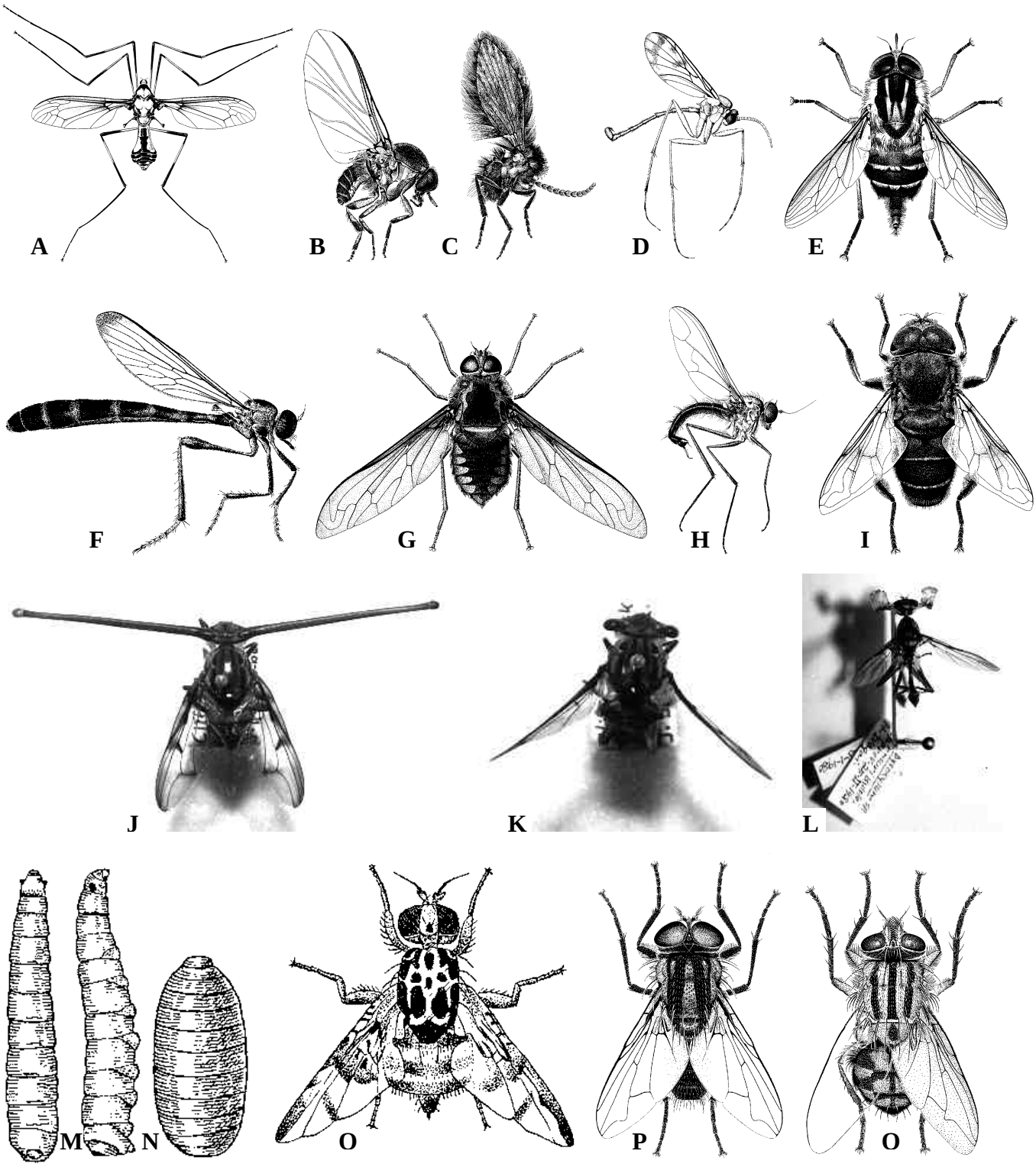

Fig. 5-46: Diptera (Flies): (A) *Leptotarsus imperatorius* (Tipulidae), (B) *Simulium sp.* ♂ (Simuliidae), (C) *Atrichobrunnettia sp.* ♀ (Psychodidae), (D) *Orfelia sp.* ♂ (Mycetophilidae), (E) *Trichophthalma spp.* (Tabanoidea), (F) *Leptogaster sp.* ♀ (Asilidae), (G) *Comptosia lateralis* ♀ (Bombyliidae), (H) *Heteropsilopus sp.* ♂ (Dolichopodidae), (I) *Eristalis sp.* (Syrphidae), (J) ♂ stalk-eyed fly *Achias sp.* (Platystomatidae), (K) *Achias sp.* ♀ (Platystomatidae), (L) ♂ antlered fly, (M†) larvae of *Creatitis capitata* (Tephritidae), (N†) pupa of *Creatitis capitata* (Tephritidae), (O†) adult fruit fly *Creatitis capitata* (Tephritidae), (P) *Musca sp.* ♂ (Muscidae), (Q) *Sarcorohdendorfia sp.* ♀ (Sarcophagidae) (reproduced from CSIRO, 1991; Hill, D.S. and Waller, J.M., 1988†; photos Schneider, M.F.)

wild as well as domesticated mammals, living amongst the feathers or hair of their host. The flies are of economic importance since they infest livestock like sheep, horses and cattle. A number of these pests are introduced.

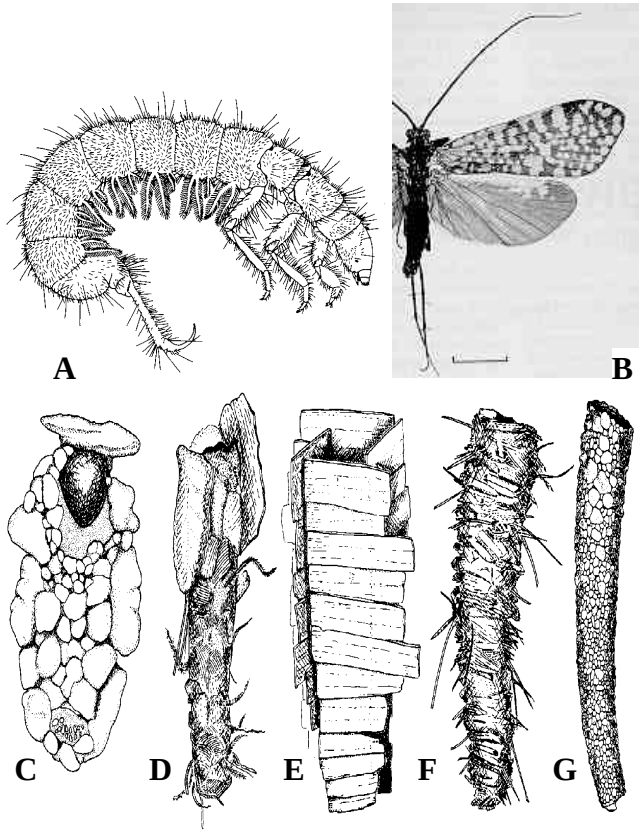

Fig. 5-47: Trichoptera (Caddis Flies): (A) aquatic larva of *Baliomorpha sp.*, (B) adult of *Stenopsychodes sp.*, portable larval cases of (C) *Tasimia sp.*, (D) *Tascuna sp.*, (E) *Oecetis sp.*, (F) *Plectotarsus sp.*, (G) *Antipodoecia sp.* (reproduced from CSIRO, 1991)

5.6.3.28 Trichoptera (Caddis Flies)

[hairy wings]

General biology: Small to medium-sized, endopterygote neopteran insects that are closely related to Lepidoptera. The mouth-parts of adults are poorly developed and suitable for imbibing liquid food only. The compound eyes are usually well developed, the ocelli mostly absent or rarely 3 or 2 ocelli present. The antennae are long and slender, multisegmented and mostly filiform. The legs are strong and slender with 5-segmented tarsi and two terminal claws. The tibiae sometimes possess long spines or are fringed with hairs. The femora sometimes have a row of setae or stout bristles on the outer surface. The adults have two pairs of functional, subequal membranous wings that are folded roof-like or flat above the body during rest. The wings show poor cross-venation. A wing coupling mechanism (**frenulum**) is present. Body and wings are densely covered with hairs and occasionally with groups of scales (**fig. 5-47 B**). The aquatic larvae have well developed chewing mouthparts, peg-like antennae, compound eyes, functional thoracic legs, one pair of abdominal prolegs and abdominal tracheal gills (**fig. 5-47 A**). The free living caterpillar-like larvae build fixed protective shelters or portable cases shown in **fig. 5-47 C-G** to protect their soft, membranous and pale abdomen. The shelters are spun from silk incorporating grains of sand, small stones, diatoms, algae, bits of twigs and other materials. Each species seems to have its own characteristic shelter, allowing it to be used for the species identification. Silken threads are also used by the larvae as an anchoring line in strong currents and for the construction of nets to capture food particles from the water current. The larvae use a wide range of food sources, some are herbivores, others are predators, piercing, scraping, filtering or swallowing their food. Most species prefer cool running waters. The pupae are exarate with strong mandibles for biting their way through the pupal case. The pupae are hidden inside the protective structure made by the last larval instar. Caddis flies undergo complete metamorphosis. The insects are one of the largest aquatic orders. The largest families of caddis flies are the **Hydrobiosidae**, **Ecnomidae** and **Leptoceridae**.

Economic and ecological significance: The aquatic larvae of caddis flies play an important role in the food chain of freshwater ecosystems, however larvae of some herbivorous species cause damage to young rice plants or ornamental water plants like water lilies. Trichoptera larvae are very sensitive to pollution, therefore they are used as indicator organisms for the assessment of water quality.

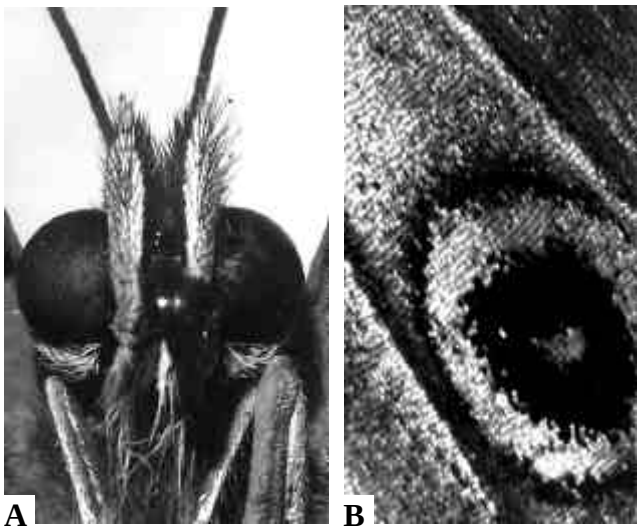

Fig. 5-48: Lepidoptera (Moths and Butterflies): (A) view of a butterfly head showing the partly hidden proboscis, (B) scales of a butterfly wing (photo Schneider, M.F.)

5.6.3.29 Lepidoptera (Moths and Butterflies) [scale wings]

General biology: Small to large, endopterygote Neoptera with robust and elongated bodies. The mouthparts bear a proboscis and are of the siphoning-tube type, rarely with chewing mouthparts in adults. The proboscis or **haustellum** (**fig. 2-17**) is coiled when not in use and might be completely or partly hidden in dense scales at its base as shown in **fig. 5-48 A**. The head has two prominent compound eyes and lacks a median ocellus or is without ocelli. The antennae are 3-segmented and variable in shape and are either flagellate, pectinate, 'clubbed' as in most butterflies or 'hooked' as in the **Hesperiidae**. Head, body and appendages like antennae, proboscis, wings and legs are clothed with usually overlapping pigmented scales. The large legs are usually well developed in adults and adapted for walking. The mid- and hind tibiae usually have one or two pairs of spurs. The forelegs of some **Papilionoidea** and the hindlegs of some **Hepialidae** and **Geometridae** might be reduced. The tarsi are 5-segmented with a pair of articulated, curved terminal claws. The two pairs of large membranous wings are covered on both surfaces with two layers of overlapping, broad and flattened scales, as shown in **fig. 5-48 B**. The iridescent physical colours of the scales are due to the structure of the scales and are caused by **interference of light**. The wings are absent or non-functional in females of a few species. The wing venation, only visible when the scales are removed, is of diagnostic importance. Different types of wing coupling mechanisms (**frenulum**, **fig. 5-49**) are usually present in moths but lacking in butterflies. The frenulum holds together fore- and hindwings and in general results in a better flight performance of the moths. During rest, the wings are folded roof-like above the abdomen or outspread in most moths, and raised back to back above the body in most butterflies. Sound producing and tympanal organs are present on the abdomen of some groups. Lepidoptera always lack cerci. Females of nocturnal species possess dermal, abdominal sex pheromone glands. The male and female genitalia are of diagnostic significance.

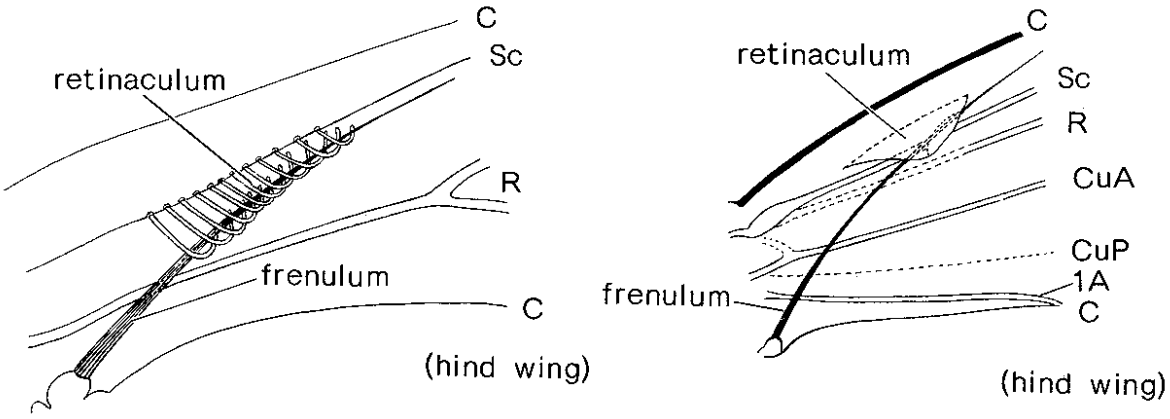

Fig. 5-49: Different types of wing-coupling mechanisms (frenulum) between the fore- and hindwings of Lepidoptera; for abbreviations see fig. 2-21 (reproduced from CSIRO, 1991)

The larvae called caterpillars (**figs. 2-42** and **5-50**) have 10 visible abdominal segments, chewing mouthparts, are **eruciform**, mostly **peripneustic** and rarely **holopneustic**. Usually the hypognathous or prognathous head is heavily sclerotized. In most species the labium bears a silk gland (**spinneret**) for spinning a cocoon or shelter. The antennae are short and 3-segmented. Each thoracic segment has one pair of 5-segmented legs, that might be reduced or lost in some species. False legs (**prolegs**) can be present on the abdominal segments 3-6 (**ventral prolegs**) and segment 10 (**anal prolegs**). Terminally the prolegs bear sclerotized hooks (**crochets**), that are of diagnostic importance. The larval head and body is covered with sensory **setae** which are a useful tool for identification. The hairs of particular caterpillars, eg. of **Lymantriidae** and **Limacodidae** can cause severe irritations of the skin when touched. Coleopteran larvae are most often confused with those of Lepidoptera. The difference however, is that caterpillars almost always have at least one of the following features:

- **a median labial gland developed into a spinneret**
- **paired adfrontal ridges**
- **crochet-bearing prolegs on S3 to S5 or S6 and S10**

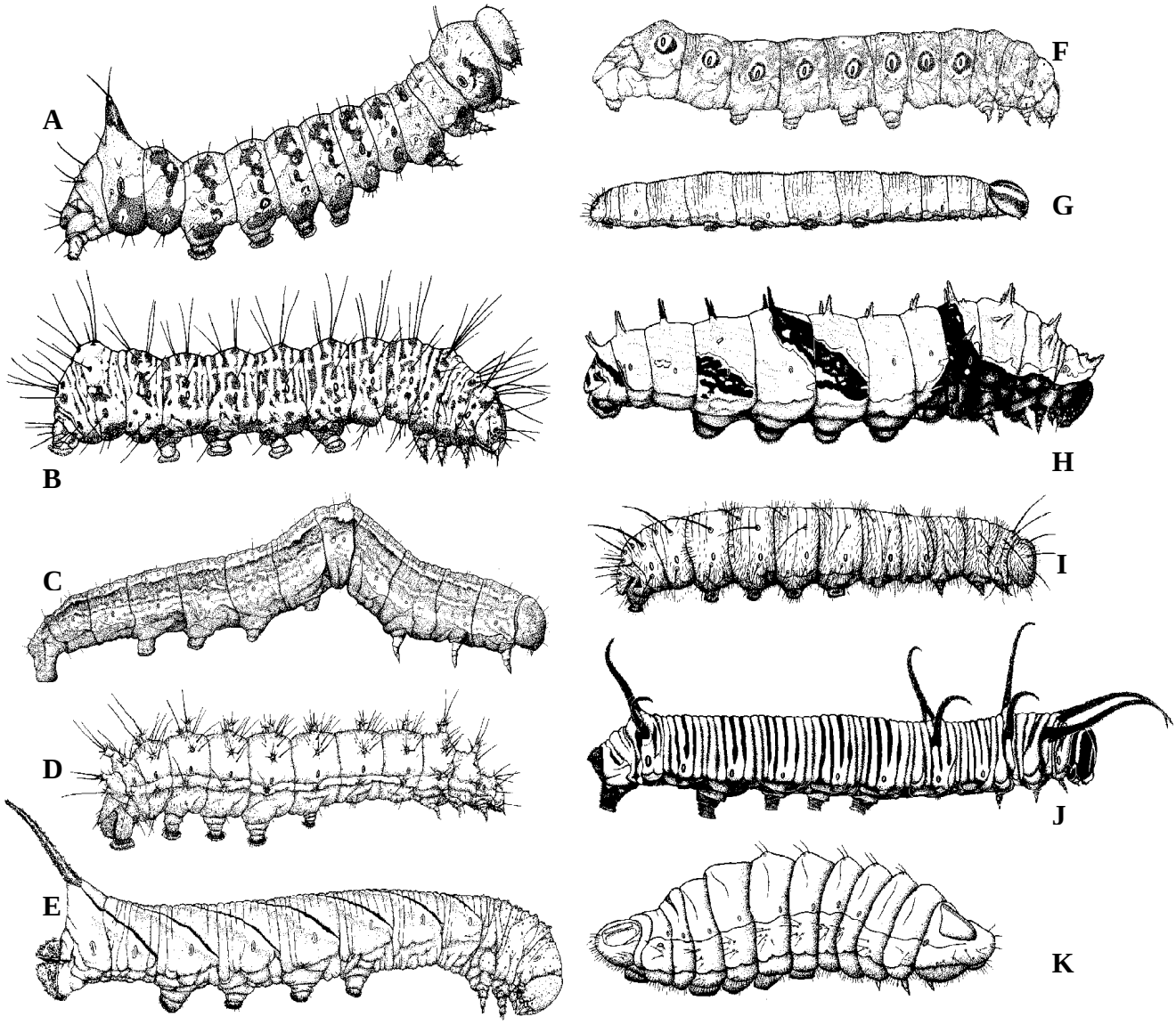

Fig. 5-50: Larval Lepidoptera (Butterflies and Moths): (A) *Danima sp.* (Notodontidae), (B) *Phalaneoides sp.* (Noctuidae), (C) *Mnesamplea sp.* (Geometridae), (D) *Opodiphtera sp.* (Saturniidae), (E) *Psilogramma sp.* (Sphingidae), (F) *Carthaea sp.* (Carthaeidae), (G) *Cephrenes sp.* (Hesperiidae), (H) *Papilio sp.* (Papilionidae), (I) *Delias sp.* (Pieridae), (J) *Euploea sp.* (Nymphalidae), (K) *Ogyris sp.* (Lycaenidae) (reproduced from CSIRO, 1991)

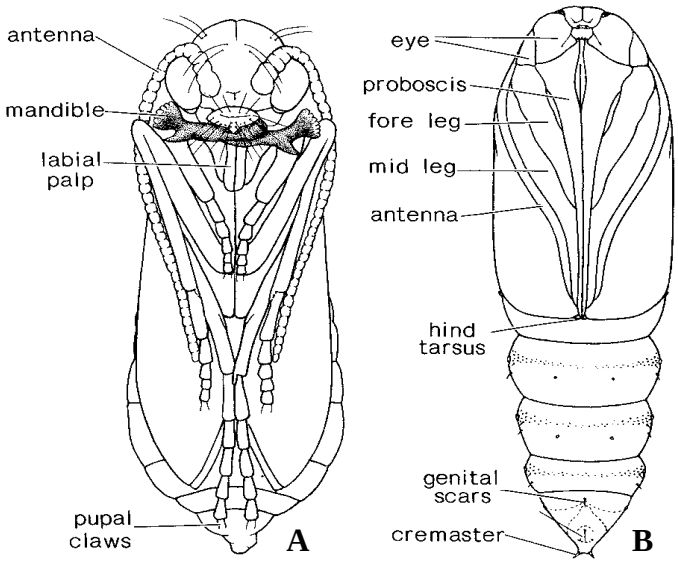

Fig. 5-51: Pupal Lepidoptera (Butterflies and Moths): (A) decticous, exarate pupa, (B) adecticous, obtect pupa (reprod. from CSIRO, 1991)

The pupae are rarely **decticous**, usually **adecticous** and **obtect** (**figs. 2-43** and **5-51**). Usually the pupae of moths are housed in a silken case spun by the caterpillars, whereas the pupae of butterflies are naked. Butterflies and moths undergo complete metamorphosis.

The evolutionary success of the Lepidoptera seems to be due to a close adaptation to **angiosperms**, allowing the exploitation of almost all parts of the plant. The adults are closely associated with the flowers; their long proboscis allows them to recover nectar from very narrow flowers such as **Leguminosae**. In return, the flower is pollinated by the insects. Adult Lepidoptera usually imbibe only water or nectar with dissolved minerals and sugar. However, adults of some species have a reduced proboscis and/or gut. They do not feed at all but live from the lipids that were accumulated during the larval instars.

The often fragile Lepidoptera might seem rather defenceless, however they have developed a great variety of strategies to deter or scare off potential predators. The scales, typical of this order, are believed to be one of those major strategies: once trapped in a spider net the caught animal can escape, since the sticky spider web only gets stuck to the scales, which slip off when the animal moves vigorously. This can be compared with an attempt to glue dusty surfaces. Many nocturnal moths like **Sphingidae**, **Arctiidae** and **Noctuidae** can 'hear' ultrasound produced by bats, one of the moths' major natural enemies. Bats use their ultrasonic radar system for orientation during the night, like an aircraft uses its radar system during low visibility. Apart form this, bats use ultrasound for locating their prey, especially moths. As soon as a moth hears an approaching bat, it drops, in most cases out of the reach of the bat. Another effective defence mechanism of the larvae of some **Papilionidae** caterpillars such as *Troides oblongomaculatus* are eversible stink glands (sing. **osmeterium**) located dorsally between head and thorax. When the caterpillar is disturbed, the osmeterium pops out, as shown on **plate 2 I**, releasing an unpleasant, deterrent scent. Hairy caterpillars, causing skin irritations, are generally refused by predators. Such stinging hairs can be found on caterpillars for instance of **Anthelidae**, **Limacodidae**, **Lymantriidae** and **Arctiidae** (**fig. 4-13 B** and **plate 2 C**, **D**). Camouflage is very common, especially in **Geometridae** and **Noctuidae** (**fig. 4-11**, **plate 1 A**, **E**, **F**). Effectively used against predators are scare tactics such as 'sinister faces' on the wings of **Noctuidae** and **Sphingidae**, shown in **figs. 4-12**, or false eye spots, eg. on the wings of **Noctuidae** and **Nymphalidae**, shown on **plates 2 A**, **B** and **10 Y - Z1**. Many caterpillars that feed on poisonous foodplants accumulate the respective poisons in their body, making the animal itself poisonous. Thus, the animals gain protection from being eaten. Some examples of caterpillars and their poisonous hosts are listed in **box 5-6**. Being poisonous is often correlated with a conspicuous warning coloration (**aposematic coloration**). Some palatable Lepidoptera mimic the warning coloration of a poisonous or otherwise distasteful species in order to gain protection, a phenomenon known as **Batesian mimicry**. An amazing example of **Müllerian mimicry** is the swallowtail butterfly *Papilio laglaizei* that mimics the Uraniidae moth *Alcides agathrysus* (**plate 2 E** to **H**). Further

examples of the various defence mechanisms of Lepidoptera are outlined in **chapter 4.4** and in **fig. 5-53 D - G**.

Sex and aggregation **pheromones** as means of chemical communication are common in Lepidoptera and are discussed in **chapter 3.1.3**. Sex pheromones are wide-spread, particularly in the mainly nocturnal moths to enable the males to locate the females (**fig. 3-5**). Males often possess eversible brushes at the tip of the abdomen. At the base of the brushes, there is a scent gland (**Stobbe's gland**) that discharges its contents on the inverted brush. The scent is dispersed, when the male locates a female and the brushes are everted. The scent acts as an **aphrodisiac** and is essential for successful mating.

Economic and ecological significance: Lepidoptera have always attracted man's attention due to their colourful patterns, their elegance and the economic significance of their caterpillars as pests as well as beneficial insects. Of economic importance are the mainly phytophagous caterpillars of various species, damaging agricultural, horticultural and forestry crops worth millions of Kina annually. Others severely damage stored products like the clothes moths of the genus *Tineola*. Agriculturalists face a great loss of crops caused by caterpillars of various families like the cutworms (**Noctuidae**), **Notodontidae**, **Geometridae** and **Pyralidae**. Detrimental to tree crops in PNG are *Lymantria* (**Lymantriidae**) defoliating *Pinus*, *Milionia* (**Geome**

Family	Species	Larval Foodplant
Papilionidae:	*Troides oblongomaculatus*	*Aristolochia tagala* ☠
	Ornithoptera spp.	*Pararistolochia kepara* ☠
	O. paradisea	*P. paradisiana* ☠
	O. goliath	*A. goliathiana* ☠ (not *A. crassinervia* ☠)
	O. meridionalis	*P. meridionaliana meridionaliana* ☠
		P. meridionaliana milnensis ☠
	O. alexandrae	*P. meridionaliana popondettensis* ☠,
		P. alexandriana ☠, *P. schlechteri* ☠
	O. priamus	*P. kepara* ☠
	O. victoriae	? (Aristolochiaceae ☠)
	O. chimaera	? (Aristolochiaceae ☠)
	Atrophaneura polydorus	? (Aristolochiaceae ☠)
	Graphium spp.	Annonaceae, Lauraceae
	P. euchenor	*Euodia elleryana, E. allata, Litsea spp., Cinnamomum spp.*
	P. ulyssis	*Euodia elleryana, E. allata*
	Papilio aegeus, P. fuscus, P. ambrax	*Citrus spp., other* Rutaceae
Pieridae:	*Eurema blanda*	*Albizia falcataria*
	Delias spp.	Loranthaceae, Santalacaea
Nymphalidae:	*Taenaris spp.*	*Musa spp., Pandanus spp.,* Arecaeae, Liliaceae, *Cocos nucifera, Pinus spp.*
	Charaxes latona	*Litsea spp., Dalbergia spp., Aglaia spp., Pterocarpus spp., Dysoxylum spp.*
	Polyura jupiter	*Caesalpinia bondoc, Albizia spp.*
	Doleschallia spp.	Acanthaceae, Rubiaceae
	Vindula spp., Cethosia spp.	Passifloraceae
	Hypolimnas spp.	Urticaceae, Malvaceae, etc.
	Junonia spp.	Acanthaceae, Malvaceae,
	Cyrestis spp.	Moraceae
	Danaus spp., Euploea spp.	Apocynaceae ☠, Asclepiadaceae ☠
	Paranticia spp.	Apocynaceae ☠, Asclepiadaceae ☠
Noctuidae:	*Coscinocera hercules*	*Dysoxylum spp.*
Arctiidae, **Aganaidae:** various species		Apocynaceae ☠, Asclepiadaceae ☠

Box 5-6: Foodplants of selected larval Lepidoptera (☠ poisonous foodplants)

Feature	Moths	Butterflies
• coupling apparatus (**frenulum**)	present, holding wings together during flight	absent, therefore poorer flight performance, therefore sometimes called 'flutterby'
• antennae	mostly not clubbed	clubbed
• flight	mostly nocturnal	mostly diurnal
• wings at rest	outspread or wrapped around the body	raised above the body
• coloration	mainly dull	mostly colourful
• pupa	often housed in silken case	always naked

Box 5-7: Major differences between moths and butterflies (there are many exceptions!)

tridae) attacking *Araucaria*, and *Hypsipyla* (**Pyralidae**) interfering with *Toona*. In the following outline of the lepidopteran families, those considered as pests are indicated with an asterisk *****. However, there are also a great number of beneficial Lepidoptera. As pollinators of particular plant families moths and butterflies play a crucial ecological role in the survival of these plants. Of commercial value is for instance the **silk worm** *Bombyx mori*. The cocoons made by the silk worms are used for the production of natural silk. This species originated from the Indian subcontinent. The foodplants are mulberries (**Moraceae**). Apart from that, Lepidoptera offer vast opportunities for scientists, especially in a tropical country like PNG, where many species remain yet to be described. The beauty of butterflies has always attracted collectors and PNG's particularly rich butterfly fauna provides income for many local insect collectors. Butterflies like the two protected Birdwing genera *Troides* and *Ornithoptera* can be farmed or ranched if their respective foodplants are provided. By means of ranching and farming, the specimens are not caught from the wild, making the butterfly business ecologically sound and sustainable. Further details of the insect business in PNG and implications related to species conservation are outlined in **chapter 1.3**. For Papua New Guinea the importance of Lepidoptera as natural heritage is reflected by the fact that seven out of the 52 species of National Animals are butterflies, namely Birdwings.

The order Lepidoptera is the second largest insect order. About 9 % of all described species of plants, animals and microorganisms are Lepidoptera. Some of the largest insects can be found amongst the Lepidoptera, such as the world's largest butterfly, the Queen Alexandra Birdwing *Ornithoptera alexandrae* and the world's largest moth and largest insect of all, the Hercules moth *Coscinocera hercules*, both occurring in PNG. About 90% of the Lepidoptera species are moths and only approximately 10% of the species are butterflies. The terms **moth** and **butterfly** are common names and are not of any taxonomic relevance. Some of the major differences between moths and butterflies are shown in **box 5-7**. However, many moths as well as butterflies do not have all of the listed features, but at least several in combination. Generally, butterflies are a small number of day-active moths with clubbed antennae. Sometimes moths and butterflies are divided into the large '**macros**' (Macrolepidoptera) with broad, large hindwings and the smaller, slender '**micros**' (Microlepidoptera) with narrow and pointed hindwings or with hindwings bearing a long posterior fringe. Both terms are of no taxonomic relevance.

PNG's Lepidoptera fauna is one the world's richest and most exciting. For instance 958 butterfly species can be found in PNG. The whole of Europe which is 6-times as large as PNG, has only 380 butterfly species to offer. In the Wau-Bulolo valley only, more than 600 butterfly species can be found. The order Lepidoptera contains about 130 families of which approximately two thirds occur in PNG. The order is divided into four sub-

orders, the **Zeugloptera** with one single family, the **Aglossata** with one single family whose adults lack a proboscis, the **Heterobathmiina** and the **Glossata** with proboscis-bearing adults. The Glossata are divided into five infraorders, the **Dacnonypha**, **Lophocoronina**, **Neopseustina**, **Exoporia** and **Heteroneura**. The latter four infraorders are contained in the clade **Myoglossata**.

One group of the **Exoporia** is the

Superfamily Hepialoidea:

- **Hepialidae*** Swift or ghost moths are the dominating family of the Hepialoidea. The adults are often very large, lack a proboscis, lack a frenulum and have short antennae. The wings of the rapid fliers usually have false eyes and are folded roof-like during rest. The caterpillars channel the bark of trees or burrow into the soil to feed on roots

The series **Ditrysia** of the infraorder **Heteroneura** contains 90 % of all lepidopteran species in about 100 families and some 30 superfamilies:

Superfamily Tineoidea:

- **Psychidae*** Bag worms or case moths take their name from their bag- or case-bearing caterpillars. The mobile bags or cases are often tapered at both sides with an opening through which the caterpillar feeds. The cases are made from various materials such as leaves and sticks and are diagnostic of the species. During feeding, the caterpillars drag the case along the surface of a leaf. The pupa remains in the case, as do the adult females in some species. The adults are small. The bag worms of the genus *Hyalarcta* (**box 6-1 M**) and *Eumeta* feed on *Eucalyptus*

- **Tineidae*** The clothes moths are small, grey or white, inconspicuous cosmopolitan moths of economic importance. The adults have long and narrow often silvery wings, with the hindwings tapering towards the tip. The pale caterpillars possess prolegs and some carry cases. The larvae of the genus *Tineola* cause damage to clothes made from wool and silk, those of the genera *Nemapogon* and *Niditinea* are pests of stored grain food

- **Gracillariidae*** A family of minute to small, variously coloured moths with lanceolate wings and long filiform antennae. The moths are similar to the Tineidae, but during rest, the adults usually sit up on their long forelegs so that the anterior part of their body is raised at a steep angle. The caterpillars are flattened, with an enlarged thorax and rudimentary legs. The larvae of many species are leaf miners, producing blister-like, serpentine or blotch mines. Therefore, this family is called leafblotch miners. A number of species are pests of cultivated and ornamental plants

Superfamily Gelechoidea:

- **Oecophoridae** The adults of this family are very small to medium-sized with lanceolate or broad, often very colourful wings. A number of caterpillars are important, highly specialised feeders of *Eucalyptus* litter. Due to the large number of *Eucalyptus* species, the Australian fauna is very rich in Oecophoridae. The more than 5500 species outnumber all other lepidopteran families. In countries without these specific leaf decomposers, leaf litter piles up under introduced eucalypts. This is because hardly any other arthropods feed on the leaves that contain considerable amounts of poisonous essential oils. Caterpillars of the subfamily **Xyloryctinae** bore under the bark of living trees

- **Gelechiidae*** Gelichiid moths are one of the largest lepidopteran families with tiny or small, usually colourful adults, with long, upcurved, pointed labial palps. The pinkish hairless caterpillars are known as ‘pink bollworms’. Most larvae are leaf miners, leaf rollers or leaf tiers. A couple of species are severe pests of cotton and stored grain

Superfamily Cossoidea:

- **Cossidae*** Wood moths or goat moths are the dominating cossid family. The adults are small to very large with strong, elongate wings and a strongly reduced proboscis. The mainly grey adult Cossidae (**fig. 5-52 A**) are the heaviest of all moths. The stout caterpillars bore large J-shaped tunnels in the heartwood or larger roots of living trees like *Eucalyptus*. The larval development takes up to three years in some species. A destructive

species occurring in Australia on smooth-barked eucalypts is *Endoxyla cinerea*. In PNG *Zeuzera coffeae* bores the heartwood of eucalypts and thus makes the host tree susceptible to wind damage

Superfamily Torticoidea: with only one family

- **Tortricidae*** Leaf rollers and bell moths are a large family of economic importance. The small adults usually have square-like, brown or grey spotted forewings that are folded roof-like above the body during rest. Some adults have a bell-shaped appearance, others resemble a bird's dropping. Most adults bear cryptic coloration and hide under leaf litter or on trees. The name 'leaf roller' comes from the greenish caterpillars' habit of spinning together leaves for hiding and feeding inside. Usually the caterpillars are decomposers, however a large number of species feed on eucalypts, avocado, lucerne, cotton and other shrubs and trees. Fruit moths or coddling moths belong to the subfamily **Olethreutinae** which is considered by some authors as a separate family. Adults of some species are day-flying and metallic coloured. The leaf rolling caterpillars are serious pests of fruit trees, others tunnel pulp or seed pods and various other parts of their host plant

Superfamily Sesioidea: one of the three families

- **Sesiidae** (**Aegeriidae**)* The small to medium-sized adult clear wing moths are brightly coloured and resemble bees and wasps due to their narrow, transparent wings and the way they fly. After the final emergence the wings are scaled, but the scales get lost during the first flights

Superfamily Zygaenoidea have nine families world-wide, but only four occur in PNG, like

- **Zygaenidae*** The foresters or burnets are small, day-flying moths with aposematic, brilliant-coloured wings without frenulum and with clubbed antennae. The hairy and fat larvae resembling those of the **Limacodidae** feed on the flower buds of their foodplants
- **Limacodidae*** The name of the cup moths originates from the cup-like cocoon of the pupae. The brightly coloured slug-like caterpillars have severely irritating hairs and lack prolegs (**fig. 4-13 B**) making the caterpillars look very much like minute sea anemones. Some species like the 4-spotted cup moth *Doratifera quadriguttata* found in Australia feed on tree crops like *Eucalyptus*

Superfamily Pterophoroidea:

- **Pterophoridae** Adult plumed moths are delicate, rather small and are quite distinctive due to the plumed forewings and the division of the hindwings into three feather-like parts

Superfamily Hyblaeoidea: with only one family

- **Hyblaeidae*** A small family of medium-sized moths that can be easily confused with Pyraloidea or Noctuoidea. A distinguishing feature amongst others is, that Hyblaeidae lack tympanal organs. The larvae of *Hyblaea puera* feed on **Verbenaceae**. In PNG, this species can cause severe defoliation of teak (*Tectona grandis*). See **chapter 6.2.6**, **box 6-1 U** and **plate 4 B** for more details

Superfamily Pyraloidea: only one large family

- **Pyralidae*** Grass moths (**plate 4 C-E**) are one of the largest lepidopteran families. The smaller moths with long, filiform antennae have very long and brittle legs and abdominal tympanal organs. Their beak-like proboscis is covered with scales. The moths have narrow, triangular forewings and broader hindwings. The coloration of the wings is more or less drab but often with subtle iridescent patterns. Many Pyralidae can be easily confused with other moths of the families **Agaristidae** and **Geometridae**, however the thread-like antennae of Pyralidae are held backwards above the thorax. The naked caterpillars show many different habits. A few species even have aquatic larvae with gills building portable cases like the larvae of the caddis flies. Many species are severe pests of cultivated plants and stored products. The larvae bore in corn, rice, sugarcane and the stems of various other herbaceous plants, like *Ostrinia furnacalis*, the Asian corn stem borer. A pest of *Toona* in PNG is the cedar shoot borer *Hypsipyla puera* (**plate 4 C**, **box 6-1 S** and **chapter 6.2.6**). Other common genera are *Glyphodes*, *Parotis*, *Cirrhochrista*, *Conogethes* and *Agrioglypta*.

Superfamily Drepanoidea: with one family:

- **Drepanidae** Adults of the camouflaged hook-tipped moths are conspicuous for the

extension or hook at the tip of the forewings (**fig. 5-52 D**). The mainly tropical Drepanidae can be easily confused with **Geometridae**, since both families are close relatives. Some authors consider them as one family

Superfamily Geometroidea: only one family

- **Geometridae*** The emerald moths are the second largest family of moths. The small to medium-sized adults have slender bodies and legs and broad wings. The adults spread their wings flat on the substrate during rest, thus eliminating shadows. In some species, eg. *Pingasa* the front margins of the forewings form right angles to the body median. Most adults are mottled and perfectly camouflaged or of bright vivid emerald, green, brown, white or yellow colour (**plate 4 F - R**, **5 A - I, fig. 5-52 E**). The antennae of the adults are often pectinate or filiform. Females of some species lack wings. The thin and somewhat cylindrical, hairless larvae have two or three pairs of false abdominal prolegs (**fig. 5-50 C**). Geometridae means '**earth measurer**' which is a precise description of the caterpillars' movement: they walk by a series of 'loops', stretching and taking hold with the frontal true pairs of legs, then looping the body, until the false legs at the rear grasp the substrate. Therefore the caterpillars are called looper caterpillars or earth measuring worms. The larvae are protected from predation by cryptic colour patterns, camouflage or mimesis. During rest for instance, some caterpillars stay erect and resemble a dead twig, the bud of a plant or any other structure of the environment that is of no interest to a potential predator. Many species are severe defoliating pests of agricultural and tree crops. A number of loopers feed on the buds and leaves of *Eucalyptus* seedlings. In PNG *Milionia, Alcis, Paradromulia* and *Hyposidera* (**plates 4 J**, **K**, **5 A - F** and **chapter 6.2.6**) interfere with *Pinus* and *Araucaria.* Common genera are *Anisocyga, Parasinocyma, Uliocnemis, Dysphania, Chlorocoma, Eucyclodes, Comostola, Xanthorhoe, Euphyia*

Superfamily Uranoidea: only one family, the

- **Uraniidae** are a small family that is mainly confined to tropical countries. An amazing example of **Müllerian mimicry** is *Alcides agathrysus* that is mimicked by *Papilio laglaizei* (**plate 2 E to H**, **chapter 4.4.5**). Common in PNG are *Micronia spp., Alcides agathrysus*, *Balantiucha* (**plate 5 J**) and *Nyctalemon toxopensi* (= *Lyssa patroclus*) (**plate 5 K**). The latter always rests head down

Superfamily Bombycoidea: important are

- **Saturniidae** Wild silk moths or emperor moths are some of the world's largest moths: the Hercules moth *Cosinocera hercules*, found in New Guinea and Northern Queensland, can reach a wingspan of 35 cm. A female is shown on **plate 5 L**. The males are smaller and have more slender tails. The adults lack functional mouthparts and live solely on the lipid reserves accumulated during the larval stages. Saturniidae moths are quite conspicuous due to the usually four scale-less, transparent 'eyes' or 'windows' on their wings and their feathery antennae. Since the population density of Saturniidae is quite low, the females release sex pheromones for mate finding. The largely increased surface area of the antennae enables the males to detect pheromones in utterly minute concentrations and to eventually locate the females (**fig. 3-5**). The larvae (**fig. 5-50 D**) spin cocoons for pupation. A pest species in Australia is the Emperor gum moth *Opodiphtera eucalypti* defoliating eucalypts. In PNG larvae of the genus *Syntherata* defoliate *Pinus* and *Eucalyptus* (**plate 5 M - O**, **chapter 6.2.6**)
- **Lasciocampidae*** The Lappet moths are a small family of medium-sized, brown or grey moths with stout bodies and feathery bipectinate antennae in both sexes. The more or less hairy and dark caterpillars are often of deep concern for agriculturalists and foresters because they defoliate various trees and shrubs. Some caterpillars build webbed nests on trees and are therefore called tent caterpillars. Some species were recorded feeding on *Eucalyptus* and *Casuarina* in PNG
- **Anthelidae*** The family of the woolly bears occurs only in Australia and PNG. The densely 'haired', mainly yellow or brown, medium-sized adults have bipectinate or pectinate antennae. The labial palps are

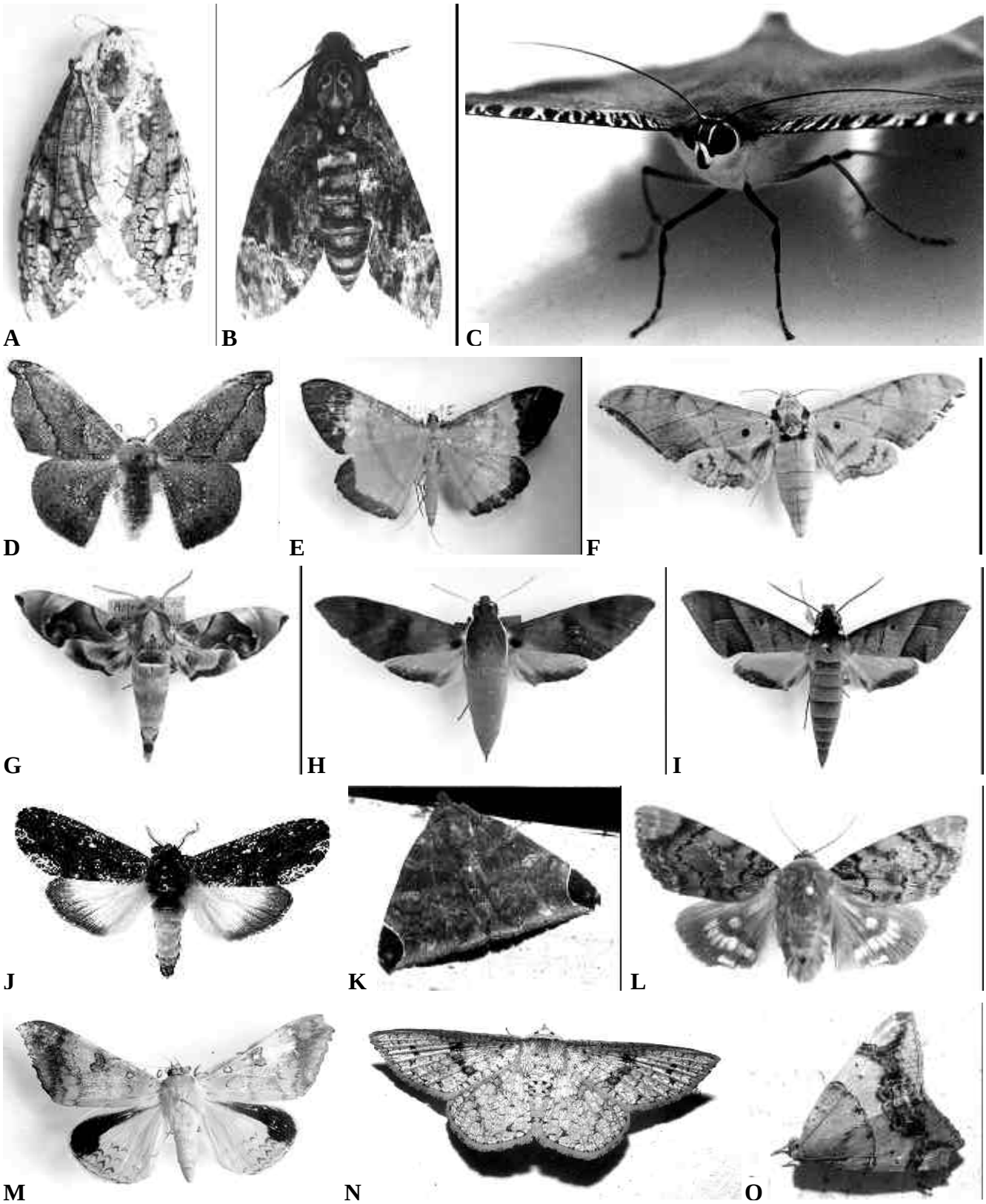

Fig. 5-52: Lepidoptera (Moths): (A) *Xyleutes sp.* (Cossidae), (B) 'deaths head moth' *Acherontia lachesis* (Sphingidae), (C) *Nyctalemon toxopensi* (= *Lyssa patroclus)* (Uraniidae), (D) *Oreta sp.* (Drepanidae), (E) *Celerena sp.* (Geometridae), (F) *Oxambulyx* (=*Ambulyx*) *dohertyi* (Sphingidae), (G) *Daphnis protrudens* (Sphingidae), (H) *Gnathothlibus erotus eras* (Sphingidae), (I) *Gnathothlibus heliodes* (Sphingidae), (J) *Neola sp.* (Notodontidae), (K) *Pindara sp.* (Noctuidae), (L) *Nagia episcopalis* (Noctuidae), (M) *Oxyodes sp.* (Noctuidae), (N) Noctuidae, (O) *Achaea sp.* (Noctuidae) (photos Schneider, M. F.)

forward pointing and beak-like, the proboscis may be absent in some species. The caterpillars possess long irritating hairs and feed on *Eucalyptus* and various other host trees. Common in PNG is *Anthela ekeikei* (**plate 5 P**, **Q**), defoliating *Pinus spp.*

- **Bombycidae*** Silk moths are a very small family of moths. The antennae of adults in both sexes are bipectinate, the proboscis and maxillary palps are absent. The caterpillars are more or less densely covered with hairs, the pupae are housed in a dense cocoon of silk. Some species like the silk worm *Bombyx mori* are of economic importance for the production of natural silk. The insects are reared on mulberries (**Moraceae**)

Superfamily Sphingoidea: with one family, the

- **Sphingidae*** Sphinx or hawk moths are very handsome moths (**figs. 2-26**, **4-12**, **5-52 B**, **F - I** and **plates 5 R**, **6 A - H**). The large and robust adults have long, narrow, pointed forewings and much shorter hindwings. The aerodynamic, tapered, spindle-shaped body is often twice as long as the width of the wings. The dominant colour of the adults is brown, but there are clear-winged genera like *Cephonodes* (**plate 5 R**). The fast fliers can often be seen at dusk and whilst hovering over flowers the animals are drinking nectar with their long and prominent proboscis. The fact that they become active only in the early morning hours, is to avoid coming across bats. Apart from this defence strategy Sphynx are well camouflaged and a large number have '**sinister faces**' (**fig. 4-12**) on their wings to scare away aggressors. The large naked caterpillars (**fig. 5-50 E**) are bright green or otherwise colourful and have a conspicuous extension or hawk at the tip of their abdomen, so they are also known as 'horn worms'. The larvae can cause a lot of damage on solanaceous crops in gardens, for instance *Manduca spp.* feeds on tomato and tobacco plants. PNG has about 100 species to offer. Common genera are *Hippotion*, *Agrius*, *Angonyx*, *Daphnis*, *Gnathothlibus*, *Panacra*, *Psilogramma*, *Oxyambulyx* (= *Ambulyx*), *Ascomeryx*, *Macroglossum*, *Theretra* and *Hyles*. The migrating '**deaths head moth**' *Acherontia* with the amazing skull on the back of the thorax (**fig. 52 B** and **plate 6 H**) apparently made its way from South East Asia to PNG

Superfamily Noctuoidea: with nine families, eg.

- **Notodontidae*** The prominents are a large family of medium-sized to large moths with obese, furry bodies, long forewings and shorter hindwings. The wings are held roof-like over the body during rest. Typically, there is a 'tooth' of hair or scales at the hind margin of the forewings, that is visible during rest in the middle of the folded wings. In adults camouflage and aposematic coloration are very common. The caterpillars (**fig. 5-50 A**) are large, brightly coloured and equipped with often very irritating hairs. The animals raise their abdomen defensively, when disturbed. This way either the stinging hair or the 'false eyes' at the end of their abdomen are displayed (**fig. 5-53 E**, **F**). Many species destroy various agricultural and tree crops like *Neola* (**fig. 5-52 J**) feeding on *Acacia*

- **Arctiidae** The distinctive tiger moths and footmen are small to medium-sized, brightly orange, red, black or white coloured, robust moths. Aposematic coloration with bright spots or bands is common in day-active unpalatable species or those mimicking other poisonous insects, eg. beetles. Usually the adults sham death, drop or present the brightly coloured wings when disturbed. *Rhodogastria crokeri* produces a foam-like defensive secretion from paired thoracic glands upon disturbance (**plate 2 J**). Most nocturnal species can detect ultrasound of an approaching bat allowing them to escape. Some even have the ability to produce ultrasonic clicks to confuse the bats' echolocation system. However, then the bats simply change the frequency of their echolocation system so that there is no longer negative interference. The caterpillars are densely covered with hairs and many of them are distasteful since they accumulate cardiac glycosides from their foodplants of the families **Apocynaceae** and **Asclepiadaceae**. A large number of caterpillars are destructive defoliators of many agricultural crops, trees and shrubs. Common in PNG are *Amata*

(**plate 6 K**, **L**), *Creatonotus*, *Rhodogastria crokeri* (**plates 2 J**, **6 J**), *Spilosoma* (**plate 6 M**), *Oeonistis*, *Nyctemera*, *Utethesia*, *Ceryx* and *Euchromia*

- **Aganaidae** (**Hypsidae**) A small family of medium-sized, aposematically coloured, nocturnal moths. Aganaidae are closely related to the Arctiidae which they can be easily confused with. The noctuid-like caterpillars feed on *Ficus*, **Asclepiadaceae** and **Apocynaceae**. Commonly found in PNG are *Agape chloropyga*, *Asota caricae*, *A. orbona queenslandica*, *A. versicolor*, *A. heliconia dama*, *A. heliconia doryca* (**plate 6 I**, **fig. 5-53 A - C**)
- **Lymantriidae** (**Liparidae**)* Gypsy moths, tussock moths or woolly bears are distinctive, small to large, obese and 'hairy' moths, mostly of white and orange coloration with various white and black markings. The proboscis of many species is absent. The antennae are often feathery in females. Males and females often strongly differ (**sexual dimorphism**) as in *Lymantria ninayi* (**plate 7 D**, **E**). In general, Lymantriidae are poor fliers and wings are lacking in the females of some species. The mostly colourful larvae, also called 'woolly bears', are often densely covered with irritating hairs (**plate 7 F**, **G**) and live in communal silken nests spun in the foliage of trees. Upon disturbance, some of these caterpillars defensively erect the front part of their bodies, as shown in **fig. 5-53 D**. Some of the most destructive forest insect pests are Lymantriidae that specifically feed on cultivated tree crops like *Acacia*, *Pinus* and *Eucalyptus*. A severe pest of deciduous trees

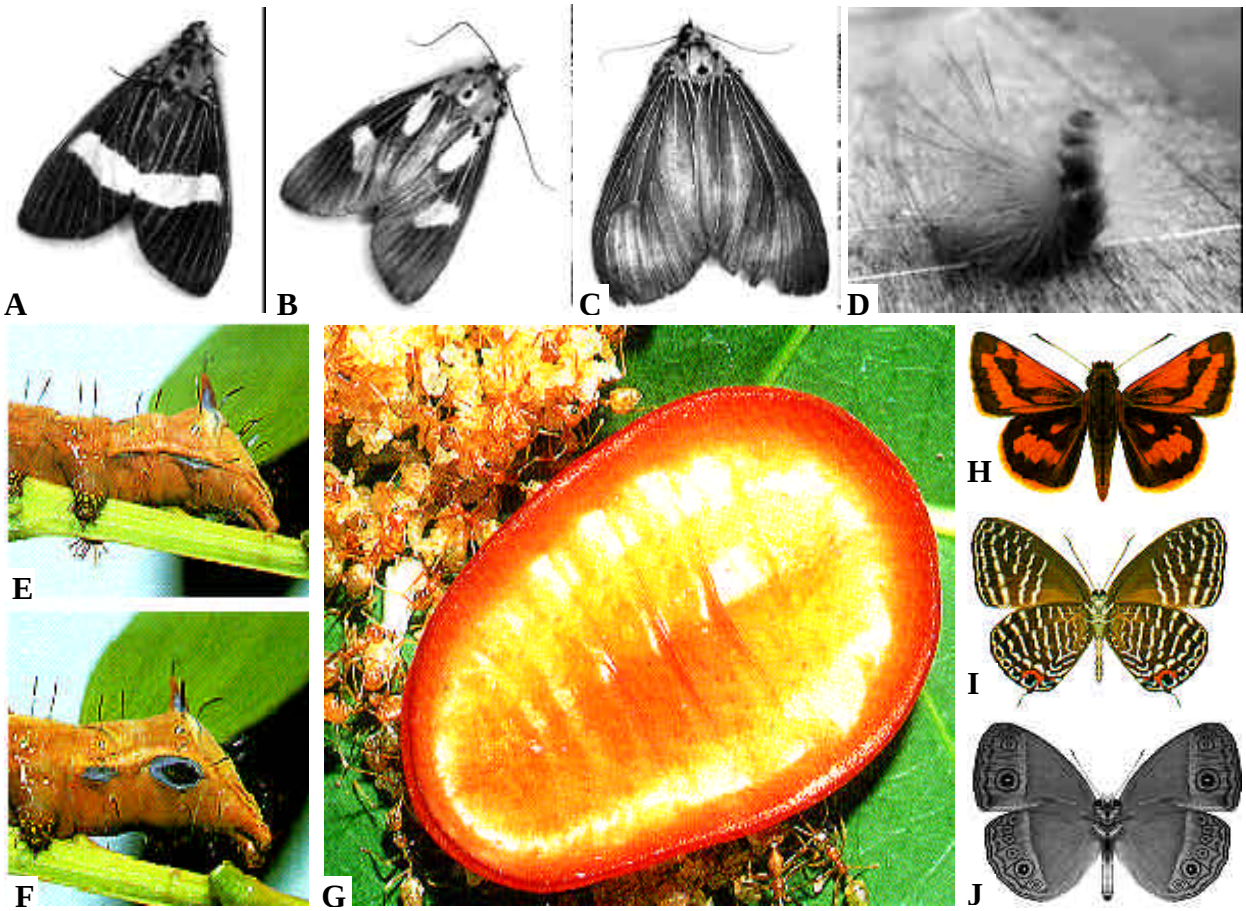

Fig. 5-53: Lepidoptera (Moths): (A†) *Asota versicolor* (Aganaidae), (B†) *A. orbona queenslandica* (Aganaidae), (C†) *A. heliconia doryca* (Aganaidae), (D††) defensively erected Lymantriidae caterpillar, (E‡), *Neola semiaurata*, eye-spot closed (Notodontidae), (F‡) *Neola semiaurata*, eye-spot opened (Notodontidae), (G‡‡) ant caterpillar *Liphyra brassolis* (Lycaenidae), (H) *Telicota sp.* (Hesperiidae), (I) *Jamides reverdini* (Lycaenidae), (J) *Mycalesis phidon* (Nymphalidae: Satyrinae) (photos: Mebs, D.†; Schneider, M.F††; Samson, P.‡‡; Parsons M., 1991; Common I.F.B., 1990‡)

like beech and oak in Europe is *Lymantria dispar*, its close relative *L. ninayi* causes a lot of troubles in PNG, defoliating *Pinus patula*. The biology of *Lymantria* (**plate 7 B - G**) and other pests like *Dasychira* and *Calliteara* is further outlined in **chapter 6.2.6**.

- **Noctuidae*** Owl moths or 'underwings' are one of the most diverse Lepidoptera families with about 20,000 described species world-wide. The adults are nocturnal, small to large, heavy-bodied and have filiform antennae. Typically, Noctuidae have tympanal organs at the back of the thorax and the ocelli are visible through the scales of the head in most cases. The hindwings are broader than the forewings. The insects are of dull or dark brown coloration, but they often have bright orange or red marks on the hindwings (**plates 2 B**, **7 N** and **8 B**). During rest, the wings are folded roof-like above the body thus covering the false eyes on the hindwings ('**underwings**'). When the moths are disturbed, the wings are opened and the eye-spots are displayed. Additionally some species release an unpleasant odour. The name '**owl**' is derived from the owl-like faces and huge eye-spots, as demonstrated on **plates 2 A**, **7 M**, **O**, **S**, that some species have on their wings. The shape, especially of smaller species, is variable, some peculiarly fold their wings and erect the abdomen which makes them look like a broken-off twig juncture. Males often have a bundle of hair on the tip of the abdomen. Some species of Noctuidae can migrate considerable distances, a fact that hampers the effective control of noctuid pests. Furthermore, gregarious aggregations can be found amongst species of this family (**fig. 3-6**). The naked, grey, blackish or colourful larvae have five or sometimes three pairs of abdominal prolegs. The phytophagous caterpillars are called army worms or cutworms (**fig. 5-50 B**, **plate 8 E**) due to their voracious appetite. They live in the upper layer of the soil during the day and feed during the night. When feeding, the cutworms cut off young plants right above the soil. Noctuidae pupate in the soil, hence Lepidoptera pupae found in the soil of gardens quite likely belong to this family. Many species are common and serious pests of agricultural and horticultural significance. The cutworms feed on foliage, but also bore fruits and other parts of plants such as tomatoes, corn, rice, citrus, etc. Common pests are *Agrotis*, *Helicoverpa*, *Spodoptera*, *Mythimna* and many more. Common in PNG are the amazing *Phyllodes imperialis* (**plate 8 B**), *Othreis* (**plate 2 B**, **8 D**), *Ophiusa* (**plate 7 N**, **P**), *Serrodes* (**plate 7 I**), *Calyptra*, *Lophoptera*, *Calogramma* (**plate 7 L**), *Spirama revolvens* (**plate 7 M**), *Erebus* (**plate 7 O**), *Hulodes* (**plate 7 R**), *Cyclodes* (**plate 7 S**), *Helicoverpa*, *Cosmodes*. The 'day moths' of the subfamily **Agaristinae** are considered a separate family by some authors. Day moths are a small group of mainly diurnal, brightly coloured moths, mostly found in the tropics. The male 'whistling moth' *Hacatesia* can produce a whistle-like sound by means of a transparent, ribbed area and adjacent knobs on the forewings that are hit together above the body during flight. Upon disturbance, the whistle stops and the moth silently and quickly flies away. The caterpillars are colourful, some of them like *Agarista* and *Apina* feed on cultivated plants

Families of Butterflies:

Superfamily Hesperioidea: only one family, the

- **Hesperiidae** The darters and skippers are believed to be the link between moths and butterflies, sharing features of both groups. The primitive, small to medium-sized, robust butterflies have dull, brown body coloration and thick, hairy bodies (**fig. 5-53 H**). The large heads have protruding compound eyes and clubbed, 'hooked' antennae, which are separated at their base. Their flight is fast, skipping and darting. The wings are usually held above the body during rest. Some species possess a wing coupling mechanism (**frenulum**). The hairless caterpillars have thick heads and are constricted at the neck (**fig. 5-50 G**). The larvae live sheltered in folded leaves, where they also pupate. Both, larvae and pupae are commonly covered with white powder. The caterpillars feed on the foliage of various cereals, grasses, legumes and palms, but are usually not destructive.

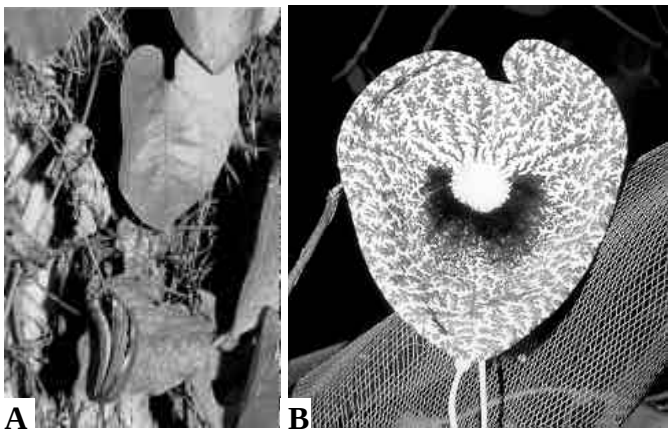

Fig. 5-54: (A) *Aristolochia tagala*, (B) *A. elegans* (Aristolochiaceae) (photos Schneider M.F.)

Superfamily Papilionoidea: with four families

• **Papilionidae** Swallowtails are very large, colourful butterflies with often long, tale-like projections at the hind wings (name!). Their flight is usually high above the ground. The difference between male and female Papilionidae (**sexual dimorphism**) is quite remarkable, particularly in Birdwings (**plate 9**). This family developed a wide range of defence mechanisms. Many of the hairless caterpillars (**fig. 5-50 H**) are distasteful, because they accumulate the poisons contained in their foodplants. Others are well camouflaged and look like bird droppings (**fig. 4-11 A**, **plate 1 E**). Eye-spots and aposematic coloration are very common. When disturbed, the larvae of some species press out a pair of coloured, eversible stink gland called **osmeterium** (**plate 2 I**) dorsally from the 'neck'. For pupation the caterpillars attach themselves to a plant by means of a belt. This type of pupa called '**girdle pupa**', is shown in **figs. 2-43 I** and **plate 9 S**. In PNG the following genera can be encountered: the Birdwings *Ornithoptera* (7 spp.) and *Troides* (1 sp.), *Atrophaneura* (1 sp.), *Graphium* (9 spp.) and *Papilio* (6 spp.). The two birdwing genera are considered together by some authors and referred to as *Troides*. The world's largest butterfly, the Queen Alexandra Birdwing *Ornithoptera alexandrae* can be found only in Oro Province in PNG. The females have a wingspan of about 30 cm, for males it is 25 cm. The species became known to science in 1907, when the naturalist Meek shot down a female which he mistook for a bird. Unfortunately, there are not many individuals of this species left due to the removal of the rain forest for the establishment of oil palm plantations. Once the forest has been cleared, the foodplants of this butterfly disappear as well. There is some evidence of illegal trade in *O. alexandrae*. The Oro Conservation Project aims in the conservation of this species, for instance by encouraging the local people to propagate the larval foodplant and thus to farm the butterfly. One of the world's rarest butterflies, the Paradise birdwing *O. paradisea* was believed to be extinct. It was rediscovered in the Kau Wildlife Area at Baitabag, Madang Province, at the beginning of the 90's. All eight Birdwing species, *O. alexandrae*, O. *goliath*, *O. chimera*, *O. priamus*, *O. meridionalis*, *O. vicoriae*, *O. paradisea* and *Troides oblongomaculatus* (**plate 9**) are protected. However, trade in these species, except in *O. alexandrae* is allowed, but subject to the **Convention on the International Trade in Endangered Species** (**CITES**), as long as regular surveys prove, that the wild populations are not decreasing. Further details of the insect business in PNG and implications regarding CITES can be found in **chapter 1.3**. According to the revision of the family **Aristolochiaceae** (Parsons, M., 1996), the larval foodplants of the Birdwings belong to the two genera *Pararistolochia* and *Aristolochia*. As a result of this revision, the scientific names of the larval foodplants of *Ornithoptera*, *Troides* and *Atrophaneura* have changed as shown in **box 5-6**. In general, caterpillars of the genus *Ornithoptera* mainly feed on *Pararistolochia*, whereas those of *Troides* prefer *Aristolochia*. The term *Aristolochia* is of Greek origin, *aristos*- meaning the best or the most noble and -*locheia* meaning birth. In traditional Melanesian medicine, the plant was used and is still in use as a contraceptive, as an 'after pill' to induce abortion. It is also used to ease delivery due to some of the chemical compounds contained in it which cause contractions of the uterine muscles. Apart from having medicinal properties, some species of *Aristolochia* are said to contain the

poisonous **aristolochic acid**. According to the literature, Birdwing caterpillars can somehow handle the poison and incorporate it when feeding upon the leaves, thus gaining protection by becoming unpalatable. Even other stages of the life cycle not feeding on *Aristolochia* leaves are supposedly poisonous and thus protected. However, my own research has revealed that none of the analysed eggs, caterpillars, pupae and adults of various Birdwing species, and only one out of six analysed *Aristolochia* species contained a minute trace of aristolochic acid. This was *A. crassinervia* in which 1.80 µg aristolochic acid per gram of dried leaves were found. But *A. crassinervia* is not a foodplant of any of the Birdwings. Some other species of PNG's Papilionidae fauna are the beautiful *Graphium weiskei* and *G. eurypylus* (**plate 8 H** and **I**), *Atrophaneura polydorus* (**plate 10 A**), the iridescent blue Mountain butterfly *Papilio ulysses*, *P. euchenor*, *P. ambrax*, *P. aegeus*, *P. woodfordi* (**plate 8 J - O**) and *P. laglaizei* (**plate 2 E**, **F**). The latter mimics the day-flying moth *Alcides agathrysus* (**plate 2 G**, **H**). This amazing example for Müllerian mimicry is outlined in **chapter 4.4.5**

- **Pieridae*** Whites and yellows are a large family of distinct, often white or yellow, small to medium-sized butterflies, with black marginal marks on the wings. The adults have well developed forelegs with forked claws. The caterpillars (**fig. 5-50 I**) are mainly of green or yellow colour, either hairless or with short hairs. There is a number of destructive pests feeding mainly on leguminous and cruciferous crops like the introduced cabbage worm *Pieris rapae* or *Eurema blanda* (**fig. 6-4 S**), a defoliator of *Albizia falcataria*. Common genera in PNG are *Catopsilia*, *Eurema*, *Elodina*, *Appias*, *Leuciacria*, *Cepora* and the huge genus *Delias* (**plate 10 B - P**). Some of the foodplants are listed in **box 5-6**

- **Nymphalidae*** Nymphs, admirals, browns or angelwings are a large family of medium-sized to large butterflies with long hindlegs and short, hairy forelegs without claws used for cleaning. The upperside of the wings typically shows bright aposematic coloration, in some subfamilies like **Morphinae** and **Satyrinae** often with eye spots. The underside is usually brown and inconspicuous. During rest the wings are folded above the body, hiding the vividly coloured upper sides and displaying the dull under sides only. Some species of the subfamily **Danainae** like the Monarch *Danaus plexippus* (**plate 2 K - M**) are famous for their migratory behaviour. The caterpillars often have paired horns on some segments (**plate 2 K**, **fig. 5-50 J**). Many species of the subfamily **Danainae** feed on poisonous **Asclepiadaceae** and **Apocynaceae** and are distasteful due to the accumulated poisonous **cardiac glycosides**. The pupae, often of metallic coloration, are suspended upside down and are free swinging (**plate 2 L**). The subfamilies are **Satyrinae** ('**browns**') for instance *Melanitis*, *Mycalesis*, *Erycinidia*, **Acraeinae**, **Tellervinae**, **Libytheinae** (beaks), **Morphinae** (**Amanthusiinae**) like *Taenaris*, **Charaxinae** like *Charaxes latona*, *Polyura jupiter*, **Nymphalinae** like *Vindula*, *Cethosia*, *Doleschallia*, *Hypolimnas*, *Junonia*, *Cyrestis*, *Mynes*, *Parthenos*, *Yoma*, **Apaturinae** like *Apaturina* and **Danainae** such as *Danaus*, *Parantica*, *Euploea* and *Tirumala*. For illustrations refer to **plate 2 K - L**, **10**, **11** and **fig. 5-53 J**. The larval foodplants of some species are listed in **box 5-6**

- **Lycaenidae** The coppers or blues are the largest family of butterflies. The small and delicate adults often have one or two hair-like tails and one 'false eye' at the margin of the hindwing (**fig. 5-53 I**). Thus, the caudal end of these butterflies resembles the head with antennae and compound eyes and is a useful strategy to confuse a predator. The upper sides of the wings are brightly blue, purple or green, the under sides often have colourful marks. The flight is quick and short. Males and females differ in size and shape (**sexual dimorphism**). The male and female genitalia are important for the identification of the species. The phytophagous, in a few cases predacious caterpillars are rarely destructive. They are flattened and slug-like (**figs. 5-50 K** and **5-53 G**), usually green and possess **honey glands** from which a sweet fluid is excreted.

This is collected by ants. Due to this fact there is a close mutualistic relationship between particular species of Lycaenidae and ants. The latter tend eggs and young caterpillars and receive sweet excretion in return. The ant caterpillars *Liphyra brassolis* (**fig. 5-53 G**) occurring in Australia, live inside ant nests and feed on larval ants. Subfamilies occurring in PNG are **Lycaeninae**, **Curetinae** and **Riodininae**. Some genera are *Jamides*, *Deudorix*, *Hypochrysops*, *Celastrina*, *Philiris*, *Arthopala*.

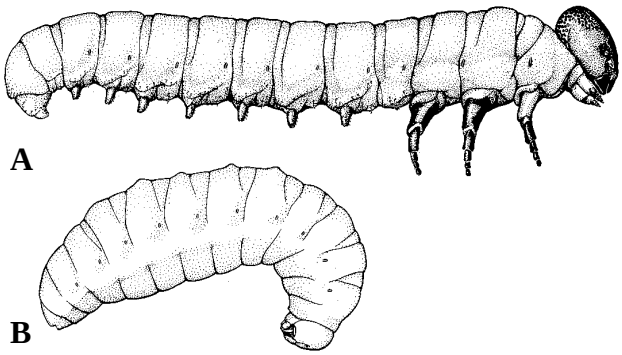

Fig. 5-55: Hymenoptera (Sawflies, Wasps, Bees, Ants): (A) Symphyta larva, (B) apodous Apocrita larva. (reproduced from CSIRO, 1991)

5.6.3.30 Hymenoptera (Sawflies, Wasps, Bees and Ants)

[membranous wings]

General biology: Minute to large, endopterygote neopteran insects with orthognathous or prognathous, very mobile head. The mouthparts are usually of the chewing type, or a combination of chewing and sucking in bees (**Apoidea**). The mandibles are used for cutting the way out of the pupal cell or host during final emergence, for defence, for killing and holding prey and for nest construction. The compound eyes are usually large. In general three ocelli are present, but sometimes they are absent or reduced in number. The antennae are usually long but their form and shape are often sexually dimorphic. The antennae are 9- to 13-segmented, sometimes clubbed, and in ants and particular wasps often 'elbowed' (**fig. 5-59**). The legs are highly modified in some species for digging, jumping, grasping, collecting pollen, raking soil particles, or cleaning various body parts. The tibiae are equipped with spurs which are of diagnostic importance, the tarsi are usually 5-segmented, sometimes 4-segmented and with two terminal claws and a pad-like **arolium** between the claws for attachment to smooth surfaces. The two pairs of unequal membranous wings are usually present showing a characteristic reduced venation. The forewings are usually larger and longer and often have a heavily pigmented area (**stigma**) near the apex. Fore- and hindwings are coupled by rows of hooks (**hamuli**). The wings are absent for instance in ant workers or a particular sex of some species. In **Aopcrita** the first abdominal segment is closely associated with the metathorax. The abdomen is constricted between the first and second abdominal segment ('**waist**'), as shown in **fig. 5-59**. The constricted zone is called the **petiole**. Finger-like, one-segmented cerci are common. Females usually possess a highly mobile ovipositor, sometimes with teeth for cutting or sharply pointed for piercing or elongate for stabbing. In **aculeates** the ovipositor is modified to a stinger, a hollow hypodermic needle for the injection of paralysing or otherwise venomous fluids, experienced by everybody who has been stung by a bee or wasp. In some species the ovipositor is used to assist feeding, like a drinking straw.

The larvae shown in **figs. 2-42** and **5-55**, are eruciform, caterpillar-like in most Symphyta and apodous, maggot-like in Apocrita. The head of symphytan larvae is usually poorly developed. The mouthparts are of the chewing type but are reduced in some symphytan larvae. The larval labium sometimes has silk glands (**spinneret**). The larvae have one pair of ocelli and short, mainly multisegmented antennae. Legs are absent in the apod apocritan larvae. The larvae of Symphyta have three pairs of thoracic legs and often six or more pairs of false abdominal prolegs, so that they can be confused with lepidopteran caterpillars. However, firstly the prolegs of symphytan larvae lack crochets and secondly, the number of prolegs of lepidopteran larvae

never exceeds five. The pupae (**fig. 2-43**) are adecticous, generally exarate and sometimes housed in silken cocoons spun by the last larval instar, but this is never seen in bees and ants. Hymenoptera undergo complete metamorphosis. The males are usually haploid, the females diploid (**haplodiploidy**), parthenogenesis is universal. Hymenopterans developed a wide range of adaptations to maintain reproduction, even if the environmental conditions are unfavourable. Hymenopterans are one of the two colony forming insect orders. Many species of bees, wasps and ants are **social insects**. Their complex behavioural patterns and their outstanding abilities to communicate are outlined in **chapter 3.2**.

Economic and ecological significance: The Hymenoptera are divided into two suborders, the ancient, mostly phytophagous **Symphyta** with their caterpillar-like larvae and the more advanced, much more abundant **Apocrita**. The latter are widely adapted to parasitic, predacious, melliferous (honey collecting), fungivorous and scavenging life styles. The eggs of Symphyta are often injected into plant tissue, where the developing eggs or larvae might induce a tumour-like growth (**gall**) of the affected plant tissue. Feeding and sometimes pupation takes place inside the gall. Phytophagous larvae of non gall-forming species feed internally on plant tissues causing mines, or feed externally. The eggs of **parasitic** or **parasitoid** Apocrita are laid into a host which can be a spider, or the eggs, larvae, pupae, or adults of various insect orders, including other Hymenoptera. Some families practise **Hyperparasitism** where a parasitic wasp is parasitized. Some species are specific to one host species, others parasitize a variety of hosts. The predacious solitary wasps provide their brood with the required prey. For this purpose, female wasps prepare the host and a suitable cavity or concealed nest. When a suitable host is found, it is not necessarily killed, but sometimes only paralysed by a venomous sting of the female. This has the advantage over killing the host, that the latter does not rot. Although it is still alive, it is immobilised and cannot escape. The host, sometimes much larger than the parasite, is then carried to the prepared nest. This can be a cavity dug into soil or bored into wood, or a concealed nest built from a concrete-like mixture of soil and saliva (**fig. 5-58**), or a paper-like nest made from chewed wood, suspended from a twig or attached to the substrate. Once the host is deposited into the nest, one or several eggs are laid into or onto the host and the nest is finally sealed. Usually there is tough competition within the same species for the host or prey as well as for suitable sites for building the nest. Apart from this intraspecific competition, the females of **cleptoparasitic** species are already waiting to open up the nest in order to replace the eggs with their own. Complex behavioural patterns have evolved in many species to defend territory, brood or mating partner. Various quite effective defence strategies can be found, for instance bites by means of strong mandibles or painful or even deadly stings are suitable to prevent Hymenoptera from being attacked by most other animals. Being disastrous is often advertised by a conspicuous warning coloration to indicate *don't touch me, I am dangerous!* Many wasps have a typical yellow and black aposematic coloration, that is mimicked by various harmless insects such as Diptera and Lepidoptera.

A number of Hymenoptera, mainly sawflies, are pests in agriculture and forestry, largely due to their phytophagous and gall forming life styles. For instance *Megastigmus spp.* (**Torymidae**) forms stem, leaf, shoot and fruit galls on *Eucalyptus* in PNG. Other pests are recruited from the families **Tenthredinidae**, **Cephidae**, **Siricidae**, **Anthophoridae** and a few others. However, compared to other parts of the world, fortunately not many of the phytophagous and destructive Symphyta occur in PNG. Apart from phytophagous pests, a large number of wasps and ants are a nuisance for humans inflicting painful or sometimes even fatal stings or, as in the case of ants, infesting buildings and stored products. However most Hymenoptera species are of invaluable benefit to mankind and nature in general. The domesticated bees

produce honey and wax. Predacious and parasitic wasps play an important role in the natural and biological control of insect pests. *Trichogramma* (**Trichogrammatidae**) for instance is commercially reared and sold as a specific biocontrol agent against particular agricultural pests. Lastly, many plants depend on the impact of pollinators like bees and wasps, culminating in the specific mutualistic relationship between pollinating fig wasps (**Agaonidea**) and their corresponding hosts, the figs (**Moraceae**).

Hymenoptera are one of the most diverse orders of insects and organisms in general. 7.7% of the world's described species of animals, plants and microorganisms are Hymenoptera. Estimates, based on studies of the tropical rain forest on Borneo, indicate that the number of Hymenoptera species could be almost 20% of all species of organisms and about one third of the insect species. The Hymenoptera are the third largest insect order following the Coleoptera and Lepidoptera, but according to the estimates, the Hymenoptera could easily outnumber the Lepidoptera. There is a lot of taxonomic work left to be done, especially for myrmecologists, to describe all the new species. The most diverse hymenopteran family are the ants (**Formicidae**). The almost 100 Hymenoptera families are divided into the two suborders **Symphyta** and **Apocrita**.

The **Symphyta** or **sawflies** are primitive Hymenoptera without constriction or 'waist' in adults. The wings have numerous closed cells. The small to large adults do not sting and can be often seen feeding on nectar. The phytophagous, caterpillar-like larvae have segmented legs and antennae. Sawflies are generally more numerous in temperate areas and are only poorly represented in PNG. Some symphytan superfamilies and families are further outlined:

Superfamily Cephoidea:

- **Cephidae** The stem sawflies are small slender and elongate sawflies with the abdomen laterally compressed. The larvae bore in stems of grasses, grains and fruits. However, this family does not occur in PNG

Superfamily Siricoidea:

- **Siricidae** This small family not (yet) represented in PNG originates from Europe. The family contains some major pest species of *Pinus*, like *Sirex noctilio*, whose larvae feed inside *Pinus radiata*. *Sirex* was accidentally introduced into Australia and could be theoretically established in *P. radiata* plantations in PNG, if appropriate quarantine procedures are neglected

Superfamily Tenthredinoidea:

- **Tenthredinidae** World-wide, this is the largest family of Symphyta with more than 5000 species, mainly represented in the Northern Hemisphere. In PNG only the genus *Senoclidea* with one species occurs. As leaf miners and defoliators the larvae of this family are very destructive on trees and shrubs like raspberry and blackberry in the Northern Hemisphere
- **Pergidae** The 'spitfires' are the largest symphytan family occurring in PNG and Australia. The caterpillar-like larvae often sit together in tight formations. They have the ability to regurgitate or 'spit' unpleasant defensive liquids, an ability advertised by bright aposematic coloration. The larvae are mainly leaf-miners, or they feeding externally on leaves, or feed on and develop in wood. Some are severe defoliating pests of several *Eucalyptus* species in Australia, like *Perga*, *Pseudoperga* and *Pergagrapta*.

The more graceful adults of the suborder **Apocrita** usually have a distinct constriction or 'waist'. Their larvae are normally without legs (**apod**). The parasitic families are called **terebrant**, whereas the non-parasitic, are referred to as **aculeate**. The aculeates have the ovipositor modified into a stinging organ for the injection of venom. Some aculeates have complex social organisation. Some important superfamilies and families are:

Superfamily Ichneumonoidea:

- **Ichneumonidae** This family is one of the largest hymenopteran families. The wasps are small to large, elongate and slender and are exclusively endoparasitic or hyperparasitic. The antennae are long and filiform with more than 16 segments. The elongate wings have a

well-defined venation. The legs are long and gangly. Most species are internal parasitoids of immature stages mainly of Lepidoptera and sawflies and some other insect orders. The females possess a strong and extended ovipositor, that is often as long or longer than the body. This enables the female to probe for a host that is hidden deep in plant tissue. For host-finding, a female follows the concentration gradient of a synomone, released by the prey's foodplant. The wasp approaches the foodplant and searches the surface with her antennae for the host's entrance hole. Once the host is located, she bores her ovipositor into the foodplant in order to reach the host. The host is then paralysed by means of a venomous injection and the wasp lays some eggs either inside or on the host's body. This is shown in **fig. 5-56** for *Megarhyssa nortoni*, the parasite of *Sirex noctilio* (**Siricidae**) living in *Pinus radiata*. Once the eggs hatch, the larvae feed on the host. The host usually survives until the larvae pupate either in the host or in a cocoon.

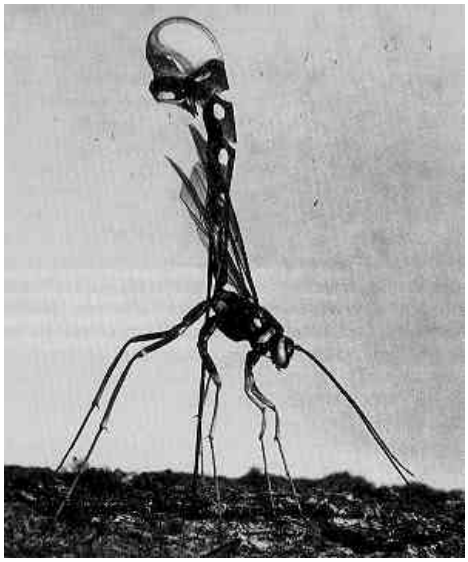

Fig. 5-56: A female parasite *Megarhyssa nortoni* (Hymenoptera: Ichneumonidae) probing *Pinus radiata* in search of *Sirex noctilio* (Siricidae); see text for further explanations (reproduced from CSIRO, 1991)

- **Braconidae** (**fig. 2-39**) are a large hymenopteran family closely related and very similar to Ichneumonidae wasps. However the two families differ in the forewing venation. Braconids are small to medium-sized, slim wasps with long, multisegmented antennae and sparsely-veined wings. The females possess short or long ovipositors. Braconidae are internal or external parasites of the larval stages of Lepidoptera, Coleoptera, Orthoptera, Hemiptera and Hymenoptera. Some species parasitize eggs or larvae. Various Braconidae species are most valuable biocontrol agents

Superfamily Platygasteroidea:
This superfamily contains only two families the **Scelionidae** and **Platygasteridae**. The minute to small wasps, used as biological control agents, are parasites of eggs and larvae

Superfamily Cynipoidea:
This superfamily contains major gall-formers in the Northern Hemisphere. Many species severely affect cultivated plants. In Australasia however, this family is not well represented. Most of the species of this region are not associated with galls but are mainly endo- or hyperparasites of various insects

Superfamily Chalcidoidea:

- **Chalcidae** Chalcid wasps are minute to small compact wasps with almost veinless wings, that are held flat over the body during rest. The antennae are short and prominently elbowed. The adults of most species are strongly metallic. Typically, Chalcidae have greatly enlarged hindlegs. A few species are non-parasitic but the majority are beneficial parasitoids or hyperparasitoids of Lepidoptera larvae or other parasitic Hymenoptera. The latter are parasitized within the body of the primary host. Many species are of economic importance as they parasitize the eggs and larvae of many insect pests

- **Agaonidae** Fig wasps are usually minute, pale or dark metallic coloured, soft-bodied wasps. All aganoids develop in the **syconia** of figs (*Ficus spp.*, **Moraceae**) and show an amazing specialised life history: the wingless males live only in the fruit in which they developed. The females are fertilised in the fruit, before they emerge to fly from flower to flower in search of suitable sites for oviposition. By doing so, pollen gets stuck to the females, pollinating the fig flowers. The shape of the fig syconia allows only fig wasps to visit and pollinate the flowers, in return the

fig has to tolerate wasps developing inside a syconium. This sort of mutualism is essential and highly specific, since only particular wasp species are able to pollinate particular *Ficus* species. These complex interactions are further outlined in **fig. 4-3**. Some Agaonidae are gall-formers, others are parasites

- **Trichogrammatidae** This order contains some of the smallest known insects down to 0.15 mm body length. The adult wasps often have fringed wings as shown in **fig. 5-57 A**. All species are egg parasites of Lepidoptera, Coleoptera, Diptera, Hemiptera, Neuroptera, Thysanoptera and Odonata. The females lay their eggs on the host's egg (**fig. 5-57 B**), which is successively eaten by the internally developing larvae. The wasps usually parasitize one particular host species and are thus valuable biocontrol agents for the control of particular insect pests. A famous and common biocontrol 'tool' against lepidopteran pests is *Trichogramma*. Its lifecycle is shown in **fig. 5-57 C**. The wasps are commercially mass-reared in the lab and released upon oviposition of the host. Due to their minute size, the wasps are easily spread by wind, another factor contributing towards successful biocontrol properties. In PNG, *Trichogramma* is reared at the **Bubia Agricultural Research Centre** and released in the Markham Valley to control the Asian Corn Stem Borer *Ostrinia furnacalis* (**Lepidoptera**, **Pyralidae**). Other species of *Trichogramma* that can be obtained commercially are effective against heliothis *Helicoverpa*, fruit stem borers *Maroga melanostigma*, codling and fruit moths *Cydia*, flower caterpillars *Cryptophlebia*, apple moths *Epiphyas*, cabbage moths *Plutella xylostella* and loopers of the genus *Chrysodeixis*

- **Mymaridae** The fairy flies share many features with the closely related **Trichogrammatidae**. They are beneficial, minute, soft-bodied egg parasitoids with fringed wings and are very important for the natural regulation of insect pest species

- **Encyrtidae** and **Aphelinidae** These two closely related families of minute to small, soft-bodied wasps contain a large number of utterly beneficial parasitoids for the biological

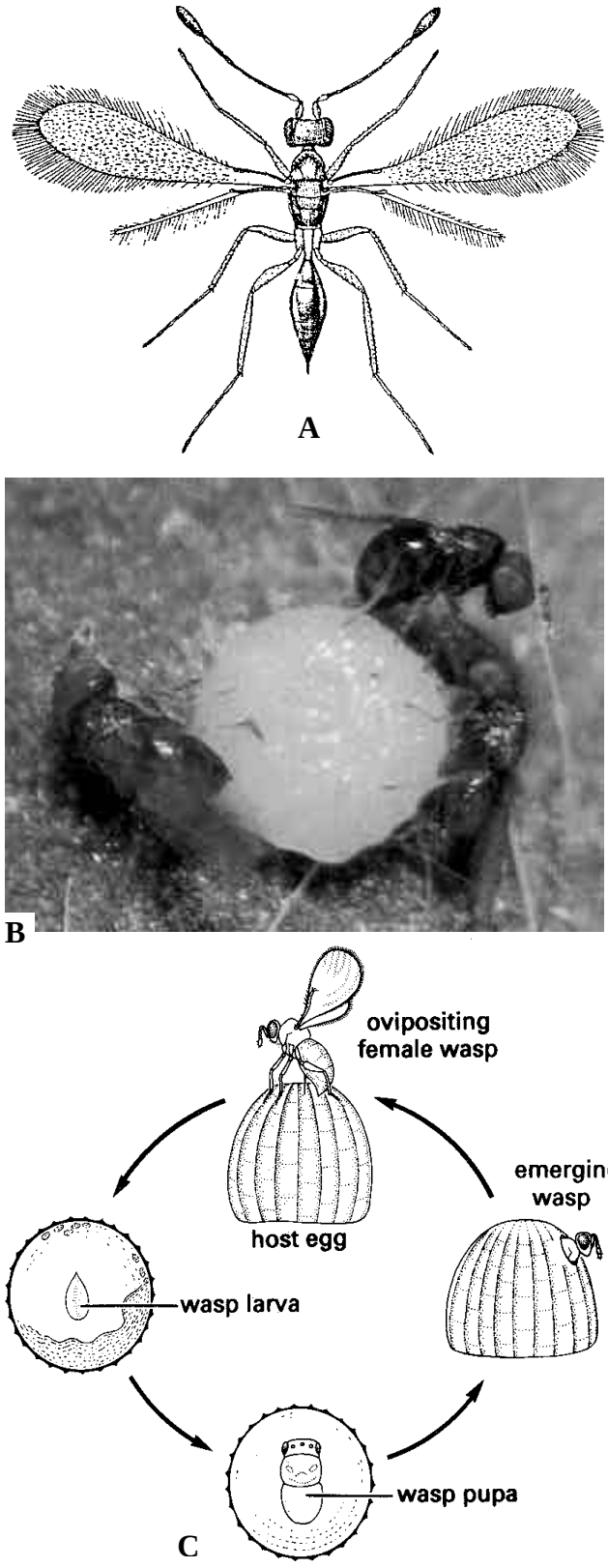

Fig. 5-57: *Trichogramma* (Trichogrammatidae): (A‡) dorsal view, (B‡‡) inspection and parasitization of heliothis egg, (C) lifecycle of *Trichogramma* (reproduced from Gullan P.J. and Cranston P.S., 1994; Papacek, D. et al., 1995‡‡; source unknown‡)

control of various insect pests. The wasps parasitize larvae, eggs and pupae mainly of Lepidoptera, Coleoptera, Hemiptera, Blattodea and Orthoptera. A number of species shown in **fig. 8-7 E - G** are commercially reared, like *Aphytis* used against red scales (**Coccidae**), *Leptomastix dactylopii* for the control of citrus mealybugs (**Coccidae**) and *Encarsia formosa* against whiteflies (**Aleyrodidae**)

Superfamily Chrysidoidea:

- **Torymidae** are a larger family of soft-bodied, small to medium-sized, colourful, metallic wasps. The larvae are either gall-forming or **inquilines** of galls or parasites of gall-forming wasps. The gall-formers affect *Casuarina*, *Banksia*, *Acacia*, *Eucalyptus*, *Citrus* and other hosts. A pest found in PNG is *Megastigmus* (**fig. 6-4 U**, **chapter 6.2.7**), a leaf, shoot and fruit gall-former of *Eucalyptus*

- **Chrysididae** The cuckoo wasps are small to medium-sized, usually brightly blue or green metallic coloured, stockily built wasps. Even though these wasps belong to the aculeate group, they are exclusively parasitic and do not sting. The wasps can often be seen hovering in the garden or bush. The waist is hardly recognisable and the abdomen has only a few visible segments. The underside of the adults is slightly concave, allowing the wasp to roll into a ball for protection. Common in PNG is a more fly-like, metallic green, iridescent wasps shown on **plate 3 V**, that sometimes can be found dead after having been trapped between the mosquito screen and louver blades of a window

Superfamily Vespoidea:

- **Vespidae** The yellow jackets, paper wasps, potter wasps and hornets are medium-sized to rather large, robust to elongate-slender, parasitic, predacious and/or melliferous insects. Typically they have a notch in the inner margin of the compound eyes on either side of the antennae. The wings are folded along the body during rest. The mandibles of many species are prominent and cross over. Most species possess potent stingers. This is advertised by a conspicuous black and yellow aposematic coloration. Hornets are usually harmless and defensive if not disturbed, however their venom has the potential to kill a child. Yellow jacket wasps, like the European species *Vespula germanica*, are rather aggressive and attack humans out of the blue, causing a painful sting. In some cases, the sting can be fatal if the wasp is swallowed accidentally. If stung in the throat, the swelling of the sting can constrict the wind-pipe and suffocate the victim. A considerable number of people develop immunological hypersensitivity against *V. germanica* venom and if stung again, suffer from severe anaphylactic shock with fatal consequences if immediate intensive care is not available. Most species are **solitary**, however some are **eusocial**, forming colonies. Social behaviour in insects is outlined in **chapter 3.2.** The solitary mud or potter wasps build their nests from mud or use existing holes as breeding sites. The paper wasps use chewed wood to construct their paper-like nest. The adult wasps provide their brood with paralysed insects or spiders, shown in **fig. 5-58**. Others feed their young during their development.

Fig. 5-58: Opened wasp nest showing various paralysed larval insects (photo Schneider, M.F.)

- **Formicidae** Ants are minute to medium-sized, winged or wingless insects with geniculate (elbowed) antennae and prominent mandibles. Ants are the closest relatives of the **Vespidae**. Ants have a nodiform, scale-like or binodal 'waist' behind the articulated constriction as shown in **fig. 5-59**. All ant species form colonies, consisting of particular castes, the reproductive female **queen**, a huge

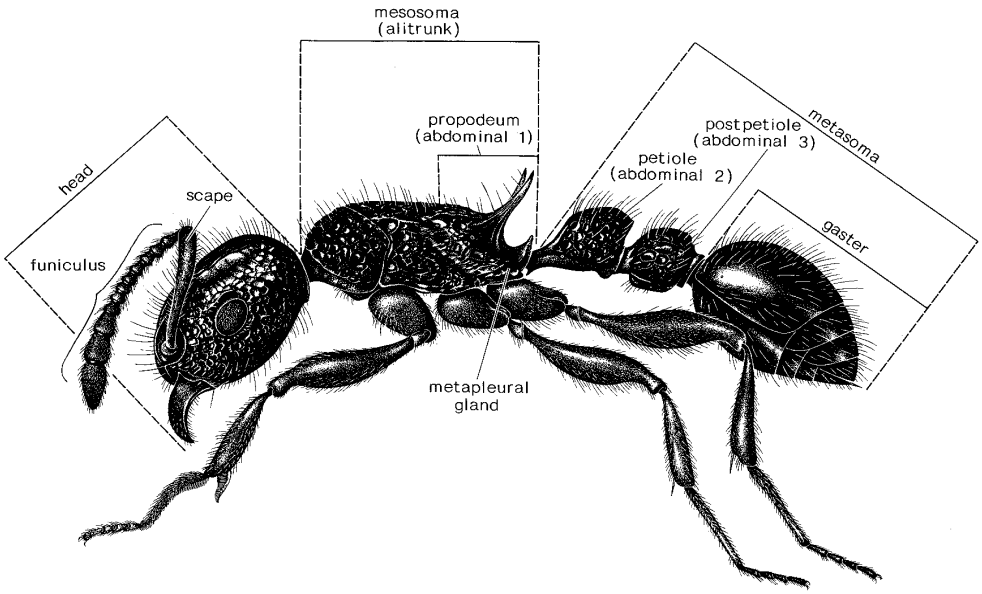

Fig. 5-59: General view of a worker ant (Formicidae, Myrmicinae) (reproduced from CSIRO, 1991)

number of always wingless, non-reproductive **workers** and the disposable reproductive males, the **kings**. The males are only required during the initial stage of founding a colony to inseminate the queen. The colonies usually have between 100 and one to several million individuals. Specialised workers of some arid **Dolichoderinae** and **Formicinae** are called 'honeypots' (**fig. 3-21**) due to the fact that they store liquid nectar in their greatly enlarged crops. The nectar is regurgitated to feed other individuals of the colony. Ants use **scent traces** for their orientation by means of volatile pheromones marking the 'ant highway'. Wiping off the scent trace causes considerable confusion within the ants but it does not take long for the ants to get back on the right track. Ants have quite a number of natural enemies like predacious birds, reptiles, spiders and many more. The **spiny ant eaters** or **echidnas** (*Tachyglossus aculeatus* and *Zaglossus bruijni*) however, prefer termites, that are also called white ants. When disturbed, ants spray **formic acid** from an abdominal 'nozzle', a fact that gave them the name **Formicidae**. Additionally, they bite or use their well-developed stinger for defence. The social organisation of ants and their mutualistic interactions with aphids, scales and antplants (**myrmecophytes**) are outlined in **chapter 3.2.3**.

As predators and omnivores most ant species are of ecological importance. However, there is also quite a number that are nuisances or even pests. The small pharaoh or hospital ants *Monomorium pharaonis* and *M. destructor*, the fire ants *Solenopsis spp.*, Madeira ants *Phediole spp.*, Argentine ants *Iridomyrmex humilis*, meat ants *Iridomyrmex purpureus* and the black house ant *Technomyrmex spp.* are common pests in buildings in the tropics and are attracted in huge numbers to all sorts of food stuffs that are sweet or contain protein or fat. Some of those pest species can even cross a barrier of water since they are light enough to walk on it. A bit of detergent dissolved in the water decreases the surface tension and makes the ant sink. The huge bulldog ants *Myrmecia spp.* (**fig. 5-60**) can cause severe allergic reactions when a human is stung. Particular ant species are of medical relevance since they are the intermediate hosts for tapeworms, which affect humans. Some ant species are a nightmare for agriculturalists. Actually, it's not the impact of ants, but the fact that they tend and maintain the aphid colonies that are vectors for various plant diseases. The fungivorous leaf-cutting ants of the genus *Atta*, not occurring in PNG, can completely defoliate a tree within a very short period of time. They carry the pieces of leaves into their nest to grow fungi. The fungi are the

diet of the ants. These ants can go anywhere and if there seems to be an invincible obstacle they simply build living bridges. A number of ant species like *Pheidole* are used as bio-control agents, due to their being predacious. The native stingless **crazy ant** *Anoplolepis longipes* ('long legs') received the name because these ants run very quickly when disturbed. The species was introduced to some areas in PNG for the control of the weevil *Pantorythes spp.* in cocoa, but the ants became a pest and nuisance themselves, molesting people even during sleep. Now entomologists are thinking about how to get rid of the crazy ants. The arboreal ants *Oecophylla smaragdina*, commonly known as *kurakum* in Melanesian Pidgin, build their nests by weaving together leaves with a silken thread (**fig. 3-18**). Often they are associated with fruit trees like mangoes or soursop. Interestingly, only those trees inhabited by red ants bear fruits. The ability of *Oecophylla* to spray **formic** acid can be impressively demonstrated by spitting *buai* on to an arboreal ant nest. The chewed betel pepper *Piper betle* acts as a pH-indicator: the red colour due to high pH (alkaline effect of lime) changes to yellow in low pH (sour), when the ants spray formic acid on the betelnut spit. Other arboreal ants occurring in PNG belong to the genus *Polyrhachis*

Superfamily Sphecoidea:

- **Sphecidae** Mud daubers, sand wasps or digger wasps are a large family of predatory or cleptoparasitic ('stealing'), small to very large, often slender insects. These metallic coloured wasps are close relatives of the bees (**Apidae**). The differences however are the branched body hairs and the broad hind tarsi of the bees. Adult mud daubers excavate soil or wood for the construction of their nest or build their nest from mud and saliva. The latter type of nest can be often found attached to buildings. If opened up, the compartments stocked with paralysed insects or spiders become visible (**fig. 5-58**). The lifestyles of the wasps ranges from solitary to subsocial. Some genera use a stone as a tool for excavation.

Fig. 5-60: Giant bulldog ant *Myrmecia sp.* (Formicidae). The comparison with the gas lighter in the foreground demonstrates the size of the ant (photo Schneider, M.F.)

Superfamily Apoidea:

- **Apidae** Bees and bumblebees are medium-sized to large, robust or elongate-oval insects. Typically, the body of adults is covered with branched hairs and the first tarsal segment as well as the tibia of the hindleg are enlarged for collecting pollen ('pollen basket'). Bees usually use nectar and pollen as food for their larvae but a few species parasitize other bee nests. Only a few species show social organisation, the majority is solitary. A very famous and common representative is the domesticated, introduced honey bee *Apis mellifera* ('honey carrying'). Another social Apidae genus is *Bombus*, the bumblebees. The social organisation and some of the complex behavioural patterns of bees like the 'waggle' dance, are outlined in **chapter 3.2.2**

- **Anthophoridae** Carpenter bees are large, robust bees with dark wings and dark cuticle. In females, the head and thorax are covered with dense golden hairs and black abdomen. The males are completely covered with gold hairs. The adults make round nesting holes in wood or plant stems. Carpenter bees of the genus *Xylocopa* are very large, densely haired, robust insects that are metallic coloured. Their abdomen is somewhat flattened. The nests are made inside the branches of dead trees or occasionally in pine timber of poor quality.

5.6.4 Literature for the Identification of Insects

D'**A**brera, B. (1986): Sphingidae Mundi: Hawk Moths of the World; E.W. Classey; London; UK

D'**A**brera, B. (1990[3]): Butterflies of the Australian Region; Landsowne Press, Melbourne; Australia

Andersen, A.N. (1991): Ants of Southern Australia; CSIRO Information Services; Melbourne; Australia

Baker, G. (1996): Locusts and Grasshoppers of Australasia; CSIRO Information Services; Melbourne; Australia

Barlow, H.S. (1982): An Introduction to the Moths of South East Asia; Malaysian Nature Society; Kuala Lumpur; Malaysia

Barrett, C. and Burns, A.N. (1951): Butterflies of Australia and New Guinea; Seward; Melbourne; Australia

Bigger, M. and Schofield, P. (1983): Checklist of Cerambycidae, Curculionidae, Attelabidae, Scolytidae and Platypodidae of Melanesia; Centre for Overseas Pest Research; London; UK

Blackman, R.L. & Eastop V.F. (1994): Aphids on the World's Trees; CAB-International; Wallingford; UK

Booth, R.G. et al. (1990): Coleoptera, Vol. 3; International Institute of Entomology; London; UK

Burton, M. and Burton, R. (1975): Encyclopaedia of Insects and Arachnids; Octopus; London; UK

Calder, A.A. (1996): Click Beetles. Genera of the Elateridae (Coleoptera); CSIRO Information Services; Melbourne; Australia

Carnaby, K. (1986): Jewel Beetles of Western Australia; CSIRO Information Services; Melbourne; Australia

Child, J. (1961[2]): Australian Insects: An Introduction for Young Biologists and Collectors; Penwickle Press; Gladsville; Australia

Common, I.F.B. (1990): Moths of Australia; Melbourne Univ. Press; Carlton; Australia

Common, I.F.B. (1993): *Oecophorinae* Genera of Australia (Lepidoptera). I. The *Wingia* Group; CSIRO Information Services; Melbourne; Australia

Common, I.F.B. and Waterhouse, D.F. (1981): Butterflies of Australia; Melbourne Univ. Press; Carlton; Australia

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (1991[2]): The Insects of Australia - A Textbook for Students and Research Workers; Volume 1 & 2; Melbourne University Press; Carlton; Australia

Cornwell, P.B. (1968): The Cockroach; Hutchinson; London; UK

Cranston, P.S. (1996): Identification Guide to the Chironomidae of New South Wales; CSIRO Information Services; Melbourne; Australia

Curran, C.H. (1946): Insects of the Pacific World; Mcmillan; New York; USA

Eisenbeis, G. and Wichard, W. (1987[2]): Atlas on the Biology of Soil Arthropods; Springer Verlag; Berlin; Germany

Gauld, I. and Bolton, B. (eds.) (1988): The Hymenoptera; British Museum of Natural History and Oxford University Press; London; UK

Giam, A.N., Hamb, A.K., Noga, T. and Mask, I. (in press): Description and Biology of the newly discovered Lentilburgeroptera; Parascience in New Guinea; Universe of Papua New Guinea; Port Moresby, PNG

Gressitt, J.L. (1959): Longicorn Beetles from New Guinea I: Cerambycidae; in: Pacific Insects 1(1); Bernice P. Bishop Museum; Honolulu; USA

Gressitt, J.L. and Hornabrook R.W. (1977): Handbook of Common New Guinea Beetles, Wau Ecology Institute Handbook No. 2; Wau; PNG

Halliday, B. (1998): Mites of Australia - A Checklist on Invertebrate Taxonomy Vol. 5; CSIRO Publishing; Collingwood; Australia

Holloway, J.D. (1989): The Moths of Borneo; 18 volumes; Malaysian Nature Society; Kuala Lumpur; Malaysia

Kim, S.P. (1994): Australian *Lauxaniid* Flies; CSIRO Information Services; Melbourne; Australia

Lachaume, G. (1982): Beetles of the World (Les Coleopteres du Monde), Vol. 3: Goliathini; Sciences Nat.; Venette; France

Lachaume, G. (1982): Beetles of the World (Les Coleopteres du Monde), Vol. 5: Dynastini; Sciences Nat.; Venette; France

Lacroix, J.P. (1982): Beetles of the World (Les Coleopteres du Monde), Vol. 4: Odontolabini; Sciences Nat.; Venette; France

Lawrence, J.F. and Britton, E.B. (1994): Australian Beetles; CSIRO Info Services; Melbourne; Australia

Lawrence, J.F. and Hastings, A., Dallwitz, M. and Paine, T. (1993): Beetle Larvae of the World. Interactive identification and retrieval for families and subfamilies; CD-ROM; CSIRO Information Services; Melbourne; Australia

McFarland, N. (1988): Portraits of South Australian Geometrid Moths; CSIRO Information Services; Melbourne; Australia

Moulds, M.S. (1991): Australian Cicadas; CSIRO Information Services; Melbourne; Australia

New, T.R. (1995): Exotic Insects in Australia; CSIRO Information Services; Melbourne; Australia

Nielsen, E.S. and Kristensen, N.P. (1990): Primitive Ghost Moths; CSIRO Information Services; Melbourne; Australia

Orsak, L. (1993): Common Moths of the Tari Gap Region; CRI; Madang; PNG

Parsons, M.J. (1991): Butterflies of the Bulolo-Wau Valley, Wau Ecology Institute Handbook No. 12; Wau; PNG

Parsons, M.J. (1996): New Species of *Aristolochia* and *Pararistolochia* (Aristolochiaceae) from Australia and New Guinea; Botanical Journal of the Linnean Society, 120, 199-238

Parsons, M.J. (1998): The Butterflies of Papua New Guinea, Academic Press; New York; USA

Preston-Mafham, K. (1990): Grasshoppers and Mantids of the World; Blandford; London; UK

Preston-Mafham, R. (1988): Butterflies of the World; Facts on File; New York; USA

Rentz, D.C.F. (1985): Tettigoniidae of Australia 1; CSIRO Information Services; Melbourne; Australia

Rentz, D.C.F. (1993): CD with Calling Songs of Tettigoniid species described in Vol. 1 & 2; CSIRO Information Services; Melbourne; Australia

Rentz, D.C.F. (1993): Tettigoniidae of Australia 2; CSIRO Information Services; Melbourne; Australia

Rentz, D.C.F. (1996): Grasshopper Country: Australia's abundant Orthopteroid Insects; including audio CD; CSIRO Information Services; Melbourne; Australia

Rigout, J. (1982): Beetles of the World (Les Coleopteres du Monde), Vol. 2: Batocerini; Sciences Nat.; Venette; France

Robinson, G.S. and Nielsen, E.S. (1993): Tineid Genera of Australia (Lepidoptera); CSIRO Information Services; Melbourne; Australia

Robinson, G.S., Tuck, K.R. and Shaffer, M. (1994): A Guide to the Smaller Moths of South East Asia; Malaysian Nature Society; Kuala Lumpur; Malaysia

Samuelson, G.A. (1973): Alticinae of Oceania (Coleoptera: Chrysomelidae); Department of Entomology of Bernice P. Bishop Museum; Honolulu; USA

Schedl, K.E. (1970): Another Collection of Scolytidae and Platypodidae of Economic Importance from the Territory of Papua and New Guinea; 254. Contrib. to the Morph. and Taxonomy of the Scolytidae; Proc. of the Linnean Soc. of N. S. W. 94 (2): 128

Schedl, K.E. (1972): New Scolytidae and Platypodidae from the Papuan Subregion and New Caledonia I. 271. Contribution to the Morphology and Taxonomy of the Scolytidae; reprinted from the PNG Agric. Journal 23(3)

Schedl, K.E. (1972): Scolytidae and Platypodidae from the Papuan Subregion and Australia. 279. Contribution to the Morphology and Taxonomy of the Scolytidae; reprinted from the PNG Agric. Journal 23(4)

Stanek, V.J. (1969): The Pictorial Encyclopaedia of Insects; Hamlyn; London; UK

Stanek, V.J. (1977): The Illustrated Encyclopaedia of Butterflies and Moths; Octopus; London; UK

Stork, N.E. (1986): An Annotated Checklist of the Carabidae recorded in Borneo; British Museum of Natural History; London; UK

Tyndal-Biscoe, M. (1990): Common Dung Beetles; CSIRO Information Services; Melbourne; Australia

University of Queensland, Department of Entomology and Cooperative Research Centre for Tropical Pest Management (1997): LucID Player - Contemporary Identification Tools for Biology, CD-ROM; Version 1.0; Brisbane; Australia

Uvarov, B.P. (1966): Grasshoppers and Locusts: A Handbook of Acridology; Cambridge University Press; Cambridge; UK

Watson, J.A.L. and Abbey, H.A. (1993): Atlas of Australian Termites; CSIRO Information Services; Melbourne; Australia

Watson, J.A.L., Theischinger, G. and Abbey, H.A. (1991): Australian Dragonflies; CSIRO Information Services; Melbourne; Australia

Wilson, M.R. and Claridge, M.F. (1991): Handbook for the Identification of Leafhoppers and Planthoppers of Rice; CAB Internat.; Wallingford; UK

Wootton, A. (1984): Insects of the World; New York Facts on File; New York; USA

Zborowski, P. and Storey, R. (1995): A Field Guide to Insects in Australia; Reed Books; Chatswood; Australia

Zimmermann, E.C. (1994 to 1998): Australian Weevils; Vols. I to VIII; CSIRO Information Services; Melbourne; Australia

Further reading:

Ackery, P.R. (ed.) (1988): The Biology of Butterflies; Princeton University Press; Princeton; USA

Clements, A.N. (1992): The Biology of Mosquitoes; several Volumes; Chapman & Hall; London; UK

CSIRO (1996[2]): Insects - Little Creatures in a Big World; CD-ROM; CSIRO Publishing; Collingwood, Australia

Dean, J. and al. (1990): The defensive Spray of the Bombardier Beetle: A biological Pulse Jet; Science 248: 1219-1221

Ewers, W.H. and Jeffrey, W.T. (1971): Parasites of Man in Niugini; Jacaranda Press; Milton; Australia

Gressitt, J.L. (1968): Bibliography of New Guinea Entomology; Pacific Insects Monograph 18; Bernice P. Bishop Museum; Honolulu; USA

Groombridge, B. (1994): Global Biodiversity - Status of the Earth's living Resources; IUCN; Cambridge; UK

Gullan, P.J. & Cranston, P.S. (1994): Insects - An Outline of Entomology; Chapman & Hall; London; UK

Henwood, A. (1993): Still Life in Amber; New Scientist 137 (1859): 31-34

Herington, J. (1977): Wildlife Introduced and Imported into Papua New Guinea; Department of Environment and Conservation (77/1), Waigani; PNG

Hölldobler, B. and Wilson E.O. (1994): Journey to the Ants - A Story of Scientific Exploration; Harvard University Press; Cambridge; USA

Hoydt, E. (1996): The Earth Dwellers - Adventures in the Land of Ants; Touchstone; New York; USA

Lapedes, D.N. (ed.) (1978[2]): Dictionary of Scientific and Technical Terms; McGraw-Hill; New York; USA

Parsons, M.J. (1996): The Stalk-Eyed Flies; Terra; Vol. 33 (4): 8-9

de la **T**orre-Bueno, J.R. (1989[2]): The Torre-Bueno Glossary of Entomology; New York Entomological Society in Cooperation with the American Museum of Natural History; New York; USA

Walter, D. E. (1996): Living on Leaves: Mites, Tomena and Leaf Domatia; Annu. Rev. Entomol. 41: 101-114