Training Workshop on Diagnostics of Leafminers of Agricultural Importance

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Research Center for Biology, Indonesian Institute of Science (LIPI), Cibinong, Bogor, Indonesia

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Biology and Ecology of Leafminers

1. Terms

Leafmining: A feeding habit of insects which consume live foliage while simultaneously dwelling inside it.

Leaf mine: A cavity or tunnel which a leafmining insect creates in the leaf. In the majority of leafmining insects, leaf mines are constructed by larvae.

Leafminer: An insect which has the habit of leafmining.

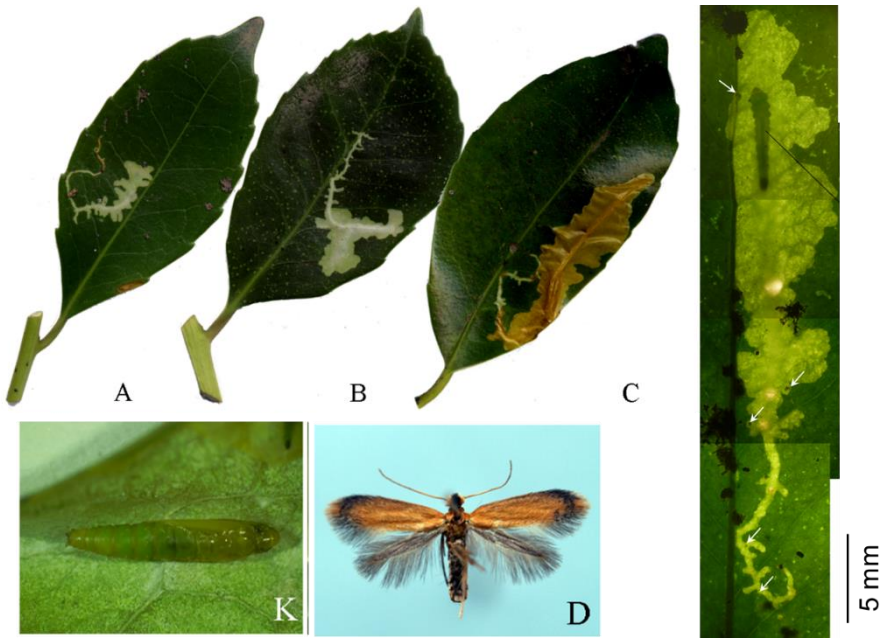
2. Leafmines

2-1. Various forms

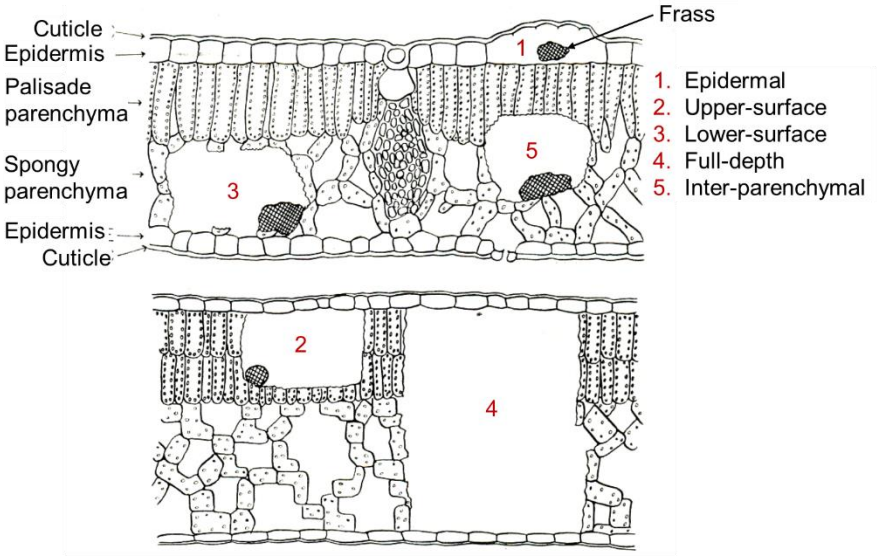
"The form of the mine, together with the plant species, can often be diagnostic of a particular species; even weeks after the larva has vacated, its creator can sometimes be confirmed from the empty mine" (Sterling and Parsons 2013).

Mines are classified according to vertical and horizontal extension as follows:

- Vertical extention
  - Epidermal
  - Upper-surface
  - Lower-surface
  - Inter-parenchymal
- Horizontal extension
  - Linier
    - Serpentine
    - Intestinally coiled
  - Blotch
    - Irregular blotch mines
    - Star
  - Linear-blotch
    - The shape changes from linear to blotch with larval growth

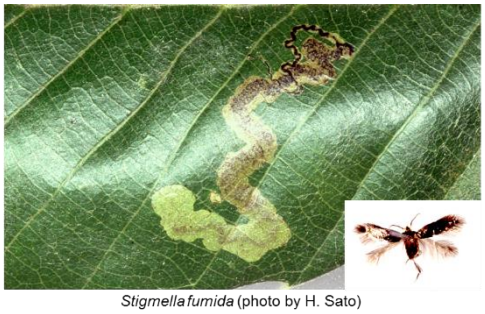


An leafmining insect, *Cototriche symplocosella* (Tischeriidae, Lepidoptera). A: young mine. B: later mine; C: old mine. D: last instar larva and mine (arrows indicate head capsules); E: pupa ; F: adult. (Kobayashi et al. in submission)

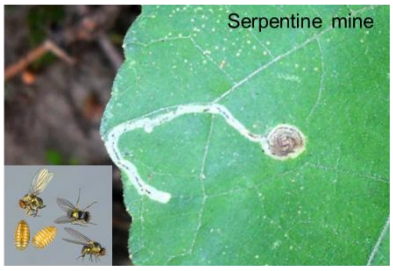


Cross sections of a leaf and classification of leaf mines according to vertical extension (Hering 1951).

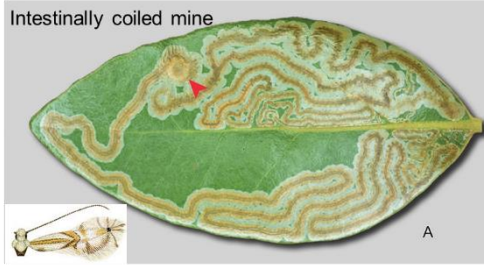
Phyllocnistis populiella (http://www.fs.usda.gov/Internet/ FSE_DOCUMENTS/stelprdb5347213.pdf)



Stigmella fumida (photo by H. Sato)



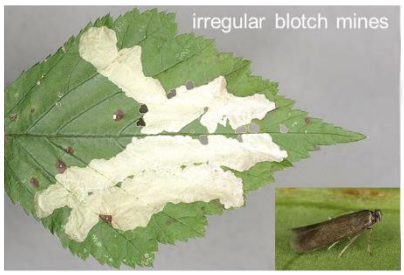
Liriomyza eupatorii (http://bugguide.net/node/view/839350)



Phyllocnistis hyperpersea (after Davis and Wagner 2011)

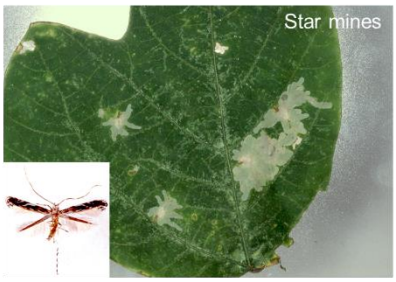
Linier mines

Fenusa dohrnii (http://wanda.uef.fi/biologia/nyman/Leafminers.htm)



Cototriche heinemanii (http://www.lepiforum.de/lepiwiki_vgl.pl?Coptotriche_Heinemanni)

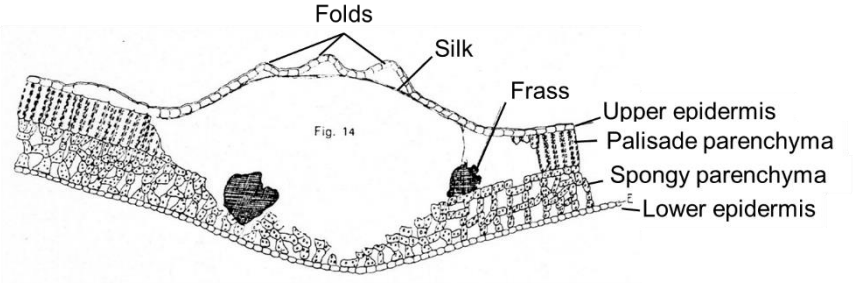
Phyllonorycter tritorrhecta (photo by H.Sato)



Lyocrobyla lobata (photo by H.Sato)

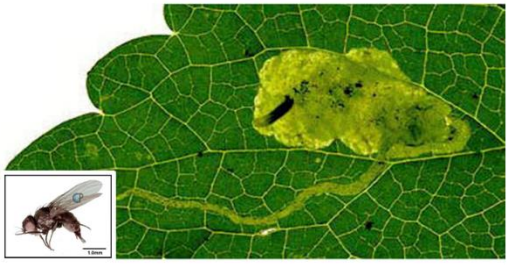
Blotch mines

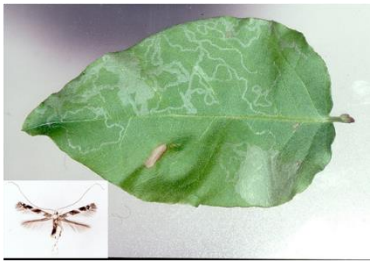
Upper-surface mine of *Phyllonorycter leucographella* (http://www.naturespot.org.uk/species/firethorn-leaf-miner)



Cross section of an upper surface mine of *Phyllonorycter* sp. (after Hering 1951)

Tentiform mines of *Phyllonorycter*.





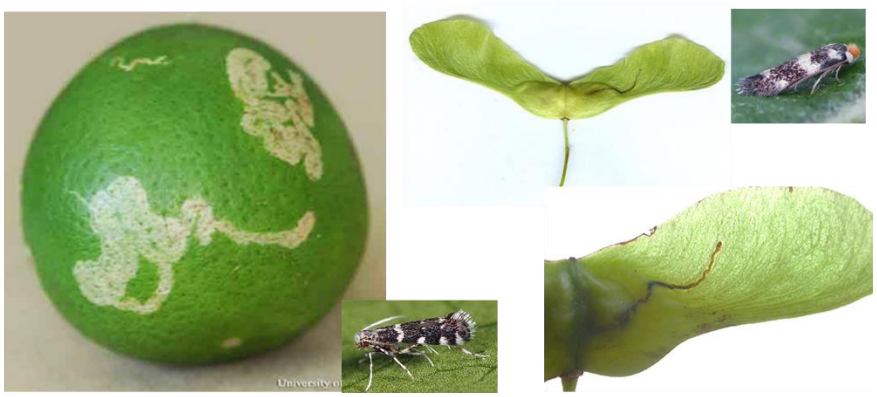
Linier-blotch mines. Left: *Amauromyza labiatarum* (http://www.ukflymines.co.uk/Keys/GLECHOMA.php). Right *Spulerina parthenocissi* (photo by H. Sato)

2-2. Mines on Other Parts of Plants

Mines are found on not only leaves but also stems and fruits.

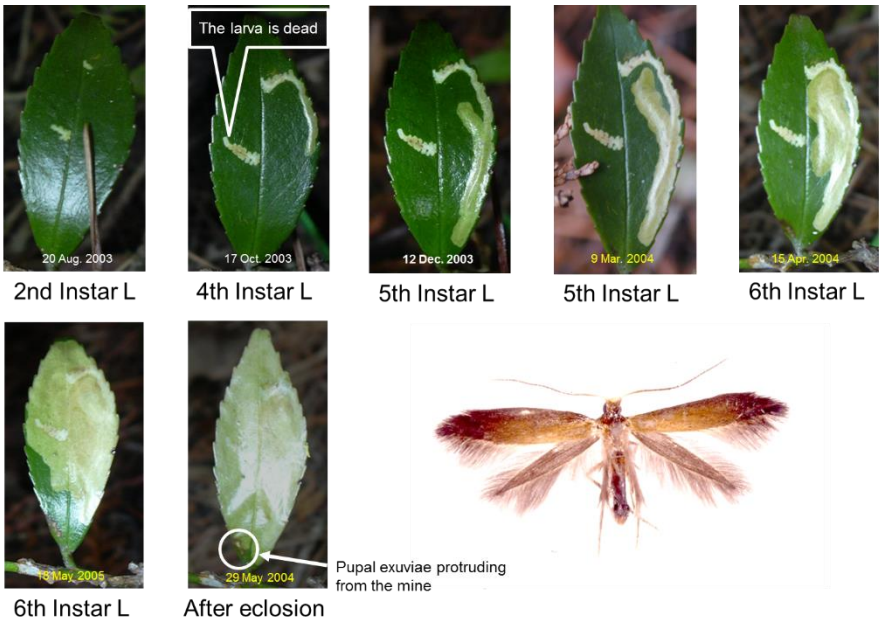
2-3. Permanent and Temporal Mines

All leafminers do not complete their development within the mine. Some leafminers live within the mine in early instars, and leave it to feed on leaves externally or to pupate on the leaf surface or on the ground. When the occupant of a mine spends the immature stage from hatching to pupation in the mine, it is called a permanent mine. When the occupant spends part of the immature stage in the mine, it is called a temporal mine.

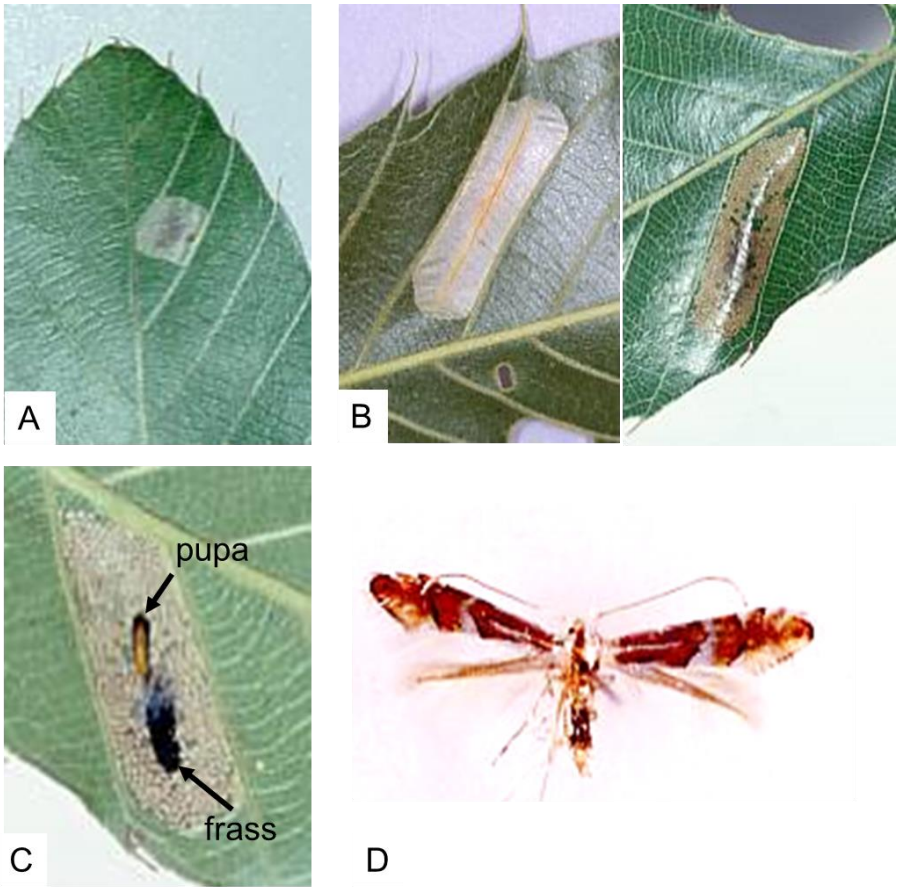


Mines on bark surface. Left: *Marmara gulosa* http://entnemdept.ufl.edu/creatures/citrus/citrus_peelminer.htm. Right: *Ectoedemia sericopeza* http://www.bladmineerders.be/nl/content/ectoedemia-sericopeza-zeller-1839

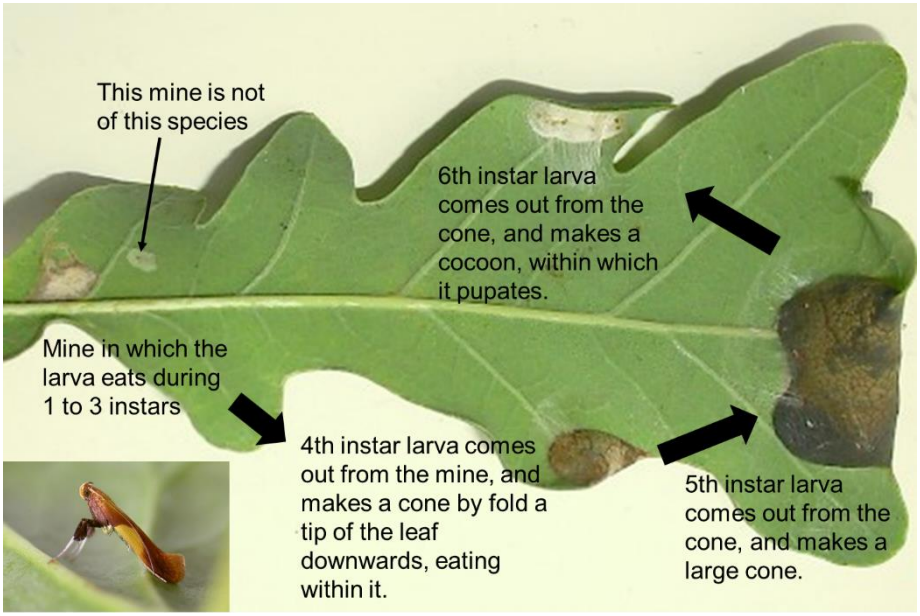
Mines on bark surface. Left: *Spulerina astaurota* http://www.jpmoth.org/Gracillariidae/Gracillariinae/Spulerina_astaurota.html. Right: *Phyllocnistis saligna*. http://www.ladmineerders.nl/minersf/lepidopteramin/phyllocnistis/saligna/saligna.htm



Permanent mine of *Coptotriche japoniella*



Permanent mine: of *Phyllonorycter nipponicella.* A: mine of 2nd Instar larva, sap-feeding, epidermal; B: mine of 5th Instar larva, tissue feeding, full-depth, (left) lower surface, (right) upper surface; C: mine of pupa, epidermis removed; D: adult.



Temporal mine, cones and cocoon of *Caloptilia robustella*. http://www.ukmoths.org.uk/species/caloptilia-robustella/adult/

Temporal mine of *Incurvaria praelatella.* The larva makes a blotch mine and then excises a elliptic case from the mine. The larva continues feeding and simultaneously enlarges the case to fiddle-shaped with silk and plant hairs. http://www.ukflymines.co.uk/Moths/Incurvaria_praelatella.php

Temporal mines and cocoons of *Stigmella aurella.* The final instar larva comes out from the mine, and then makes a silken cocoon within which it pupates. http://charlielepidopteraofcalderdale.blogspot.jp/2011/11/neps-1.html

3. Taxa Including Leafminers

"Approximately 10,000 described species of leafminers occur in at least 51 families of holoetabolous insects in the orders Coleoptera, Diptera, Lepidoptera, and Hymenoptera" (Connor and Taverner 1997).

"The leafmining habit is most widely distributed in the Lepidoptera occurring in 34 families. Leafmining probably evolved only once in the Lepidoptera first appearing in the primitive Heterobathimiidae. The most primitive Lepidoptera, the Micrtopterigidae, were probably associated with moist forest habitats consuming spores and pollen of bryophytes and some angiosperms. Most non-Ditrysian families and many of the primitive Ditrysian families are exclusively leafmining or at least primitively leafmining. Given the pattern of distribution of leafmining within the Lepidoptera and the tendency toward external feeding in the derived Ditrysia and macrolepidoptera, leafmining should be considered a primitive trait within the Lepidoptera" (Connor and Taverner 1997).

"In the Coleoptera, leafmining occurs in six families, but is most extensively developed in the Chrysomelidae. Leafmining evolved at least four times in the superfmilies Buprestoidea, Chrysomeloidea, Cucujoidea, and Curculionoidea. However, it is likely that within these superfamilies leafmining evolved more than once. … In contrast to the Lepidoptera, leafmining in the Coleoptera is a derived trait in each mining lineage" (Connor and Taverner 1997).

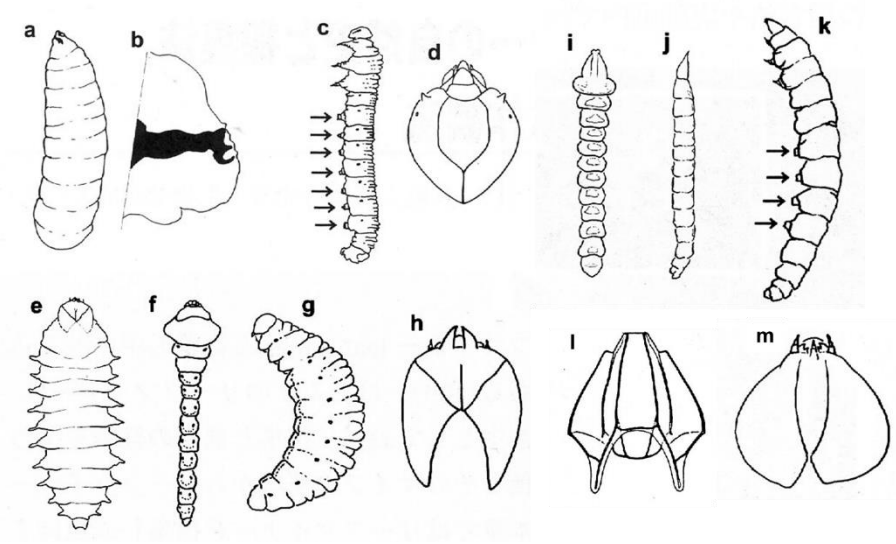
"In the Diptera, leafmining occurs in nine families, but is most extensively developed in the Agromyzidae and the Ephydridae. Leafmining evolved at least six times in the Diptera, and also appears to be a derived trait. Leafmining appears to have evolved from a variety of ancestral feeding habits including: internal root, stem and bark feeding (Agromyzidae), saprophagous (Tipulidae), and coprophagous (Scatophagidae) ancestors" (Connor and

Families with at least one leafmining species

Coleoptera	Diptera	Lepidoptera	Hymenoptera
Buprestidae	Tephritidae	Heterobathmiidae	Pergidae
Nititulidae	Ephydridae	Eriocraniidae	Argidae
Chrysomelidae	Drosophilidae	Acanthopteroctetidae	Tenthredinidae
Belidae	Agromyzidae	Nepticulidae	
Attelabidae	Scathophagidae	Opostegidae	
Curculionidae	Anthomyiidae	Tischeriidae	
	Tipulidae	Palaephatidae	
	Chironomidae	Incurvariidae	
	Phoridae	Prodoxidae	
		Adelidae	
		Heliozelidae	
		Gracillariidae	
		Bucculatricidae	
Major families shown in red		Lyonetiidae	
		Coleophoridae	
		19 others	
6	9	34	3

Taverner 1997).

"Fewer than 100 described species of leafmining insects occur in the Hymenoptera all in the superfamily Tentredinoidea. Leafmining probably evolved six times in the Hymenoptera, and as in the Diptera and Coleoptera is a derived trait. Leafmining arose from ancestral taxa that were external feeding folivores in the Hymenoptera, as they did in the Chrysomelidae (Coleoptera)" (Connor and Taverner 1997).



a, b: Diptera, Agromyzidae; a: dorsal view; b: mouth parts. c, d: Hymenoptera, Tenthredinidae; c: lateral: d: head capsule, dorsal. e, f, g,h: Coleoptera; e: Chrysomeridae, dorsal; d: Bupresitidae, dorsal; g: Curculionidae, lateral; h: Chrysomeridae, head capsule, dorsal. i, j, k, l, m: Lepidoptera, Gracillariidae; i, j: sap-feeder, dorsal and lateral; l: sap-feeder, head capsule, dorsal; k: tissue-feeder, lateral; m: tissue-feeder, head capsule, dorsal. Arrows indicate ventral prolegs. (Kawakita and Okuyama 2012)

Coleopteran leafminer. Beech flea weevil *Rhynchaenus fagi* (Curiculionidae)

Coleopteran leafminer. Locust leafminer Odontota dorsalis (Chrysomeridae)

Hymenopteran leafminer. *Kaliofenusa ulmi* (Tentredinidae)

Hymenopteran leafminer. *Scolioneura tirolensis* (Tentredinidae)

4. Adaptive Significance of the Leafmining Habit

Several hypotheses have been presented for adaptive significance of the leafmining habit, being summarized below:

- Avoidance of plant defenses
  - Structural defenses such as spines and trichomes
  - Chemical defenses
- Protection from pathogens
- Buffer against variation in the physical environment
  - Maintenance of hygro-thermal balance
  - Protection from UV

5. Ecological Studies of Leafminers

It is easy to find mines in the field and to rear mines/miners in the laboratory. Accordingly we can easily get the following information from the mines:

Densities of leafminers
The fate of the occupant
    Survival or death
    The instar of death
    The cause of death
Parasitoids associated with leafminers

"The ease with which leafmines can be studied has made them a popular system for ecological research. In North America, the first major descriptive review of leafmining insects was that of Needham et al (1928). In Europe, the monumental and encyclopedic works of Hering (1951, 1957) and Fulmek (1962) provided a firm base for subsequent ecological work. In the past two decades, interest in leafminers has increased, perhaps stimulated by Opler's classic papers on the ecology of leafmining Lepidoptera of California oaks (1974a,b), and by Askew's and Shaw's study of parasitoid communities in England. Other major workers on natural systems of leafminers include J. H. Lawton in England and D. Simberloff, T.L. Bultman, and S.H. Faeth in the United States. In general, this research has focused on a small number of major systems: oaks in California, Arizona, Florida, and England; hollies in North America and England; and beech in Europe. Agricultural research other than that on *Liriomyza* (Parella 1987) includes the classic study by Taylor (1937) on the biological control of the coconut palm leafminer in Fiji and, more recently, studies on the alfalfa blotch leafminer *Agromyza frontella* (Drea and Hendrickson 1986) and on *Lithocolletis* (=*Phyllonorycter*) species on apple (Pottinger and LeRoux 1971)" (Hespenheide 1991)

References

Connor FF and Taverner MP (1997) The evolution and adaptive significance of the leaf-mining habit. Oikos, 79: 6-25.

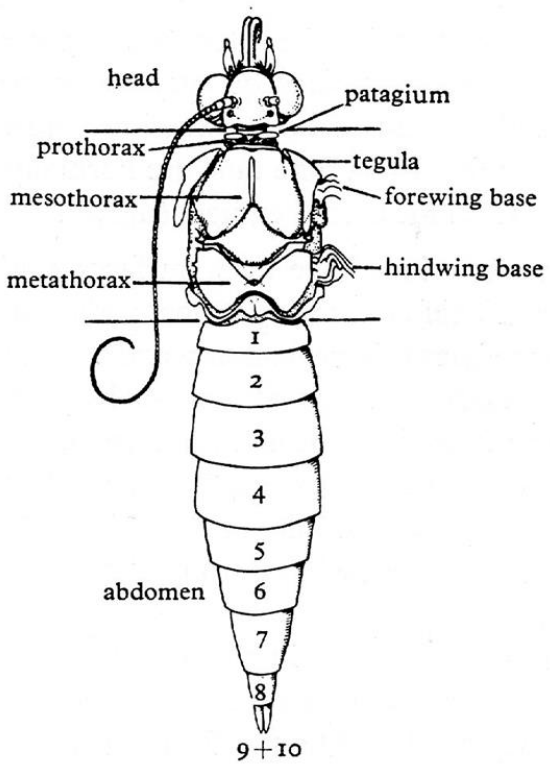
Hespenheide HA (1991) Bionomics of leaf-mining insects. Annual Review of Entomology, 36: 535-560.

Kawakita A and Okuyama Y (2012) Biology of species interactions. Bun-ichi Sogo Shuppan, Tokyo, Japan.

Morphology and Terminology of the Lepidoptera

1. Imago, or Adult

"Lepidoptera may be readily distinguished from other insect orders by the presence of a clothing of usually broad, overlapping scales on wings, head, thorax, abdomen and appendages of the imago. An epiphysis is present on the foretibia of almost all the families including the primitive Zeugloptera and Dacnonypha. This structure is not found in any other order. Except the primitive Zeugloptera, the galeae are modified into a haustellum or proboscis, a structure unique to the Lepidoptera." (Heath 1983).



Heath (1983)

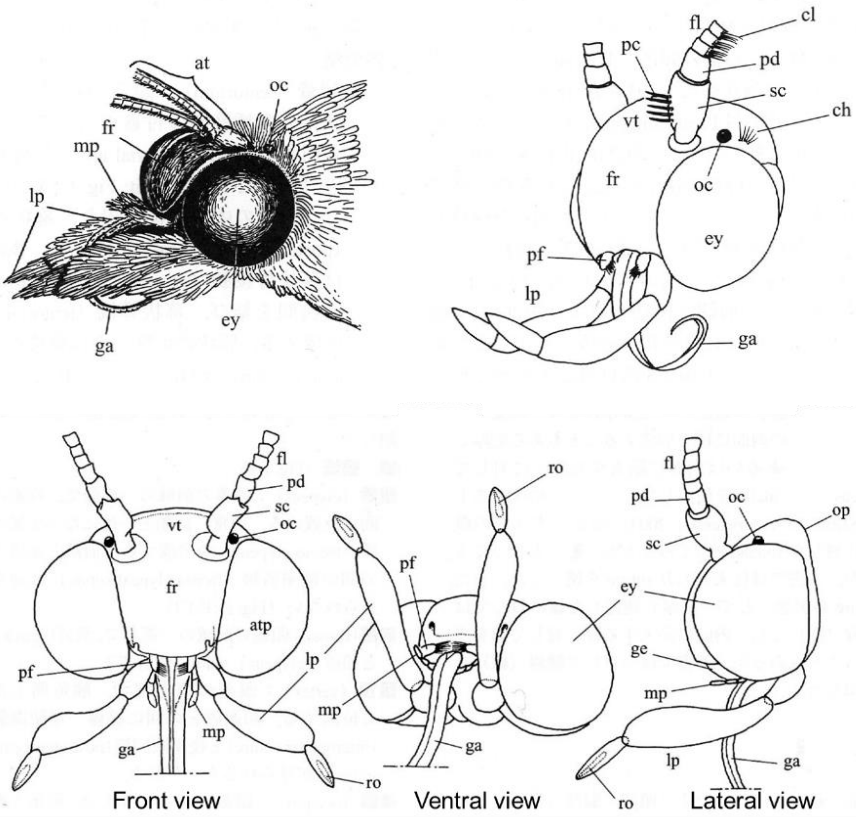
1-1. Adult Head

"The lepidopteran head has been divided into a number of genral areas, but these areas cannot be defined precisely in terms of their development. They are used by ledpidopterists mainly as topographical guides in description" (Scoble 1992).

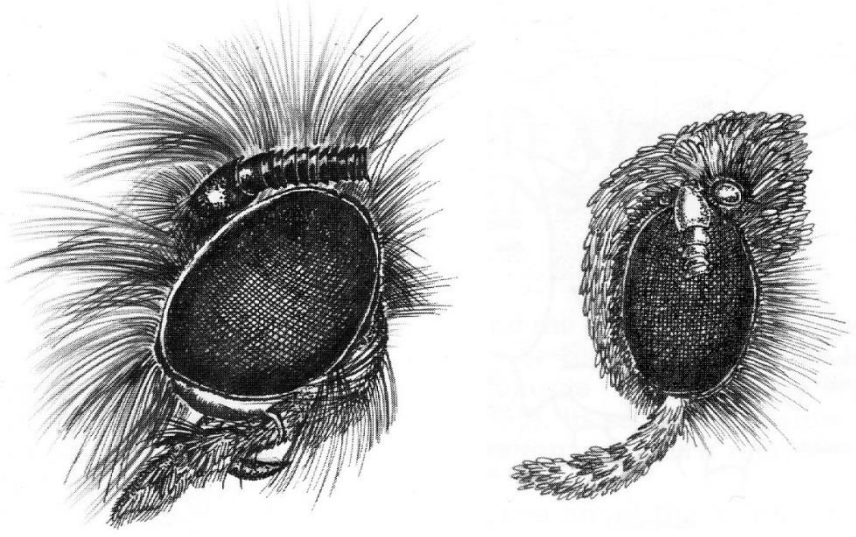
"The head is usually covered with scales which may be hair-kike or lamellate. In many groups they form a tuft on the vertex and the frons or on the vertex alone. In the tufted condition the head is said to be rough-scaled In contrast with the situation where the scales

are appressed to the head capsule and said to be smooth-scaled. Amongst microlepidopterans the smooth-scaled condition is found more often in the less primitive families, but the character is of limited diagnostic importance" (Scoble 1992).

"The dominat feature of the mouthparts of most Lepidoptera is the long coilable proboscis - a structure formed from the union of the two extended galeae of the maxillae. The proboscis is coiled under the head when the insect is a rest, and it is extended for imbibing fluids. The structure is unique to the Glossata, a taxon including all but a small fraction of the Lepidoptera. Although the occurrence of vestigial mandibles is widespread in adult Lepidoptera fully developed and functional mandibles are rare" (Scoble 1992).



Head of *Cryptophlebia* sp. (Tortricidae). at: antenna; atp: anterior tentorial pit; ch: chaetosema; cl: cilia; ey: compound eye; fl: flagellum, fr: frons (or face); ga: galea (*pl.*, galeae); ge: gena; lb: labrum; lp: labial palpus; mp: maxillary palpus; oc: ocellus (*pl.*, ocelli); op: occiput; pf: pilifer; pc: pecten; pd: pedicel; ro: vonRath's organ: sc: scape; vt: vertex. (Komai et al. 2011)



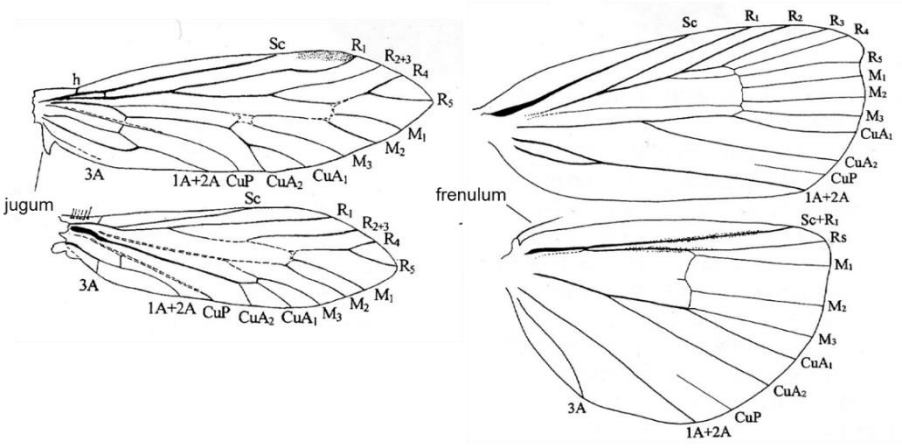
Left: rough-scaled head (*Monopis pavlovski*); right: smooth-scaled head (*Glyphipteryx antidota*) . (Scoble 1992)

1-2. Wings

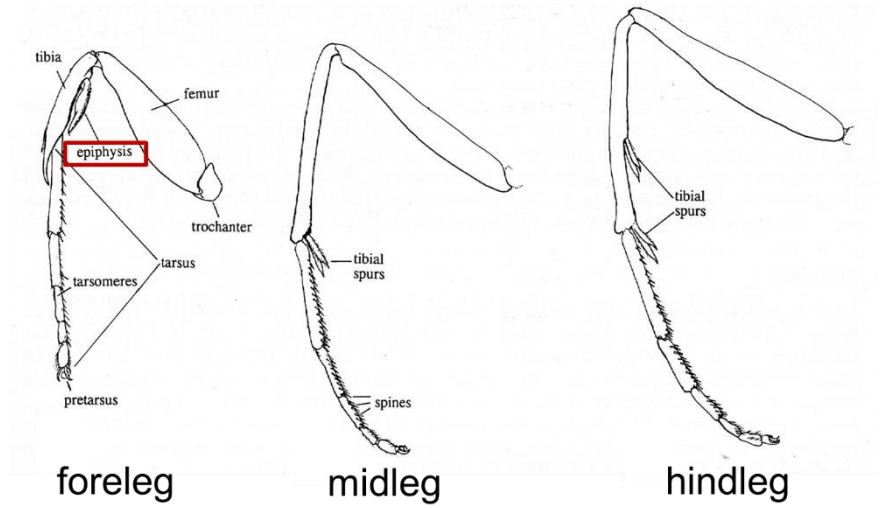
"The wing veins, represented by a special notation, are of great value in moth classification. The more primitive groups, Micropterigidae, Agathiphagidae, Lophcornidae and Exoporia, in which are enation of fore and hind wings is similar, are said to be homonerurous. The more advance groups, in which the number of veins in the hind wing is less than that of the fore wing, are said to be heteroneuros. There are six main series of veins in the moth wing: costa, subcostal, radius, media, cubitus and anal veins" (Common 1990).

1-3. Adult Legs

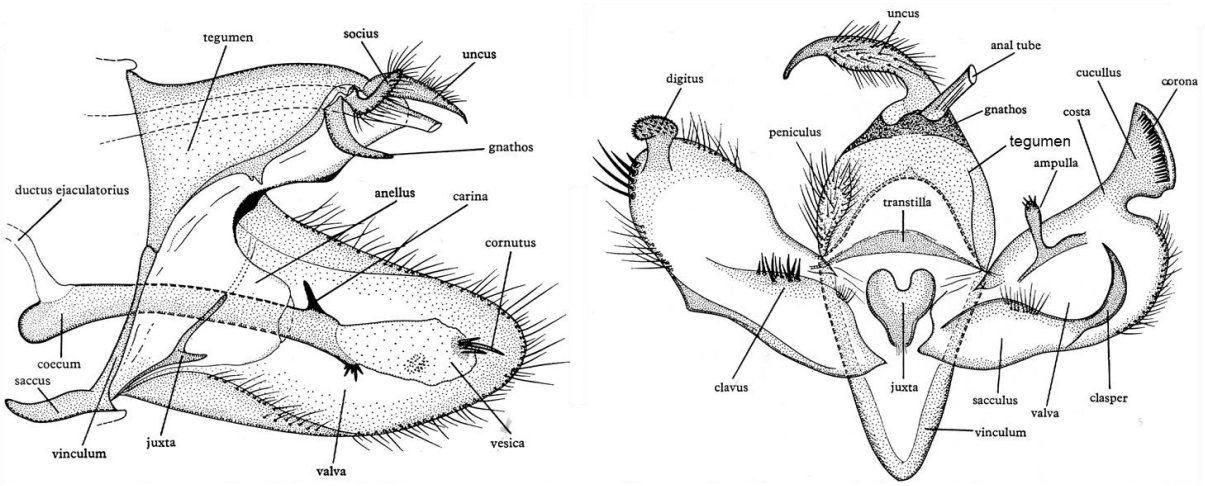
"Each thoracic segment bears a pair of legs. A leg is divided (proximally to distantly) into a coxa, trochanter, femur, tibia, tarsus, and pretarsus" (Scoble 1992).



C: costa; Sc: subcosta; R: radius; M: media; Cu: cubitus; A: anal. (Komai et al. 2011)



Scoble (1992)



Male genitalia (Heath 1983). Left: generalized lateral view. Right: ventral.

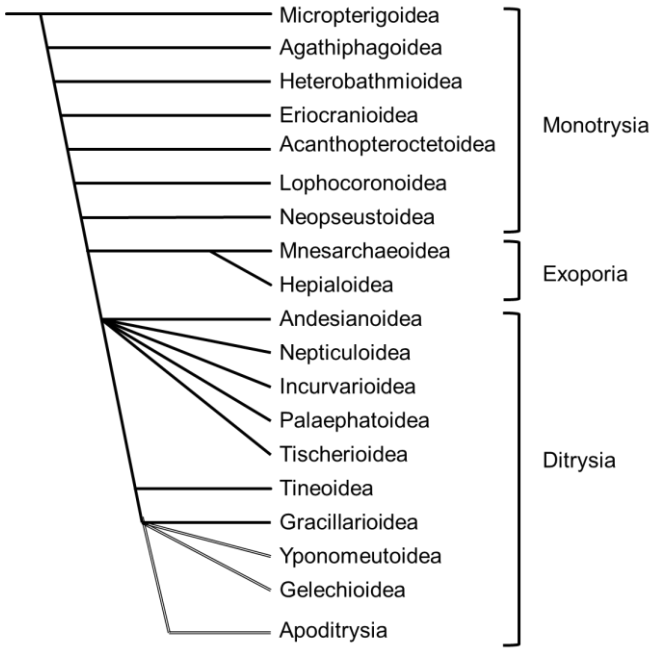
"The tibia of the prothoracic leg (=foreleg) typically bearsa comb-like epiphysis, used for cleaning the antenna or the proboscis. It arises from the inner wall of the foretibia. The epiphysis is a structure unique to Lepidoptera, which has frequently been secondarily lost " (Scoble 1992).

1-4. Male Genitalia

“The male genitalia consist, dorsally, of a tegumen from which arise the paired valvae and a posterior extension, the uncus; ventrally, of a vinculum, extended anteriorly as a saccus. The valvae articulate with the tegumen and function as claspers during copulation. The spermatozoa are contained in a spermatophore, produced by accessory glands, which is transferred to the female through the aedeagus” (Heath1983).

1-5. Female Genitalia

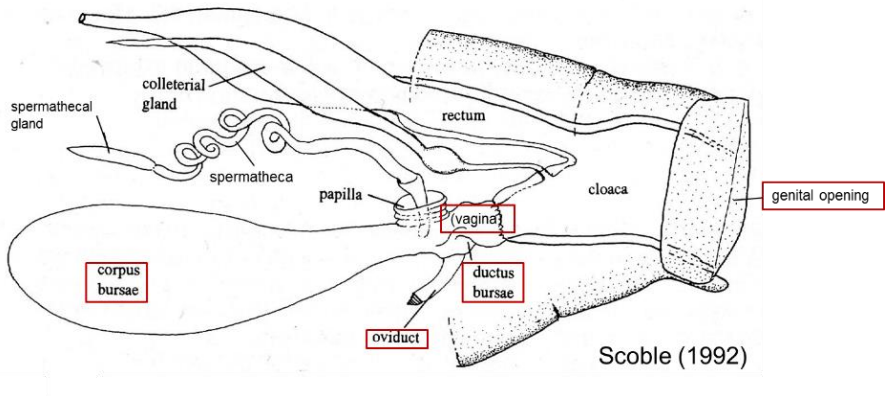
Three types of genitalia are represent in the female and form the basis of the higher classification of the Lepidoptera: monotrysian, exoprian and ditrysian.



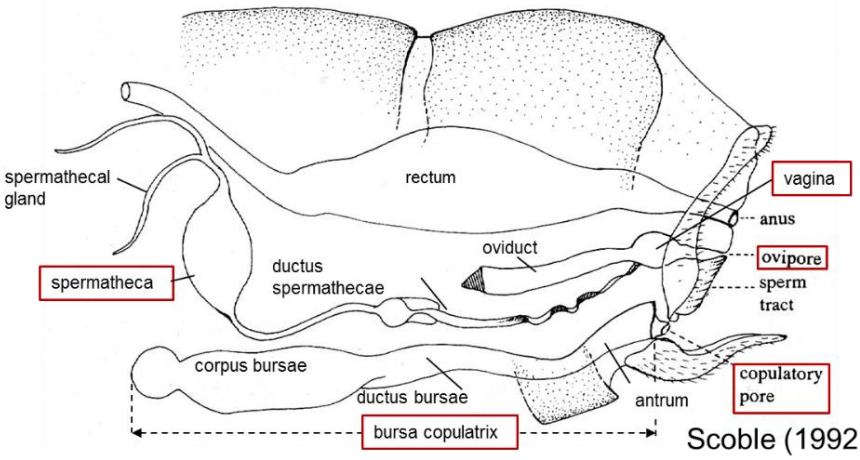
Phylogeny of superfamilies and female genitalia types in Lepidoptera

Monotrysian type

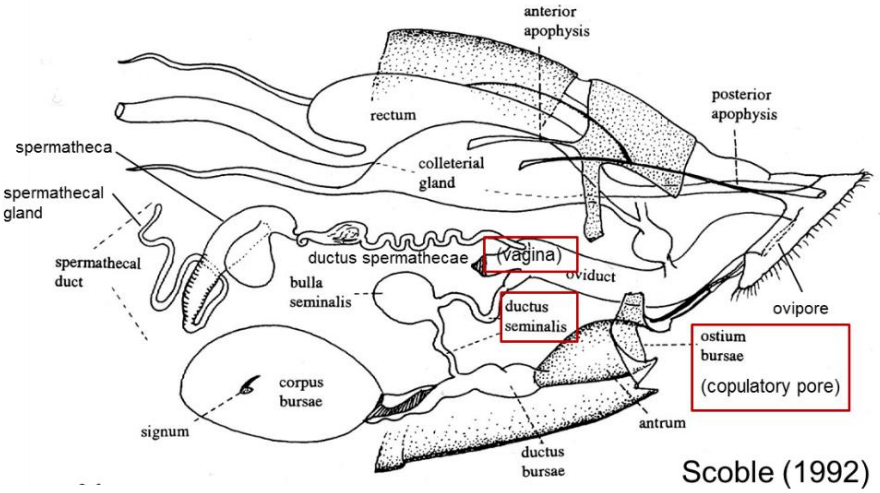
In Monotrysia, “the common oviduct enters the vagina ventrally. The bursa copulatrix (corpus bursae plus ductus bursae) lies dorsal to the oviduct. A single genital opening serves as both an ovipore and a copulately pore. The ductus bursae enters the vagina directly; there is no ductus seminalis, but spermatozoa may be stored in a seminal receptacle (receptaculum seminalis) before passing to the vagina along he spermathecal duct. A cloaca, into which both anus and ovipore open, may be present” (Scoble 1992).



Monotrysian female genitalia (diagrammatic)



Exoporian female genitalia (diagrammatic)



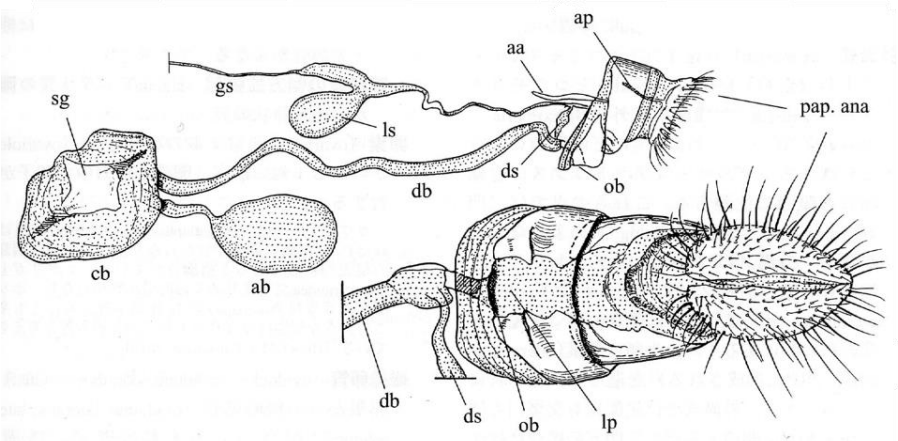
Exoporian female genitalia (diagrammatic)

Exoporian type

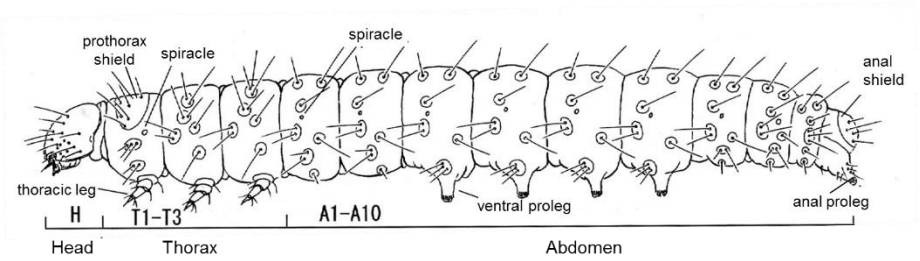
Unlike Monotrysia, "in Exoporia there are two genital apertures one for egg-laying and the other for mating. In this respect the exporian condition resembles that of the Ditrysia. But there are two important differences between the exoporian and ditrysian conditions. Firstly, no ductus seminalis exists in Exoporia, so spermatozoa released from the bursa copulatrix must presumably travel externally to the vagina, where they are temporarily stored in the spermatheca. “ “Secondly, both the ovipore and the copulatory pore open on the same segment (A9), whereas in Ditrysia the ovipore opens terminally but the copulatory pore is situated ventromedially between segments A8 and A7, on segment A8 or on segment A7." (Scoble 1992)

Ditrysian type

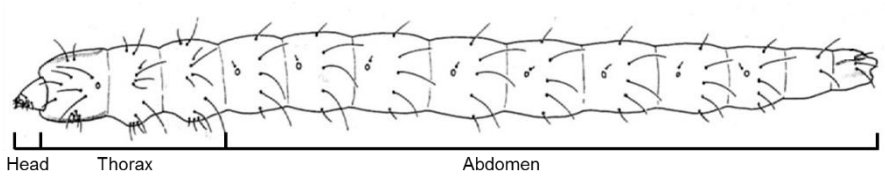
"The Ditrysia include about 95% of all Lepidoptera. The common oviduct is situated dorsal to the bursa copulatrix. As with Exoporia, all members have two genital apertures (one for egg-laying and the other for mating), but in Ditrysia the copulatory pore opens ventrally on sternum A8, between sterna A8 and A7, or on sternum A7. Spermathoza travel along a free ductus seminalis to the vagina." (Scoble 1992).



Ostrinia furnacalis (Crambidae). aa: apophysis anterioris; ab: appendix bursae; ap: apophysis posterioris; cb: corpus bursae; db: ductus bursae; ds: ductus seminalis; gs: spamathecal gland; lp: lamella postvaginalis; ls: lagena: ob; ostium bursae; pap.ana: papilla analis (*pl*., papilla anales); sg: signa. (Komai et al. 2011)



Larva of *Scythropiodes* sp. (Lecithoceridae) with hypognathous head (Komai et al. 2011)



Larva of *Ectoedemia* sp. (Nepticulidae) with prognathous head (Kristensen 1999).

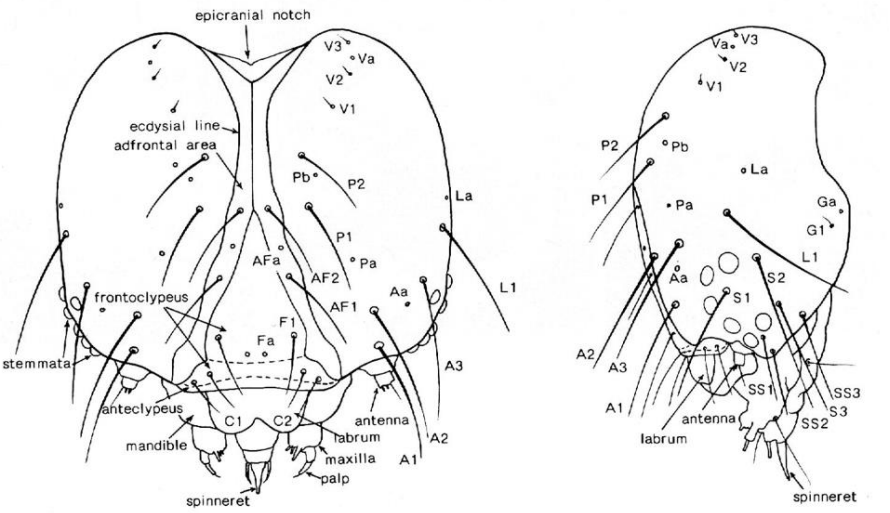
2. Larva

Three main divisions of a larva may be recognized: head, thorax and abdomen.

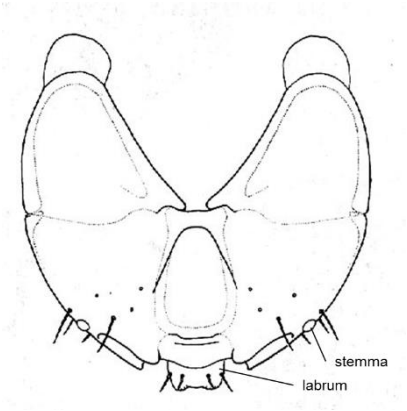
2-1. Larval Head

"In most larvae that feed in exposed situations, the head is hypognathous and the mandibles are oriented approximately at right angle to the longitudinal axis of the body. At the other extreme, exhibited principally by leaf miners, the head is prognathous so that the mandibles lie in line with the body - an orientation associated with life in a vertically restricted habitat." (Scoble 1992).

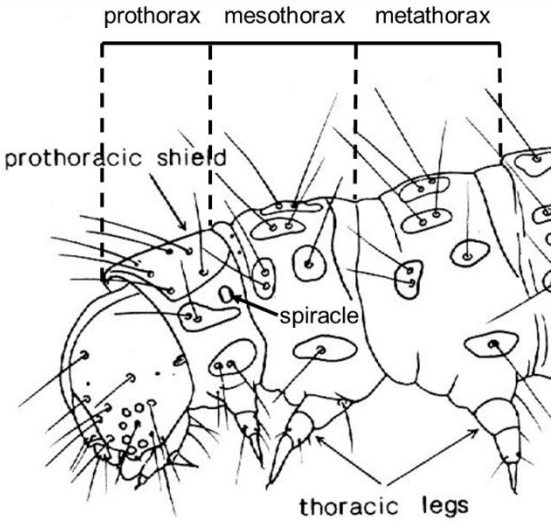
"There are typically six stemmata (often, but not incorrectly, referred to as ocelli with which they are not homologous) on each side of the head, arranged apporximately in a semicircle and situated towards the mouth. … In leafminers, where the head is flattened, some stemmata are situated on the dorsal surface of the head capsule while others lie on theventral surface. In Nepticulidae there is only a single stemma on each side of the head" (Scoble 1992)



Hypognathous head of *Hyalobathra* sp. (Pyralidae), dorsal view (left) and lateral (right). (Common 1990)



Prognathous head of *Ectoedemia* sp. (Nepticulidae), dorasal view (Kristensen 1999).



Larval head and thorax of *Hyalobathra* sp. (Pyralidae), lateral, showing setae. (Common 1990)

2-2. Larval Thorax

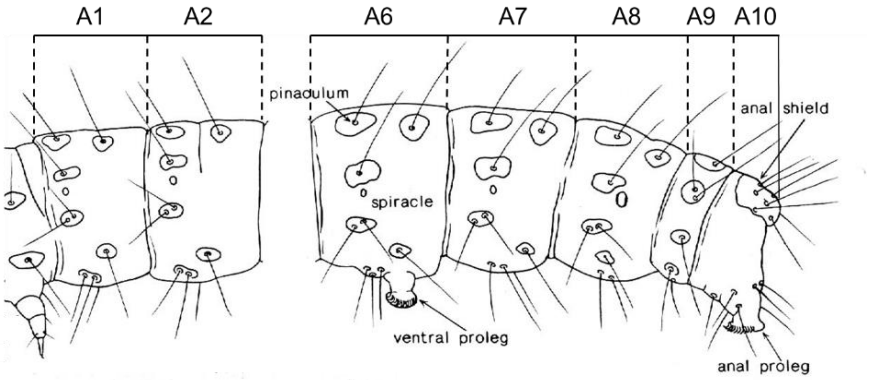
"The larval thorax is divided into three segments, the pro-, meso- and metathorax, each of which usually bears a pair of true legs. The prothorax carries a middorsal seclerotized area, the prothoracic shield or plate. In most larval Lepidoptera there is a pair of lateral spiracles on the prothorax" (Common 1990).

"The thoracic legs of lepidopteran larvae are remarkably constant in form throughout the order, but are reduced in some leafminers and elongated in certain Notodontidae"(Scoble 1992)

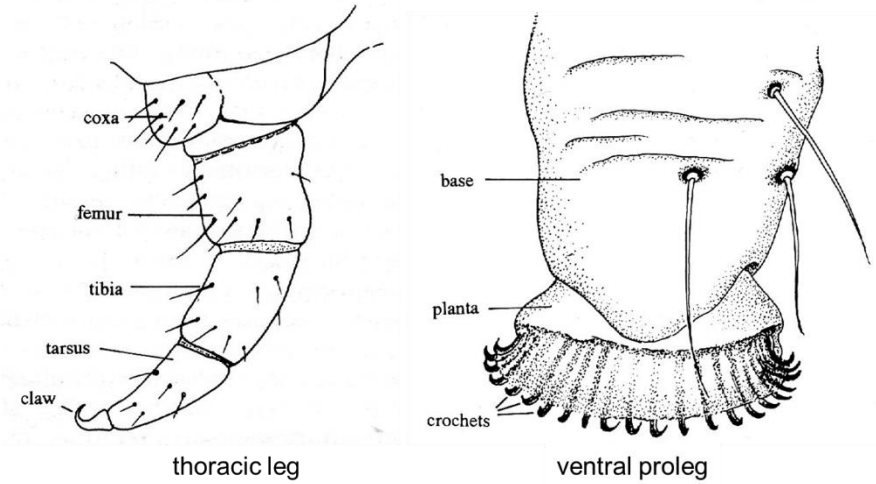
2-3. Larval Abdomen

"The abdomen consists of ten segments with series of sensory setae and sometimes glandular organs. In the larvae of most moths there are paired lateral spiracles on abdominal segments 1 to 8. Ventral leg-like organs, the ventral prolegs, are usually present on segments 3 to 6. On segment 10 there is usually a pair of anal prolegs or anal claspers. Dorsally on segment 10 there is also a sclerotized plate, the anal shield or plate." (Common 1990).

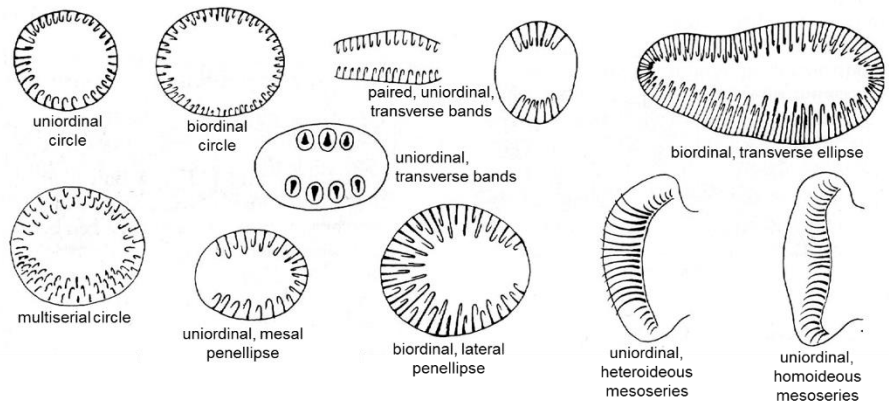
The prolegs may sometimes be modified or reduced in number and, especially in leafmining larvae, may be lost altogether. The flattened end of each proleg forms the planta,



Larval abdomen of *Hyalobathra* sp. (Pyralidae), lateral view, abdominal segments 3-5 omitted, showing setae, (Common 1990)



Thoracic leg and ventral proleg in larva. (Scoble 1992)

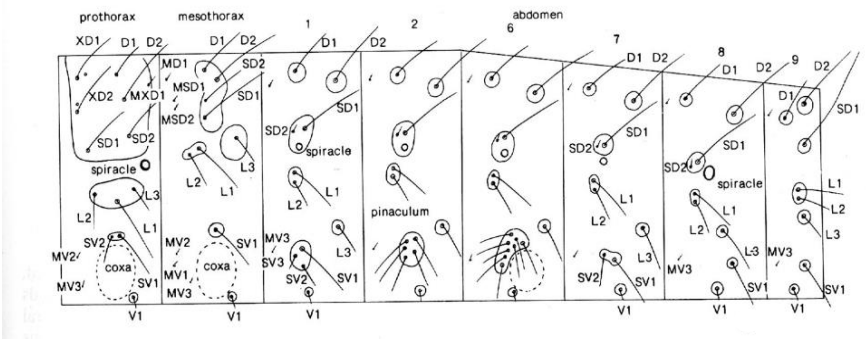


Arrangements of crochets (Common 1990)

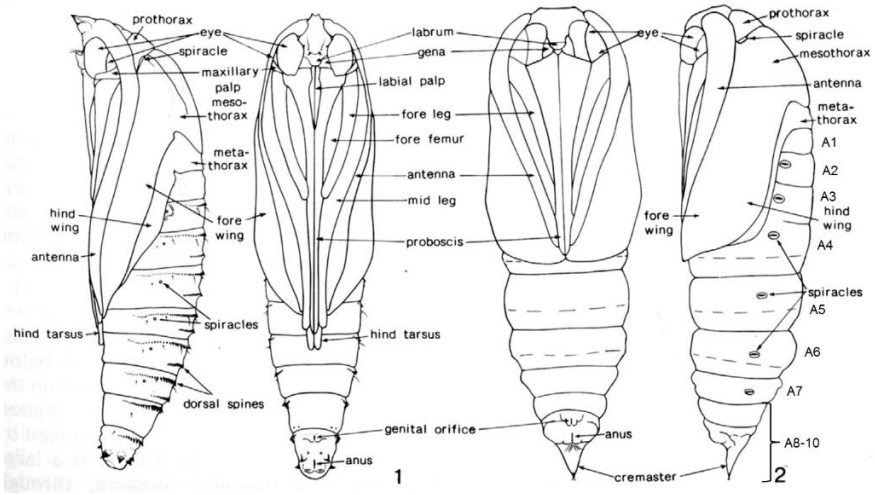
which usually carries a series of small sclerotized hooks or crochets. The presence, number and arrangement of the crochets provides information of taxonomic value. When they are all of one length the crochets are said to be uniordinal, of two or three lengths biordinal or triordinal, and of many lengths multiordinal. Sometimes the crochets are in two or more roughly concentric circles or rows and are then called biserial or multiserial. In more primitive larvae they are usually arranged in a complete or almost complete circle but are sometimes in one or two transverse bands, whereas in larvae of advanced groups they are usually arranged in a longitudinal row known as a mesoseries" (Common 1990).

2-4. Chaetotaxy

"The occurrence and distribution of the setae and punctures of the larval head, thorax and adomen are of major taxonomic significance. They are known as the chaetotaxy, and is depicted diagrammatically in setal maps. Setae present in the first-instar larva are known as primary setae and punctures, but additional subprimary and secondary setae are often acquired in the second or later instars. Primary and subprimary setae have a characteristic arrangement and have received special names. They occur singly or in groups, often on sclerotized plates called pinacula (singular: pinaculum)." (Common 1990).



Setal map of *Phlobota* (Oecophoridae), metathorax and abdominal segments 3-5 and 10 omitted. (Common 1990)



Pupae, lateral and ventral view: 1. *Synanthedon tipuliformis* (Sesiidae); 2, *Hypobapta eugramma* (Geometridae) (Common 1990).

3. Pupa

"The head, thorax and abdomen of the pupa can readily distinguished. However, the appendages are each ensheathed in cuticle. The head features a pair of prominent eyes, well-defined antennae, a labrum, and often a proboscis and maxillary and labial palpi; other structures such as pilifers and mandibles, when present, are less easily distinguished.

The thorax is divided into three distinct segments, visible dorsally. Portions of the legs, especially the tibiae and tarsi of the fore and mid legs, as well as some tarsal segments of the hind legs, are exposed ventrally. The prominent fore wings largely conceal the hind wings. A pair of spiracles is usually visible at the junction of the pro- and mesothorax.

The abdomen consists of ten segments, the last three of which are always fused together. Lateral spiracles are always present on the first seven segments of the abdomen, and often on segment 8; those on segment 1 are nearly always covered by the wings. Short straight grooves represent anus, situated midventrally on segment 10, and the genital openings. In male pupae the genital groove usually occurs midventrally on segment 9, and in females of Ditrysia two, sometimes confluent, genital grooves are usually found midventrally on segments 8 and 9. Segment 10 is frequently modified in the more advanced groups to form the cremaster, which may bear a series of often hooked setae" (Common 1990).

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Basic Classification of Leafminers – Lepidoptera

1. Families of Lepidopteran Leafminers

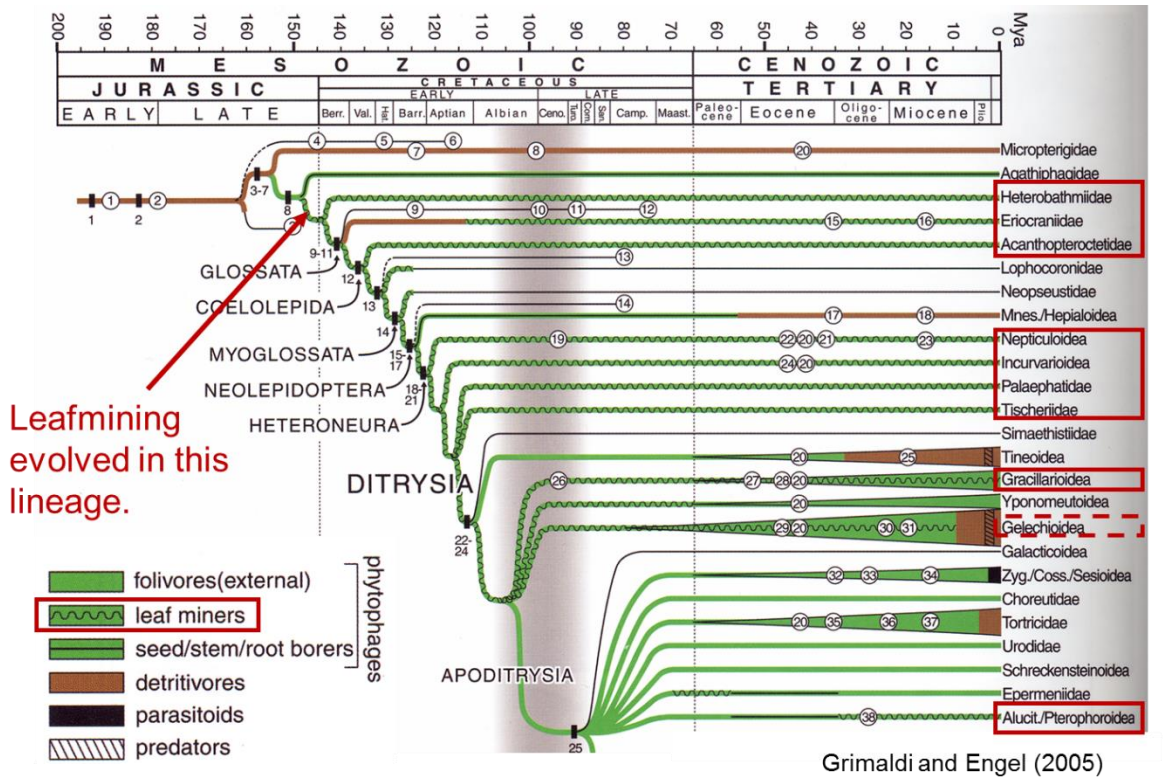
Thirty-three families with at least one leafmining species are known from Lepidoptera.

Superfamily	Family
Heterobathmioidea	Heterobathmiidae
Eriocranioidea	Eriocraniidae
Acanthopteroctetoidea	Acanthopteroctetidae
Nepticuloidea	Nepticulidae
	Opostegidae
Incurvarioidea	Heliozelidae
	Adelidae
	Prodoxidae
	Incurvariidae
Palaephatoidea	Palaephatidae
Tischerioidea	Tischeriidae
Gracillarioidea	Amphitheridae
	Gracillariidae
	Bucculatricidae
	Douglasiidae
Yponomeutoidea	Yponomeutidae
	Ypsolophidae
	Acrolepiidae
	Glyphipterigidae
	Heliodinidae
	Lyonetiidae
Gelechioidea	Elachistidae
	Scythrididae
	Oecophoridae
	Coleophoridae
	Momphidae
	Cosmopterigidae
	Gelechiidae
Tortricoidea	Tortoricidae
Pterophoroidea	Pterophoridae
Copromorphoidea	Copromorphidae
	Carposinidae
Pyraloidea	Pyralidae

Families with at least one leafmining species. Names of families are underlined when almost all members of the familiy are leafminers. Numerals in parentheses represent the approximate numbers of species described (Connor and Taverner 1997; Komai et al. 2011)

2. The Evolution of the Leafmining Habit in Lepidoptera

Phylogeny of basal Lepidoptera exhibits that the evolution of the leafmining habit occurred only once in the order. In contrast to the Lepidoptera, leafmining occurred several times independently in each of the Coleoptera, Diptera and Hymenoptera.



Phylogeny of families and superfamilies of basal Lepidoptera, showing principal larval diets (Grimaldi and Engel 2005).

3. Lepidopteran Leafminers Recorded from South-East Asia

According to Robinson et al. (1994) and Holloway et al. (2001), South-East Asian leafminers have been largely unstudied. I hope that you develop and advance scientific knowledge of leafminers in South-East Asia.

Major families of leafminers and the approximate numbers of species recorded from the world and South-East Asia.

Superfamily	Family	World	SEA	
Eriocranioidea	Eriocraniidae	25	0	homoneurous Glossata
Nepticuloidea	Nepticulidae	>1000	5	monotrysain Heteroneura
	Opostegidae	200	8	
Incurvarioidea	Heliozelidae	100	5	
	Incurvariidae	100	0	
Tischerioidea	Tischeriidae	120	0	
Gracillarioidea	Gracillariidae	1800	60	primitive Ditrysia
	Bucculatricidae	250	0	
Yponomeutoidea	Lyonetiidae	200	0	
Gelechioidea	Coleophoridae	1050	0	

4. Major Families of Leafminers

4-1. Eriocraniidae (Eriocranioidea)

"Eriocraniidae are small moths confined to the Holarctic region. Within the Palaearctic they extend across the region into northern Japan within an area approximately match in the distribution of one of their main host plants, *Betula pendula* (Betulaceae). They are the first moths to have developed a functional proboscis and are the most primitive Glossata." (Scoble 1992).

"Adults are typically diurnal and often moderately iridescent with a wingspan of around 6 to 16 mm" (Scoble 1990). "The head has spiky scales on the top and on the face. The mouth parts are reduced to rounded lobes" (Sterling and Parsons 2012).

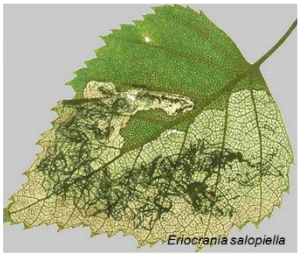
http://www.lepiforum.de/lepiwiki.pl?Fotouebersicht_Eriocraniidae

Adults of Eriocraniidae

http://www.leafmines.co.uk/html/Lepidoptera/E.unimaculella.htm

http://www.leafmines.co.uk/html/Lepidoptera/E.cicatricella.htm

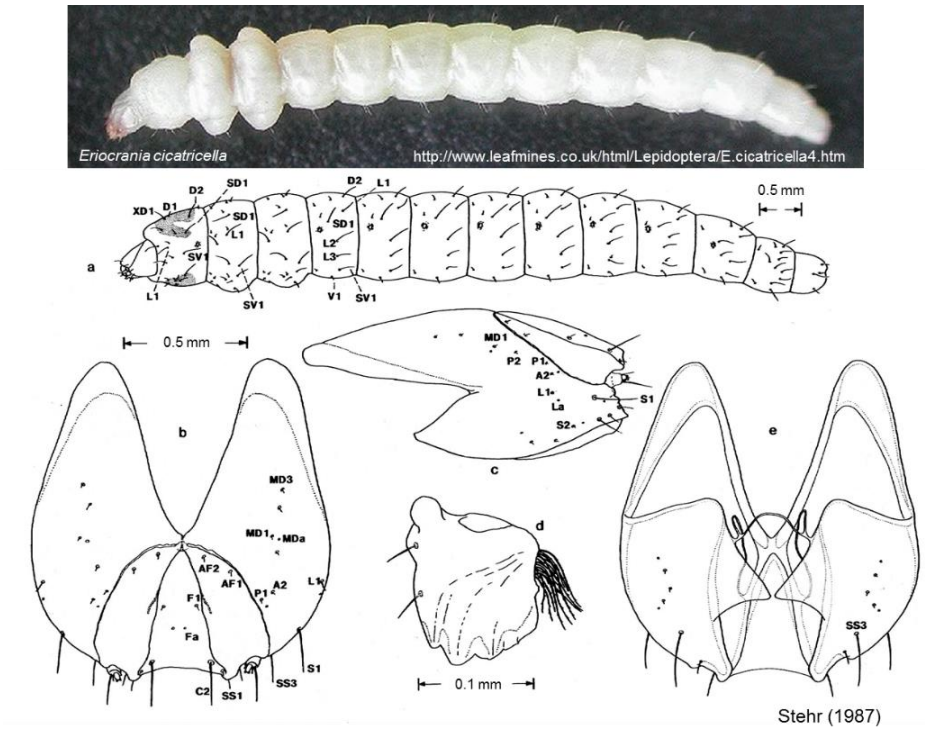
http://www.leafmines.co.uk/html/Lepidoptera/E.sparrmannella6.htm



http://www.leafmines.co.uk/html/Lepidoptera/E.salopiella5.htm

http://www.leafmines.co.uk/html/Lepidoptera/E.sangii.htm

Leafmines of Eriocraniidae



Larvae of Eriocraniidae. a-e: *Dyseriocrania griseocapitella*; a: lateral view; b: head, dorsal fiew,; c: head, lateral; d: mandible; e: head, ventral view.

"The larvae form large blotch mines containing intertwining strands of frass, on oaks, birches. Hornbeam or Hazel, depending on species, these appearing shortly after the leaves are fully expanded in mid spring" (Sterling and Parsons 2012).

"The larva has an approximately cylindrical head and body, unlike the typically flattened condition occurring in most leafminers. The head is prognathous and partially restracted into the body. Cranial setae are greatly reduced. The vertex is deeply divided and the adfrontal sclerite broad. A spinneret is present. Only a single stemma is present; although rudimentary it is innervated. The antenna is 3-segmented. Thoracic legs are absent but paired ventral swellings (calli) occur. Prolegs (and crochets) are absent from the abdomen" (Scoble 1992).

"Pupation occurs in a silken cocoon in the soil" (Scoble 1992).

4-2. Nepticulidae (Nepticuloidea)

"Nepticulidae, the most speciose of the monotrysian families with around 600 described species and probably many undescribed, include the smallest Lepidoptera. On average, the wingspan is about 5-6 mm, but in some species it is under 4 mm" (Scoble 1992).

"The adults are either rather drab, fuscous and ochrous moths, or metallic typically with one or more shining silver fasciae and an iridescent background of gold or purple" (Scoble 1992). "The head has spiky scales on top; the face hardly projects below the eyes. The antennae are rather short, one-third to two-thirds the length of the forewing, with an eye-cap at the base, usually contrasting in colour with the head " (Sterling and Parsons 2012).

https://science.naturalis.nl/en/people/scientists/camiel-doorenweerd/

http://charlielepidopteraofcalderdale.blogspot.jp/2011/11/neps-1.html

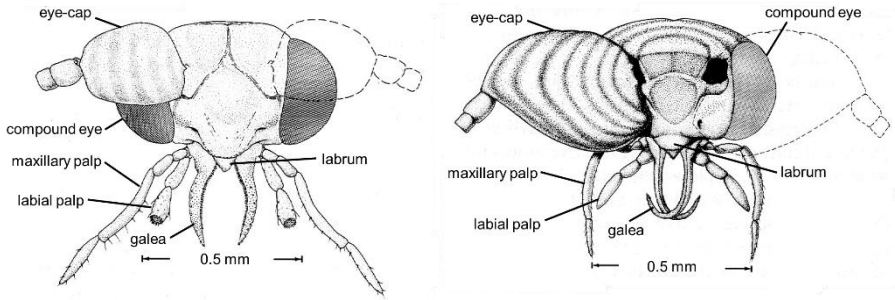
http://charlielepidopteraofcalderdale.blogspot.jp/2011/11/neps-1.html

http://charlielepidopteraofcalderdale.blogspot.jp/2011/11/neps-1.html

http://www.naturespot.org.uk/taxonomy/term/19287

http://bugguide.net/node/view/321323/bgpage

Adults of Nepticulidae

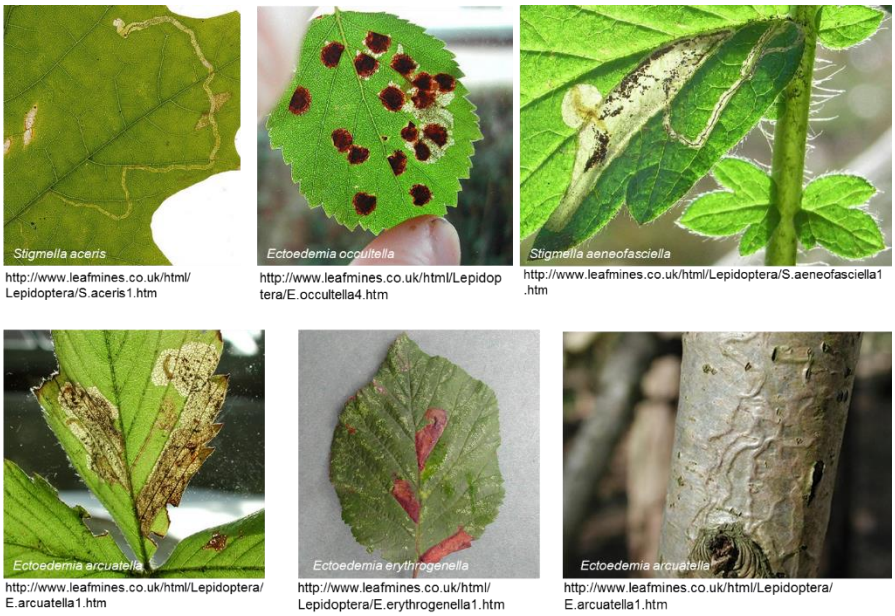


Heads of Nepticulidae (left) and Opostegidae (right) (Kristensen 1998)

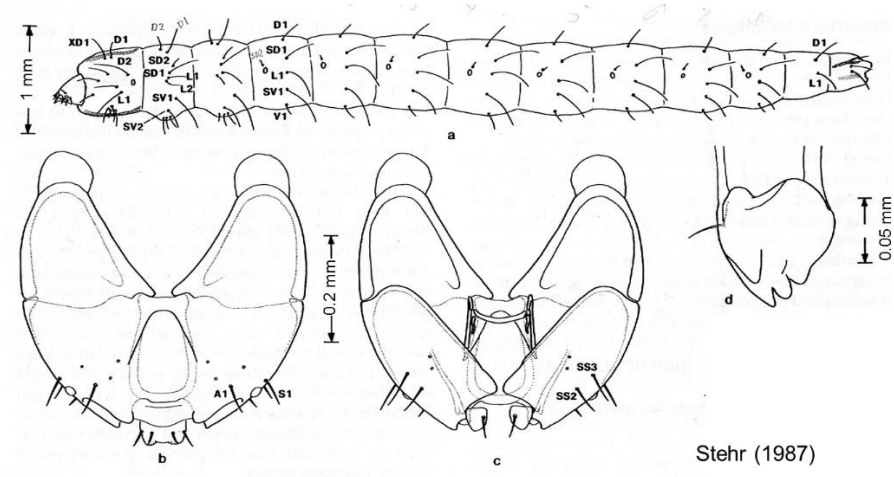
"The larva forms a gallery or blotch mine (which often starts as gallery) in leaves, although the mine may begin in the petiole. A few species mine the buds and winged fruits of Sycamore and its relatives, the outer (cortical) layer of stems of Broom, or the young bark of oaks and elms. The egg, which is surprisingly large for a small moth, is visible even to the naked eye at the start of the mine. In nearly all species, the larva vacates the mine to pupate in a small, pale-coloured silken, elliptical cocoon" (Sterling and Parsons 2012) among leaf litter or in the soil.

"Most species are restricted to one or a few food plants, which is helpful for species identification. The larva usually leaves behind a distinctive track or pattern, and the distribution and colour of the frass, position of the egg on the under- or upperside of the leaf, colour of the larva, and time of year of appearance may be important in identifying the species" (Sterling and Parsons 2012).

"In the larva, the head is strongly flattened and prognathous, there is a single stemma on each side, and the antenna (1-segmented) is strongly reduced. The head capsule is retracted deeply into the prothorax. Unlike the condition in Opostegidae, the epicranial



Leafmines and barkmine of Nepticuldae



Larva of *Ectpedemia phleophaga*. a: lateral view; b: head, dorsal fiew,; c: head, ventral; d: mandible.

ambulatory calli are found on 2 - 3, and are prominent in the large and cosmopolitan genus *Stigmella*. Such calli are usually present on abdominal segments A1 - 7. Prolegs and crochets are absent" (Scoble 1992).

4-3. Opostegidae (Nepticuloidea)

"The family, cosmopolitan in distribution, has relatively few species compared with the Nepticulidae" (Scoble 1992).

"Adults may be diurnal, crepuscular, or nocturnal. The forewing length is 3 - 6 mm. The forewings are white or pale, with few, if any, markings. The hindwings are narrower than the forewings, but have long dorsal cillia. The head has flat scales, apart from a tuft of erect scales between the antennae. The antennae are thread-like, about two-thirds the length of

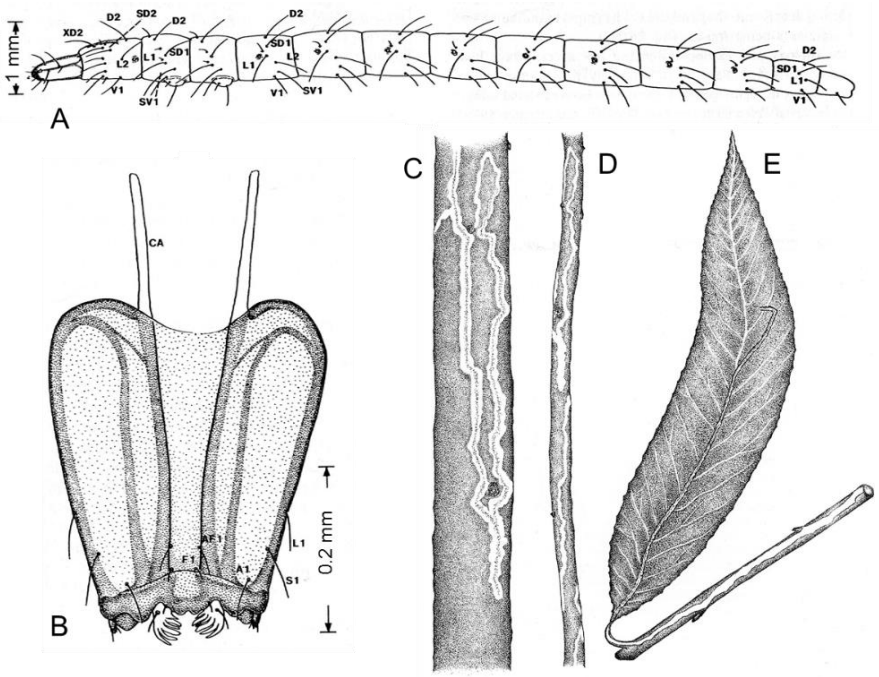
http://uahost.uantwerpen.be/vve/checklists/lepidoptera/opostegidae/Pauritella.htm

http://www.sequella.co.uk/uklepidoptera/systematic_list/Opostegidae/121.html

http://www.discoverlife.org/mp/20p?see=I_MPG201&res=mx&flags=no_slide_show:

http://www2.nrm.se/en/svenska_fjarilar/o/opostega_salaciella.html

Adults of Opostegidae



Larva and mines of Opostegidae. A, B: *Opostega scioterma*, A: lateral view; B: head, ventral (CA: cranial apophysis (Stehr 1987); C-E: mines of *O. spatulella* (host plant: *Salix* sp.) (Puplesis and Dišks 2003).

the forewing, with characteristically large scapes, forming broad white or pale eye-caps. The presence of large eye-caps makes Opostegidae appear similar to Nepticulidae, but the latter are generally smaller and darker, with eye-caps that contrast in colour with the thorax" (Scoble 1992).

"The larva is prognathous and has a flattened head with reduced mouthparts. Each mandble bears a large spinose seta. The setae of the head are much reduced, with but a single stemma on each side of the head. The body of the larva is strongly elongated, slender, and cylindrical. On both thoracic and abdominal segments are found a pair of conspicuous,

elongate pronotal sclerites similar to those of Nepticulidae. Paired ambulatory callositties are present on the meso- and metathorax, but the larva is essentially apodal. Opostegidae larvae differ from those of Nepticulidae by the shallower epicranial notch. Also, the hypostoma of the strongly depressed head is lengthened anteriorly much more than in Nepticulidae" (Scoble 1992).

"Larvae are miners in the cambial layer under bark, in leaves, petioles, or in the stalks of flowers" (Scoble 1992).

4-4. Heliozelidae (Incurvarioidea)

"Heliozelidae are found worldwidee, but there are no representatives in New Zealand" (Scole 1992).

"Adults can be found in numbers on sunny days in spring and early summer, flying around trees and shrubs; they also settle on flowers. Adults rarely fly far from their host tree, and this can be a guide to identification" (Sterling and Parsons 2012). "Adults are very small and frequently dark in ground colour with silver spots or fasciae on the forewings" (Common 1992). "The ovipositor of the female is of the piercing kind, a condition typical of Incurvarioidea" (Scoble 1992).

"The egg, which is laid singly, is often inserted beneath the bark of a twig of the hostplant. From this position, the larvae mines from the twig into the petiole of the leaf and then into the lamina. The egg may also be inserted directly into a leaf or petiole. Sometimes the larva mines for a time in the midrib. At the end of its mining life the larva constructs an oval case from two pieces of epidermis cut at the end of the mine, which leaves a characteristic oval hole in the leaf" (Scoble 1992). The larva pupate in the oval case, usually on the ground.

http://www.hantsmoths.org.uk/species/0158.php

http://ukmoths.org.uk/species/antispila-treitschkiella/

http://www.hantsmoths.org.uk/s@ecoes/0158.php

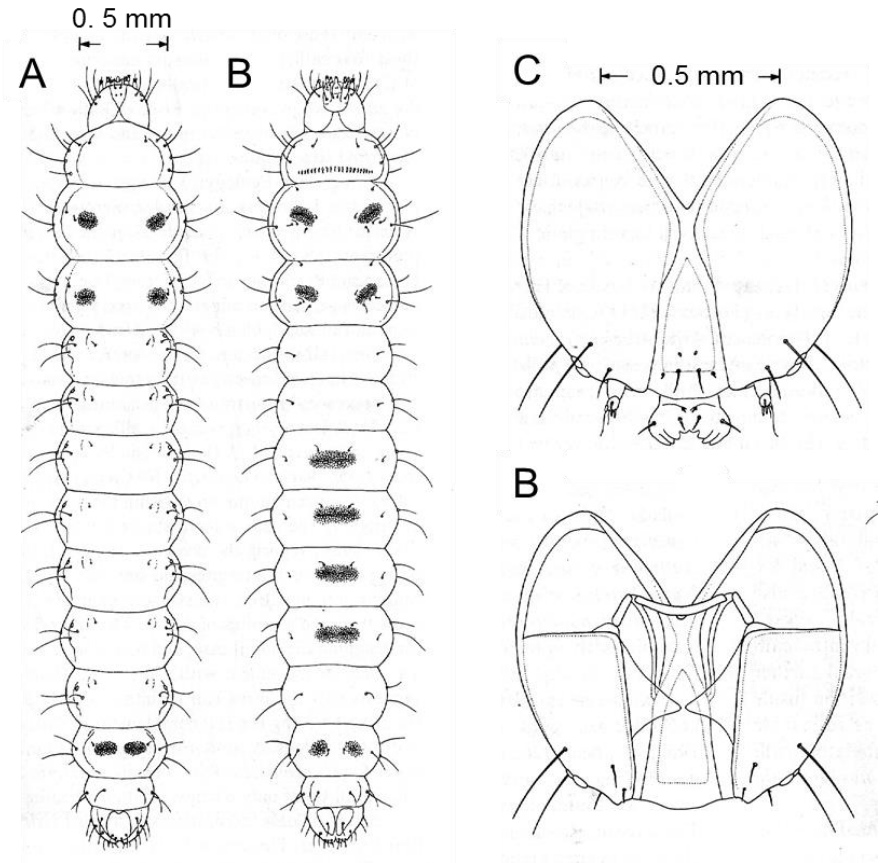
Adults of Heliozelidae

http://www.leafmines.co.uk/html/Lepidoptera/H.hammoniella2.htm

http://www.leafmines.co.uk/html/Lepidoptera/H.sericiella1.htm

http://www.leafmines.co.uk/html/Lepidoptera/A.treitschkiella.htm

Leafmines of Heliozelidae



Larva of Heliozelidae. A, D: *Coptodisca arbutiella*. A: dorsal view; B: ventral; C: head, dorsal; E: head, ventral (Stehr 1987).

In the larva, "thoracic legs are usually absent; when present, they are well developed or represented by ambulatory calli. Abdominal prolegs are typically absent or rudiminetary; sometimes crochets, arraganed in multiserial rows, are present. When reduce, prolegs are represented by calli" (Common 1992).

http://ukmoths.org.uk/species/incurvaria-pectinea/

http://ukmoths.org.uk/species/incurvaria-pectinea/

http://ukmoths.org.uk/species/incurvaria-oehlmanniella/

http://ukmoths.org.uk/species/phylloporia-bistrigella/adult-2/

Adults of Incurvariidae of Heliozelida.

http://www.leafmines.co.uk/html/Lepidoptera/I.pectinea.htm

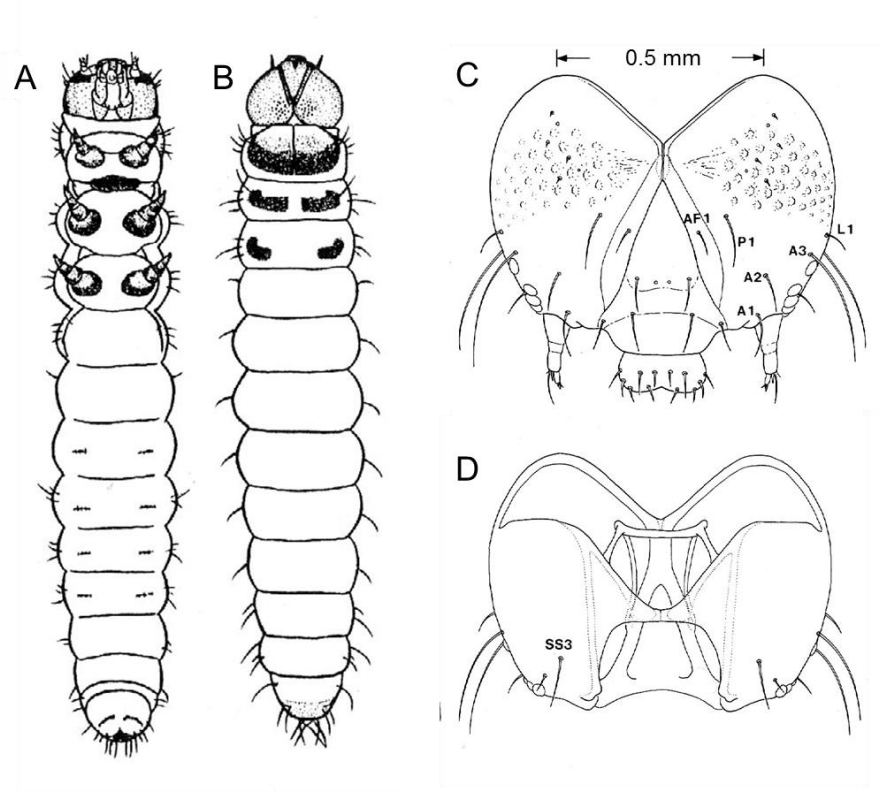
http://www.leafmines.co.uk/html/Lepidoptera/P.bistrigella.htm

Leafmines of Incurvariidae

4-5. Incuvariidae (Incuvarioidea)

"The family is widespread, but absent from New Zealand. " (Scoble 1992).

"The adults are often fairly drab, but several are metallic" (Scoble 1992). They "bear a superficial resemblance to those of the Tineida, with their heads clothed in roughened piliofrm scales, with their 5-segmented maxillary palpi and with their wings folded in a steeply roofwise fashion over the abdomen. However, they may be distinguished by the piercing ovipositor, which usually protrudes from the tip of the abdomen in the female. The female genitalia are monotrysian, not ditrysian as in Tineidae" (Common 1990).



Larvae of Incurvariidae. A, B: *Paraclemensia caerulea* (Komai et al., 2011); C, D: *Paraclemensia acerifoliella* (Stehr 1987). A: dorsal view; B: ventral; C: head, dorsal; D: head, ventral.

"Typically, the larvae are leafminers in the first instar and subsequently case bearers. However, there are some exceptions including a gall dweller, a mode of life rare for Incurbarioidea other than in Cecidosidae. The generalized habit iis exemplified by the holarctic genus *Alloclemensia*. *A. mesospilella*, for example, cuts an oval case from its blotch mine and, after attaching the case to the same leaf, becomes a leaf skeletonizer. Pupation occurs in the case, which falls to the fround when the larva is fully fed. " (Common 1992). In some species, the case-bearing larva feed on dead leaves on the ground.

"The larvae are prognathous and often with reduced thoracic legs and prolegs " (Common 1992).

4-6. Tischeriidae (Tischerioidea)

"The adults are small with a wingspan of around 5-11 mm. The colour or the forewing varies - pale whitish or yellow, yellow, bronzy, dark grey or blackish. The head narrows ventrally, the vertex is smooth scaled or rough scaled, and the front of the head is smooth scaled. The antenna is about as long as the forewing. Although the scape bears characteristic projecting scales, it is not expanded into an eye-cap" (Scoble 1992).

"In the larva, the body is depressed, and the segments often markedly rounded laterally. The head is strongly depressed, and has a deep epicranial notch. Typically, the 4 - 6 stemmata form a horizontal line. Thoracic legs are much reduced or absent; when present they are composed of two minute segments or they take the form of small pads. A pair of

amurlatory calli are found on the dorsum of T1 - 3. Abdominal proglegs are present on A3 - 6" (Scoble 1992).

http://ukmoths.org.uk/species/tischeria-ekebladella/adult-3/

http://ukmoths.org.uk/species/tischeria-dodonaea/#prettyPhoto

http://ukmoths.org.uk/species/coptotriche-marginea/adult-2/

http://ukmoths.org.uk/species/coptotriche-angusticollella/adult/

Adults of Tischeriidae

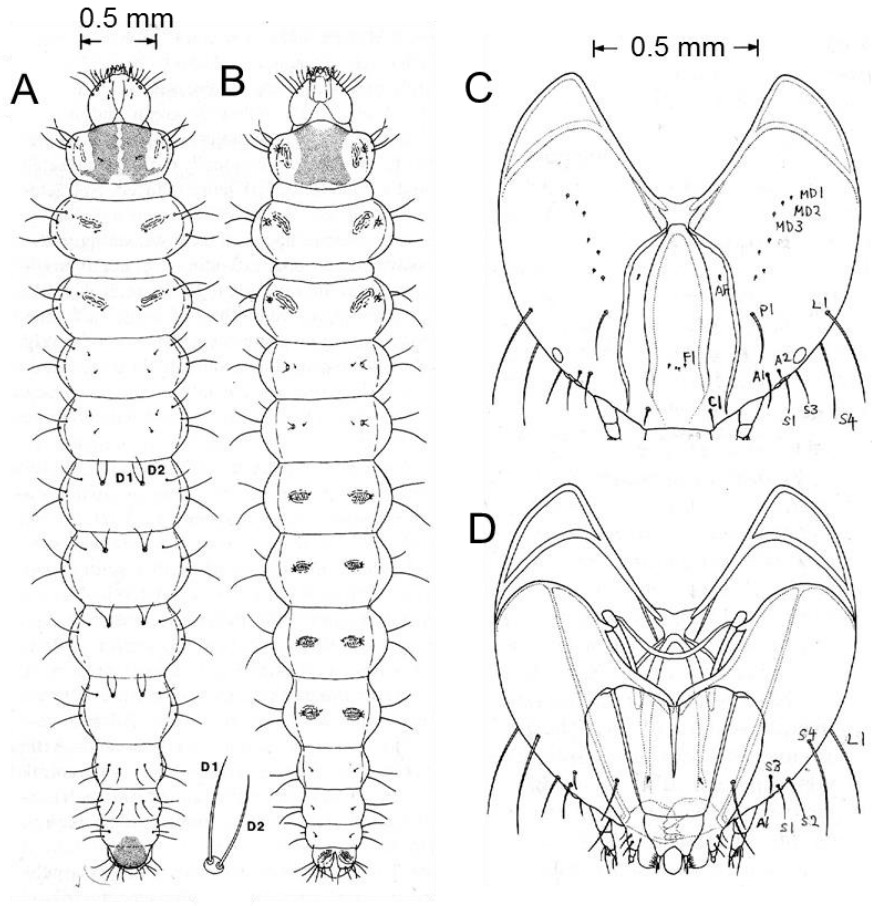
http://ukmoths.org.uk/species/tischeria-ekebladella/mines-on-oak/

http://www.leafmines.co.uk/html/Lepidoptera/T.dodonaea5.htm

http://www.leafmines.co.uk/html/Lepidoptera/C.heinemanni.htm

http://ukmoths.org.uk/species/coptotriche-angusticollella/larva-mine-on-rosa/#prettyPhoto

Leamines of Tischeriidae



Larva of Tischeriidae. A-D: *Tischeria malifoliella*. A: dorsal view; B: ventral; C: head, dorsal; D: head, ventral.

"The larvae mine leaves of various trees and shrubs, pupating in the mine. The mine may expand rapidly from the initial short linear section into a 'trumpet mine', or may become enlarged into a blotch. Frass is ejected through a hole cut by the larva in the surface of the leaf at the beginning of the mine. The main function of the silk spun by larvae throughout their lives is probably to provide them with a surface on which they may more easily walk. In some species a circular 'nidus' of silk is constructed to which the larva retreats when disturbed" (Scoble 1992).

4-7. Gracillariidae (Gracillarioidea)

Gracillariidae are worldwide in distribution, including over 2000 species.

The adults "are very small and often colourful, frequently with shining white markings, long antennae, and narrow wings with prominent fringes. At rest, the front of the moth is typically raised while the back touches the substrate. However, in some the head is kept down while the abdomen is raised. The head is nearly always smooth-scaled. The wings are lanceolate or narrow-elongate, the hind wings being even more narrow than the forewings" (Scoble 1992).

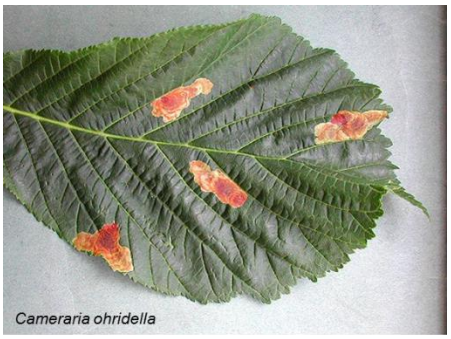
http://ukmoths.org.uk/species/caloptilia-populetorum

http://ukmoths.org.uk/species/parornix-loganella

http://ukmoths.org.uk/species/phyllonorycter-quercifoliella

http://uahost.uantwerpen.be/vve/checklists/lepidoptera/Gracillariidae/Psaligna.htm

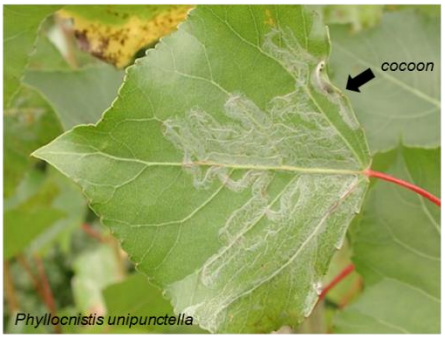
Adults of Gracillariidae.



http://www.leafmines.co.uk/html/Lepidoptera/C.ohridella6.htm

http://ukmoths.org.uk/species/acrocercops-brongniardella/leafmine-on-quercus/

http://ukmoths.org.uk/species/phyllonorycter-roboris/mine-on-quercus-3/



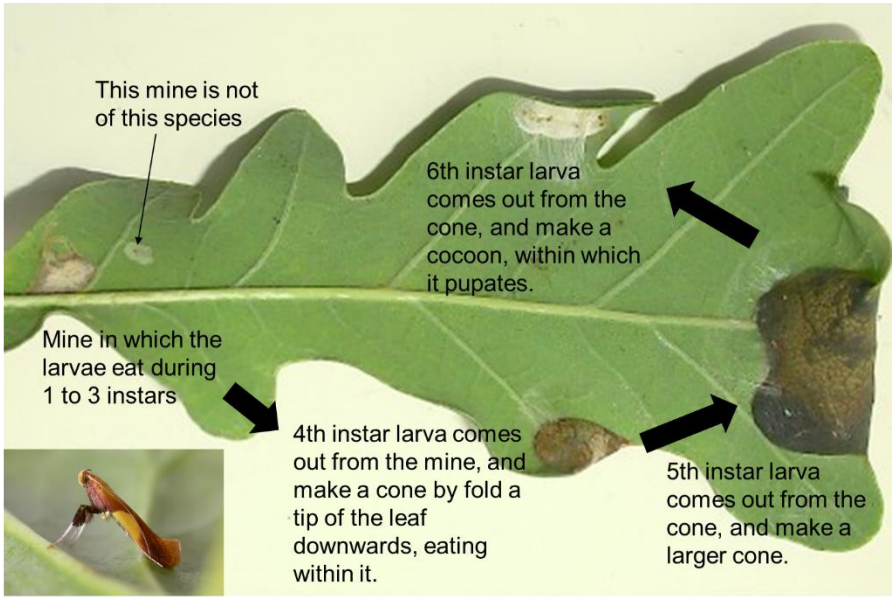
http://ukmoths.org.uk/species/phyllocnistis-unipunctella/mine-on-populus/

Leafmines of Gracillariidae.

"The larvae are sap-feeders in the early instars; later instars are tissue-feeders. Hypermetamorphosis occurs when the mode of life changes. The number of larval instars varies from 4 to 11. Early (sap-feeding) instars are prognathous with a dorsoventrally flattened head. The body is also flattened. The labrum is enlarged and edges sometimes serrated. Mandibles are scissor-like for piercing the cells of plant tissue. The hypopharynx is

usually broad and hairy, and the labium is reduced with the spinneret absent or vestigial. Thoracic setae are much reduced or absent, and legs, and prolegs are absent or vestigial. In tissue-feeding instars the head and body are cylindrical and the mandible bears distinct chewing cusps. Thoracic legs and abdominal prolegs are usually present" (Scoble 1992).

"The tissue-feeding stages of some of the more primitive species feed outside the mine, although the larvae are concealed in folded or rolled leaves. Mines are typically blotches. Pupation may occur outside the mine in a chamber formed by a rolling-over of the leaf, or within the leaf mine. Chambers in mines are sometimes expanded by the contraction of drying silk. The genus *Phyllocnistis* forms a long, epidermal mine terminating in a small blotch. The larva is sap-feeder throughout its development apart from the final instar, which does not feed and in which the legs and mouthparts, with the exception of the spinneret, are lost " (Scoble 1992).



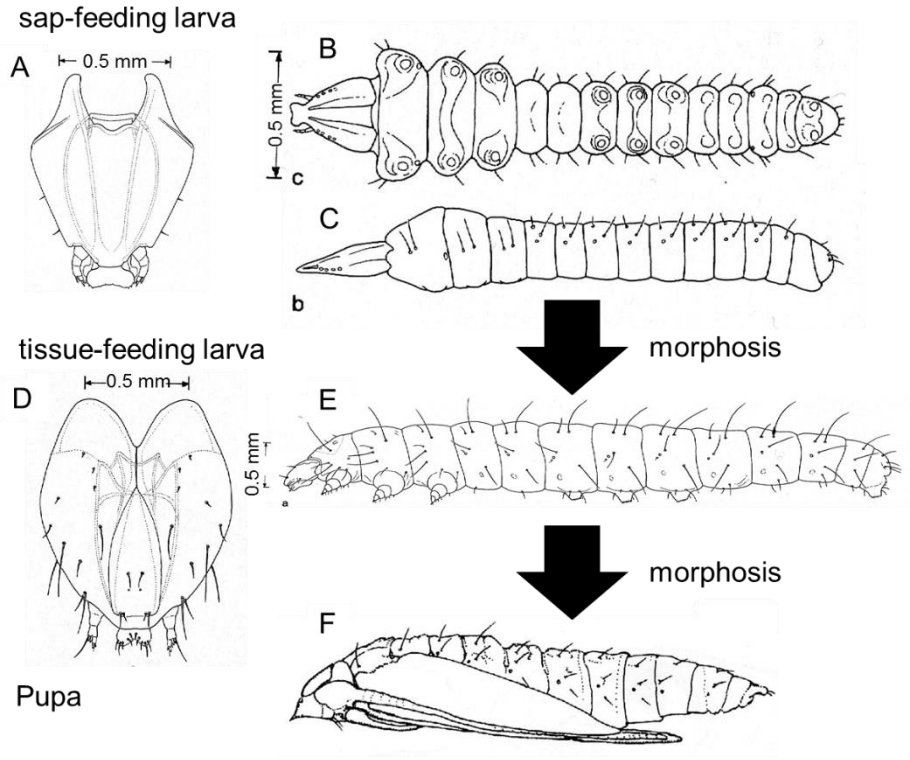
Caloptilia robustella

Caloptilia robustella, which make a leafmine, and subsequently construct cones.

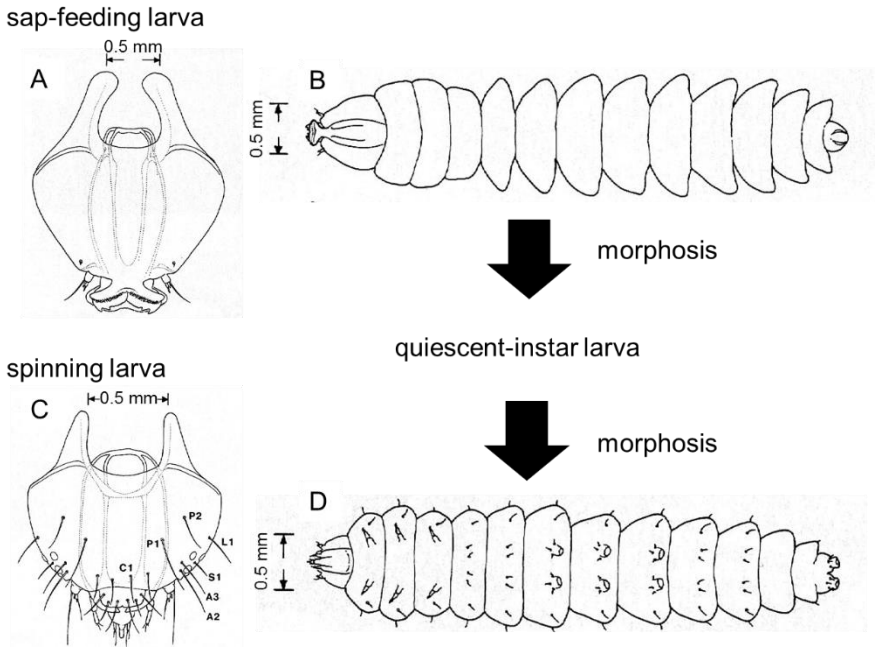
http://www.ukmoths.org.uk/species/caloptilia-robustella/adult/

	Instar								
Species	I	II	III	IV	V	VI	VII	VIII	IX
Caloptilia stigmatella	SF	SF	TF	TF	TF	P			
Aristaea pavoniella	SF	SF	TF	TF	P				
Dendrorycter marmaroides	SF	SF	SF	SF	SF	SF	Q	SP	P
Phyllonorycter blancardella	SF	SF	SF	TF	TF	P			
Cameraria niphonica	SF	SF	SF	SF	SF	SP	SP	P	
Chrysaster hagicola	SF	SF	SF	SF	SF	Q	SP	P	
Phyllocnistis sp.	SF	SF	SF	SP	P				

Types of hypermetamorphosis in Gracillariidae. P: pupa; Q: quiescent; SF: sap feeding; SP: spinning; TF: tissue feeding. Squares represent the immature within the mine. (after Komai et al. 2011)



Hypermetamorphosis with sap-feeding and tissue-feeding forms in *Phyllonorycter*. A, head of 3rd instar larva, dorsal view; B: 3rd instar larva, ventral; C, 3rd instar larva, lateral; D: head of 5th instar larva, dorsal; E: 5th instar larva, lateral; F: pupa. A-E: Stehr (1987); F: Komai et al. (2011)



Hypermetamorphosis with sap-feeding, quiescent and spinning instars in *Marmara*. (Stehr 1987)

4-8. Bucculatricidae (Gracillarioidea)

"The family is widely distributed in all regions and is especially well developed in North America" (Common 1990)

In the adult "the head is distinctively subtriangular when viewed anteriorly, and usually has tufted vertex; rarely it is smooth-scaled. At the base of the antenna, the scape is

http://ukmoths.org.uk/species/bucculatrix-thoracella/adult/

http://ukmoths.org.uk/species/bucculatrix-nigricomella

http://ukmoths.org.uk/species/bucculatrix-frangutella

http://ukmoths.org.uk/species/bucculatrix-demaryella#prettyPhoto

Adults of Bucculatricidae.

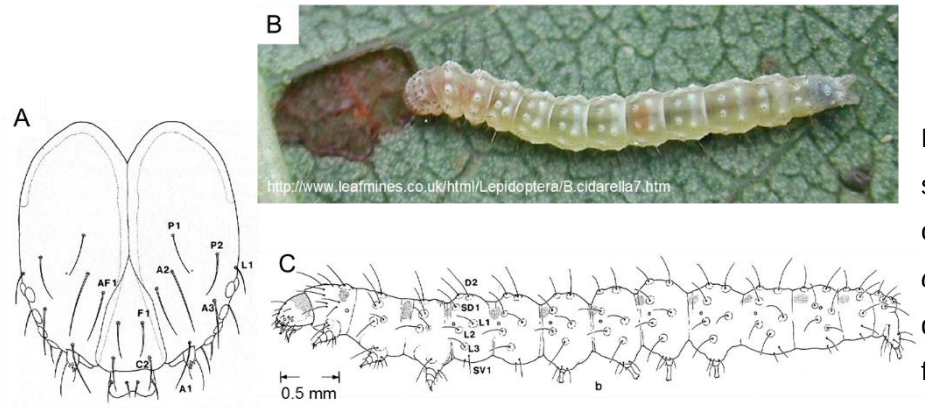
http://ukmoths.org.uk/species/bucculatrix-thoracella/adult/

http://ukmoths.org.uk/species/bucculatrix-nigricomella

http://www.leafmines.co.uk/html/Lepidoptera/B.albedinella5.htm

http://ukmoths.org.uk/species/bucculatrix-frangutella/larval-mine/

Leafmines of Bucculatricidae.



External leaf skeleteonizing larva of *Bucculatrix cidarella.* A: head, dorsal view; B: in feeding; C: lateral.

expanded somewhat, although only rarely does it reach the size of the characteristic eye-cap of certain other groups. In males, the first flagellar segment is often deeply notched; in some species the notch is slight, and in others it is absent" (Scoble 1992).

"In the larva the body is typically falttened in early instars but more rounded in later stages. On the abdomen setae L1 and L2 are widely separated on A1-8. Prolegs are elongate and slender" (Scoble 1992).

"First instar larvae eat their way through the egg shell and enter the leaf directly. Typically, the larvae are leafminers in their early instars and then become external leaf-skeletonizers. Sometimes the larvae mine throughout their leaves. Occasionally, late instars eat complete holes in the leaf" (Scoble 1992)

"Pupation takes place in a characteristic ribbed cocoon" (Scoble 1992)

4-9. Lyonetiidae (Yponomeutoidea)

"Lyonetiidae include about 200 named species of small moths with representation worldwide" (Scoble 1992).

In the adult "the front of the head is smooth-scaled and the vertex rough-scaled. The forewings are mostly shining white with striking black and yellow-orange markings, which take the form of bars and an apical spot. In some species the ground colour is grey. The antennal scape is often expanded to form an eye-cap" (Scoble 1992).

"The head of the larva is prognathous or semiprognathous and the body is cylindrical in later instars but more flattened in early instars. Thoracic legs are usually fully developed, but in the first two instars they are frequently absent. Although typically absent from the first two instars, in final instars ventral prolegs are present on A3-6" (Scoble 1992).

"Most species are leafminers, many mining one leaf throughout their larval life, others moving to different leaves. The cocoon is usually white and spindle-shaped" (Scoble 1992).

http://ukmoths.org.uk/species/lyonetia-clerkella

http://ukmoths.org.uk/species/lyonetia-prunifoliella/adult/

http://ukmoths.org.uk/species/leucoptera-laburnella/adult/

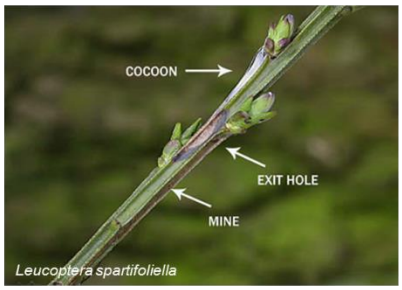
http://charlielepidopteraofcalderdale.blogspot.jp/2011/11/lyonetiidae-and-bucculatricidae.html

Adults of Lyionetiidae

http://ukmoths.org.uk/species/lyonetia-clerkella

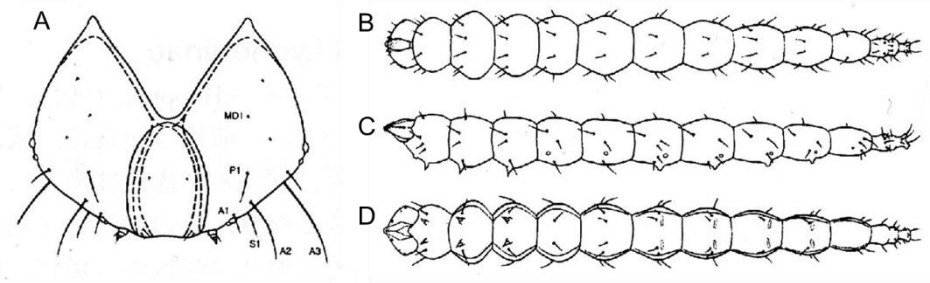
http://www.leafmines.co.uk/html/Lepidoptera/L.laburnella.htm

http://www.leafmines.co.uk/html/Lepidoptera/L.malifoliella1.htm



http://charlielepidopteraofcalderdale.blogspot.jp/2011/11/lyonetiidae-and-bucculatricidae.html

Mines and cocoons of Lyionetiidae



Larva of Lyonetia euryella. A: head, ventral view; B: dorsal; C: lateral; D: ventral. (Komai et al. 2011)

4-10. Coleophoridae (Gelechioidea)

"This family is especially well represented in the Northern Hemisphere, with most of the species referred to one genus, *Coleophora*" (Common 1990).

http://ukmoths.org.uk/species/coleophora-albitarsella

http://ukmoths.org.uk/species/coleophora-serratella

http://ukmoths.org.uk/species/coleophora-conspicuella

Adults of Coleophoridae

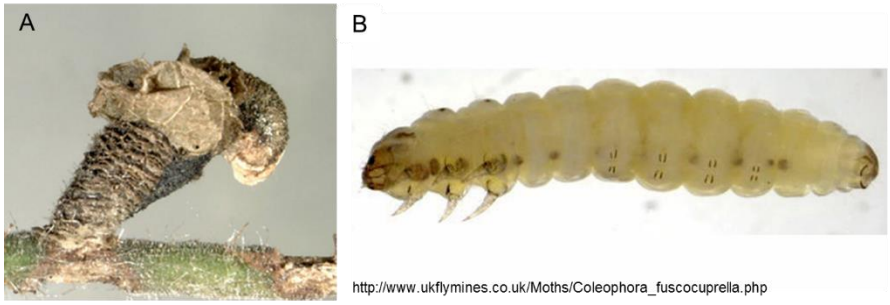
http://www.leafmines.co.uk/html/Lepidoptera/C.serratella12.htm

http://www.leafmines.co.uk/html/Lepidoptera/C.albitarsella.htm

http://www.leafmines.co.uk/html/Lepidoptera/C.pariipennella1.htm

http://www.leafmines.co.uk/html/Lepidoptera/C.lusciniaepennella9.htm

Leafmiens and cases of Coleophoridae



Case and larvae of *Coleophora fuscocuprella*

"The forewings are narrow and elongate, without a tornal angle. They are generally plainly coloured, or lightly speckled, or with pale streaks. The hind wings are narrower than the forewings, with very long dorsal cilia. The head is smooth-scaled. The long antennae are thread-like, the base in a few species thickened with scales or hairs, and two-thirds to three-quarters the length of the forewing" (Sterling and Parsons 2012)

"In the larva, the head is semiprognathous. Ventral abdominal prolegs are reduced. The first instars are leafminers. Second instars construct cases, sometimes characteristic of the species, form fragments of leaves, frass and silk. Subsequent instars continue to live as case bearers and pupation occurs within the case. Case bearing stages are often termed 'external' leafminers because the larva extends into the leaf as a typical miner while the case remains attached to the surface of the leaf" (Scoble 1992).

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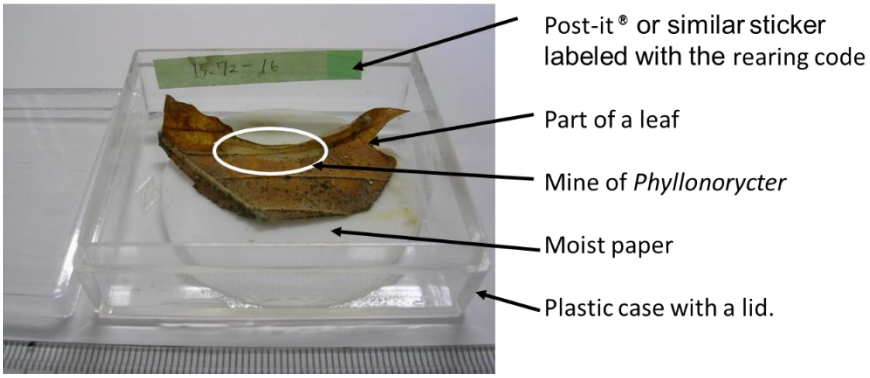
Techniques for Studying Leafminers

1. Rearing Leafmines/Miners

It is not difficult to rear leafmines/miners in containers, as long as you keep the leaves moist. There are two methods: one is a 'moist-paper' method, and the other is a 'vein-wrapping' method. The former saves time and effort, while the latter takes them. Which method should be adopted depends mainly on larval period and leaf resistance to decay. When you collect leafminers which spend several weeks within the mine or those from plants leaves of which deteriorate easily (e.g., leguminous plants), I recommend that you adopt the vein-wrapping method. In both methods, transparent cases containing leaves with mines must be placed under adequate light conditions.

(1) Moist-paper method

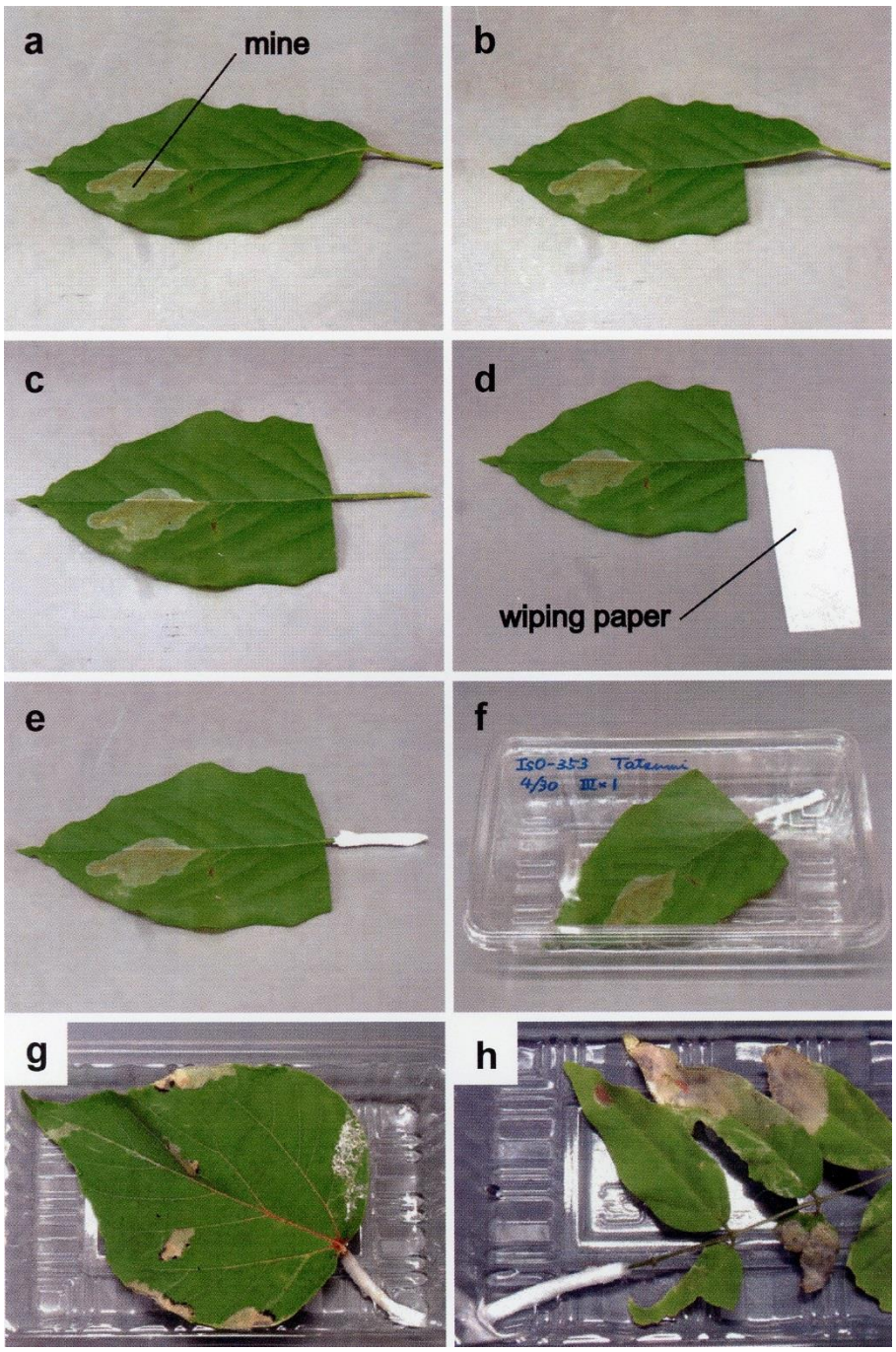
This method is very simple and common. You put a sheet of moist paper on the bottom of a plastic case, and placed a leaf with a mine(s) on it. You should add water to the paper when it dries. If the leaf is large for the size of a plastic case, you can cut out the part of the leaf with a mine.



There is a pupa in the mine, which is over-wintering. The leaf is being kept in the incubator at 5℃.

(2) Vein-wrapping method

This method is originated with Dr. Issei Oshima, who studies speciation of a lepidopteran leafminer, *Acrocercops transecta*. Although taking some time and effort, this method preserve the freshness of cut leaves for more than one month.



a. A leaf of *Lyonia ovalifolia* with a mine of *Acrocercops transecta*.

b-c: Cut and remove the basal part of the leaf blade but the main vein.

d: Wrap the vein in a sheet of Kimwipe8 or similar paper

e: soak the wrapped vein in 1 5% sucrose (or granulated sugar).

f: Keep the leaf in an airtight plastic container.

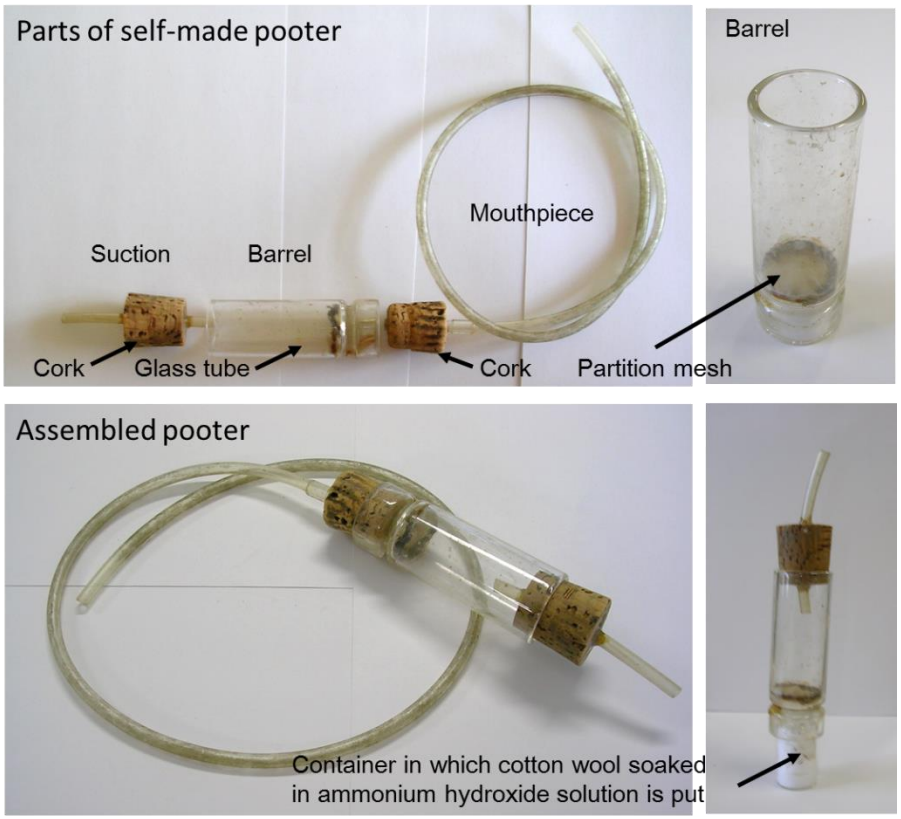
g, h: When it is difficult to wrap around the main vein, cut the petiole crosswise at the base, and wrap the vein in Kimwipe8.

(By the courtesy of Dr. I Oshima)

2. Collecting and Killing Adults

I use a self-made glass pooter for collecting leafmining moths. The pooter is composed three parts: mouthpiece, barrel and suction. The barrel is partitioned by a fine mesh. You can make a pooter with a plastic tube and silicon plugs.

When you kill a moth in the barrel, you replace the mouthpiece with a glass container in which cotton wool soaked with ammonium hydroxide solution is put.



Self-made pooter,

3. Pinning and Setting

3-1 Setting equipment

Spreading boards and boxes. I use specialized spreading boards and boxes for micro-moths. They are made of wood by a Japanese craftsman, and hence are hard to get in other countries than Japan. You could make them out of polyethylene foam and plastic boxes.

Minuten pins. I recommend that you use minuten pins 0.10, 0.14 or 0.19 mm in diameter and 10 mm in length as inserting pins and those 0.31 mm in diameter and 15 mm in length as point-holding pins. These pins are available from an English supplier, Watkins & Doncaster (http://www.watdon.co.uk).

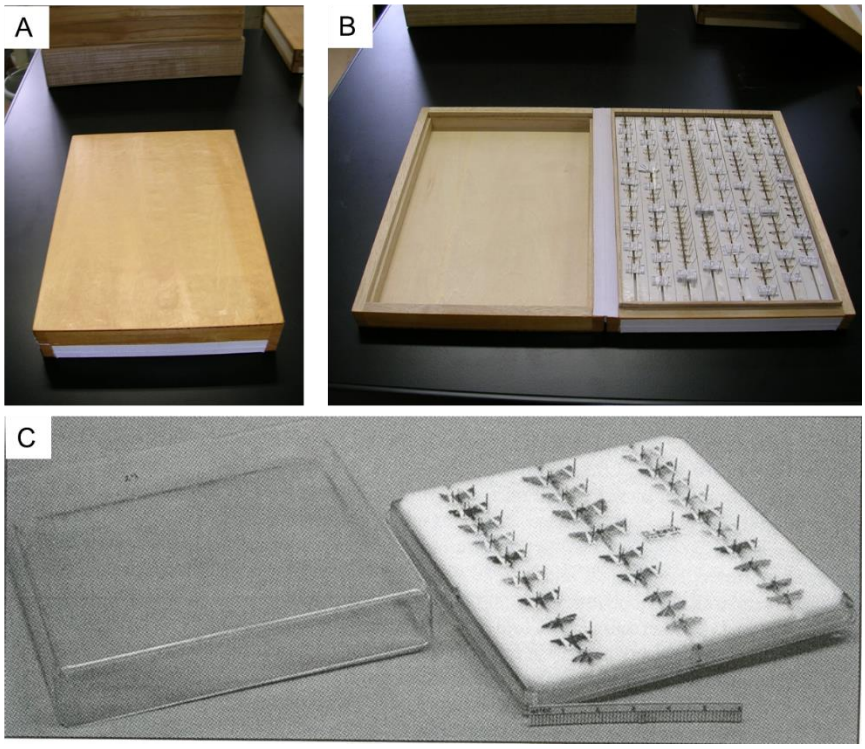
Pinvise. Used as a minute-pin holder for dissecting genitalia.

Inoculation loop. Self-made from fine wire, for transferring genitalia from solution to solution.

Pinning pad. I use a pad of polyethylene foam 5 mm in thickness.

3-2. Pinning and Setting

The pinning and setting operations should be done under a stereoscope.



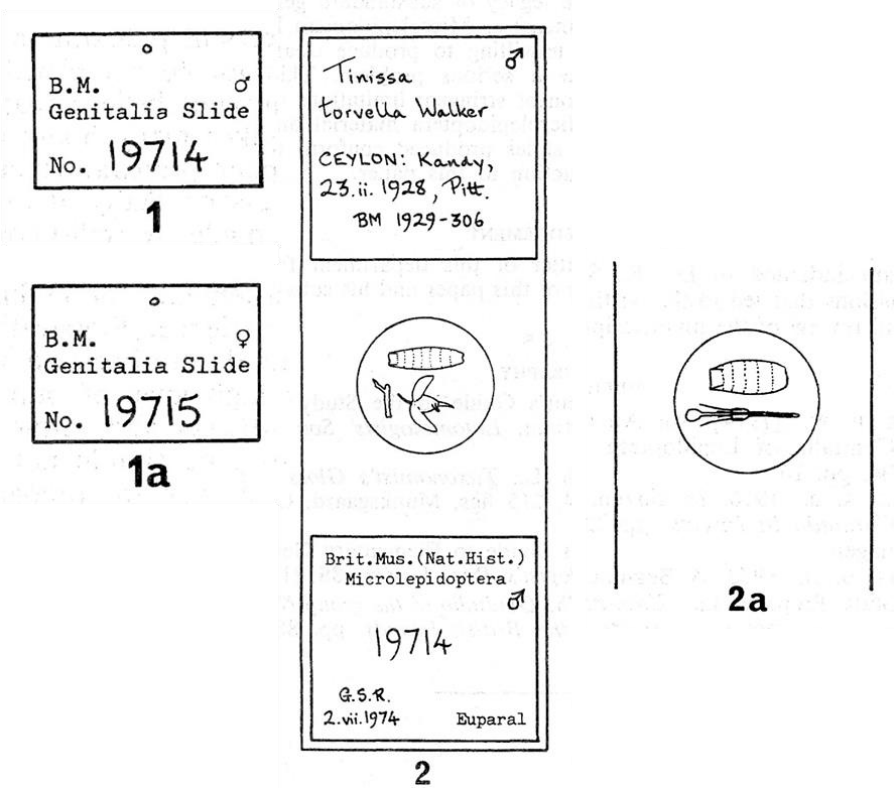
A, B: Spreading boards and carrying case made of woods by a Japanese craftsman.

C: Self-made spreading box. The pad is a piece of polyethylene foam 1 cm in thickness, with three V-shaped grooves. (Winter 2000)
D: Inserting the minuten pin through the center of the mesothorax on the pad of polyethylene foam
E: Inserting the specimen into the grove with the wings partly opened.
F: Moving an antenna and one set of wings forward with a minuten pin while lifting the paper, and pining the paper strip down to secure the wing into position.
G: Set specimens.
H: Labels including rearing code, collection date of larva, emergence date of adult, locality (geographical name, township, state), collector, species of leafminer and host plant.
J: Staged specimens (adult and pupal exuviae) and labels. The staging block is made of polyethylene foam.

4. Preparing Genitalia

It is very difficult to identify the species of small moths such as leafminers by external features. Thus we often identify the species by the genitalia. Furthermore, when we describe new species, we are most always required to present photographs or figures of the genitalia. To meet the requirements, we have to prepare genitalia slides. Procedures of genitalia preparation vary from person to person. The following is based on my procedure.

(1) Remove the entire abdomen from the specimen carefully, taking care not to dislodge the hindwings.
(2) Transfer the abdomen in a small Petri dish containing a small amount of 10% (by weight) potassium hydroxide (KOH; caustic) solution.
(3) Cover the dish and leave it on a hot plate at 70℃ for 1 hr.
(4) Transfer the abdomen to a watch glass containing purified water, and then remove external scales and internal fat and soft tissue with a very fine hair brush, forcepts and a hooked needle.
(5) Transfer the abdomen in a small Petri dish containing Chlorazol Black E solution (1% solution in 70% alcohol) and leave for a few minutes.
(6) Transfer the abdomen in a small Petri dish containing acid fuchsin solution [2% acid fuchsin in lactophenol (mixture of lactic acid 1 and phenol 1/3)]
(7) Cover the dish and leave it on a hot plate at 70℃ for 2 hrs.
(8) Transfer the abdomen to a watch glass containing 95% ethanol and practice procedurers (9) - (11) there.
(9) Remove the genitalia from the abdomen. In the case of females, remove the genitalia together with abdominal segments 7 - 10 in which the ventral external opening (ostium) contains.
(10) Fix the genitalia in the position required, in the case of the male genitalia with the valvae spread out and the gnathos pulled ventrally.
(11) Flatten the abdomen dorso-ventrally in 95% ethanol.
(12) Soak the genitalia and abdomen in the following solutions in order, for 5 min in each:
    99.9% ethanol (for dehydration)
    acetosalycilate (for dehydration and color development)
    carboxylol (mixture of xylol 4 and phenol 1)
    carboxylol
    xylol
(13) Mount the genitalia and abdomen as follows:
    Place a drop of Canada balsam in the centre of a microscope slide.
    Set the genitalia and abdomen in the drop in the position of ventral side uppermost.



Labelling and slide arrangement used for Microlepidoptera by Bristish Museum (Natural History). (Robinson 1976)

Put a cover glass on the drop gently so as to avoid any air bubbles forming.

(14) Keep the slide flat and allow to dry on a covered tray at room temperature or in an oven at 45℃ for 48 hrs.

(15) Label the slide: (the following is cited from Robinson 1976)

A standard form of labelling is in use in the Microlepidoptera Section of the British Museum (Natural History) for both slides and the specimens from which the preparations are made. The specimen carries a three line label (figs. 1, 1a) which is placed on the pin so as to protrude below the data label, thus obviating the need to remove a specimen from a drawer to read the preparation number. Slides are labelled in a standard manner (fig. 2) and the abdomen and genitalia arranged beneath the coverslip in a consistent pattern (fig.2, 2a). The form of labelling of the slide with the complete label data of the specimen permits easy reference where work is being done with slides (rather than with specimens), where slides are loaned and where the specimen label may have been lost or the specimen cannot be found.

5. Preparing Wings

Wing venation is one of diagnostic characters for classification of Lepidoptera. In particular, when you classify moths of Nepticulidae, I recommend that you first observe wing

venation to identify the genus and then compare the genitalia with photographs and figures in taxonomic papers or books.

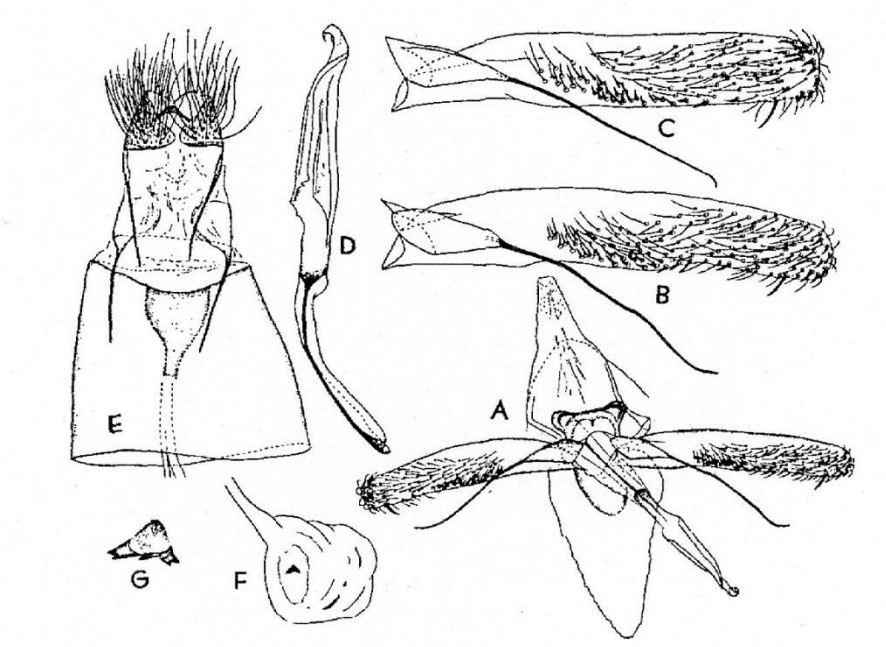
(1) Remove the forewing and hindwing by lifting and lowering them with a fine pin.
(2) Soak the wings in 95% ethanol and remove scales by gently stroking and blushing with a fine hair blush.
(3) Stain the wings with acid fuchsin according to the procedures (6) and (7) in the section of preparing genitalia
(4) Dehydrate and mount the head and larval skin according to the procedures (12) - (15) in the section Preparing Genitalia.

6. Preparing Larvae

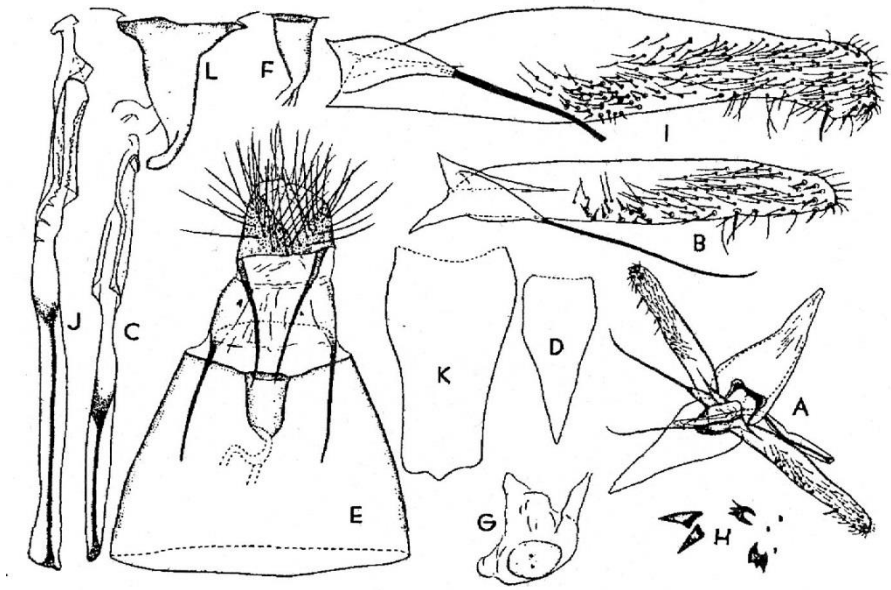
The occurrence and distribution of the setae and punctures of the larval head, thorax and abdomen are of major taxonomic significance (Common 1990). To observe those structures, we need to prepare larval skin and head.

(1) Macerate the larva in 10% KOH as described in the procedures (2) - (3) of the section Preparing Genitalia.
(2) Transfer the abdomen to a watch glass containing purified water and practice the procedures (3) and (5).
(3) Separate the head capsule form the body.
(4) Cut the right-lateral side of the body longitudinally from anterior to posterior with a surgical micro-knife or surgical micro-scissors.
(5) Remove the internal fat and soft tissue with forcepts and a hooked fine needle.
(6) Stain the head and body with acid fuchsin according to the procedures (6) and (7) of the section Preparing Genitalia.
(7) Transfer the head and larval skin to a watch glass containing 95% ethanol, and fix the larval skin open and flattened.
(8) Dehydrate and mount the head and larval skin according to the procedures (12) - (15) in the section Preparing Genitalia.

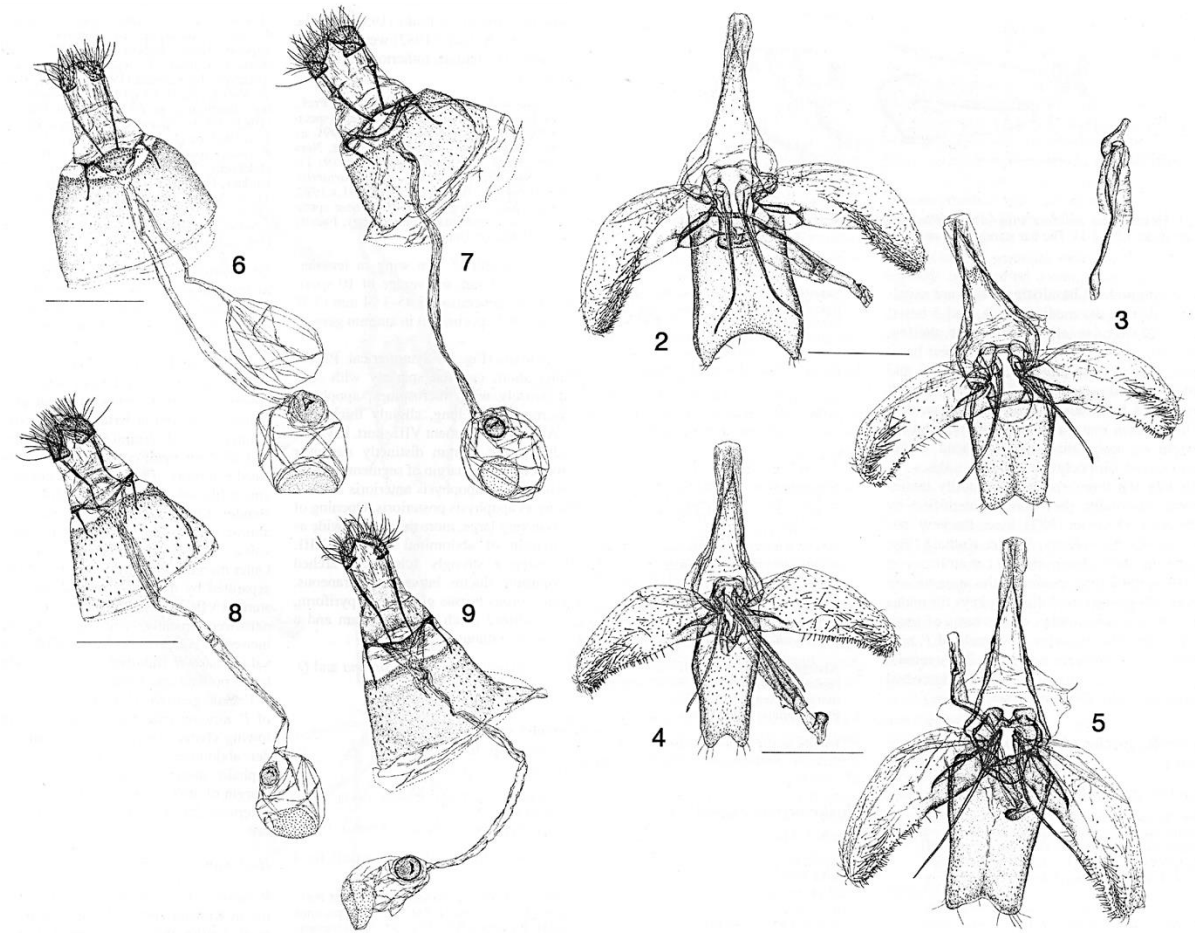
Appendix 1. Male and female genitalia of Japanese Phyllonorycter spp. (Gracillariidae) associated with oaks (Quercus spp., Fagaceae)



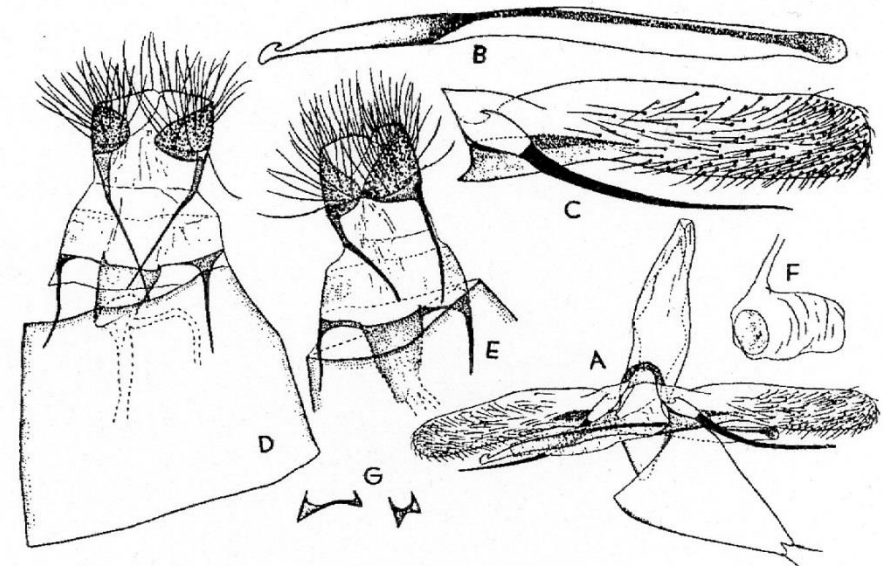
P. pseudolautella (Kumata) (after Kumata 1963)



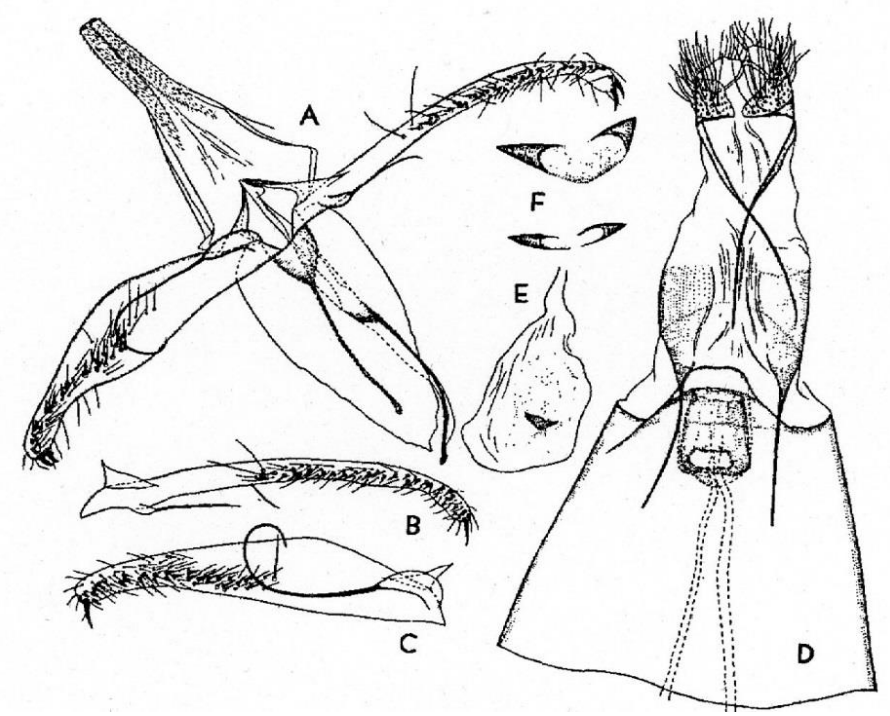
A-H: *P. pygmaea* (Kumata). I-L: *P. lautella* (Zeller) (not distributed in Japan) (after Kumata 1963)



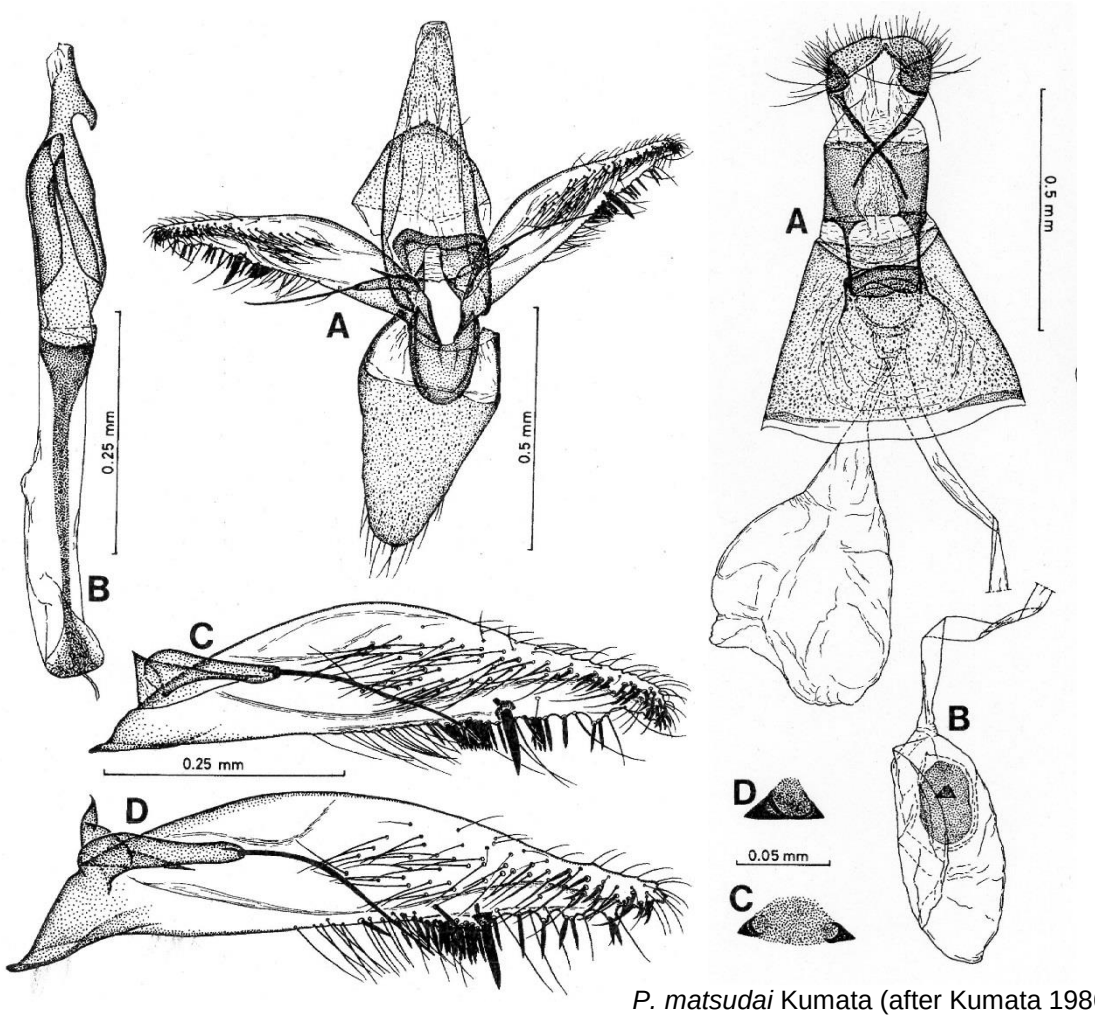
2, 6: *P. acutissimae* (Kumata). 3, 7: *P. nipponicella* (Issiki). 4, 8: *P. similis* Kumata. 5, 9: *P. persimilis* Fujihara, Sato and Kumata. (after Sato et al. 2001)



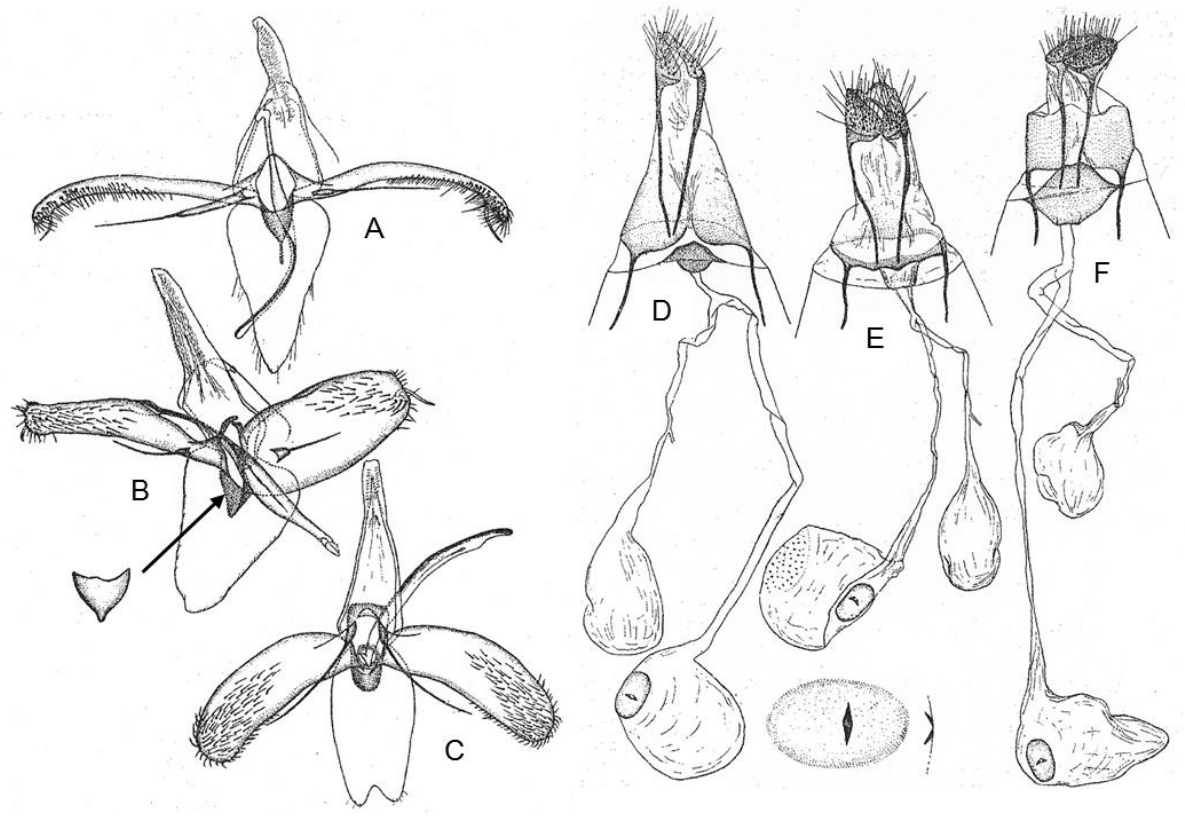
P. kamijoi (Kumata) (after Kumata 1963)



P. mongolicae (Kumata) (after Kumata 1963)

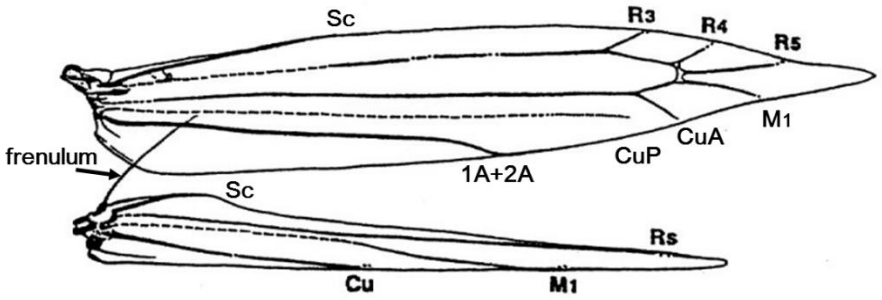


P. matsudai Kumata (after Kumata 1986)



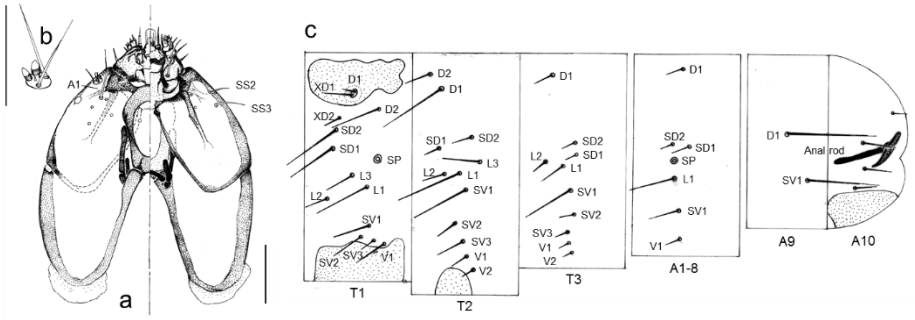
A, D: *P. nigristella* (Kumata). B, E: *P. leucocorona*. C, F: *P. cretata* (Kumata). (after Kumata 1957)

Appendix 2. Wing venation of *Phyllonorycter malayana* Kumata.



(after Kumata 1993)

Appendix 3. Head capsule and setal map of *Ectoedemia cerviparadiscola* Sato



Fifth instar larva. a: head capsule; b: antenna; c, setal map. Bars, 0.1 mm. (after Shinozaki et al.

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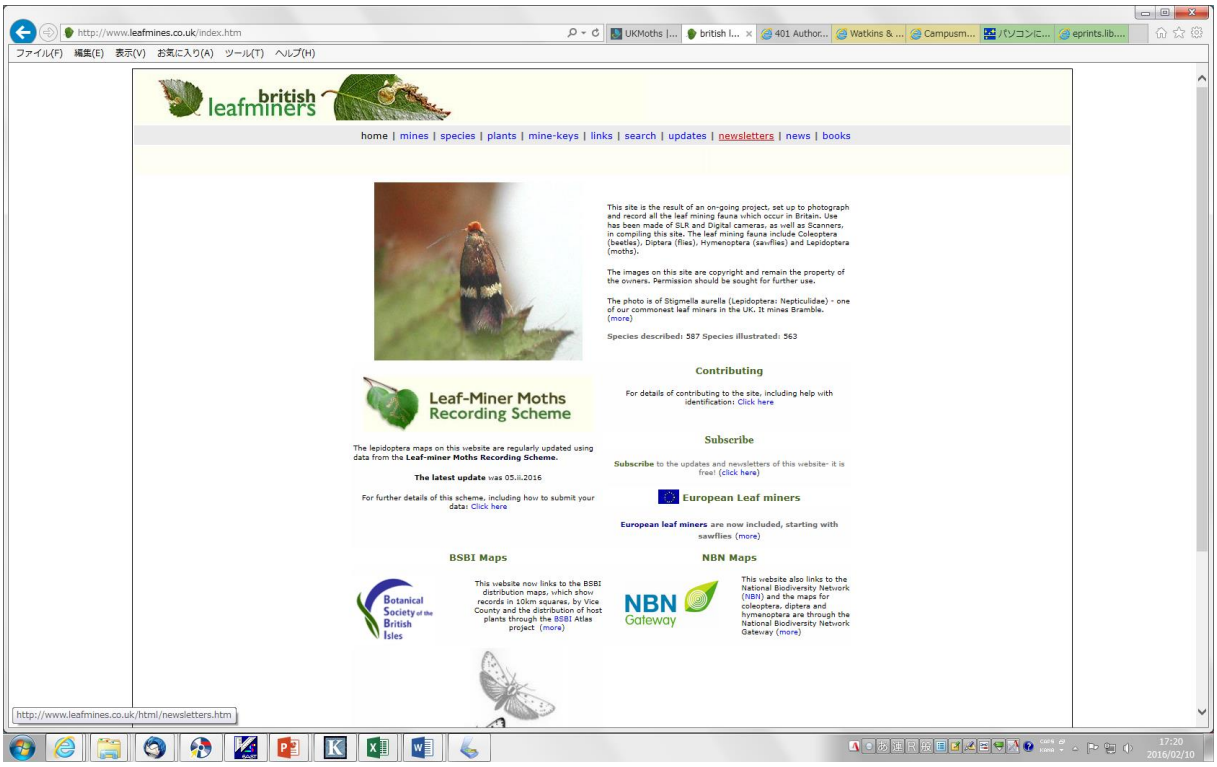
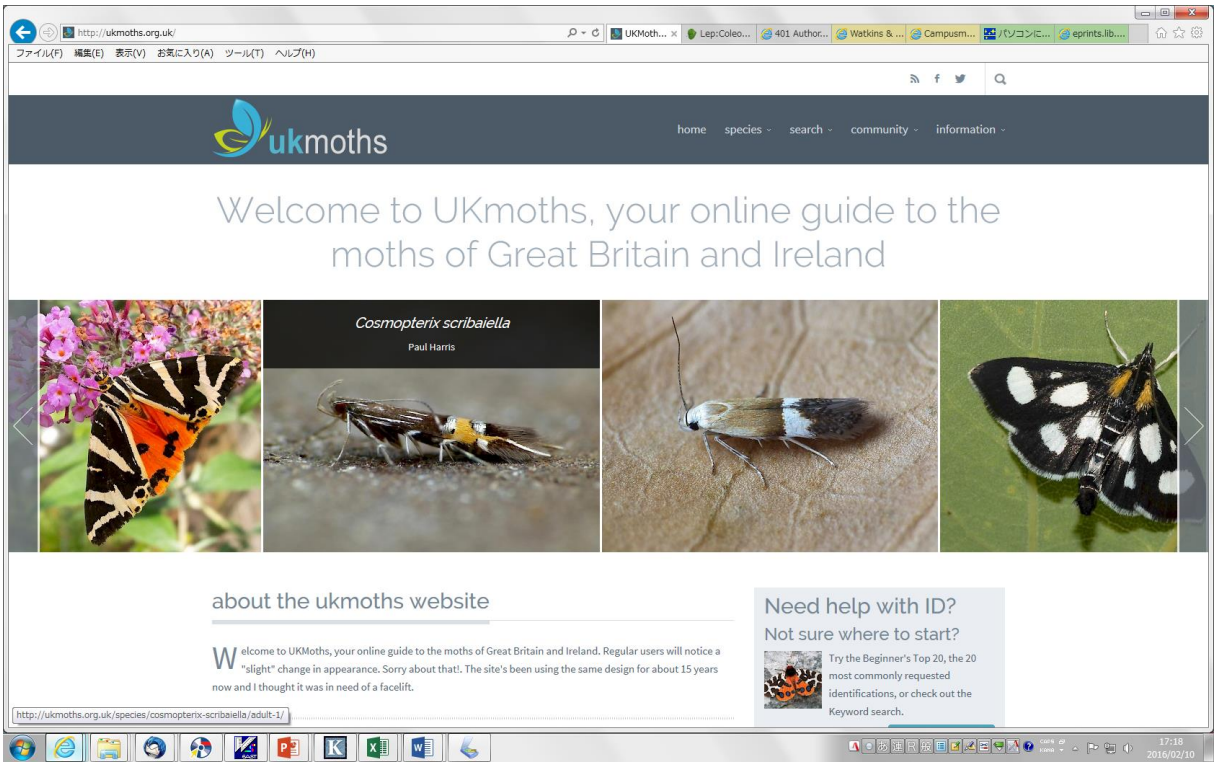
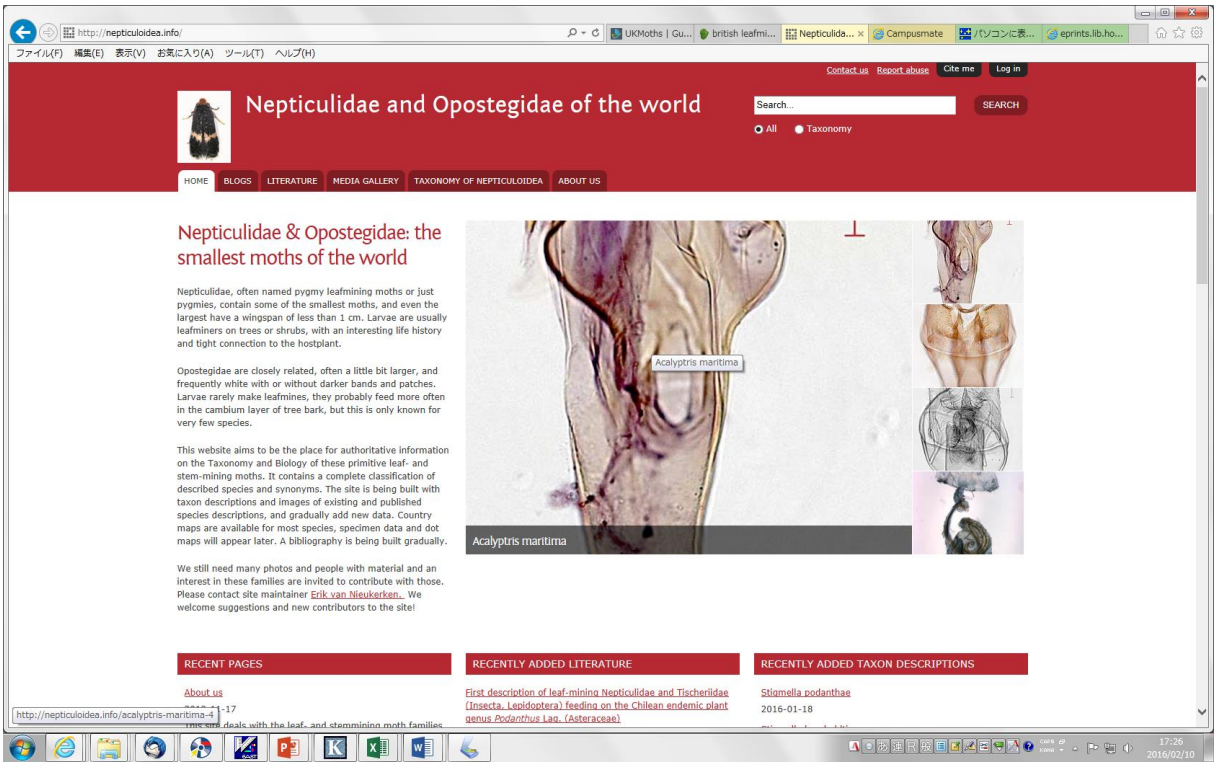


UKmoths <http://ukmoths.org.uk/>

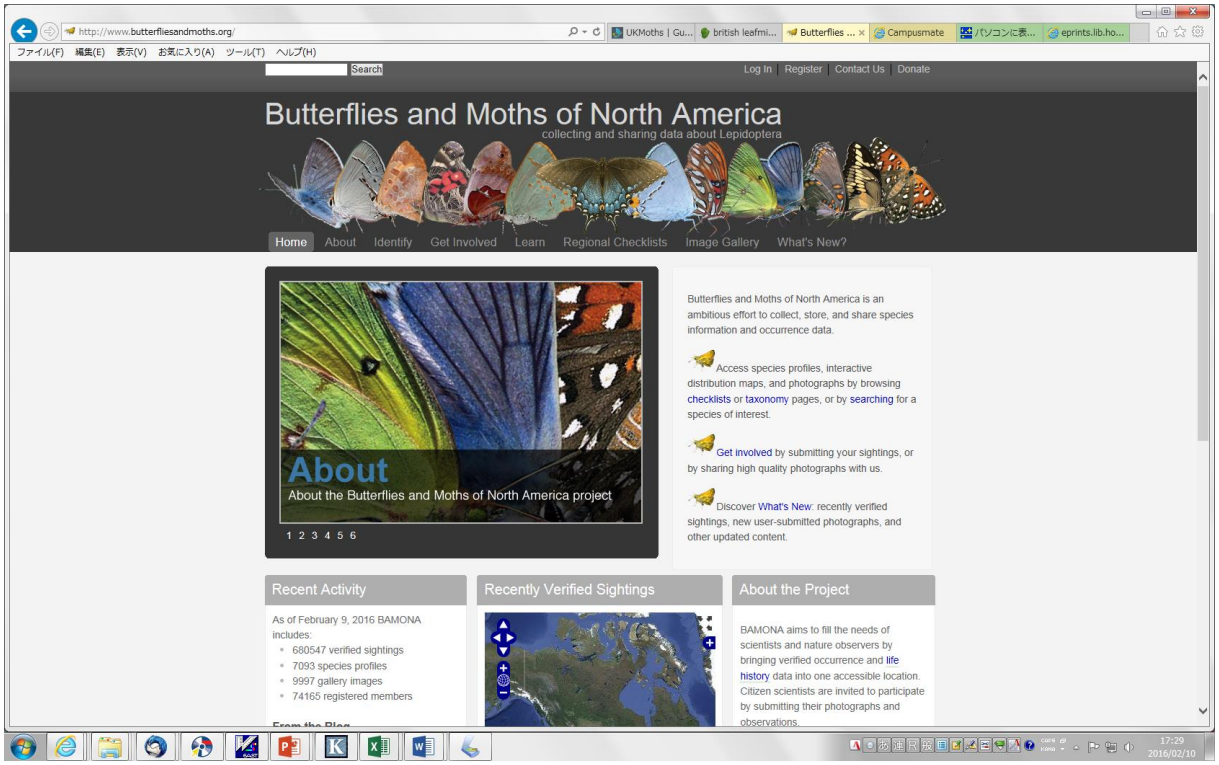


Global Taxonomic Database of Gracillariidae (Lepidoptera) <http://www.gracillariidae.net/>

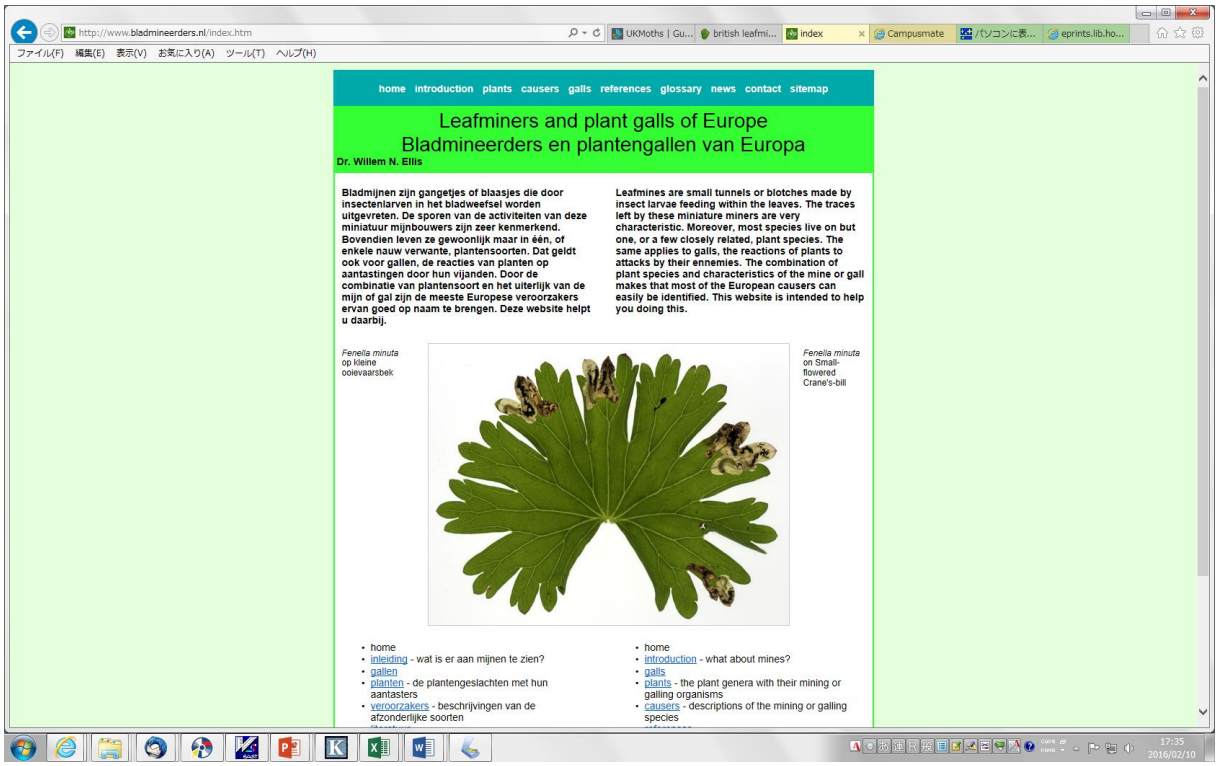
Nepticulidae and Opostegidae of the World <http://nepticuloidea.info/>



Butterflies and Moths of North America <http://www.butterfliesandmoths.org/>

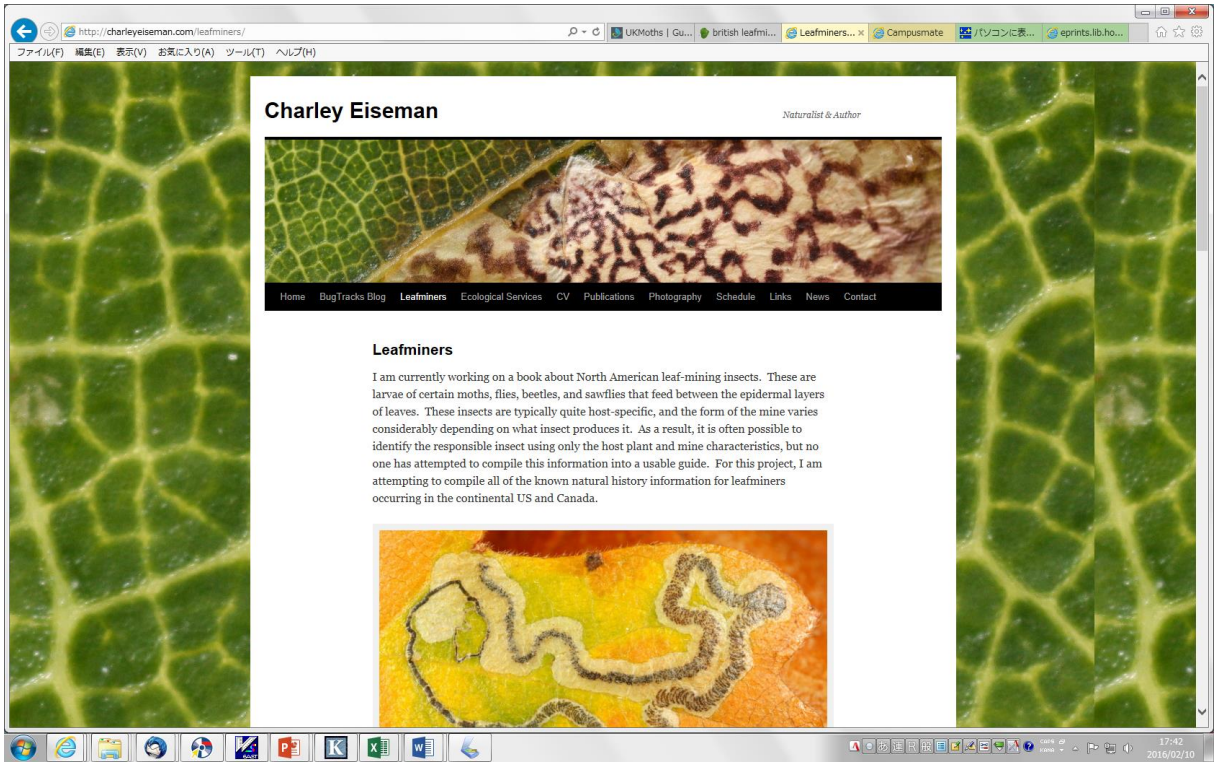


Leafminers and Plant Galls of Europe <http://www.bladmineerders.nl/index.htm>



The Leaf and Stem mines of British Flies and Other Insects (Coleoptera, Diptera, Hymenoptera and Lepidoptera) < http://www.ukflymines.co.uk/>

Charley Eiseman <http://charleyeiseman.com/leafminers/>



Glossary

(based on Common 1990, Majerus 2002, May 2014)

abdomen. The hindmost of the three parts of the body of a fully developed insect
adfrontal area. The area between the adfrontal sutures and the ecdysial lines on the larval head.
aedeagus. The male copulatory organ. Usually it is inserted into the bursa copulatrix of the vaginal region of the female so that sperm can be deposited. In Lepidoptera it is the main receptacle for the sperm.
amplexiform. A type of wing-coupling in which an enlarged humeral area of the hindwing is broadly overlapped by the forewing.
ampula. A sclerotized structure on the inner face of the valva in certain male moths.
anal claspers. The prolegs on the caterpillar's last segment. See claspers.
anal hooks. Hooked or clubbed setae at the posterior end of the pupa, used to attack the pupa to the cocoon or a pad of silk.
anal segment. The last segment of the insect's body on which the anus occurs.
anal shield. A sclerotized middorsal plate on abdominal segment 10 of the larva.
anal veins. One to three wing veins (1A to 3A) situated posterior of the cubitus or cubital vein.
androconia. 'Male dust'. Sometimes called plumules. These are scales on the wings of male butterflies and moths which produce scent. They often form black areas on the fore-wings of male butterflies, e.g., wall brown, silver-washed fritillary, large skipper.
anteclypeus. A transverse sclerite on the anterior border of the frontoclypeus in the larva, with which the labrum articulates.
antenna (pl., antennae). Paired sensory organs on the head of insects. They are conspicuous and are often called "feelers". Sometimes they are feather-like. They are mainly obvious in the adult. Primarily organs of touch but often also of smell.
anterior. At the front, foremost front; in front. Opposite to posterior.
apex. Near the apex (tip), usually meaning the apex of the wing.
apical. Area at or adjacent to the tip of the wing or other structure.
apodeme. Infolded or rod-like projection of the integument to which muscles are attached.
apophyses (anterioures and posteriores). Rod-like apodemes to which the muscles operating the female genital organs are attached.
arolium. A central lobe between the claws at the tip of the tarsus.
axilla. Point of attachment of the thoracic muscles to the wings.
basal. Concerning the base of a structure: that part nearest to the body.
bifid. Forked.
biordinal. Of two alternating sizes; refers to crochets of the larval prolegs.
biserial. In two series, often concentric; refers to crochets of the larval prolegs.
bulla seminalis. An expansion or diverticulum of the ductus seminalis in which sperm is stored temporarily.
bursa copulatrix. The copulatory ducts and sac in adult female moths, comprising the ostium bursae, ductus bursae and corpus bursae.
cathrema. A striated thickening at the base of the ductus ejaculatorius in Nepticulidae.
caudal. To do with the tail or area near the tail.
cell (=discal cell). The area of each wing that is totally enclosed by veins.
cerci. Paired appendages on the abdomen of many insects.
chaetosema (pl. chaetosemata). A group of setal, usually divergent sensilla present on the head of butterflies and some moths.
chaetotaxy. The arrangement and system of naming larval setae.
chalaza. A sclerotized, conical area of the larval integument, bearing a single plumose seta or up to three simple setae.
cilia. Used to describe moth antennae that are not quite thread-like.
ciliate. Fringed with hairs. Used to describe moth antennae that are not quite thread-like.
claspers. The fleshy clasping limbs at the rear of caterpillars. The term should be used only when describing the hindmost pair of "legs" on the caterpillar.

claw. A hooked, usually paired, structure at the tip of the tarsus.
cocoon. The completely enclosed "cradle" of silk spun by the caterpillar within which it becomes a pupa and from which it emerges as a butterfly or moth. May be either tough, nominal absent. It may also refer to the protective covering around the pupae or chrysalis of some insects.
colliculum. A sclerotized plate or thickening near the posteiror end of the ductus bursae in the female genitalia.
compound eye. The main visual organ in insects. It is made up of many individual ommatidia, each of which is an "eye" in its own right. This type of eye is very good for detecting distance. The image produced is like a "mosaic".
coremata. Thin-walled eversible organs of male moths used for the dissemination of pheromones.
cornutus (pl. cornuti). Sclerotized protruberances inside the tube of the aedeagus. Their structure and pattern can be useful in identification.
corpus bursae. The membranous sac of the female gentialia in which the male deposits the spermatophore during copulation.
costa. A region or vein at the leading edge of either the fore-wing or the hind-wing. Often it refers to the much strengthened first rib of the fore-wing.
costal fold. An expanded costal area folded over or beneath the forewing in the male, often covering special pheromone-disseminating scales or hairs.
coxa (pl., coxae). The short first segment (closest to the body) of an adult insect's leg.
cremaster. The hooked tip of the tail of a chrysalis, which enables it to remain firmly attached to the silk pad which the larva had spun on its support before casting the last larval skin.
crochets. Terminal sclerotized hooks on the larval prolegs.
cubitus. The fifth main longitudinal vein (Cu), with two branches CuA and CuP; CuA forms the posteior margin of the discal cell.
cucullus. A dorsal lobe at the apex of the main valva in certain moths.
dentate. Toothed.
diaphragma. The membrane closing the posterior end of the male abdomen, between the bases of the valvae.
discal cell. The central area of the wing, bounded anteriorly by veins R or Rs, posteriorly by CuA and distally by the discocellular veins.
discocellular veins. The short and often weak transverse veins or cross-veins which form or 'close' the distal end of the discal cell in the wings.
ditrysian. Having separate copulatory and oviposition apertures in the female, with the bursa copulatrix connected to the vagina by an internal duct, the ductus seminalis.
diverticulum. A blind lateral sac of the alimentary canal or other organ.
dorsal. (a) The 'back' of the insect, i.e., the surface opposite the legs (dorsum = back). (b) Along the back. A convenient adjective to describe lines, tubercles or tufts in that position on larvae or the markings on the bodies of moths. (Compare lateral and ventral).
dorsal vessel. The longitudinal, tubular organ or 'heart' responsible for circulating the haemolymph or blood.
dorsolaterla. The area between the dorsal and lateral areas.
dorsum. The upper surface; sometimes applied to the inner margin of the wing.
ductus bursae. The duct leading from the ostium bursae or copulatory aperture to the corpus bursae in the female genitalia.
ductus seminalis. The duct joining the bursa copulatrix to the vagina of the female.
ecdysial lines. Lines of weakness lateral from the adfrontal sutures of the larval head along which the head capsule splits at ecdysis.
ecdysis. Following apolysis, the second part of the moulting process, by which an insect sheds its outer coat.
eclosion. The act of emerging from the pupa.
endophallus. The inner, eversible tube of the aedeagus.
epiphysis. A sclerotised progection of the legs of moths used to clean the antennae.
exporian. Having separate copulatory and ovipostion apertures, with an external groove along which sperm pass from the bursa copulatrix to the vagina of the female genitalia.
exuviae (used only in the plural) The cast-off outer skin of an arthropod after a moult.
fasciculate. Tufted. Used to describe moth antennae which are a little "bushy".
femur. Part of the insect leg between trochanter and tibia.

flagellum. All the antennal segments after the first two.
frenulum. One or more bristles, arising at the base of the hind wing, which couple the wings together by hooking behind the retinaculum beneath the forewing.
filiform. Shaped like a thread; thread-like. Used to describe moth antennae which have no projections.
frass. Caterpillars must eat a great deal in order to grow quickly. The matter that is not digested, the feces, is pushed out as small green or black pellets. The collective word for these pellets is "frass".
frenulum (pl. frenula). A bristle on the hind-wing of many moths which is held in catch on the fore-wing and so ensures that both move together in fleight (see retinaculum).
frons. Anterior part of the head.
frontoclypeus. Fused frons and clypeus of the larval head.
fultura superior and inferior. Upper and lower sclerotized areas of the diaphragma of the male gentialia.
fusiform. Spindle-shaped.
galea (pl. galeae). The apex or outer lobe of the maxilla of an insect.
genitalia. The organs within the tip of the abdomen of an imago which enable it to couple with the opposite sex and mate.
granulose. Having a granular surface.
gnathos. A single or paired structure beneath the uncus in male genitalia.
hamuli. A row of bristles used to connect the fore and hind wings in some insects (cf., frenulum).
harpe. A sclerotized structure on the inner surface of the valva in some male moths, associated with the sacculus.
haustellum. The proboscis, usually coiled, in Lepidoptera.
heteroneurous. Having the venation of the hindwing reduced, without R2 to R5.
homoneurous. Having the full complement of veins in both fore- and hindwings.
humeral vein. A short vein arising near the base of the hindwing and running towards the base of the costa.
hypognathous. Having the mouthparts of the larval head directed ventrally.
head. The anterior most of the three main body parts of an insect.
imago (pl. imagoes or imagines). (a) The adult insect. (b) The final stage of an insect's life cycle.
inner margin. The posterior or trailing edge of the wing, joining the base to the tornus.
instar (=stadium). The growth stage between successive moults. A stage in the larval life between one moult and the next. They may be numbered, the first being from the emergence from the ovum to the first moult. The final instar larva is that which proceeds the change to pupa or chrysalis. Strictly the first instar is the ovum and the final is the imago.
intersegmental membrane. The membrane joining two segments of the insect body.
Johnston's organ. A sensory organ used to detect sound near the base of the antenna.
jugum (pl. juga) A yoke or projection from the base of the fore-wing that overlaps the hind-wing and holds them together so that both fore and hind-wings move together in flight. Compare the more usual retinaculum.
juxta. A sclerotized plate beneath the aedeagus of the male, to which the aedeagus may be hinged or fused; part of the fultura inferior.
labium. Part of the insect's mouth-parts and often referred to as the insect's "lower lip".
labial palpus (pl. palpi). Paired appendages of the insect labium.
labrum. Part of the insect's mouth-parts and often referred to as the insect's "upper lip".
lacinia. A small lobe of the maxilla present in some primitive moths.
lamella antevaginalis and postvaginalis. Sclerotized areas of the abdomen anterior and posterior or the ostium bursae in the female.
larva (pl. larvae). The second stage in the life cycle of butterflies and moths, the caterpillar or grub. The juvenile from of an insect.
lateral. The side of an organism, or along the sides. A convenient adjective to describe lines or tubercles projecting sideways from caterpillars. The spiracle are situated laterally.
maculate. Spotted or blotched.
mandible. A paired part of the mouth-parts that are used for biting or cutting arthropods. The true jaws of the caterpillar. It will be noticed that they cut sideways, not up and down as in the majority of animals. Mandibles are present in most adult insects, too, but not in butterflies and

moths.

maxilla (pl. maxllae). Part of an insect's mouth-parts. They are paired and used to hold or manipulate food.

maxillary palpus (pl. palpi). Paired, usually segmented, appendages of the maxillae.

media. The fourth main longitudinal vein (M) of the wing; its stem may be branched within the discal cell, but is more often vestigial or absent.

mesoseries. The arrangement of the crochets of the larval proleg in a single, inner or mesal, longitudinal band.

mesothorax. The middle segment of the thorax.

metamorphosis (pl. metamorphoses). The process of development of an organism that involves distinct stages with an abrupt change between them.

metathorax. The third or last segment of the thorax.

microtrichia. Minute outgrowths or spines of the cuticle present in primitive moths; those on the wings are called aculei.

monotrysian. Having a single genital aperture serving both for copulation and oviposition.

moult. The shedding of the outer layer so that growth during the next stage can occur.

moulting. Moulting of the arthropod cuticle. In its entomological ues, it is the act of shedding the larval skin. (cf., ecdysis)

mouthparts. The different appendages around the mouth that are involved in feeding - the upper labrum, mandibles, maxillae and labium at the bottom.

multiserial. Arranged in several series; refers to crochets of the larval prolegs.

notum. The upper plate of the segments of the thorax

occipital foramen. The posterior aperture of the insect head through which the alimentary canal, central nervous system and other organs pass.

ocellus (pl., ocelli). Simple light detecting organs (see (i) to (iii)). (i) Eyes. Used for the minute, usually multiple, eyes on the top of the head of adult insects and on the sides of the head of caterpillars. (iv) Patterns or scaleless areas on the wings of some moths which look like the eyes of birds or animals. The better word for this meaning is "eye spot".

ommatidium (pl. ommatidia). One of the individual units which make up the compound eye.

ostium. A slit-like opening in the dorsal blood vessel (the "heart") in each thoracic and the first nine abdominal segemnts. It allows the one-way flow of haemolymph ("blood") into the dorsal vessel.

ostium bursae. Copulatory aperture of the female bursa copulatrix.

ovary. Female reproductive organ that produces eggs.

ovipositor. A kind of usually extensile horny tube with which certain female imagoes are able to pierce stems or bark and through which the eggs are laid below the surface.

palpus, **palp** (pl. palpi or palps). One of a pair of segmented appendages of the maxillae or labium, provided with sensilla.

papillae anales. A pair of lobes at the tip of the female abdomen used in oviposition; usually clothed with sensory setae, but sometimes fused, sclerotiezed and dentate and used to pierce plant tissues.

patagium (pl. patagia) One of a pair of anterior sclerites of the prothorax.

pecten. A comb-like series of setae or scales, sometimes present either on the scape of the antenna or vein CuA on the upper side of the hindwing.

pectinated. Toothed like a comb: describes antennae with projections on one side only.

pectinifer. A comb of special setae or sensilla on the valva in males of some Nepticuloidea and Incurvarioidea.

pedicel. The second segment of the antenna of an insect.

pharate. An individual that is enclosed within the cuticle of the previous stage in the life-cycle, e.g., the adult insect, prior to emergence from a pupa, is enclosed within the cuticle of the pupa and is therefore described as pharate.

pilifer. One of a pair of lateral lobes of the labrum, usually bearing setae.

pinaculum (pl. pinacula). A sclerotized plate bearing one or more primary larval setae.

planta. The flat terminal part of the ventral proleg in larvae.

pleural membrane. The lateral membrane connecting the sclerites of the tergum and sternum.

pleurite. The side plates of the segments, one on each side of each segment.

plumule. See androconia.

posterior (adv. posteriorly). (a) Hindmost (opposed to anterior). (b) Behind, at the rear.
proboscis (pl. probosces). A long feeding tube in two sections which join together. It is open at the tip and usually coiled up when not in use. Through it a butterfly or moth can suck up liquid food. The proboscis is sometimes miscalled "the tongue".
prognathous. With the mouthparts directed anteriorly.
proleg. The fleshy hook-bearing walking devices on the ventral surface of the rear half (abdomen) of the caterpillar. Also called the "false legs" in contradistinction to the "true legs" borne by the segments of the thorax and persisting as the legs of the adult.
pronotum. The plate-like dorsal cover of the first thoracic segment.
prothorax. See thorax.
prothoracic shield. A sclerotized middorsal plate on the prothorax of larvae.
pulvilla. Paired lobes at the tip of the tarsus, associated with the claws.
pupa (pl. pupae). The third stage in the life cycle of insects undergoing complete metamophosis.
segment. The insect body is divided into rings or compartments called segments. Each segment may be considered to be made up of 4 main plates, an upper tergite (notum in the thorax), lower sternum and 2 lateral plates, pleurites. Also the term may be used for the divisions of the legs, such as the coxa etc.
pupate. The action of a caterpillar in becoming the pupa.
quiescence. A temporary suspension of activity or development in response to a brief period of unfavourable conditions.
radius. An important vein within the fore-wing of insects.
rami. The branches of a pectinate antenna.
retinaculum (pl. retinacula). A kind of catch on the fore-wing of many moths into which a bristle (frenulum) on the hind-wing fits when the wings are moved outward for flight (jugum).
sacculus. A sclerotized basal area of the ventral margin in the valva of the male genitalia.
saccus. A usually hollow apodeme directed forwards midventrally from the vinculum into the body cavity of the males of some species.
scale. A flattened and modified hair or seta.
scape. The largest, basal segment of the antenna.
sclerite. One of the hardened plates of the insect cuticle.
sclerotized. The stiffening or hardening of the structure of the cuticle caused by altering the structure of the proteins present.
scolus (pl. scoli). An outgrowth of the body wall in larvae, bearing branches or setae.
segments. The insect body is divided into rings or compartments called segments. Each segment may be considered to be made up of 4 main plates, an upper tergite (notum in the thorax), a lower sternum and 2 lateral plates, the pleurites. Also the term may be used for the divisions of the legs, such as the coxa etc.
sensillum (pl., sensilla). A small sense organ.
seta (pl. setae). A "hair" or spine rising from the skin of a caterpillar. It is made of chitin.
setal map. A diagrammatic representation of the arrangement of setae in larvae.
setose. Bearing setae.
signum (pl. signa). A sclerotized area or structure on inner wall of the corpus bursae in the female genitalia.
socius (pl. socii). One of a pair of lobes clothed with setae, sometimes present beneath the uncus in the male genitalia.
spermatheca. A small sac with an opening tot the vagina, used for storing sperm.
spermatophore. A sac containing sperm introduced into the female bursa copulatrix by the male during mating.
spinneret. An organ that produces silk. Spinnerets are possessed by spiders and some species of insect, especially Leipdoptera caterpillars. In many caterpillars it is an organ near the mouth, through which is forced, at will, a liquid which immediately hardens into a silk thread. This may be used to drop away from a twig at the first sign of danger; or to sew leaves into a roll for concealment; or t spin a pad to serve as a firm foothold for moulting or pupating; or to make a complete cocoon in which to pupate.
spinule. Minute, thorn-like projections from the cuticle of larvae.
spinulose. Covered with spinules.
spiracle. A lateral aperture of the body wall through which air passes to the tracheae.

spur. A movable spine-like structure, usually clothed with scales, on the mid and hind tibiae of adult Lepidoptera.
stadium (pl. stadia). The interval from one moult or ecdysis to the next. Most caterpillars pass through five stadia.
stemma (pl. stemmata). A simple visual organ usually present on each side of the larval head.
sterigma (pl. sterigmata). Sclerotized plate or plates surrounding the ostium bursae of the female.
sternum (pl. sterna) or sternite (pl. sternites). The underside of a segment, the ventral region.
subcosta. The second main longitudinal vein (Sc) of the wing.
suture (sulcus). A groove or furrow.
tarsomere. Sections, or "segments", within the tarsus, the final section in the leg of an insect.
tarsus. (pl. tarsi). The final section in the leg of an adult insect. It may have up to five individual tarsomeres. The last section has a pair of claws.
tegula (pl. tegulae). A small sclerite that covers the base of the front wings.
tegumen. The modified ninth tergum of the male abdomen, forming the upper basal half of the genitalia.
tergum (pl., terga or tergites). The top side of a segment, i.e., part of the back, the dorsal side.
termen. The outer margin of the wing, joining the apex and tornus.
thorax (adj, thoracic). The middle region of the insect's body. It is the section between the head and the abdomen to which true legs and wings are attached. It is made up of three segments: (i) prothorax or first segment; (ii) mesothorax or second segment; (iii) metathorax of third segment. Each of the three segments bears a pair of legs and the second and third segments may each bear a pair of wings.
tibia (pl. tibiae) The fourth segment of the leg.
tomentum. Fine hairs that cover the bodies of some insects.
tornus. The outer angle of the wing, between the termen and the inner margin.
trachea. Tubes attached to the spiracles allowing oxygen to diffuse into an insect's body.
tracheoles. The finest tubes attached to the trachea within the body of an insect. These tubes carry gases to and from the body cells, and so facilitate gaseous exchange.
transtilla. A sclerotized transverse band forming the upper margin of the diaphragma and the fultura superior of the male genitalia.
trochanter. The second segment of an insect's leg. The joint between the hip(coxa) and thigh (femur).
tubercle. A wart or bud-like projection from the body of a caterpillar. Tubercles are often armed with spines. When a caterpillar is attacked by a small fly, it rears backwards and might sometimes impale the fly between spines on front and rear tubercles.
uncus. The upper, usually lobed or hooked part of the male genitalia.
unguis. Te claw, two incurved hooks which terminate the tarsus. (cf., claw).
uniordinal. Of one more or less uniform size; refers to crochets of the larval prolegs.
vagina. The part of the female reproductive organs that receives the aedeagus of the male during copulation.
valva (pl. valvae). One of the paired lateral claspers of the male genitalia.
valvula. The ventral part of the valva, the dorsal apical part of which is differentiated to form a cucullus.
vein. Structures that support an insect's wing.
venation. The arrangement of veins in an insect's wing. Venation is very important in the identification of insect groups.
ventral. The underside of a caterpillar or imago on which are found the legs or prolegs.
vertex. The top of the head.
vesica. The penis, a membranous organ normally contained in the tubular aedeagus but everted during copulation. See endophallus.
vestigial. A structure (in biology a bodily organ or appendage) that has been reduced to the point where it no longer functions.
vindulum. The modified ninth sternum of the male abdomen, forming the ventral, U-shaped, basal part of the genitalia.

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