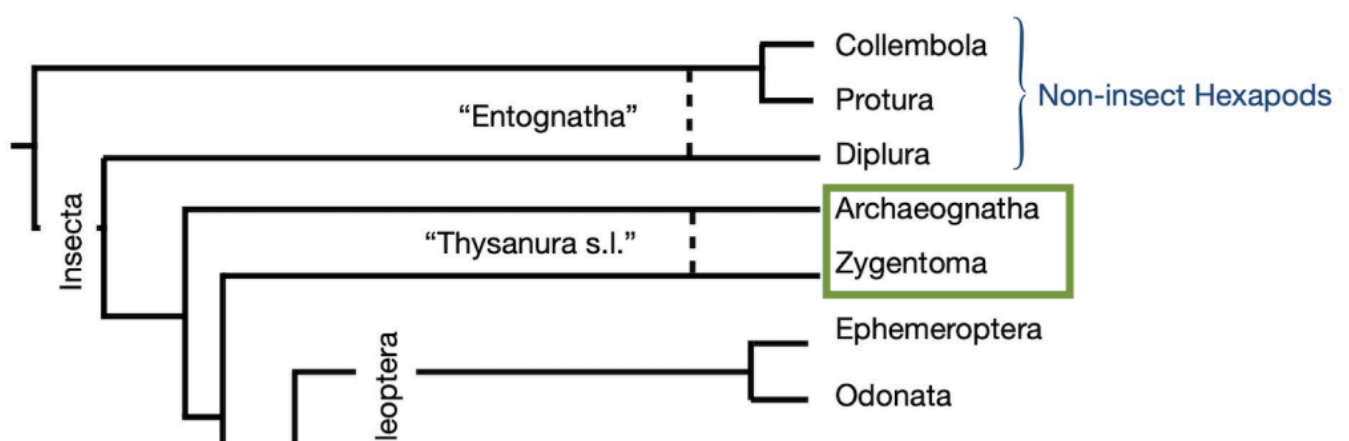
Do you know...?

- the names of the three groups of non-insect hexapods
- the special features of each group

CHAPTER 14

The Orders of Insects: Archaeognatha and Zygentoma

Archeognatha [Photo: K. Schulz, [CC BY 2.0](#), Wikimedia Commons].



Cladogram highlighting *Zygentoma* and *Archeognatha*. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER ARCHAEOGNATHA

Order Archaeognatha

- common name: jumping bristletails
- a primitive order whose members were once assigned to the Thysanura.
- scientific name (archaeo = old; gnatha = jaw) refers to primitive condition of mandible articulation
- feed on algae, moss, lichens and detritus
- found in damp environments under bark, stones, crevices, leaf litter.
- typically nocturnal
- fast and able to jump by flexing their abdomens
- No direct mating; transfer of sperm is indirect, stalked spermatophore in Aust. spp.
- moulting continues after adult ecdysis: long lived: 2-4 years

Characteristics of Archaeognatha

Adults

- elongate, laterally compressed body; moderate size 6-25mm; body covered in pigmented scales
- large, contiguous compound eyes and three ocelli; mouthparts **hypognathous** (directed downwards) with monocondylar (single-articulated) mandibles; antennae segmented
- thorax strongly arched; wingless
- some abdominal segments have paired styles and vesicles
- abdomen has three "tails": a pair of short cerci with a longer, single median caudal appendage

Immatures

- Resemble a small adult

ORDER ZYGENTOMA (THYSANURA)

Order Zygentoma

- common names: silverfish or firebrats
- named silverfish because as insects move quickly, scales of body shimmer like a silver fish.
- firebrats are the ones that prefer warmer places 32-44°C.
- Greek (thysanos = fringe, oura = tail)
- worldwide distribution; nearly 400 species
- mainly omnivorous or herbivorous; can digest cellulose
- domestic species of silverfish feed predominantly on dry paper products, book bindings, wallpaper, household debris
- found in soil, leaf litter, under bark, dark place; nocturnal
- an unusual trait: some silverfish moult after sexual maturity, which is attained between 10th and 14th instar



Zygentoma [Photo: [Paethon](#), [CC BY-SA 4.0](#), [Wikimedia Commons](#)].

Characteristics of Zygentoma

Adults

- Elongate, flattened body covered in silvery scales; 5-30mm long

- mouthparts **hypognathous** or **prognathous** (directed downwards or forwards); eyes are absent or greatly reduced; antennae slender, filiform
- wingless
- some abdominal segments have ventral styles; abdomen has three “tails”: two paired cerci and a slightly longer median caudal appendage.
- Metamorphosis simple: ametabolous; long lived: 2-3 years

Immatures

- Resemble small adults

Topic Review

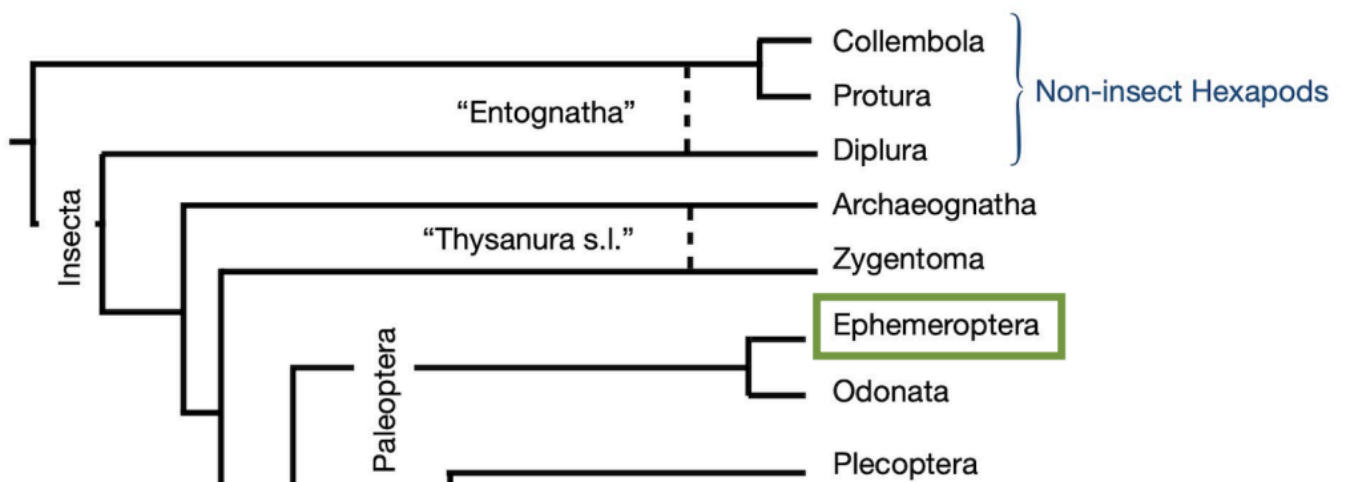
Do you know...?

- the two orders of primitively wingless insects?
- special features of each order

CHAPTER 15

The Orders of Insects: Ephemeroptera

Ephemeroptera adult [Photo: [LiCheng Shi](#), [CC BY 2.0](#), Wikimedia Commons].



Cladogram highlighting Ephemeroptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER EPHEMEROPTERA

Order Ephemeroptera

- common name: mayflies
- Greek, ephemerous = lasting a day; pteron = wing
- derived from a basal node of the phylogeny of extant winged insects
- approximately 3000 modern species, cosmopolitan, 84 Australian species
- adults very short-lived, from a few hours to a day or two; do not feed
- can show synchronised emergence in huge numbers; swarming behaviour sometimes astounding; occasionally attracted in large numbers to lights
- adults usually seen near water on vegetation or other objects
- mating occurs during flight
- all nymphs aquatic, found in fast-flowing streams or still waters of ponds; found clinging to rocks or some species burrow into bottom muck
- most nymphs feed on algae, detritus, aquatic plants; some species are predatory
- often used as valuable ecological indicators



Mayfly nymph [Photo: [Bob Henricks](#), CC BY-SA 2.0, Wikimedia Commons]

Characteristics of Ephemeroptera

Adult

- elongate insects, soft-bodied, small to medium sizes
- mouthparts reduced; compound eyes large; short filiform antennae
- wings membranous and fluted with large triangular fore wings and smaller hind wings, held above thorax at repose; (average wingspan ~15mm)
- abdomen slender compared to stout thorax, with three “tails”: paired cerci often as long as a median caudal appendage

Immatures

- Immature stages (nymphs) aquatic, with three “tails” and plate-like abdominal gills
- penultimate instar is a winged **subimago** (subadult)

THE SUBIMAGO: A UNIQUE FEATURE OF EPHEMEROPTERA

The subimago is an immature (non-sexual) stage with wings. Its body surface is covered in small hairs (microtrichia) or spines (microspines) which adults lack almost entirely. Microtrichia are thought to provide hydrofuge function for subimago emerging on water surface. Generally slower flyers than adults, weight loss of 25% (mostly water) to adult.

Watch the video: [Mayfly – a life story \(YouTube, 4m 19s\)](#).

Topic Review

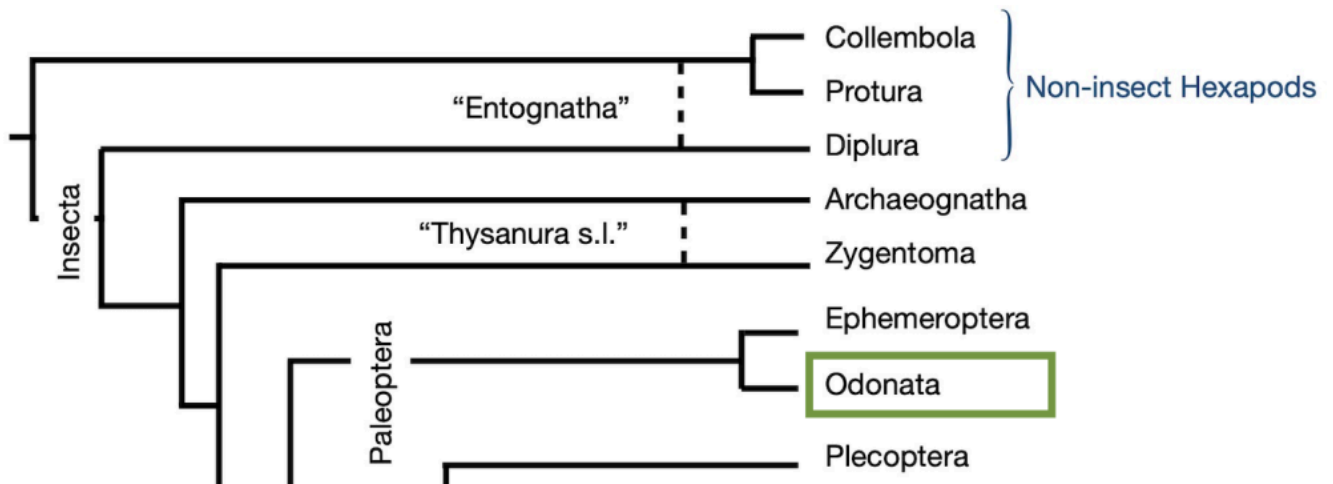
Do you know...?

- anatomy of immature and adult mayflies
- the characteristics of the subimago?

CHAPTER 16

The Orders of Insects: Odonata

Ebony Jewelwing Damselfly Calopteryx maculata (Odonata: Zygoptera) [Photo: K.Ebert].



Cladogram highlighting Odonata. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER ODONATA: DRAGONFLIES AND DAMSELFLIES

Order Odonata: Suborders Anisoptera & Zygoptera

- common names are dragonflies (Anisoptera) and damselflies (Zygoptera)
- Odonata comes from the Greek 'odon' which means 'tooth', referring to the strong, toothed jaws
- about 5500 species worldwide; about 330 species in Australia; two main suborders, both found in Australia
- require water to breed
- both adults and nymphs are predatory
- Fast fliers, use sight to locate and track the flight of prey, which is captured in flight
- mating takes place in flight
- aquatic nymphs



A female Wandering Percher *Diplacodes bipunctata* (Odonata, Anisoptera) [Photo: [John Tann](#), CC BY 2.0, Wikimedia Commons].

Characteristics of Odonata

Adults

- medium to large colourful insects with an elongate body; lengths ranging from 15-120 millimetres
- mobile head with large compound eyes widely separated in Zygoptera OR nearly in contact in Anisoptera
- three ocelli; small, bristle-like antennae; mouthparts **mandibulate** (with biting, chewing jaws)
- thorax stout with two pair of membranous, veined wings: fore and hindwings equal (Zygoptera) OR hind wings wider than fore wings (Anisoptera); (maximum wingspan 17cm!)
- abdomen slender with clasping organs

Immatures

- Nymphs aquatic, stout (Anisoptera) or narrow (Zygoptera).
- Nymphs have mandibulate mouthparts with an extensible labial "mask" used to capture prey
- Terminal or rectal gills: abdomen bears 3 large caudal tracheal gills in Zygoptera OR elaborate tracheal network in gills on inner rectal wall replaces external gills in Anisoptera

The suborders of dragonflies and damselflies can be separated by several features:

For adults:

Anisoptera (dragonflies): hind wings wider than fore wings; at rest, the wings of dragonflies are spread out perpendicular to the body (resembling aircraft wings); dragonflies tend to be more strongly built insects

Zygoptera (damselflies): fore wings and hind wings equal in size; damselflies bring their wings together loosely over the back of the abdomen; damselflies tend to be rather delicately built.

For nymphs:

Dragonfly nymphs are heavily built mud-dwellers.



Brown Hawker dragonfly nymph *Aeshna grandis* [Photo: [Charles J. Sharp](#), CC BY-SA 4.0, Wikimedia Commons].

Damselfly nymphs are more delicate and frequent tangled vegetation at the sides of the stream or pond and have two flattened abdominal appendages that are absent in dragonfly nymphs.



Blue-tailed damselfly nymph *Ischnura elegans* [Photo: [Charles J. Sharp](#), CC BY-SA 3.0, Wikimedia Commons].

IMPORTANCE

Dragonflies and damselflies form an extremely important group of predacious insects in stream and pond ecosystems. They are responsible for population control on a number of associated insect species. The adults are quite long lived and consume large quantities of insects over many weeks.

ACTIVITIES

1. Watch this 15-min video clip about [dragonflies \(YouTube, 14 m 54s\)](#).
2. Watch this 4 min movie of [dragonfly nymphs attacking prey \(YouTube, 4m\)](#) and then look at the images in this [paper](#) that describes the structure of the unusual mouthparts of the larvae.
3. Check out this link to dragonfly anatomy from Queensland Museum: [Odonata anatomy](#).

Topic Review

Do you know...?

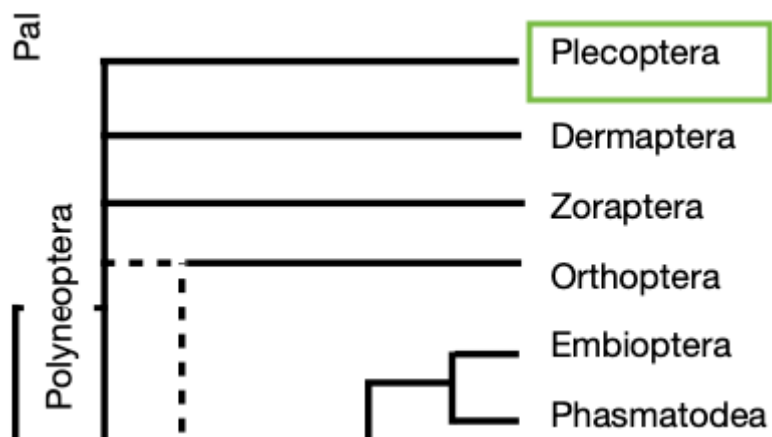
- differences between the Zygoptera and Anisoptera
- The two orders that comprise the Palaeoptera?
- The primary habitats of Odonata?

CHAPTER 17

Orders of Insects: Plecoptera



Plecoptera [Photo: JJ Harrison, CC BY-SA 3.0, Wikimedia Commons].



Cladogram highlighting Plecoptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER PLECOPTERA

Plecoptera

- common name: stoneflies
- Greek, plekein = to fold; pteron = wing
- worldwide distribution over 2,000 species; about 191 described species in Australia, mainly described from adult material
- adults are terrestrial but always live near water; immatures (nymphs or naiads) aquatic; mainly live in cool, clean, running water
- adults are herbivorous feeding on algae, lichens, detritus; nymphs are mainly herbivorous

Characteristics of Plecoptera

Adults

- Medium sized, elongate, soft-bodied insects
- large compound eyes, 2-3 ocelli; antennae long, filiform; mandibles present but reduced
- two pair of membranous wings; wings partly wrap around body at rest; hind wings somewhat larger than forewings; wing reduction is frequent; legs long and delicate
- abdomen soft with two filamentous cerci

Immatures

- Immature stages (nymphs) are aquatic; resemble wingless adults
- gills along side of abdomen or some have a tuft of anal gills; two filamentous cerci

Stoneflies are not common in Australia, in fact, only a few species are found in the Southern Hemisphere. They prefer temperate climates and cool montane streams. Most Australian species inhabit eastern Australia and Tasmania. The presence of stonefly larvae is often an indicator of high water quality as they are not found in polluted water. Nymphs of many Australian species are still unknown or undescribed.

“Surface skimming” by adult Plecoptera has been suggested to indicate how flight could have originated in insects!



Stonefly nymph [Photo: [Dave Huth](#), [CC BY 2.0](#), Wikimedia Commons].

Topic Review

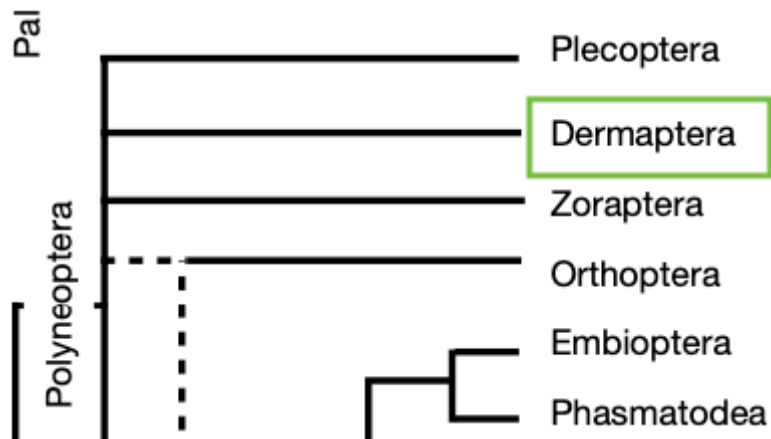
Do you know...?

- The main anatomical features of stoneflies
- The role of stoneflies in freshwater ecology

CHAPTER 18

Order of Insects: Dermaptera

Dermaptera, Dacnodes hackeri [Photo: [tjeales](#), [CC BY-SA 4.0](#), Wikimedia Commons].



Cladogram highlighting Dermaptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER DERMAPTERA

Dermaptera

- common name: earwigs; derived from folklore that European species were thought to enter ear of a sleeping person
- Greek, derma = skin; pteron = wing
- worldwide 1,800 nominal species; about 85 Australian species described so far
- best represented in tropical and warm temperate regions
- typically nocturnal, sometimes taken at lights
- thigmotactic (react positively to touch and crawl into confined spaces)
- prefers secluded and moist habitats: forest litter, under bark, stones, within soil
- most are omnivorous; some predatory forms
- earwig females care for their eggs and young nymphs



[A New Zealand shore earwig](#) (mata) *Anisolabis littorea* (Dermaptera) tending her eggs [Photo: [JamesvanAsch43](#), [CC BY-SA 4.0](#), [Wikimedia Commons](#)].

Characteristics of Dermaptera

Adults

- Small to medium-sized, bodies, 5-50mm; flattened and elongate
- prognathous, mandibulate mouthparts; antennae short to moderate length, filiform; compound eyes variable (large to absent), ocelli absent
- many species wingless; if wings present the fore wings are small leathery tegmina, hind wings semi-circular and folded fan-like under the tegmina; legs short.
- Abdomen with overlapping terga; cerci sclerotised and modified as forceps

Immatures

- Immature stages (nymphs) resemble small adults

Despite Australia being a biodiversity hotspot for earwigs, only a third of the described subfamilies of earwigs have been recorded. The distinctive forceps at the end of the abdomen are usually larger and more curved in males. The forceps can be used for defence, to hold and carry prey, for grip during copulation and sometimes to help unfold their fan-like wings.

ACTIVITIES

Some interesting reading:

- An article about [earwigs and parental care](#).

- An earwig species that squirts [defensive fluid](#) (caustic quinones).
- An unusual [species](#) of earwig that lives in caves of Borneo and feeds off the secreted body wax of hairless bats and carries bat fleas from bat to bat.

Topic Review

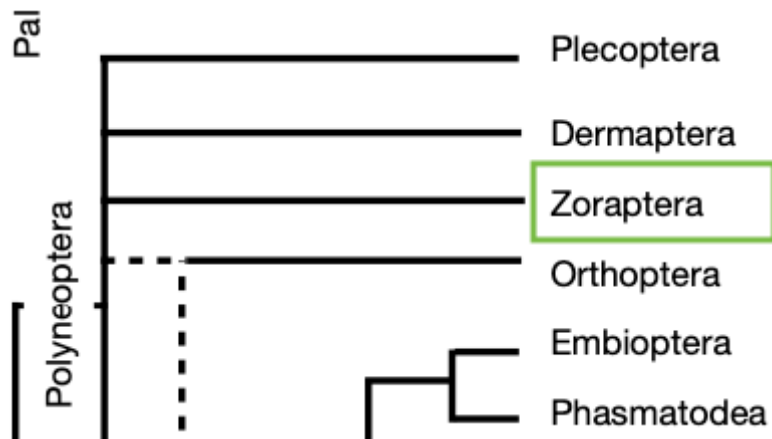
Do you know...?

- the main anatomical features of earwigs
- the strategies used for defence

CHAPTER 19

Orders of Insects: Zoraptera

[Zoraptera](#) [Photo: Angal insect, [CC BY-SA 4.0](#), Wikimedia Commons].



Cladogram highlighting Zoraptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER ZORAPTERA

Zoraptera

- common name: angel insects or zorapterans
- in Greek “zor” means pure and “aptera” means wingless; when first described the only known specimens were wingless—they have since found winged forms (alates)
- Order first described in 1913; about 30-50 species worldwide, many undescribed; distributed worldwide except not in Australia
- Tropical to warm temperate climates
- Gregarious
- Found in leaf litter, rotting wood or near termite colonies
- likely eat fungi

Characteristics of Zoraptera

Adults

- Small (<4mm), termite-like, pale
- hypognathous, mandibulate mouthparts
- winged species have compound eyes and ocelli, wingless species lack both eyes and ocelli,
- Moniliform antennae
- If winged, the wings have simple venation and are readily shed

- abdomen 11 -segmented, short and swollen with single segmented cerci

Immatures

- Immature stages (nymphs) resemble small adults

Keen to know more?

Check out these links:

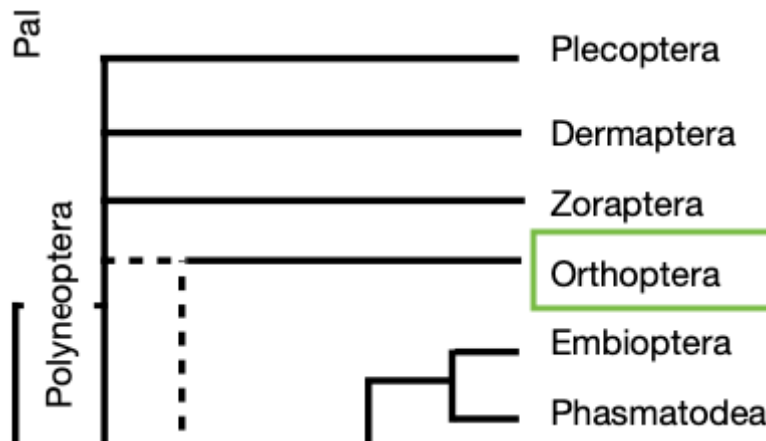
- Some Zoraptera have giant sperm, about 3 mm long, and use [external sperm transfer via a spermatophore](#). Males of one species package a single sperm into a spermatophore and deposits it on the outside of the female's abdomen.
- Check out this entertaining and informative video on zorapterans on the [Insect spotlight project \(YouTube, 10m 09s\)](#).

CHAPTER 20

Orders of Insects: Orthoptera



Katydid (Orthoptera: Ensifera). [Photograph by Andrew Maynard. Used with permission].



Cladogram highlighting Orthoptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER ORTHOPTERA

Orthoptera

- common names: grasshoppers, crickets, katydids, locusts
- Greek 'ortho' meaning straight, and aptera meaning 'wings'
- worldwide distribution; high diversity: ca. 20,000 spp. – about 3000 Australian species
- found in all terrestrial habitats in trees, shrubs, grasses and underground caves; many are cryptic
- many phytophagous, some omnivorous, some predaceous
- have diverse mechanisms for sound production & frequently use sound to attract mates

TAXONOMY

2 suborders:

- **Ensifera** – crickets, katydids, king crickets: characterised by long antennae; usually nocturnal or well-camouflaged; can be predators, omnivores, herbivores
- **Caelifera** – short-horned grasshoppers & locusts; characterised by short antennae; predominantly day-time active, fast-moving, herbivores



Grasshoppers, *Monistria pustulifera* (Orthoptera: Caelifera) [Photo: [Andrew Allen, CC BY 4.0, Wikimedia Commons](#)].

Characteristics of Orthoptera

- Medium to large (up to 10-12cm); elongate, cylindrical body
- mouthparts mandibulate and hypognathous; well-developed compound eyes; ocelli present or absent; antennae multi-segmented; long in Ensifera, shorter in Caelifera
- fore wings form a narrow, leathery tegmina; hind wings broad, folded beneath tegmina; some wingless (apterous) and some with reduced wings (brachypterous); prothorax large with a shield-like pronotum
- enlarged hind legs for jumping
- females have a well-developed ovipositor

SOUND PRODUCTION

Sound production occurs with many different insect species but is most elaborate and diverse in the Orthoptera. Stridulation occurs when two body parts are rubbed together: one part being a 'file' or finely ridged or pegged surface, the other is a 'scraper' (e.g. a plectrum). Katydid and crickets have a 'file' on one fore wing that rasps against the other fore wing. Grasshoppers and locusts have a file on their leg (femora) that rasps against the fore wing scraper. It is usually the males that "sing", but occasionally females do, too. The sounds are received via a tympanum ('ear') on the fore tibia or an abdominal tergite.

Sound can be used in courtship, aggression or distress.

[Mole crickets](#) use the shape of their burrow to amplify the sound in order to attract females.

Read about a [Western Australian cricket that uses sound for defence and social communication](#).

NOTES

Many Orthoptera are capable of jumping and their metathoracic legs are modified for this **saltatorial** habit. The forelegs and midlegs are generally **gressorial**. Burrowing forms have **fossorial** forelegs, for example, the mole cricket.

Locusts and some crickets are capable of swarming. These swarms can do much damage to crops. Australia has a Plague Locust Commission whose role is to predict locust plague outbreaks and control the swarms. Read [more about plague locusts](#).

The [mountain katydid](#), an otherwise drab insect, shows a [colourful warning display](#) when it is disturbed. It's also the feature insect on our cover!

The Cooloola monster is a relatively newly discovered species of Orthoptera, first found in sand dunes of south-east Queensland in 1980. A new family, the Cooloolidae was created for the Cooloola Monster and a further three sister species were described, all found in the same vicinity. Another three or four species have since been discovered but are yet to be described. The species are almost entirely subterranean.

Keen to learn more about Cooloola monsters?

Check out the following references:

Rentz, D.C.F. 1980. A new family of ensiferous Orthoptera from the coastal sands of southeast Queensland. *Memoirs of the Queensland Museum* 20(1): 49-63.

Rentz, D.C.F. 1986. The orthopteran family Cooloolidae, including descriptions of two new species and observations on biology and food preferences. *Systematic Entomology* 11: 231-246.

Rentz, D.C.F. 1999. Pearson's monster, a new species of Cooloola Rentz from Queensland (Orthoptera: Cooloolidae). *Journal of Orthoptera Research* 8: 25-32.

Monteith, G.B. 2020. Searching for Cooloola monsters: 40 years of discovery of these iconic Queensland insects. *News Bulletin of the Entomological Society of Queensland* 48[2]: 28-42.



[Cooloola monster](#), *Cooloola propator* (Orthoptera: Ensifera) [Photo: E.Zillman, CSIRO, [CC BY 3.0](#), Wikimedia Commons].

Topic Review

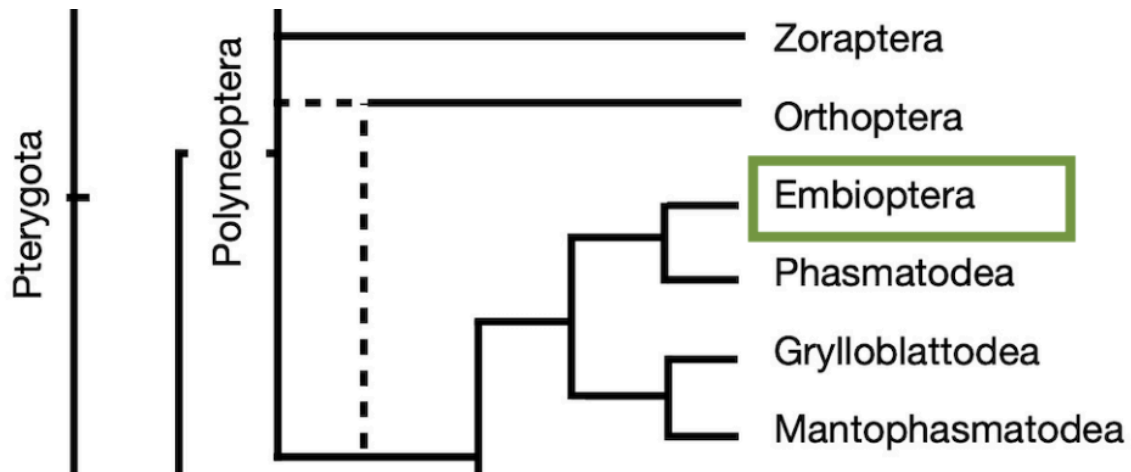
Do you know...?

- the main anatomical features of grasshoppers
- how to distinguish between the two suborders

CHAPTER 21

Orders of Insects: Embioptera

[Embioptera](#) [Photo: Entomology, CSIRO, [CC BY 3.0](#), Wikimedia Commons].



Cladogram highlighting Embioptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER EMBIOPTERA

Embioptera

- common names: web spinners or foot spinners
- Greek, 'embio' = lively, 'ptera' = wing
- widespread; about 200 species, many undescribed
- well represented in tropical and warm temperate regions
- all species gregarious
- all life stages live in silken galleries or tunnels in sheltered spots e.g. under logs, stones, or bark
- feed on bark, moss, lichen, dead leaves and other plant material

Characteristics of Embioptera

Adults

- Small to medium (4-15mm), elongate, cylindrical bodies
- prognathous, mandibulate mouthparts
- reniform (kidney-shaped) compound eyes, ocelli absent; multi-segmented antennae, slender and filiform
- females wingless, in some species the males have two pairs of soft, membranous wings
- legs short, fore tarsus swollen with silk gland

- cerci two-segmented

Immatures

- Immature stages (nymphs) resemble small adults

NOTES

The use of silk galleries are the most notable feature of Embioptera. Many of their distinctive morphological features such as prognathous head, aptery and the swollen fore-tarsi are adaptations to life in a silk gallery. The tarsal silk glands are present in the fore-tarsi in all instars. Embioptera will readily run in reverse within their gallery tunnels to escape incoming predators. In winged males, the wings will fold over the head when they run backwards!

Keen to learn more?

More about Embioptera:

- [Web spinning in Webspinners](#)
- [CSIRO Embioptera](#)
- [North Carolina State University: Embioptera](#)

Topic Review

Do you know...?

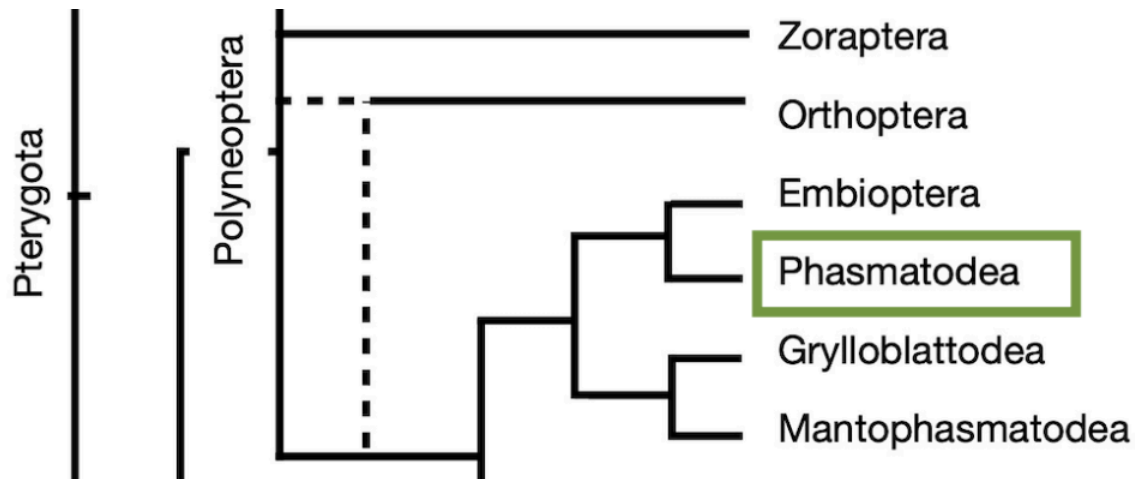
- the main anatomical features of webspinners
- how Embioptera are adapted to living in silk tunnels

CHAPTER 22

Orders of Insects: Phasmatodea



A dancing leaf insect, Walaphyllium monteithi (Phasmatodea). [Photo: K. Ebert]



Cladogram highlighting Phasmatodea. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER PHASMATODEA

Phasmatodea

- common name: stick insects & leaf insects; mimic sticks or leaves
- from the Greek, 'phasma' = apparition or ghost
- about 2,500 described species worldwide; 150 Aust. spp.
- most abundant in tropical regions; occur where ever adequate trees and shrubs occur to feed on
- all are phytophagous; some species are an occasional forest pest
- very slow moving; best know for their camouflage

Characteristics of Phasmatodea

Adults

- medium to large (30-300mm+); body cylindrical & stick-like or flattened & leaf-like
- prognathous & mandibulate
- compound eyes small, laterally placed; ocelli present in winged species
- fore wings form leathery tegmina, hind wings broad with toughened fore margin (remigium); wings are absent in many species, often restricted to males; winged species most common in tropics
- legs elongate & gressorial

- cerci one-segmented, variable in size

Immatures

- Immature stages (nymphs) resemble small adults without wings; ocelli absent

Phasmids are best known for their camouflage but may also have additional elaborate defence mechanisms:

- **thanatosis** – feigning death
- **autotomy** (shed legs when grabbed) – good powers of regeneration
- **regurgitation**
- **aposematic colouration**: startle displays of colour on hind wings
- kick with spiny legs
- repugnatorial secretions (chemical defenses)
- at least one species, the peppermint stick insect, forcibly sprays caustic solution from the prothorax. Watch [The Peppermint Stick Insect \(YouTube, 1m 30s\)](#)!



Stick insect [Photo: [John Tann, CC BY 2.0, Wikimedia Commons](#)].

MORE INFORMATION

You can read more about phasmids on the [Australian Museum's webpage](#).

One of the rarest insects in the world is the Lord Howe Island Stick insect (*Dryococelus australis*). It was believed to be extinct until 2001 when it was rediscovered on Balls Pyramid, a volcanic outcrop off the coast of Lord Howe Island. A captive breeding program is underway at Melbourne Zoo.

Video about the [Lord Howe Island Stick insect \(YouTube, 1m 50s\)](#).

[Listed as a critically endangered species](#)



Lord Howe Island Stick insect (*Dryococelus australis*) [Photo: Granitethighs, [CC BY-SA 3.0](#), Wikimedia Commons].

Topic Review

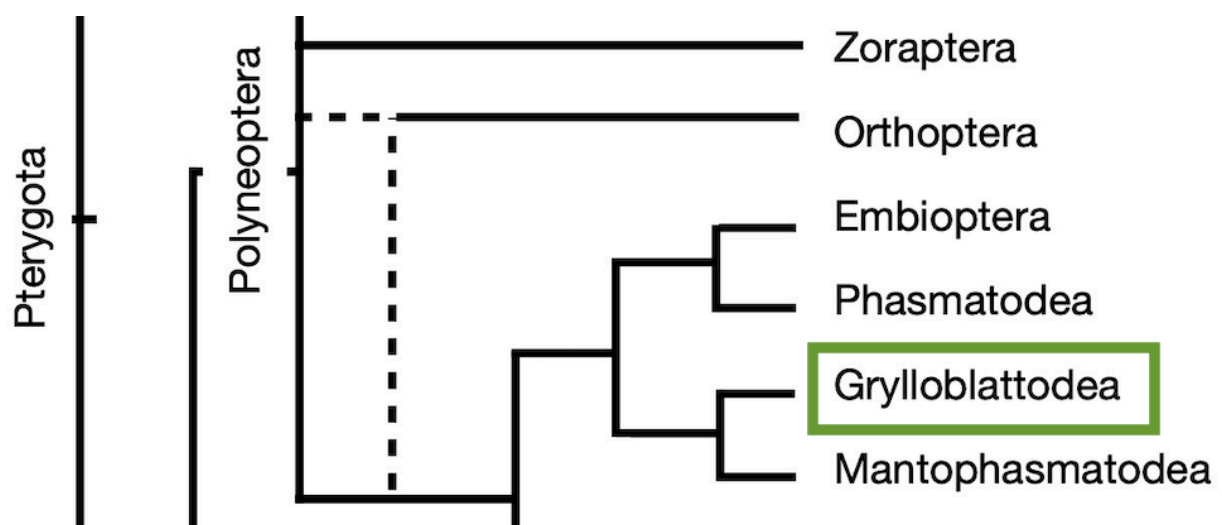
Do you know...?

- the main anatomical features of stick insects
- how stick insects defend themselves
- how stick insects differ from preying mantids

CHAPTER 23

Orders of Insects: Grylloblattodea

Grylloblattodea [Photo: Alex Wild, [CC0](#), Wikimedia Commons].



Cladogram highlighting *Grylloblattodea*. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

GRYLLOBLATTODEA

Grylloblattodea

- ice crawlers or rock crawlers
- name means 'cricket-roach'; 'gryll' from the Greek meaning cricket and 'blatta' meaning cockroach
- only 25 described species worldwide; discovered around 1906, described in 1915
- second smallest order of insects
- not found in Australia or the southern hemisphere: restricted to western North America, central to east Asia & Japan
- extremophiles: live under leaf litter, rocks, on glaciers, snowbanks in cold environments, between 1-4°C; slow development
- omnivorous but appear to feed on dead arthropods and organic material
- often nocturnal

Characters of Grylloblattodea

Adults

- Medium-sized (20-35mm), soft-bodied, elongate & pale
- prognathous, mandibulate mouthparts, compound eyes reduced or absent; ocelli absent; multisegmented filiform antennae
- wingless; cursorial legs with large coxae
- abdomen has segmented cerci; female has a short ovipositor

Immatures

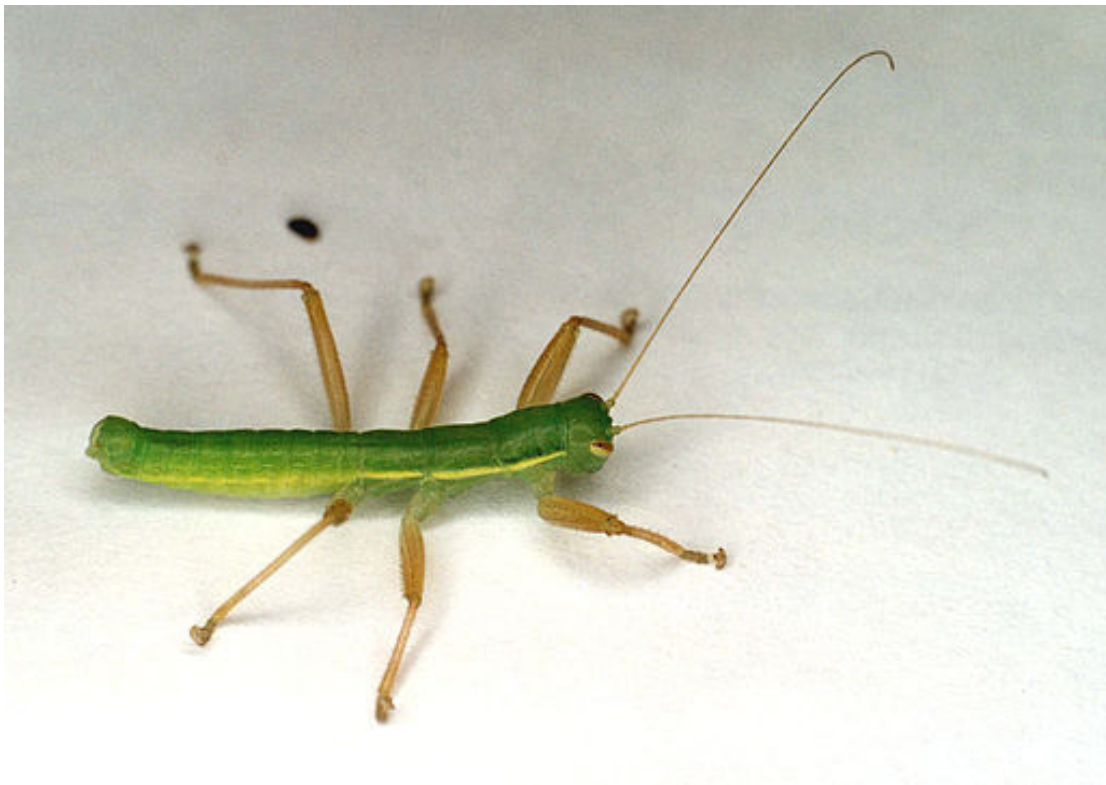
- Immature stages (nymphs) resemble small adults

Keen to learn more?

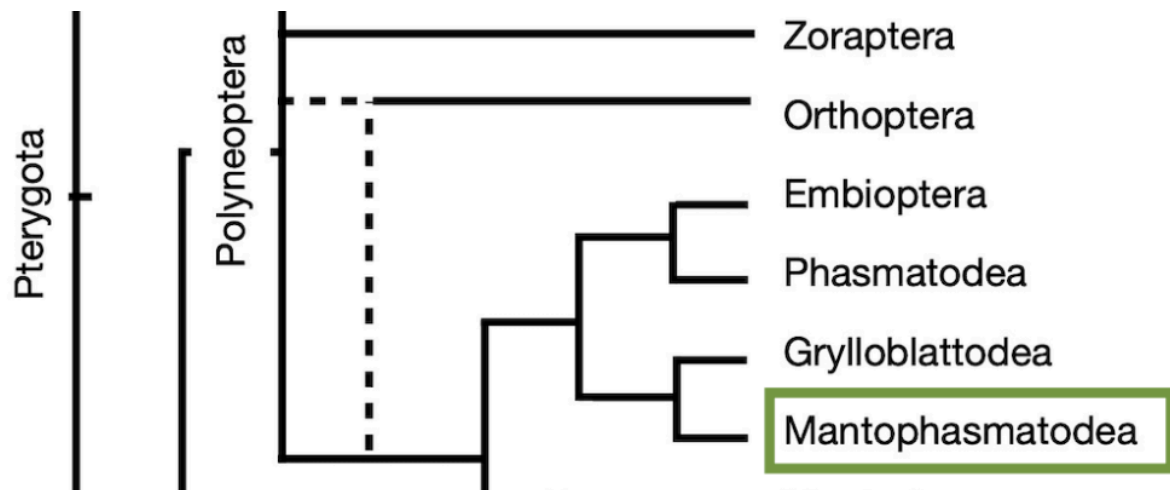
- [Some images of grylloblattids](#)
- A rare [video \(YouTube, 1m 49s\)](#) of grylloblattids traversing ice; these cold-adapted insects are not well studied.

- Watch this video from the [Insect Spotlight Project \(YouTube, 6m 10s\)](#).

CHAPTER 24

Orders of Insects: Mantophasmatodea

Mantophasma zephyra (Mantophasmatodea). [Photo PE Bragg, [CC BY-SA 3.0](#), Wikimedia Commons]



Cladogram highlighting Mantophasmatodea. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER MANTOPHASMATODEA

Mantophasmatodea

- common name: heelwalkers; so named because they hold the distal tarsomere up off the ground when walking
- a newly described order in 2002; name is a combination of Mantodea and Phasmatodea to reflect its superficial similarity to these two orders
- only six to eight species worldwide; found only in south-west Africa including Namibia and Tanzania.
- smallest order of insects; most closely related to Grylloblattodea
- most are nocturnal predators; hide in grass and rock crevices

Characteristics of Mantophasmatodea

Adults

- Small to medium (11-25mm), somewhat cylindrical body shape
- Hypognathous, mandibulate; compound eyes large, ocelli absent; antennae long, multi-segmented
- wingless; fore and mid-legs have bristles and spines
- cerci small in female but prominent in male

Immatures

- Immature stages (nymphs) resemble small adults

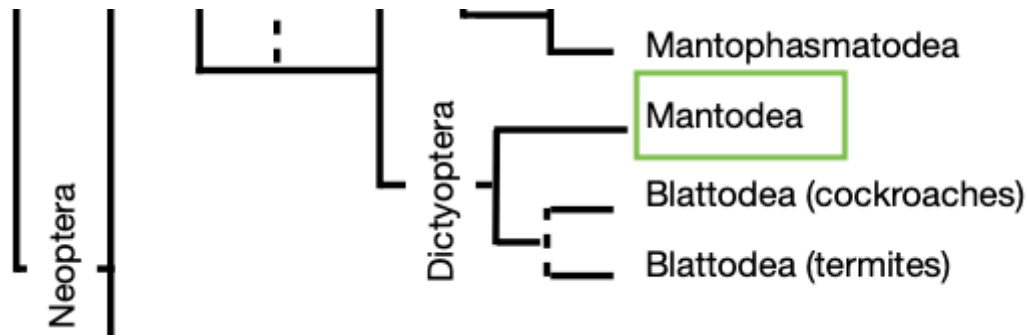
Keen to learn more?

- Here is a [great article about heelwalker biology and behaviour with photos](#)
- And an [earlier article on their discovery](#)

CHAPTER 25

Orders of Insects: Mantodea

Rainforest mantis Heirodule majuscula (Mantodea) [Photo: K. Ebert].



Cladogram highlighting Mantodea. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER MANTODEA: PRAYING MANTIS

Mantodea

- common name: praying mantis (or sometimes mantid referring to those in the Family Mantidae)
- name comes from the Greek 'mantis', which means 'one who divines, seer, prophet'
- occurs worldwide, about 2000 spp.; 162 Australian species
- found in most habitats; predominantly tropical & subtropical, but species also found in temperate climates; a few boreal species
- predators as both immatures and adults; usually lie in wait for prey
- well camouflaged; mimic leaves, bird droppings, flowers, etc.
- eggs laid in a frothy egg case called an ootheca

"The name 'praying' originates from the pose they hold their front legs in – as if they were praying. This name is sometimes confused with the fact that they capture prey and are erroneously referred to as 'preying' mantises. Some mantises belonging to the family Mantidae are referred to as mantids; many of Australia's species belong to this group and hence can be referred to as either praying mantids or praying mantises." —[Alan Henderson](#)



A brown bark mantis *Paraoxyphilus* sp. (Mantodea) [Photo: [Patrick_K59](#), CC BY 2.0, Wikimedia Commons].

Characteristics of Mantodea

Adults

- Moderate to large (1-15cm);
- Triangular shaped head, highly mobile; large, well-developed compound eyes; three ocelli; filiform antennae
- mandibulate mouthparts, hypognathous
- an elongated narrow prothorax; fore wings form leathery tegmina, hind wings broad; sometimes adults wingless or with reduced wings
- Fore legs spiny and raptorial, mid and hind legs elongate
- abdomen has short cerci

Immatures

- Immature stages (nymphs) resemble small adults without wings.

DEFENSIVE MECHANISMS:

- attack – spines on legs can draw blood
- crypsis
- aposematic coloration

- mimicry

NOTES

Mantids are famous for their predatory habit and the way they lunge and grasp their prey. Scientists have studied their use of binocular visual guidance mechanisms to focus on their prey and estimate the strike distance.

Topic review

Do you know...?

- the main anatomical features of preying mantids

CHAPTER 26

Orders of Insects: Blattodea



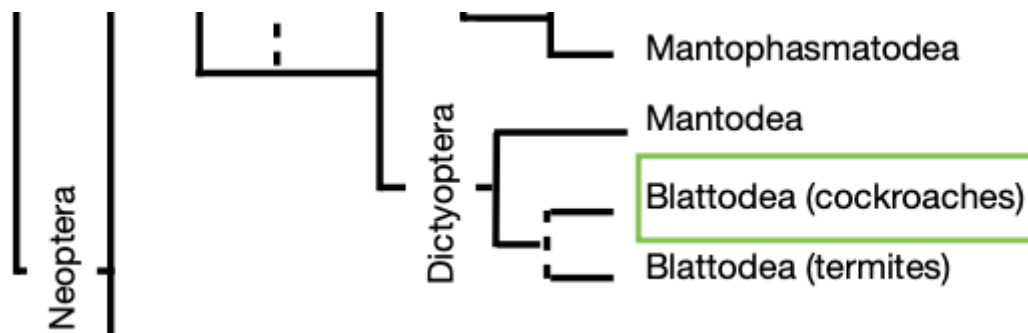
Reticulated cockroach Ellipsidion reticulatum (Blattodea) [Photo: K. Ebert].

ORDER BLATTODEA: COCKROACHES AND TERMITES

Until recently, Order Isoptera (termites) was a valid order of insects. However, phylogenetic and other analyses has shown that the termites sit within Order Blattodea. This created a problem (see Inward D, Beccaloni G,

Eggleton P. 2007. Death of an Order: a comprehensive molecular phylogenetic study confirms that termites are eusocial cockroaches. *Biol. Lett.* 2007;3:331–335) because the proposal to give Isoptera family level caused additional problems. At the moment, we can treat termites as “higher taxon Termitoidae’ within Blattodea (according to the [Australian Faunal Directory](#)) and are considered to be eusocial cockroaches (see also: [Save Isoptera](#), written by Nathan Lo at the University of Sydney with others).

Renaming of existing groups or species when new data comes available is a controversial area and causes many disagreements among scientists. There are rules that scientists must use when changing names (see Chapter 2).



Cladogram highlighting Blattodea (Cockroaches). Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

BLATTODEA (COCKROACHES)

Blattodea

- common name: cockroaches
- from the Greek word 'blatta' meaning cockroach
- worldwide est. 4000 spp.; Australian has about 428 native spp.
- most abundant in tropical and subtropical habitats;
- native roaches eat leaf material, pollen; many omnivores and saprophagous scavengers; some eat wood with help of internal microbiome
- many nocturnal and usually avoid light (negatively phototactic); some gregarious
- eggs laid in ootheca; some sp. have ovoviviparity

Characteristics of Blattodea (Cockroaches)

Adults

- Small to large (3mm-100mm), elongate, oval, dorsoventrally flattened bodies
- Hypognathous, mouthparts mandibulate; compound eyes and two ocelli present (except cave dwellers), antennae long and filiform
- prothorax has a large, shield-like pronotum
- Fore wings form leathery tegmina to protect membranous hind wings; some species wingless; legs long, cursorial, often spiny
- abdomen with segmented cerci

Immatures

- Immature stages (nymphs) resemble small adults without wings.

BIOLOGY



Giant burrowing cockroach
(*Macropanesthia rhinoceros*) [Photo: K. Ebert]

Australia has 428 spp of cockroaches; only 10 are considered pests and all these are introduced (not native). Some have colourful markings.

An unusual characteristic is the use of an ootheca to store and carry eggs. Most species are oviparous (egg-laying); the female externalises the eggs and secretes a case around them that becomes dark and sclerotised. She carries the resulting ootheca attached to her terminal segments before depositing it. Some species are ovoviviparous (the egg hatches within the female) with membranous oothecae containing eggs within a brood pouch. A few species are viviparous with ootheca incompletely developed and the embryos nourished from internal secretions by mother.

The Giant Burrowing cockroaches of eastern Australia are some of the heaviest cockroaches in the world. The female gives birth to fully developed nymphs.

The degree of wing development varies among cockroach species:

1. **apterous** – no wings e.g. Giant Burrowing cockroach
2. **brachypterous** – short wings e.g. Oriental cockroach
3. **macropterous** – fully developed wings e.g. American cockroach

PEST STATUS

We think of cockroaches as vermin but in fact only a small number of species are closely associated with humans and are pests.

Pest cockroaches are not proven to serve as obligate vector for any disease in the way that mosquitoes, for example, are vectors for malaria and dengue. However, due to their dietary habits and close association with food preparation areas, they are regarded as significant problem in transmission of bacterial diseases to humans, such as:

- food poisoning – *Salmonella*
- dysentary – amoebic, bacterial
- hepatitis
- typhoid fever

Typhoid fever is an infectious disease caused by *Bacillus typhosus* that is ingested with food or drinking water. It causes high temperature, enlargement of the spleen, inflammation of the intestine and other symptoms. It may be mechanically transmitted by cockroaches and flies.

URBAN PEST COCKROACH SPECIES

German cockroaches are surprisingly common in food preparation areas of restaurants. They are difficult to control because it appears that they can learn to avoid insecticides or baits. Ultrasonic repellents don't work despite claims to the contrary. They prefer to inhabit sheltered crevices and cavities, for example, under a refrigerator, under cracks in a floor covering or in wall cavities accessed by cracks. They seem to be gregarious, living in large numbers together and foraging at night. They learn to avoid insecticide residue and they seem to be resistant to many of the insecticides commonly used in households. Feed on any residues and food scraps in bins.

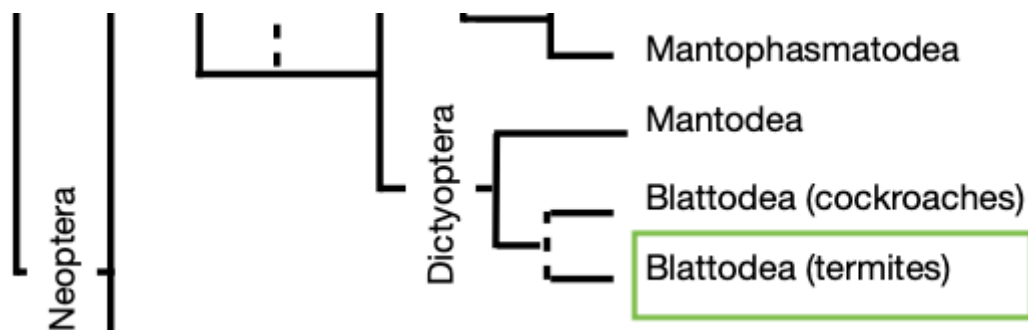
American cockroaches are a bit easier to eliminate than German cockroaches because the larger size makes them more visible and they can't reach such large numbers without being particularly noticeable. They also seem to be better-adapted to living on the periphery of human dwellings rather than within them. They can be found in huge numbers in sewerage systems and can occupy out-houses and garages. They can feed on food left out for pets.

Continue on to the next chapter to learn about the rest of the Blattodea, the termites!

CHAPTER 27

Orders of Insects: Blattodea (Termitoidae)

Nasute termites (Blattodea: Termitoidae) [Photo: [Craig Kirkwood, CC BY-SA 2.0, Wikimedia Commons](#)].



Cladogram highlighting Blattodea (Termites). Adapted from Gullan, PJ & Cranston PS (2014). The insects: an outline of entomology (5th ed.). Wiley Blackwell.

HIGHER TAXON TERMITOIDAE (TERMITES)

Blattodea – Termitoidae

- common name: termites, white ants. (Greek, isos = equal; pteron = wing)
- worldwide about 2,300 species; 350 or so Australian spp with 258 described
- best represented in tropical and subtropical regions
- eusocial, live in large colonies in wood or soil
- nests: arboreal, subterranean or termitarium (a mound, plural=termitaria)
- reproductives swarm with a royal pair (king and queen) excavating a nuptial chamber, copulating and establishing a new colony; royal pair long-lived, perhaps to 50 years
- mature termite colonies may number two million individuals
- primary dietary component is cellulose; depend upon symbiotic flagellate protozoa, ameboid protozoa, bacteria or fungi for digestion
- economically significant destruction of wood and wood products

Characteristics of Blattodea-Termitoidae

Adults

- Small to medium size (<20mm); pale, elongate soft body; polymorphic
- head large or small; mandibulate mouthparts (variable in different castes), antennae long, beaded; eyes small or absent
- Wings only present in reproductive caste and shed after mating; when present, fore and hind wings usually similar with reduced venation;
- wide junction between thorax and abdomen
- abdomen terminates in segmented cerci

Immatures

- Immature stages morphologically variable (polymorphic) according to caste.



Termite mounds in Queensland. [Photo: [Brian W. Schaller, CC BY-NC-SA 4.0, Wikimedia Commons](#)].

BIOLOGY

Termites are well-known for their ability to break down cellulose. This is done through their possession of gut fauna. Cellulose broken down by symbiotic bacteria (in derived groups) or flagellate protozoans (in less derived groups). These symbionts are passed to newly-moulted individuals via **proctodaeal feeding**, i.e. eating each others' faeces.

Termites are eusocial so the majority of individuals are not reproductives and are allocated to a functional form called a **caste**. The main non-reproductive castes of termites are *workers* and *soldiers*. Soldiers are marked by their enlarged heads and mandibles and in some species they have additional protective structures. Examples include the [nasute termites](#) where the soldiers have a modified appendage on their head that ejects a toxic, glue-like secretion.

Using substrate vibration [communication](#), soldiers bang their heads against the substrate about 11 times per second. Upon detecting the signal, in-radius soldiers propagate the warning by repeating the signal.

Keen to know more?

- Read about [termite gut microbiota](#)!

PEST STATUS

Most termites are not pests. They play important ecological roles by recycling plant nutrients through feeding on and disintegrating and decomposing dead wood and plant debris. Excavations and nests of termites alter

the structure of trees,- providing spaces used as habitat by many vertebrate species including bats, birds, reptiles and arboreal mammals.

Pest termites are grouped into three categories:

1. dampwood – live in damp rotting logs or rot pockets in dead or living trees
2. drywood – obtain water from wood in which they feed and have no contact with soil or other source of moisture
3. subterranean – ground-dwelling or require contact with the soil or some constant source of moisture

Only 20 or so species of termites are of economic importance to timber-in-service in buildings in Australia. The risk of infestation by termites is greatest in the tropics and warm temperate coastal and inland regions. It is negligible in both Tasmania and the highlands of south-eastern Australia.

Drywood termites are widely distributed throughout coastal and adjacent tableland areas in Queensland. Most of the species of termites that damage timber-in-service in Australia are subterranean termites. *Mastotermes darwiniensis* and *Coptotermes* spp. are the most destructive e.g. *Coptotermes acinaciformis* is responsible for more economic loss than all the other Australian species combined. This is due to:

- its extensive range
- the severity of its attack
- its ability to survive in built-up areas such as cities and large towns

The genus *Coptotermes* contains several species complexes, the species within each complex differing biologically and chemically but not in appearance.

Some species of *Schedorhinotermes* and *Nasutitermes* are of economic importance – *Nasutitermes exitiosus* is particularly widespread in the cool temperate regions of the southern mainland states.

The annual cost of termite damage to buildings is not known, but estimates range from \$80-100 million. The cost of imported chemicals may exceed \$10 million annually. Surveys have been undertaken in Melbourne, Darwin, Sydney, Canberra, and Perth on the incidence of termite infestation, the location of infestations and the identity of the species involved. A Forestry Commission survey in 1982-83 indicated that 20% of houses in New South Wales had evidence of past or current termite activity. Other surveys were undertaken in Sydney, Melbourne, Adelaide and Canberra in which the incidence of recorded termite infestation in dwellings ranged from 0.9 – 4.5% per year, dependent on the city and age of the dwelling. Termites can cause significant damage with devastating financial and social implications for building owners and occupiers.

In some cases the first indication of a termite infestation is the audible sound of the termites communicating by head-drumming. Termites are good at indicating quality using sound. Termites don't like to be exposed to drying conditions, that is why they cover their routes to maintain a micro-climate. Inspectors look for these routes around supporting house stumps or against building slabs. When they feed on timber they tend to hollow it out so that there is a paper-thin layer protecting the feeding gallery. Sometimes, the first sign of termites is hollow-sounding wood skirting, or by accidentally breaking through the thin barrier. Pest controllers tap wooden structures of a house and investigate any hollow-sounding wood by prying with a screw-driver. Bore-scopes are also useful.

Topic Review

Do you know...?

- the main anatomical features of cockroaches
- the pest status of cockroaches
- the main anatomical features of termites
- how termites impact on people

CHAPTER 28

Orders of Insects: Psocodea

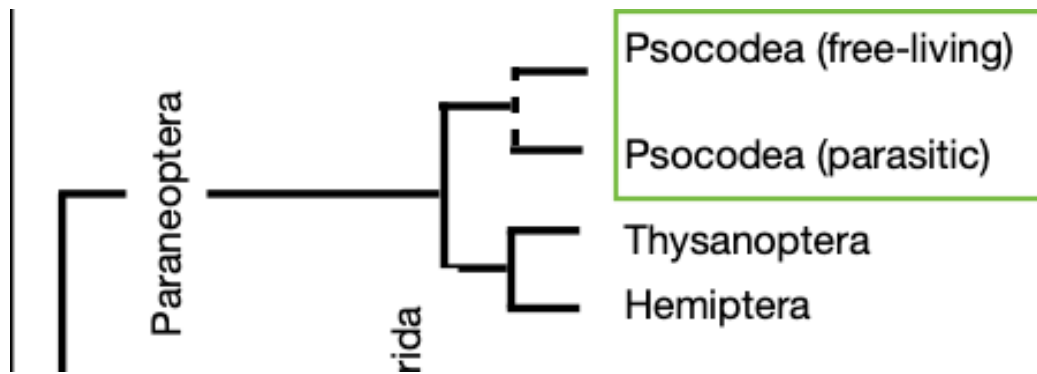


Bark louse (Psocodea:Psocoptera) [Photo: [James Niland](#), [CC BY 2.0](#), Wikimedia Commons].

ORDER PSOCODEA: BARKLICE, BOOKLICE, AND BODY LICE

Until recently barklice, booklice and parasitic lice were regarded as discrete, separate orders but now they are regarded as belonging to the same order, given the name **Order Psocodea**. Note that this classification is fairly recent so older editions of your text book might list them as discrete orders. **Psocoptera** (barklice & booklice) and **Pthiraptera** (parasitic lice) are currently classified as a 'higher taxon', not a suborder.

For additional information, go to this [website](#) and examine the relationships of barklice, booklice and parasitic lice.



Cladogram highlighting Psocodea. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

PSOCODEA: PSOCOPTERA (BARKLICE, BOOKLICE) – HIGHER TAXON

Psocodea – Psocoptera

- common names: psocids, barklice, or booklice
- scientific name: Greek, psocus = rubbed or gnawed
- worldwide distribution, ~3000spp.; about 300 species in Australia.
- live in all major habitats; found in leaf litter, foliage, bark of trees; some species associated with human dwellings, natural habitat unknown
- food includes:
 - lichens, algae, fungi, yeasts, dead insects (insect collections), pollen, exuvia
 - domestic species frequently feed on starch: flour, book bindings, grains
- some are pests in insect collections, libraries & herbaria; some are grain pests
- some species are myrmecophilous (live in ant colonies)

Characteristics of Psocodea-Psocoptera

Adults

- minute to small (1-10mm), stout, soft bodied
- head large and mobile, asymmetrical chewing mouthparts; large, compound eyes; ocelli present in winged species
- neck-like restriction between head and thorax; antennae long, slender, filiform

- wings reduced or absent (booklice); if wings present, membranous and with reduced venation; wings held roof-like over the abdomen (barklice)
- cerci absent

Immatures

- Immature stages (nymphs) resemble small adults



Head louse (Psocodea: Phthiraptera: Anoplura) [Photo: [Gilles San Martin](#), [CC BY-SA 2.0](#), [Wikimedia Commons](#)].

PSOCODEA: PHTHIRAPTERA (PARASITIC LICE) – HIGHER TAXON

Psocodea – Phthiraptera

- common name: lice
- scientific name: Greek, 'phthir' = lice and 'aptera' = wingless
- appx. 5000 spp. worldwide; found throughout Australia with about 255 described spp.
- all are obligate ectoparasites of birds and mammals; entire life spent on host
- eggs (nits) usually cemented to feathers or hair of host
- some lice carry disease vectors to humans, notably epidemic typhus (ET)
- lice of marine mammals, e.g. elephant seals, usually burrow into thick skin

Characteristics of Phthiraptera

Adults

- small (<10mm), dorsoventrally flattened, colourless
- head conical in sucking lice; broad and flat in chewing lice; eyes absent or reduced; antennae short
- mandibulate, biting mouthparts (biting lice) or beaklike, piercing and sucking mouthparts (sucking lice)
- wingless; legs well developed and stout with strong claws; adapted for clinging to host

Immatures

- immature stages (nymphs) resemble adults but smaller

THREE SUBORDERS IN AUSTRALIA:

- **Amblycera** – biting lice; feed on bird feathers and mammal skin; usually two small tarsal claws
- **Ischnocera** – biting lice; feed on bird feathers and mammal skin; usually two small tarsal claws
- **Anoplura** – sucking lice; feed solely on mammal blood (except bats); usually one large tarsal claw

For more details check out these pages from CSIRO: [Psocoptera](#) and [Phthiraptera](#)

NOTES:

Some adaptations for clinging to host.

Morphological adaptations:

- flattened body
- strong legs and claws
- powerful mandibles
- numerous setae

Behavioural adaptations:

- negatively **phototropic**
- settle in places where they can avoid being dislodged by grooming
- most bite skin at base of hair or feathers for blood (and skin oils)

Some examples of Human Lice:

Crab louse: *Phthirus pubis*

- favored habitat is pubic area (also other body hair)
- not implicated in any disease transmission.

Body louse: *Pediculus humanus*

- scatters eggs unattached
- transmits epidemic typhus.

Head louse: *Pediculus capitus*

- glues eggs to hair
- no disease transmission
- increasingly common in school children.

Topic Review

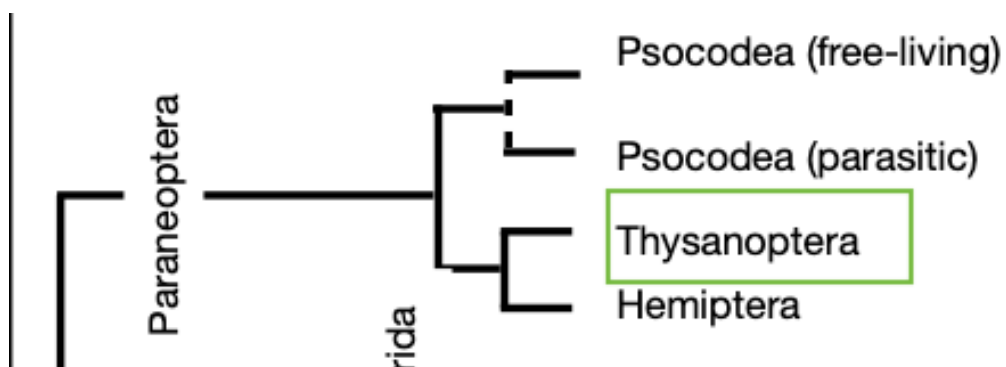
Do you know...?

- the main anatomical features of Psocoptera
- the main anatomical features of Phthiraptera
- how lice are adapted to their lifestyle

CHAPTER 29

Orders of Insects: Thysanoptera

Adult male thrips (Thysanoptera: Tubulifera) [Photo: [Alandmanson, CC BY 4.0](#), Wikimedia Commons].



Cladogram highlighting Thysanoptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER THYSANOPTERA (THRIPS)

Thysanoptera

- common name: thrips. Singular is thrips as well: “one thrips among many thrips”
- Greek: thysanos=fringe, ptera=wing
- diversity: about 6000 spp. worldwide; about 900 in Australia
- can be serious pests of crops
- most species phytophagous but some predators, a few omnivores
- some feed on mosses, ferns fungi, pollen, flower or leaf tissue
- gall formers: the gall provides insect shelter from weather and enemies

Two suborders:

Terebrantia – wings parallel at rest; saw-like ovipositor

Tubulifera – wings overlap at rest, ovipositor eversible, cylindrical

Characteristics of Thysanoptera

Adults

- Small (0.5-15mm), slender, cylindrical body
- head elongate, hypognathous; mouthparts modified to form a feeding tube with three stylets: the maxillary laciniae plus the left mandible
- short antennae; compound eyes small to large, ocelli present in winged species
- With or without wings; if present, wings subequal, strap-like, with long setal fringe around the edge
- legs short, gressorial; pretarsus has a protrusible, adhesive arolium (bladder) instead of a tarsal claw

Immatures

- Immature stages (nymphs) resemble small adults



A thrips nymph (Thysanoptera:Terebrantia) [Photo: [M.J.](#), [CC BY-SA 2.0 DE](#), Wikimedia Commons].

[More about thrips](#) from the Australian Museum and the CSIRO: [Thrips \(CSIRO\)](#)

Need to identify thrips? See [Thrips of Australia](#).

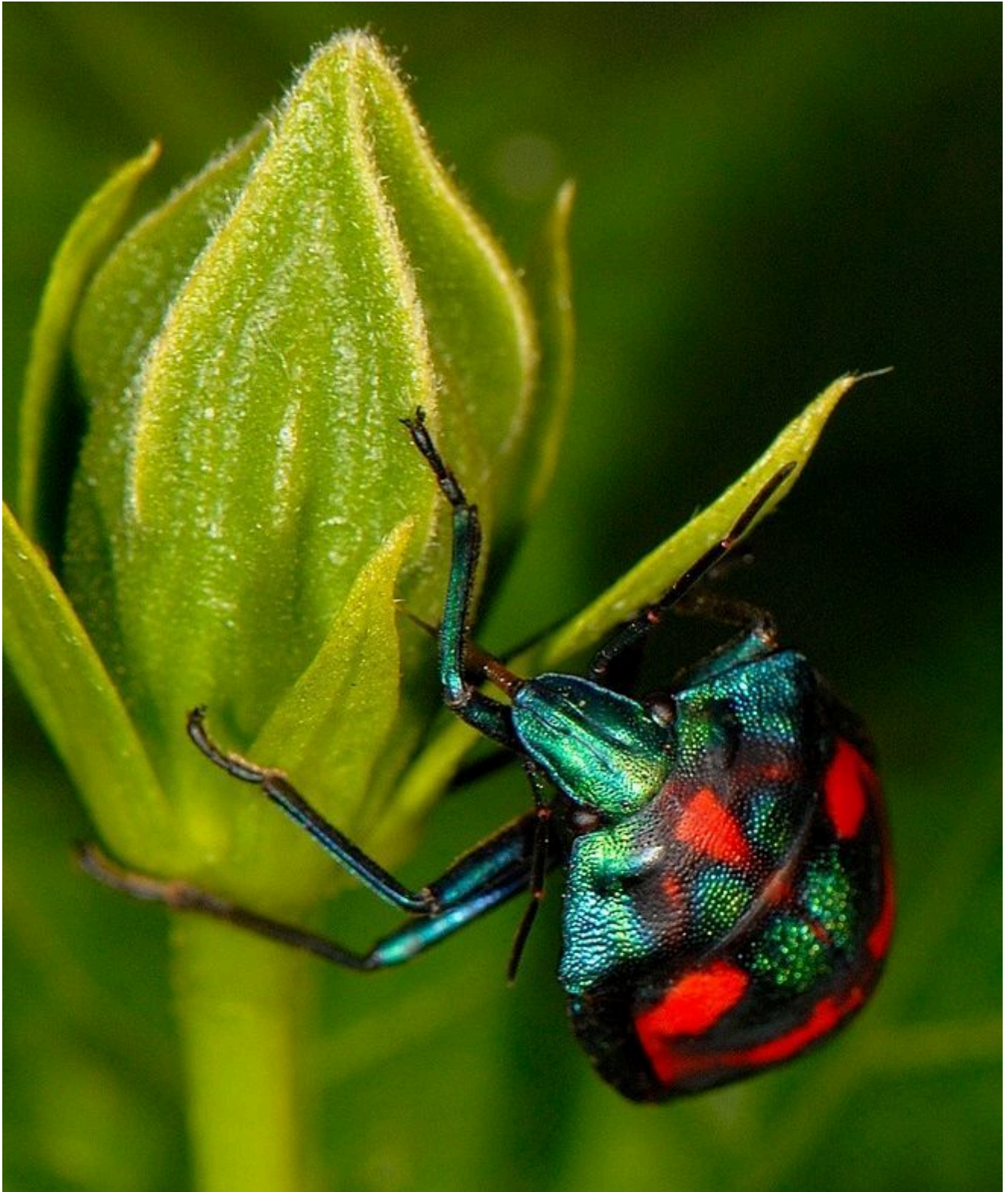
Topic review

Do you know?

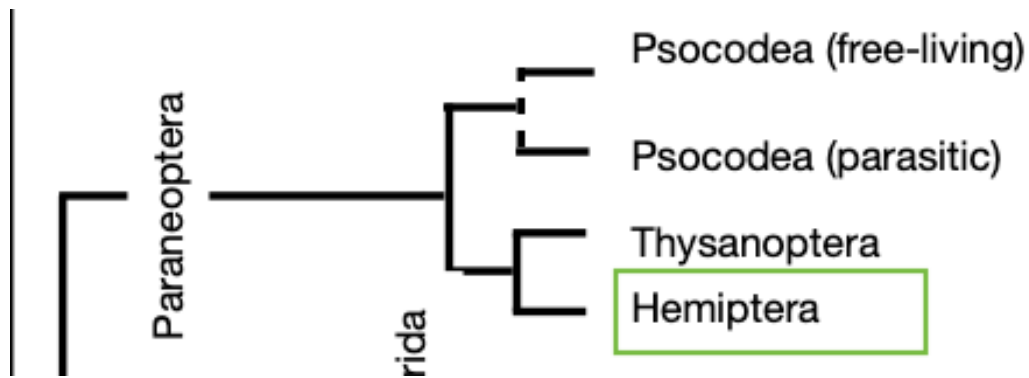
- the main anatomical features of thrips

CHAPTER 30

Orders of Insects: Hemiptera



A harlequin bug (Hemiptera: Heteroptera) [Photo: [Sam Fraser-Smith](#), [CC BY 2.0](#), Flickr].



Cladogram highlighting Hemiptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER HEMIPTERA: BUGS, LEAFHOPPERS, CICADAS, APHIDS, SCALE INSECTS

Hemiptera

- Greek, hemi = half; pteron = wing
- common name: true bugs
- A hyper-diverse group with more than 90,000 described species, 5650 Aust. spp.
- distributed worldwide; about 4000 aquatic or semi-aquatic species
- an important characteristic feature is their piercing-sucking mouthparts
- most species are plant feeders & seed feeders but also many predators, blood suckers, scavengers
- contain many important agricultural pests
 - they cause direct feeding damage
 - they can be vectors of many plant diseases, including viruses such as cucumber mosaic and banana bunchytop viruses



Sheild bug nymphs (Hemiptera-Heteroptera) newly emerged from eggs [Photo: K. Ebert].

Characteristics of Hemiptera

Adults

- Small to large
- generally, mouthparts modified into needle-like stylets forming a rostrum; directed posteriorly at rest
- in most, compound eyes large; ocelli present or absent; variable antennae
- Fore wings may be thickened to form hemelytra (Heteroptera), or membranous (Auchenorrhyncha) and held roof-like over the body; wing reduction or absence is common (Sternorrhyncha)
- legs gressorial, raptorial in some spp.
- cerci absent; abdominal scent glands present in Heteroptera

Immatures

- Immature stages (nymphs) resemble small adults

THREE SUBORDERS:

Sternorrhyncha

- Includes whiteflies, aphids, coccids, mealybugs, scale insects
- Mouthparts appear to arise from between first pair of legs (Sternorrhyncha translates to “chest snout”)
- soft delicate insects; in winged forms, wings membranous
- Sedentary existence; phytophagous
- many species have a symbiotic relationship with ants
- some species are serious plant pests and vectors of plant pathogens



Scale insects: two adult females (large, dark, disc-like), a winged, adult male about to emerge (pink and white) and several nymphs. [Photograph by Lyn Cook. Shared under a [CC BY-NC 4.0 licence](https://creativecommons.org/licenses/by-nc/4.0/)].

Auchenorrhyncha

- cicadas, spittlebugs, leafhoppers, treehoppers, planthoppers
- Mouthparts appear to arise posteriorly on head (Auchenorrhyncha translates to “neck snout”!)
- bristle-like antennae
- wings usually held roof-like over abdomen.
- Free-living and phytophagous



Leaf hopper (Hemiptera: Auchenorrhyncha). [Photo: K. Ebert]

Heteroptera

- stink bugs, jewel bugs, seed bugs, assassin bugs
- mouthparts arise anteriorly on head but tucked back between legs
- Forewing has sclerotised base, membranous apex (hemelytron)
- have a large scutellum and forewings overlap forming a 'x' or 'y' pattern
- plant feeders, predators and blood feeders; aquatic groups are predators.



A pod-sucking bug, Riptortus serripes – note the large triangular scutellum and the 'x' pattern formed by the wings. [Photo: K. Ebert].

FEEDING MECHANISMS

Stylet-ensheath

- Found in many Sternorrhyncha and Auchenorrhyncha including aphids:
 - A sheath of solidified saliva forms around the stylets as they penetrate; feed on xylem or phloem vessels. Both are very watery food (especially xylem) and need to excrete large quantities of water while feeding to acquire enough nutrients to survive. Many have a filter chamber to shunt excess water and sugar from foregut to hindgut and avoid the midgut, while filtering out amino acids to the midgut.

Lacerate-and-flush

- Found in all predators and many heteropteran herbivores:
 - The stylets are repeatedly pushed one way then another. In essence, they “liquefy” a pocket of cells. Contents of the pocket are flushed with watery saliva and sucked. In predaceous Heteroptera, salivary enzymes immobilise prey very quickly – extremely painful to human (e.g. assassin bugs).



A predatory assassin bug impales a fly with its rostrum.[Photograph by Collen Foelz. Used with permission].

Blood-sucking

Found in specialised Heteroptera, e.g. bedbugs.



Adult bed bug (Cimex lectularius) [Photo: [Centers for Disease Control and Prevention's Public Health Image Library, Harvard, Public Domain](#)].

Topic Review

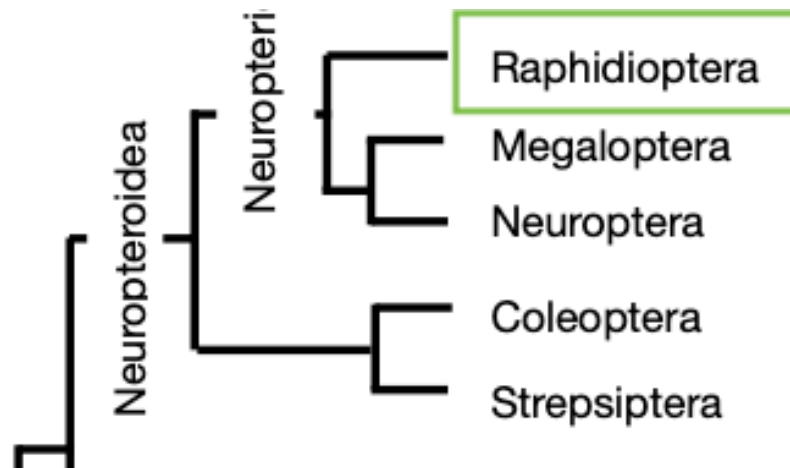
Do you know...?

- the main anatomical features of bugs
- the feeding mechanisms used by bugs

CHAPTER 31

Orders of Insects: Raphidioptera

A snake-fly (Raphidioptera) [Photo: [Beentree](#), CC BY-SA 3.0, Wikimedia Commons].



Cladogram highlighting Raphidioptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER RAPHIDIOPTERA: SNAKEFLIES

Raphidioptera

- common name = snakeflies
- from the Greek: 'raphis' for needle, 'pteron' for wing; a reference to them looking like flying needles
- found in temperate regions worldwide, but not in Australia or southern hemisphere; about 260 spp.; a relict group, more common in the Cretaceous
- live in leaf litter, under bark, often in coniferous forest; diurnal
- predators as adults and larvae (holometabolous)

Characteristics of Raphidioptera

Adults

- Medium size (15-30mm),
- head long and flattened, mobile; prognathous, mandibulate mouthparts
- Compound eyes large and separated; many without ocelli; antennae filiform, long, & multi-segmented
- Prothorax much longer than meso- and metathorax
- Fore wings rather longer than otherwise similar hind wings; fore wings have a pterostigma; numerous cross-veins near leading edge, branching venation
- females have a long ovipositor to deposit eggs under bark; no cerci

Immatures

- Immature stages (larvae) are terrestrial, large heads, first segment sclerotised, projecting mandibles
- pupa is mobile



Raphidioptera larva [Photo: [Nikita Kluge](#), [CC0](#), Wikimedia Commons].

Keen to learn more?

Check out [Insect Spotlight video on snakeflies](#) (YouTube, 6m 36s)!

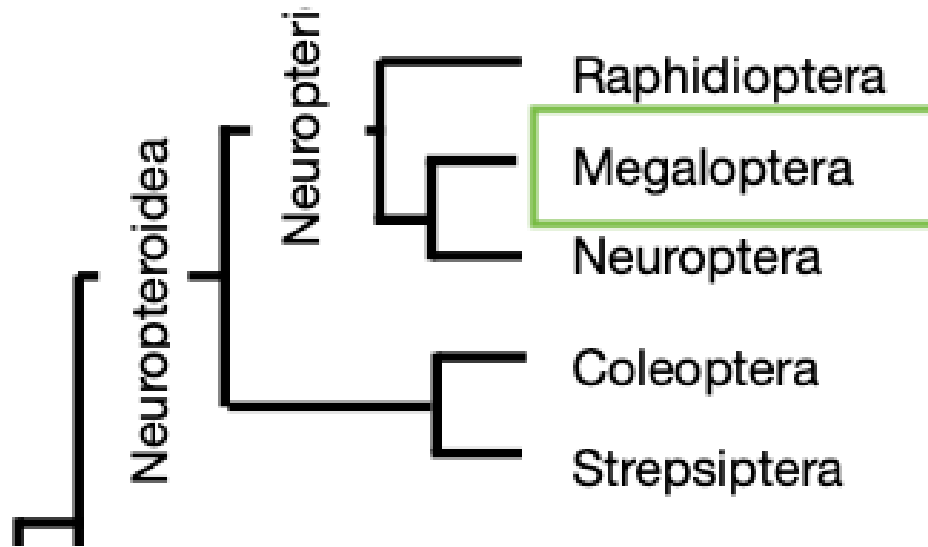
Read more about [fossil snakeflies](#).

CHAPTER 32

Orders of Insects: Megaloptera



Western dobsonfly, *Corydalus texanus* (Megaloptera). [Photo: [Whitney Cranshaw, Colorado State University, CC-BY 3.0, Bugwood.org](#)].



Cladogram highlighting Megaloptera. Adapted from Gullan, PJ & Cranston PS (2014). The insects: an outline of entomology (5th ed.). Wiley Blackwell.

ORDER MEGALOPTERA: ALDERFLIES AND DOBSONFLIES, FISHFLIES

Megaloptera

- common name: alderflies, dobsonflies
- from Greek, 'megas' = large, 'ptera' = wing
- most diverse in temperate regions; about 300 species worldwide; 26 Australian spp.
- Australian species found in headwaters of streams along Great Dividing Range in eastern Australia; associated with cool, clear waters, usually found where submerged detritus collects; one sp. in SW Australia
- Larvae are aquatic; live under rocks and debris and are active predators, feeding on small aquatic invertebrates; pupate in soil adjacent to stream
- adults tend to be short-lived, do not appear to feed, found on vegetation surrounding larval habitat
- large mandibles in males are for courtship displays,
- adults crepuscular or nocturnal, attracted to lights



Dobsonfly larvae (Megaloptera) [Photo: [Whitney Cranshaw, Colorado State University, CC-BY 3.0, Bugwood.org](#)].

Characteristics of Megaloptera

Adults

- Medium to large (20-100mm)
- compound eyes large and separated; antennae filiform, tapering at the end
- Prognathous, mandibulate mouthparts
- prothorax longer than meso- and metathorax
- Membranous fore and hind wings with cross veins along the edge & often with dark spots; wings held roof-like over the body at rest

Immatures

- Immature stages (larvae) aquatic, prognathous, with stout mandibles, jointed legs only on thorax, with lateral abdominal gills

More information: CSIRO [Megaloptera page](#), and [Australian Freshwater Invertebrates](#).

Topic Review

Do you know...?

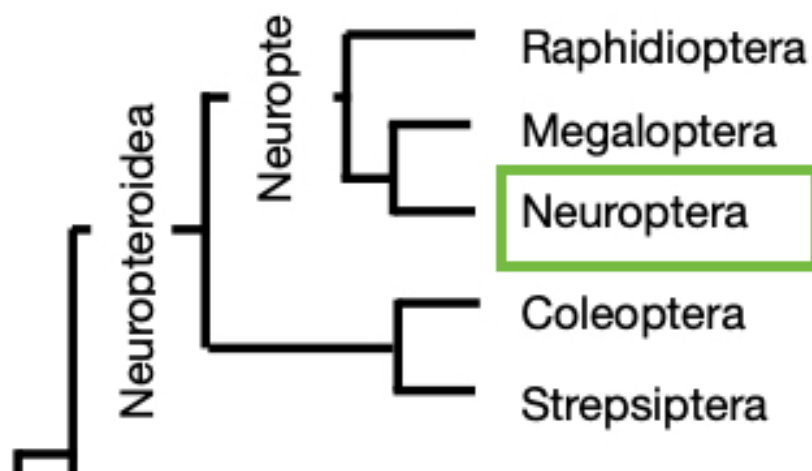
- the main anatomical features
- how to distinguish Megaloptera larvae from other aquatic larvae

CHAPTER 33

Orders of Insects: Neuroptera



Adult Lacewing (Neuroptera) [Photo: [Jean and Fred Hort](#), [CC BY 2.0](#), Wikimedia Commons].



Cladogram highlighting Neuroptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER NEUROPTERA: LACEWINGS

Neuroptera

- common names: lacewings, mantis flies, antlions, owlflies
- from Greek: neuro = nerve, pteron=wing ; refers to the pattern of wing venation
- about 5000 spp. worldwide with the greatest diversity in Australia; over 600 described spp. in Australian
- common throughout Australia; found in most habitats
- eggs laid singly or in batches; may be scattered in or on sand, or cemented to the substrate; in many species the eggs are laid on stalks to raise them above the substrate to protect them from predation
- Larvae and adults usually predatory and terrestrial
- highly beneficial to human agriculture



Lacewing larva with bits of debris attached to its body to help camouflage it from predators. [Photo: [John Tann](#), CC BY 2.0, Wikimedia Commons].

Characteristics of Neuroptera

Adults

- medium size (up to 50mm), elongate soft body
- mandibulate mouthparts; large compound eyes; multi-segmented, filiform antennae, sometimes clubbed at the end
- Prothorax often larger than meso- and metathorax

- Wings membranous, similar size; held roof-like over abdomen at rest; wings have numerous cross-veins and forked veins
- no cerci

Immatures

- immature stages (larvae) predominantly terrestrial, larvae have sickle-shaped, hollow mandibles, prognathous; ocelli present
- the gut is discontinuous (dead end) so the gut contents are not voided until after metamorphosis!
- some species have aquatic larvae

NOTES

Neuroptera commonly lay their eggs on stalks in different patterns and arrangements. Species in the family Nymphidae lay eggs on stalks in a semicircular pattern in shaded areas. Every second egg produced is laid on the end of a silken stalk, and intermediate eggs are set perpendicular to the previous one and connected to the stalked eggs so that the eggs are arranged in a "U"-shaped pattern. Having the eggs on stalks is thought to add protection from predation. The tiny droplets along the stalks are thought to be defensive substances or to provide food for newly hatched nymphs.



Neuroptera eggs on stalks laid in a U-shape with newly hatched nymphs below [Photo: K. Ebert].

Family Mantispidae are unusual in that the adults have mantis-like forelegs to help in the capture of prey. This is an example of convergent evolution.

Antlions are larval Neuroptera that build conical depressions in dry, fine soil to trap insects walking along the ground. Their hooked mouthparts are adapted for piercing and sucking.



Antlion larva (Neuroptera: Myrmeliontidae), [Photo: [Joseph Berger, CC-BY-3.0-US](#), Wikimedia Commons, [© Bugwood.org](#)].

Green Lacewings as Biocontrol Agents

The biocontrol supplies company, [Bugs for Bugs](#), based at Toowoomba send lacewing eggs in the mail. Adult female lacewings live for approximately three or four weeks and lay up to 600 eggs. Each egg sits on the end of a slender silken stalk. The eggs take approximately four days to hatch.

Larvae range in size from 1 mm at first emergence up to 8 mm just before they pupate. They have small spines on their backs upon which they impale the remains of prey. This provides a form of camouflage and allows the larvae to appear inconspicuous amongst the prey. Larvae pass through three moults over a period of 12 days before pupating inside a silken cocoon. Adults emerge after nine days and start laying eggs seven days after emergence.

They target pests such as aphids, mites, whitefly, scales, and mealy bugs.

Keen to learn more?

Check out this paper on the [Chemical Ecology of Neuroptera](#)

Topic Review

Do you know...?

- the main anatomical features of immature and adult lacewings

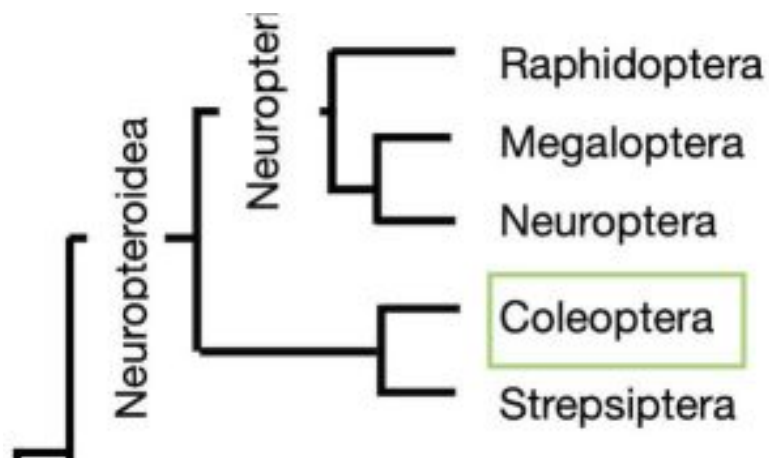
- the economic significance of lacewings

CHAPTER 34

Orders of Insects: Coleoptera



A wasp-mimicking beetle, *Hesthesis* sp., with shortened elytra (Coleoptera: Polyphaga). [Photograph by James Tweed. Used with permission].



Cladogram highlighting Coleoptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER COLEOPTERA: BEETLES

Coleoptera

- common name: beetles
- from the Greek: koleos=sheath, ptera=wings
- worldwide distribution and highly diverse: about 400,000 species; largest order in the Class Insecta; over 28,000 spp. in Australia; nearly 30% of all animal species are beetles!
- Found in almost all habitats; some aquatic species
- diverse feeding strategies: herbivores, predators, scavengers; some parasitic
- life cycle: holometabolous

TWO SUBORDERS:

- **Adephaga** – the first abdominal sternum is divided by the hind coxae; includes ground beetles , tiger beetles (predominantly predaceous as larvae and adults)
- **Polyphaga** (largest suborder) – the first abdominal sternum is undivided; includes click beetles , lady beetles , blister beetles , darkling beetles, leaf beetles

Characteristics of Coleoptera

Adults

- very small to very large (0.25mm up to 10cm), body usually sturdy and compact
- mandibulate mouthparts; compound eyes in most; antennae highly variable
- fore wings are hardened into elytra (single = elytron); form a protective covering over the membranous hind wings which are folded beneath the elytra; hind wings are responsible for power in flight although some species lack hind wings, i.e. flightless
- Legs with various modifications

Immatures

- Immature stages (larvae) terrestrial or aquatic
- short antennae, chewing mouthparts
- legs may be present or absent
- highly variable



An interactive H5P element has been excluded from this version of the text. You can view it online here:

<https://uq.pressbooks.pub/insect-science/?p=325#h5p-8>

Longicorn beetle larvae boring through the wood of a poinciana tree. The larvae are legless and have strong mandibles to chew through the wood. Note the dark brown spiracles along the side of the body. [Photo: K.Ebert].

FOOD, FEEDING HABITS, BEHAVIOUR, HABITATS

Herbivores

Beetles feed on a large range of plants and relatives: algae, fungi, conifers, angiosperms, dicotyledons, monocotyledons. Individual species are usually specialists. There are many specialisations within plant species e.g. foliage and flower feeders, stem and bark feeders (shallow borers), wood feeders (deep borers), root feeders, seed, nut and fruit feeders.

Fungus feeders

Many families or parts of families are associated with fungi. Fungi utilised usually have long-lived fruiting bodies – not toadstool type.

Keen to learn more?

Some interesting fungus feeders:

- [Read about Ambrosia beetles](#) that are “fungus farmers” and cultivate fungi in dead trees.
- A few Australian native dung beetles are mushroom specialists: here is an older paper that shares the [interesting behaviour of *Onthophagus dunningi*](#).
- And here’s some information on the [fungus-feeding lady beetle](#).

Predators

Many species are predatory; some are primarily-predaceous species eating freshly killed animals, e.g. tiger beetles, some are primarily-scavenger species and they may feed on other scavengers. Predaceous beetles generally are more active than herbivores, except those that specialize on slow moving prey. The head is generally more prognathous and mandibles have pointed incisors. About 25 families are primarily predaceous. Most are generalists but a few are specialists e.g.:

- ground beetles (Carabidae): primarily nocturnal predators on ground
- predaceous diving beetles (Dytiscidae): aquatic predators

- whirlygig beetles (Gyrinidae): predators on water surface
- hister beetles (Histeridae): predators in carrion or dung,
- lady beetles (Coccinellidae): primarily aphid predators.



An interactive H5P element has been excluded from this version of the text. You can view it online here:

<https://uq.pressbooks.pub/insect-science/?p=325#h5p-6>

Predatory beetles: a lady beetle eating an aphid (top left), a diving beetle (Cybister sp.) eating an insect carcass (top right) and a predatory ground beetle (Carabidae) below. [Photos: K. Ebert].

Scavengers

Decomposing matter is rich source of energy, well exploited by beetles. It changes in quality as it ages e.g. felled trees, dung and carrion. It is often associated with a succession of fauna adapted to the different stages of decomposition. There is competition for limited, short-lasting resources e.g:

- dung beetles (Scarabaeinae) – in this subfamily, the adults' mouthparts can process only soft moist dung; often bury dung in nest to prevent desiccation. Progression of behaviours from independent larval development in dung to parental provisioning of larvae by enclosing each egg in a ball of dung and burying it. A surprisingly diverse group. Australia has many native species adapted to native animal dung as well as some introduced species that bury bovine dung.



A native dung beetle, Onthophagus dandalu. [Photo: K.Ebert]

Parasites

Several beetles show early stages of ectoparasitism on mammals e.g. scavengers in nest. A few species are completely ectoparasitic on body of host. Parasitism of other insects (parasitoids) probably evolved from predators. The difference between predator and parasitoid is sometimes indistinct. Most advanced Coleopteran parasitoids undergo hypermetamorphosis – different forms during metamorphosis.

Kleptoparasitism: stealing provisions of others e.g. one weevil takes over the leaf roll prepared by leaf-rolling weevil; some dung beetles invade nests of others, kill resident larva and lay their eggs; some beetles kill ambrosia beetles and feed on their “fungus gardens”.

Myrmecophilous and termitophilous beetles – parasites in ant and termite nests; species from over 100 genera of Coleoptera found in social insect nests

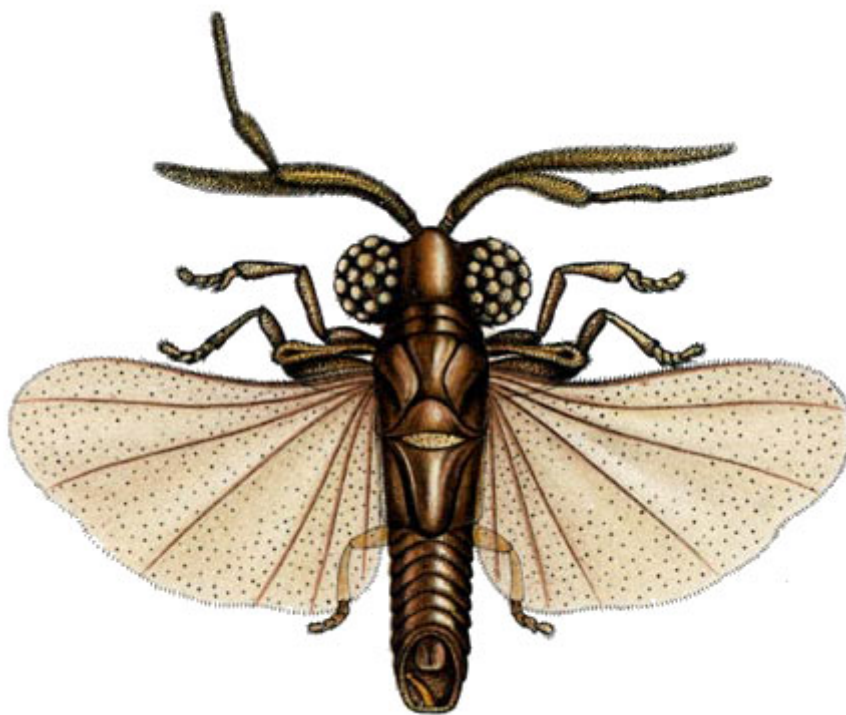
Topic Review

Do you know...?

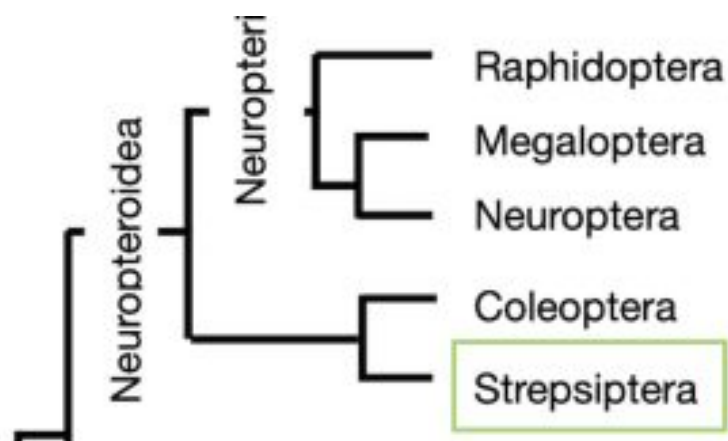
- the main anatomical features of beetles
- some of the diverse lifestyles of beetles

CHAPTER 35

Orders of Insects: Strepsiptera



A strepsipteran male [Drawing: [W.D. Pierce](#), Public Domain, Wikimedia Commons].

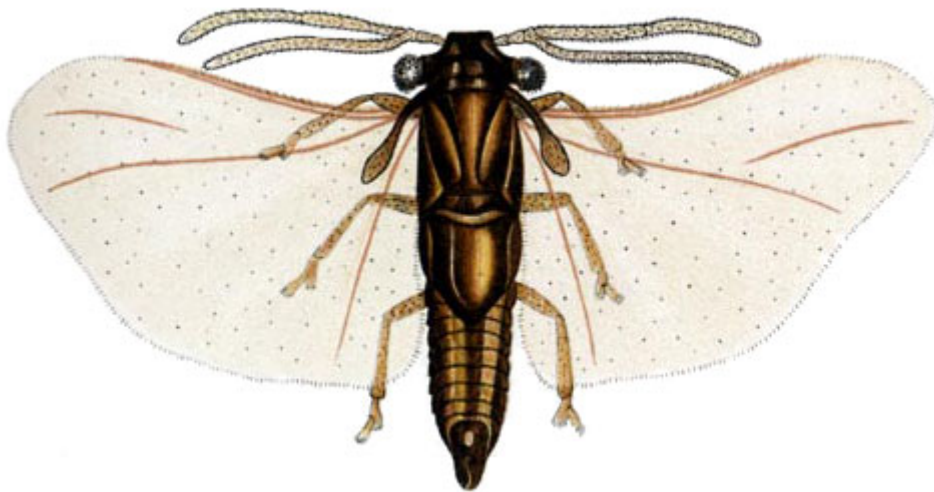


Cladogram highlighting Strepsiptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER STREPSIPTERA

Strepsiptera

- common names: twisted wing parasites, stylopids, stylops
- from Greek: streptos = twisted, ptera=wings; reflects the twisted wings of the male
- about 600 spp worldwide; not common
- larvae and females are internal parasites of other insects
- female usually permanently endoparasitic in host
- adults non-feeding as matures
- hypermetamorphosis – larvae change body form as they mature
- Recently confirmed to be a sister-group to Coleoptera



A male Strepsiptera – note the small, club-like front wings [Drawing: [W.D. Pierce](#), Public Domain, Wikimedia Commons].

Characteristics of Strepsiptera

Adults

- very small endoparasites; profound sexual dimorphism

- male have protruding eyes with few facets, greatly reduced mouthparts and do not feed; branched antennae;
- male fore wings are club-like; hind wings fan-shaped with few veins,
- females larviform; reduced mouthparts; legless, wingless & partially protrude from host abdomen

Immatures

- immature stages (larvae) hatch within the adult female body
- first instars (planidia) are free-living and highly mobile with three pair of thoracic legs; exit the female abdomen to locate and enter body of a new host
- once burrowed into a new host, subsequent instars are legless, grub-like internal parasites

NOTES:

Different Strepsiptera families parasitise different hosts, which include silverfish, ants, grasshoppers, preying mantids, leafhoppers, bugs, cockroaches, flies, wasps. The parasite does not eat vital organs or kill the host.

The parasitic lifestyle has produced great morphological and developmental modification, historically making it extremely difficult to place Strepsiptera in the insect family tree. Strepsiptera's phylogenetic position has been the subject of consternation and debate. Recent molecular sequencing studies place them as sister-group to Coleoptera.

MORE INFORMATION:

Links: [Strepsiptera life history with video](#)

[CSIRO-Strepsiptera](#)

[Australian Museum – stylops](#)

IS IT AN ALIEN OR AN EVIL POKEMON??

This scanning electron micrograph shows neither alien or evil pokemon character, but actually an unusual and elusive insect, commonly called a “stylops” (Order Strepsiptera). Stylops are **endoparasites**, which means they spend most of their lives living in and feeding on the bodies of other insects. The photo (right) shows an adult female stylops protruding from the abdomen of a fruit fly! She has no legs but is permanently stuck protruding from the fruit fly abdomen until she gives “birth”. What looks like her ‘gaping mouth’ is actually a brood canal opening. Her free-floating larvae live inside her body cavity feeding on her own haemocoel (insect equivalent of blood). When the worm-like larvae are big enough, they exit her body via the brood canal and wiggle off to find another host insect to burrow into it and begin to feed. When the larva is ready to morph into an adult it protrudes from the host abdomen either as a stationary female or as a puparium from which a free-flying male emerges. What looks like evil eyes and facial features are actually greatly reduced mouthparts! But the adult stylops never eats. The two “earholes” are actually breathing holes (spiracles)! If an insect has been parasitised by one of these creatures, they say it has been ‘stylopized’ – how freaky is that!!

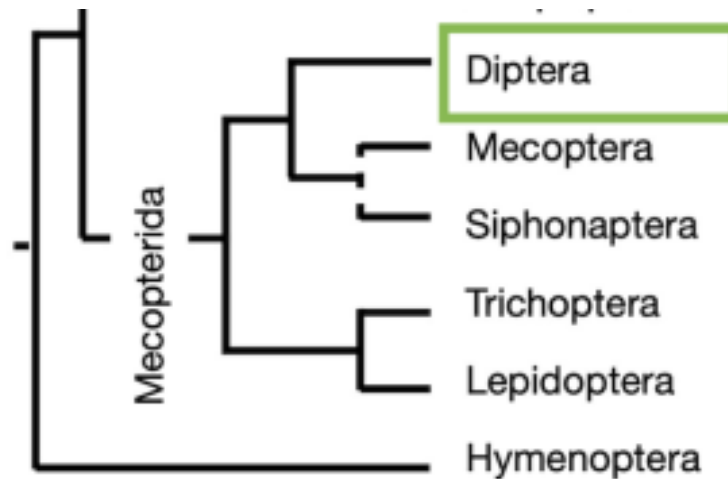


Female stylops on fruit fly abdomen (Bactrocera sp.)[Photo: K.Ebert].

CHAPTER 36

Orders of Insects: Diptera

A syrphid fly, Australis copiosa (Diptera: Brachycera) [Photograph by Jessa Thurman. Used with permission].



Cladogram highlighting Diptera. Adapted from Gullan, PJ & Cranston PS (2014). *The insects: an outline of entomology* (5th ed.). Wiley Blackwell.

ORDER DIPTERA: FLIES

Diptera

- common name: flies. Sometimes called “true flies” because other non-dipteran insects are often called flies, e.g. fireflies are Coleoptera, butterflies are Lepidoptera
- from Greek: di = two, ptera = wings
- worldwide distribution; one of the largest insect orders, about 153,000 species worldwide
- found in all types of habitats
- structurally, most highly specialised Order of Insecta
- extremely important vectors of human and animal diseases:
 - human diseases: malaria, yellow fever, dengue, cholera, Ross River Fever
 - animal diseases: dog-heartworm; blue tongue, anthrax
- reasons for their success:
 - complete separation of larval and adult niche
 - female lays eggs directly into larval food supply
 - larvae extremely well adapted to exploiting organically rich “muck”
 - adults with highly sophisticated flight are excellent dispersers, colonisers which often use nectar of flowers as fuel for flight
- only ingest liquid food in various forms

Characteristics of Diptera

Adults

- Small to medium sized
- haustellate mouthparts, collect food in liquid form; variable in form: biting, sponging, sucking
- large compound eyes; ocelli present or absent; antennae filiform, stylate or aristate
- only one pair of membranous flying wings; hindwings reduced and modified into small, club-like structures called halteres (balancing organs)
- mesothorax enlarged to accommodate flight muscles

Immatures

- immature stages (larvae, maggots) variable in habits and morphology
- without jointed legs, with sclerotised head capsule and chewing mouthparts or reduced to remnant mouth hooks
- most feed on moist, decomposing items, but some predaceous or parasitic

TWO SUBORDERS

Nematocera – mostly small, delicate flies. For example mosquitoes, crane flies; antennae filiform

Brachycera – mostly stouter and larger flies. For example march flies, hover flies, blow flies; antennae are aristate or stylate



A bee-mimicking syrphid fly (Diptera: Brachycera) on paper daisy. [Photo: K. Ebert]

NOTES:

The ancestral and still most common larval habitat is decaying vegetable matter (eg. leaf mould, compost, rotting or fresh fruit). Such substrates are moist and often considered “semi-aquatic”. Related environments are also frequently exploited, e.g. many larvae live in, and feed on, dung or carrion. Some have transitioned from feeding on putrid plant material or dead animals to feeding on putrid wounds of living animals (**myiasis**). Some have even become parasites of vertebrates. Aquatic life cycles have secondarily evolved independently many times especially in the Nematocera.

Some Diptera have become parasitoids, for example the Tachinidae, which can be useful biological control agents. One strategy is for adult female tachinid flies to stalk a caterpillar or bug and lunge forward, extending their ovipositor to place an egg on the host. The egg hatches and the 1st instar larva burrows into the host where it continues to develop.

Adult lifestyles (some common ones)

- Feed on nectar
 - Extremely common behaviour among the Diptera
 - Proboscis sometimes elongated to reach nectary in flowers with long corollas; many common flower visitors are bee or wasp mimics



A large, nectar-feeding Toxorhynchites speciosus (Diptera: Nematocera): the larvae of this nectar-feeding mosquito are predators of blood-feeding mosquito larvae. [Photo: K. Ebert].

- Feed on surfaces of decaying matter
 - Very common in many Diptera e.g. housefly: *Musca domestica*
 - Saliva secreted, surface dissolved (or in aqueous suspension) and sucked up; ingestion of microbes probably important part of diet.
- Free living (non-parasitic) blood feeders
 - Common in Nematocera e.g. mosquitoes, black flies, biting midges; in Brachycera e.g. horse flies
 - Almost always only the female sucks blood, male usually a nectar feeder. When host finding, flies are attracted to moving objects, heat and carbon dioxide and probably other odours are also attractive.
 - Some of these families feed on insect blood as well as vertebrate blood (eg. biting midges); other Diptera feed on other body fluids eg. eye exudates: some eye gnats.
- Ectoparasites on vertebrates
 - Usually ectoparasitic Diptera are blood feeders
 - Some females find hosts then shed wings and become ectoparasites on birds; larvae are scavengers in nests. Body flattened, louse-like in appearance in some groups – adaptation

for parasitic life on host. Hosts include wallabies, sheep, birds, bats, horses, cattle.



A parasitic batfly (Diptera: Nycteribiidae) on a bat host.
[Photo: [Gilles San Martin](#), [CC BY-SA 2.0](#), [Wikimedia Commons](#)].

- Aerial predators
 - Common in Brachycera, some common examples: robber flies, dance flies
 - Robber flies are best known; they are often bee and wasp mimics. They will perch on an exposed object and wait for prey (often bees, wasps, dragon flies) to fly by. They are swift flies and will capture prey in flight. Stout legs hold prey and their thick “beard” protects eyes and antennae from struggling prey. The sharp proboscis penetrates prey and then toxin is injected.



Robber fly (Diptera: Brachycera: Asilidae). [Photo: [K. Ebert](#)]

MORE INFORMATION

This CSIRO website has a fantastic interactive atlas of fly anatomy to help users learn anatomical terms used

in fly identification. The Atlas was uses high resolution digital images and enables magnification to view finer details. Check out this great resource!

[An Anatomical Atlas of Flies](#) by David Yeates and Anne Hastings.

Topic Review

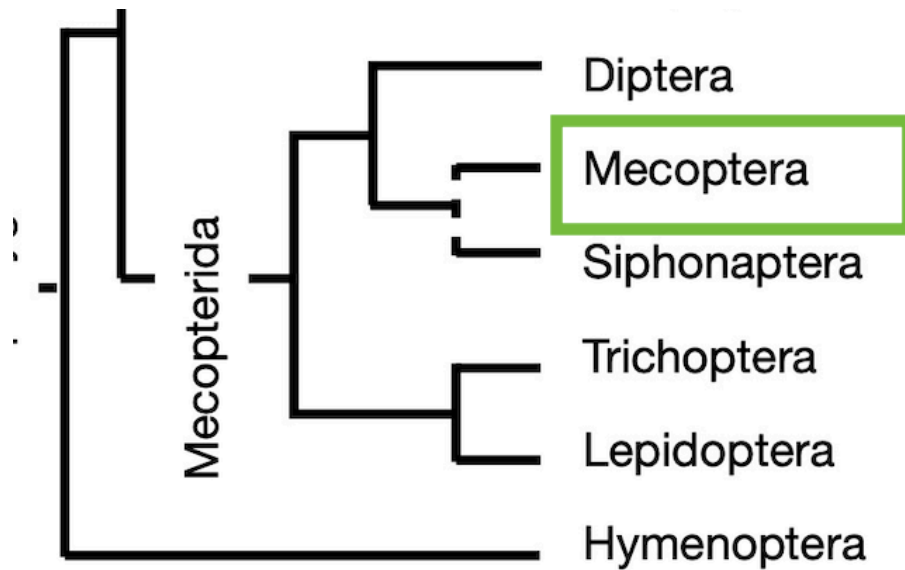
Do you know...?

- What is the etymology of the word 'Diptera'? Is this appropriate for the order? Explain.
- What are halteres? What is their function?
- How are the adults of the two suborders distinguished?
- What are the three main types of modifications of mouthparts of adult Diptera?
- Why is the mesothorax of flies much bigger than either the prothorax or metathorax?
- Why are flies economically important?
- In what ways are flies beneficial?

CHAPTER 37

Orders of Insects: Mecoptera

A Scorpionfly, *Harpobittacus australis*, Morton National Park, NSW [Photo: [John Tann](#), [CC BY 2.0](#), Wikimedia Commons].



Cladogram highlighting Mecoptera. Adapted from Gullan, PJ & Cranston PS (2014). The insects: an outline of entomology (5th ed.). Wiley Blackwell.

ORDER MECOPTERA: SCORPION FLIES, HANGING FLIES

Mecoptera

- common names: scorpion flies (refers to bulbous genitalia of males in the family Panorpidae curved over the abdomen—most common family—this family is not found in Australia) or hanging flies – most Australian species hang from vegetation by the fore- and sometimes the mid- legs
- from Greek: meco = long, ptera = wings; refers to long wings
- about 600 species worldwide—not common
- hanging flies are predators, preying upon small, flying insects
- larvae and adults generally omnivorous

Characteristics of Mecoptera

Adults

- small to medium sized (up to 50mm)
- elongated head with hypognathous rostrum and mandibulate mouthparts; filiform antennae
- long, narrow fore and hind wings, similar in size that extend beyond abdomen; some species wingless

- In Australian hanging flies, legs long and thin, with strong claws–catch prey with hind legs
- copulation in some species involves elaborate courtship procedures; sometimes with **nuptial feeding** (male provides an insect meal prior as part of courtship)

Immatures

- immature stages (larvae) mostly terrestrial,
- heavily sclerotised head capsule
- short, jointed thoracic legs
- resemble lepidopteran caterpillars but without prolegs

Topic Review

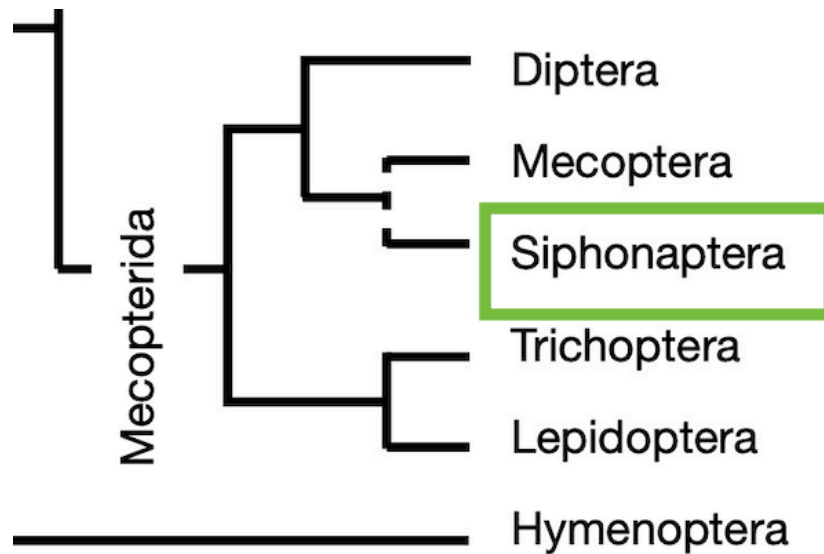
Do you know...?

- the main anatomical features of Mecoptera?

CHAPTER 38

Orders of Insects: Siphonaptera

A flea (Siphonaptera), [Photo: [Fedaro](#), [CC BY-SA 4.0](#), Wikimedia Commons].



Cladogram highlighting Siphonaptera. Adapted from Gullan, PJ & Cranston PS (2014). The insects: an outline of entomology (5th ed.). Wiley Blackwell.

ORDER SIPHONAPTERA: FLEAS

Siphonaptera

- common name: fleas
- from Greek: siphon = tube; aptera = wingless; refers to the tube-like mouthparts for blood sucking
- worldwide; about 2,500 species; greatest diversity in temperate zones
- adults are blood-sucking ectoparasites mostly on mammals but some on birds
- holometabolous; larvae free-living in nests of hosts; scavengers: consume organic debris

Characteristics of Siphonaptera

Adults

- Small (1-10mm), laterally compressed with backward pointing bristles on the body to aid with movement through fur or feathers
- Mouthparts haustellate: piercing and sucking; small antennae lying in grooves; simple eyes
- legs strong, terminating in strong claws for grasping host; hind legs adapted for jumping

Immatures

- immature stages (larvae) terrestrial, worm-like without legs (apodous), distinct head capsule

LIFE CYCLE

Eggs

- Laid on host but unattached; fall into nest.
- Eggs smooth, but with aeropyles – tiny holes in eggshell to allow gas exchange.
- Ovately rounded.

Larvae

- Feed on host-related debris on ground, usually in nest or lair.
- Primarily scavengers; blood excreted by adult fleas an essential part of larval diet in many species

Pupae

- Pupate in silken cocoon on ground; under high humidity may not spin cocoon
- Sometimes incorporate sand or other material into cocoon.

Adults

Ectoparasitic blood feeders: mostly on mammals, some on birds.

Detection of host differs in different species:

- visual (detect shadows)
- warmth
- carbon dioxide and odours
- vibrations

TRANSMISSION OF DISEASE

PLAGUE

Latin, plaga = a wound. Pl. plagues

Plague is a rodent-flea-rodent disease caused by the bacterium *Yersinia pestis* (formerly *Pasturella pestis*) – five forms

- bubonic plague
- pneumonic plague

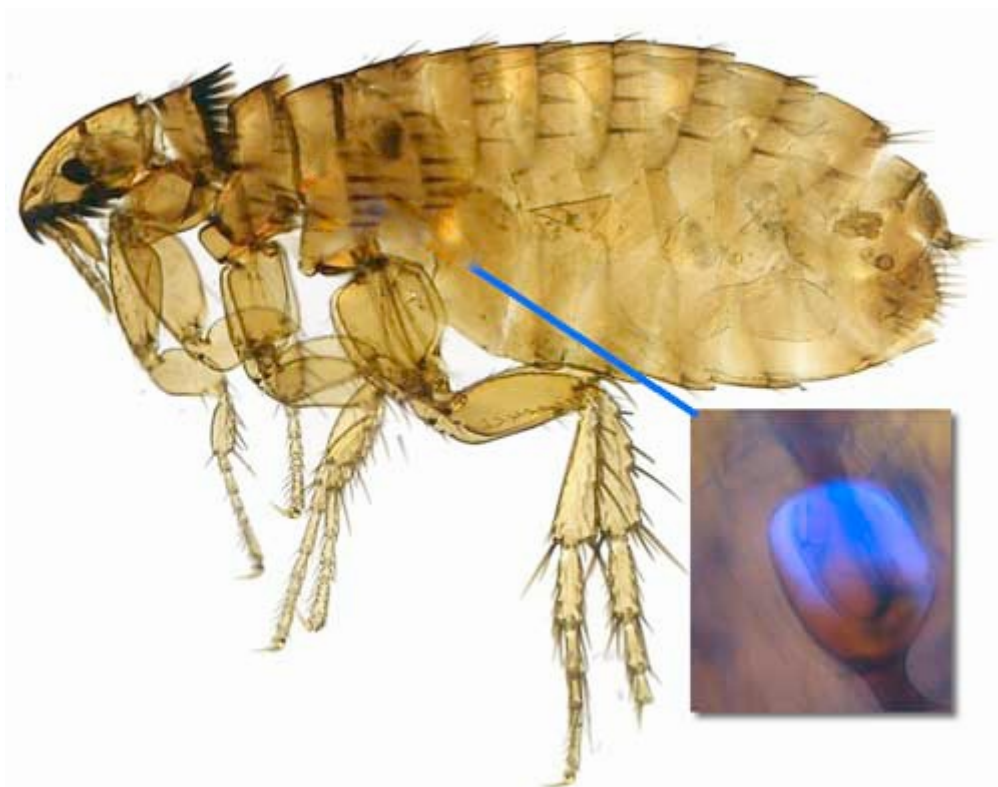
- pestis minor
- septicemic plague
- andean plague

Plague is endemic to southern Asia but spread elsewhere in 165 AD, 542 AD, 14th century and 17th Century. It is primarily a disease of rodents and exists as **sylvatic zoonosis** in colonial burrowing rodents; bacteraemia of rodents varies in degree and duration.

Plague killed 25% of human population in Europe during Middle Ages due to over-crowded and unsanitary urban conditions which led to an increased black rat (*Rattus rattus*) population. Plague is transmitted by the rat flea (and probably other fleas). The bacteria reproduce in the gut of the rat flea and cause a plug in the alimentary canal. The flea can't successfully feed so regurgitates back into its host, spreading the pathogen to other hosts. Because the flea cannot feed, it grows hungrier and initiates more feeding attempts and movements between hosts, thus spreads plague very quickly.

NOTE:

Compared to their small size, fleas are capable of prodigious jumps. Not surprisingly scientists have been curious about how they manage to do this. Fleas have no wings and the metathorax is highly modified as it is associated with the large jumping legs. The energy for the jump is stored in the cuticle. Inside the thorax there is a system of cuticular ridges called the pleural arch. This structure has a pad of resilin that stores energy for the jump. The resilin pad is compressed by slow muscle action and a series of cuticular pegs and notches engage storing energy with the flea in a crouched position. A releaser muscle is activated and the stored energy is released, catapulting the insect into the air.



A cat flea showing the region where the pleural arch has a thick pad of resilin that stores energy for the jump– the pleural arch was imaged under fluorescence microscopy to show the resilin pad (blue). [Image: D Merritt © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

Topic Review

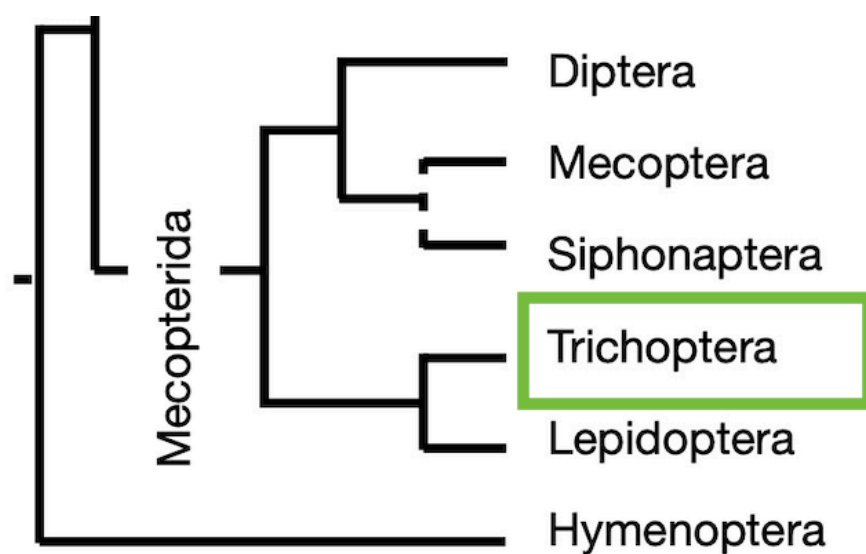
Do you know...?

- the main anatomical features of fleas
- The economical and medical importance of fleas
- The ways in which fleas are adapted for a parasitic lifestyle.
- Can you describe the life cycle of a flea.
- How do fleas detect the presence of a potential host?
- The role of fleas in the transmission of plague

CHAPTER 39

Orders of Insects: Trichoptera

Caddisfly (Trichoptera). [Photo: [Andrew C](#), CC BY 2.0, Wikimedia Commons].



Cladogram [Adapted from Gullan, P. J., & Cranston, P. S. (2014). *The insects: an outline of entomology* (5th ed.). Wiley-Blackwell].

ORDER TRICHOPTERA: CADDISFLIES

Trichoptera

- common name: caddisflies
- from Greek: tricos = hair, ptera = wings; relates to their wing covered in tiny setae (hairs)
- distributed worldwide; over 13,000 described species; over 800 Australian species
- one of largest orders of aquatic insects
- adults are weak fliers; typically crepuscular or nocturnal
- adults short-lived; may not feed
- Copulation typically occurs in flight or on vegetation
- larvae are aquatic; free-living, or construct portable or fixed shelters; when the larva pupates, the case is attached to a rock or other fixed object in water
- larvae may be herbivores, scavengers or predators
- larvae able to spin silk, which probably originated in the common ancestor of the sister-groups Trichoptera and Lepidoptera.
- the form and function of cases, nets and shelters is generally constant at the generic level.



Trichoptera larva with cylindrical case [Photo: [Dmccabe](#), [CC BY-SA 4.0](#), Wikimedia Commons].



Caddisfly larva with stick and gravel case. Trichoptera larva with cylindrical case [Photo: [Bob Henricks](#), CC BY-SA 2.0, Wikimedia Commons].

Characteristics of Trichoptera

Adults

- Small to large (2-40mm), elongate
- long, tapering, filiform antennae, reduced mouth-parts (no proboscis) but well-developed maxillary and labial palps; compound eyes present
- wings covered in tiny, dense hairs (setae), held tent-like over the body

Immatures

- Immature stages (larvae) aquatic, often case-bearing, but many free-living
- mandibulate mouthparts
- three pairs of segmented thoracic legs and no abdominal prolegs
- thread-like abdominal gills; abdominal hooks on the tip of the abdomen; keeps case connected to body as larva moves
- herbivores & scavengers have cases; predators tend to be free-living and use silk to catch prey

Caddisflies are valuable bioindicators of water quality. They are sensitive to pollution and changes in water flow, making them useful for assessing water quality in streams, lakes, and other water bodies. [Read more...](#)

Keen to know more?

- Have you heard of [caddisfly](#) art?
- More information about Trichoptera:
 - [Life in Freshwater](#)

Topic Review

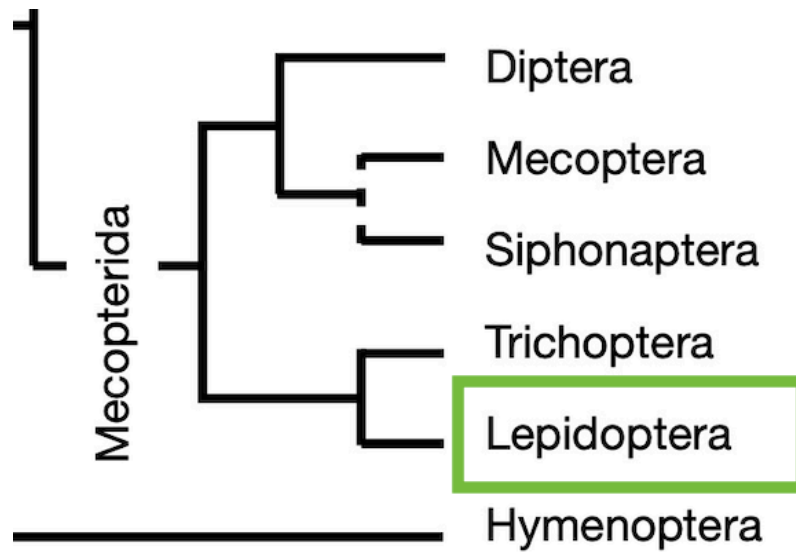
Do you know...?

- The main anatomical features of Caddisflies?
- The habitats of caddisflies

CHAPTER 40

Orders of Insects: Lepidoptera

Day-flying Zodiac Moth, Alcides metaurus (Lepidoptera). [Photograph by Jessa Thurman. Used with permission].



Cladogram highlighting Lepidoptera [Adapted from Gullan, P. J., & Cranston, P. S. (2014). The insects: an outline of entomology (5th ed.). Wiley-Blackwell].

ORDER LEPIDOPTERA: MOTHS AND BUTTERFLIES

Lepidoptera

- common name: moths and butterflies
- from Greek: lepto = scale, ptera = wings; names from the scales covering their wings
- Very high diversity: over 182,000 spp. described worldwide; about 21,000 species in Australia; second largest order of insects
- ca. 65% of Order consists of "microlepidoptera"
- occur throughout Australia with distribution mainly linked to larval food plant requirements
- butterflies: mostly diurnal (few crepuscular); generally pupate in the open, often hanging from vegetation (i.e. a chrysalis)
- moths: mostly nocturnal, although some diurnal (as in photo above)
- adults are generally nectar feeders, although some do not feed
- larvae generally herbivorous, although some carnivorous

Characteristics of Lepidoptera

Adults

- Small to large with an enormous size range, 3-250 mm wingspan; body covered in scales
- hypognathous, haustellate mouthparts, nearly all have a long coiled proboscis
- large compound eyes, ocelli present
- antennae multisegmented; long & slender or comb-like (pectinate) in moths, clubbed in butterflies
- two pair of large membranous wings covered in overlapping scales; legs slender and delicate

Immatures

- immature stages (larvae, caterpillars)
- sclerotised head with mandibulate mouthparts; labial spinnerets able to produce silk
- three pairs of jointed legs on thorax; often with abdominal prolegs (unsegmented)

Lepidoptera species diversity may be due to:

- specialised herbivorous larvae with chewing mouthparts
- ability to produce silk
- specialised nectar-feeding adults; nectar generally not protected by plant allelochemicals
- nectar feeders utilise almost any flowering plant



Common Crow butterfly [Photo: K. Ebert].

ECONOMIC IMPORTANCE

Larvae, called caterpillars, are predominantly terrestrial, phytophagous and have a narrow host range. They comprise some extremely important pests, for example, *Helicoverpa armigera* (called corn earworm, tobacco budworm or cotton bollworm, depending on country and location) that feeds on many crops including cotton.

- many agricultural pests (loopers, cutworms, armyworms, bollworms)
- pests of stored products (Indian meal moth)
- clothes moths: eat wool, fur, feather, silk, felt.

BENEFICIAL LEPIDOPTERA

- silk production

- biological control of weeds

DIVERSITY OF FEEDING HABITS

- some eat leaf margins
- pit hole feeders
- skeletonisers
- leaf miners
- leaf rollers (rolled by larva, not adult)
- stem and wood borers
- gall formers
- a few are predatory
- a few are parasites of scales, planthoppers
- a few feed on animal hair (e.g. clothes moths)
- some species, the wax moth, *Galleria mellonella*, feed in bee colonies on wax and food stores and can even [biodegrade](#) polyethylene

AVOIDANCE OF PREDATION

- **Concealment:** Use leaves, sticks etc to hide themselves e.g. leafminers, stem-borers, gall-formers, leaf-rollers, case-bearers, bagworms, web-makers.
- **Cryptic colouration**
- **Camouflage:** A few change colour to match background
- **Aposematic coloration:** Bright colours which act as warning to potential predators e.g. monarch butterfly.
- **Chemical defences:** Use repellent secretions which are often sequestered plant toxins or eversible "stink glands" or they spray irritants from prosternum.
- **Irritating hairs:** Chemical and/or mechanical irritation is caused by **urticating** hairs. They are barbed hairs that readily break off the larval epidermis. One species incorporates larval irritating hairs into its cocoon: adult collects these and distribute them over egg masses.



Processionary caterpillars, Ochrogaster lunifer, covered in urticating hairs (Lepidoptera: Thaumetopoeidae) [Photo: [CSIRO](#), [CC BY 3.0](#), Wikimedia Commons].



Cup moth caterpillar with venomous spines (Anaxidia sp.) [Photograph by Jessa Thurman. Used with permission].

Keen to learn more?

Read about one of the world's biggest moths: the [Hercules moth](#) from Australia!

One of Australia's special pollinators: the [Boronia moth](#)

Take a look at some of the Australian [micro-moths](#) — many are very challenging to identify!

Topic Review

Do you know...?

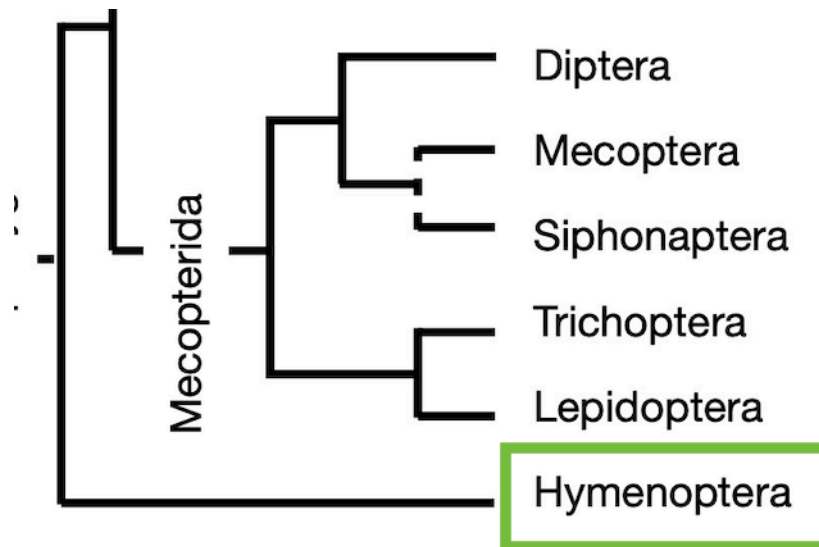
- the main anatomical features of Lepidoptera
- the economic importance of Lepidoptera

CHAPTER 41

Orders of Insects: Hymenoptera



Giant Wood Moth Parasitoid Wasp (Virgulibracon endoxylaphagus), St. Lucia, QLD [Photograph by Jessa Thurman. Used with permission].



Cladogram highlighting Hymenoptera [Adapted from Gullan, P. J., & Cranston, P. S. (2014). The insects: an outline of entomology (5th ed.). Wiley-Blackwell].

ORDER HYMENOPTERA: WASPS, BEES, ANTS AND SAWFLIES

Hymenoptera

- common names: bees, wasps, ants, sawflies
- from Greek: hymen = membrane; ptera = wings
- a large and diverse Order; estimated 150,000 species worldwide; over 14,000 species in Australia, about 30% are ants
- behaviour highly evolved and complex; ecological specialists; a very beneficial order of insects
- found in most terrestrial habitats, esp. near flowering plants
- many species are parasitoids; most effective natural enemies in applied biological control
- feed on a wide range of foods:
 - phytophagous – e.g. sawflies and some wasps
 - parasites of other invertebrates – e.g. parasitic wasps
 - predators – e.g. ants, spider wasps, paper wasps
 - many wasps & bees feed on nectar as adults
 - generalists, e.g. ants
- some are eusocial e.g. ants, bees, some paper wasps

- pollination by honeybees (domestic species) and wild bees value billions of \$\$ annually

Two suborders:

- **Symphyta** – abdomen broadly attached to thorax; most called **sawflies** (females have a saw-like ovipositor)
- **Apocrita** – abdomen constricted between segments 1 and 2 to form a “waist”; ants, bees and wasps



Native bee males (*Lipotriches* sp.) cluster together on a grass stem [Photograph by Lyn Cook. Shared under a [CC BY-NC 4.0 licence](https://creativecommons.org/licenses/by-nc/4.0/)].

Characteristics of Hymenoptera

Adults

- very small to large
- mandibulate mouthparts; maxillae and labium are modified in bees to form a proboscis for uptake of nectar
- variable: large compound eyes in most, but sometimes reduced or no eyes; ocelli often present; antennae multi-segmented, often long and held forward; ‘elbowed’ in ants
- most have two pairs of membranous wings with simple venation; forewings larger; fore and hind wings coupled together by hooks on hind wing (hamuli); some wingless, e.g. some female wasps and ants
- thorax either three-segmented OR forms a mesosoma by incorporation of first abdominal segment in which case the abdomen is petiolate (waisted)
- a stinger (ovipositor) present in some at the tip of abdomen

Immatures

- very variable: many lack legs completely; all have distinct mandibles even if head is reduced

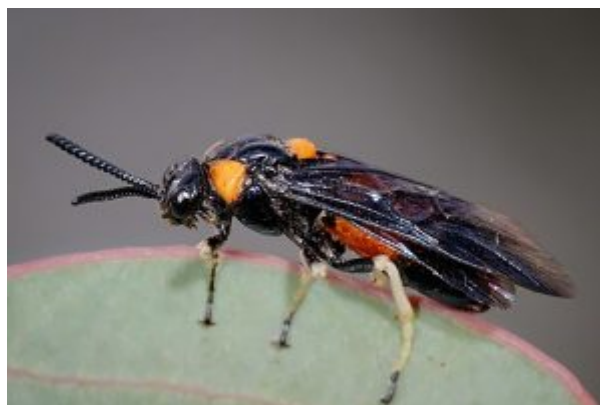


Green tree ants [Photo: [Some green tree ants](#) by James Niland, [CC BY 2.0](#), Wikimedia Commons].

NOTES

Sawflies

Family Pergidae are the sawflies whose larvae are commonly found in aggregations on eucalyptus. They are called spitfires because they spit drops of eucalyptus oil when disturbed.



A Melaleuca sawfly (Hymenoptera: Symphyta). [Photo: [Melaleuca sawfly](#) by Fir0002/Flagstaffotos, [CC BY-NC 4.0](#), Wikimedia Commons].



Sawfly larvae (Hymenoptera: Symphyta) at Girraween National Park [Photo: D. Merritt © University of Queensland, shared under a [CC BY-NC SA 4.0](#) licence].

Fairy wasps in the family Mymaridae are some of the tiniest insects—most are egg parasitoids, laying their eggs into the eggs of other insects.



A tiny wasp in the family Mymaridae [Photo: [Mymar pulchellum](#) Curtis, 1832 by Koorosh McCormack, [CC BY 2.0](#), Flickr].

Topic Review

Do you know...?

- the main anatomical features of Hymenoptera
- the economic importance of Hymenoptera