Handbook of Entomology

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Chapter- 1

Entomology

Entomology (from Greek ἔντομος, *entomologist*, "that which is cut in pieces or engraved/segmented", hence "insect"; and -λογία, *-logia*) is the scientific study of insects, a branch of arthropod. At some 1.3 million described species, insects account for more than two-thirds of all known organisms, date back some 400 million years, and have many kinds of interactions with humans and other forms of life on earth. It is a specialty within the field of biology. Though technically incorrect, the definition is sometimes widened to include the study of terrestrial animals in other arthropod groups or other phyla, such as arachnids, myriapods, earthworms, land snails, and slugs.

Like several of the other fields that are categorized within zoology, entomology is a taxon-based category; any form of scientific study in which there is a focus on insect related inquiries is, by definition, entomology. Entomology therefore includes a cross-section of topics as diverse as molecular genetics, behavior, biomechanics, biochemistry, systematics, physiology, developmental biology, ecology, morphology, paleontology, anthropology, robotics, agriculture, nutrition, forensic science and more.

History of entomology

Entomology is rooted in nearly all human cultures from prehistoric times, primarily in the context of agriculture (especially biological control and beekeeping), but scientific study began only as recently as the 16th century.

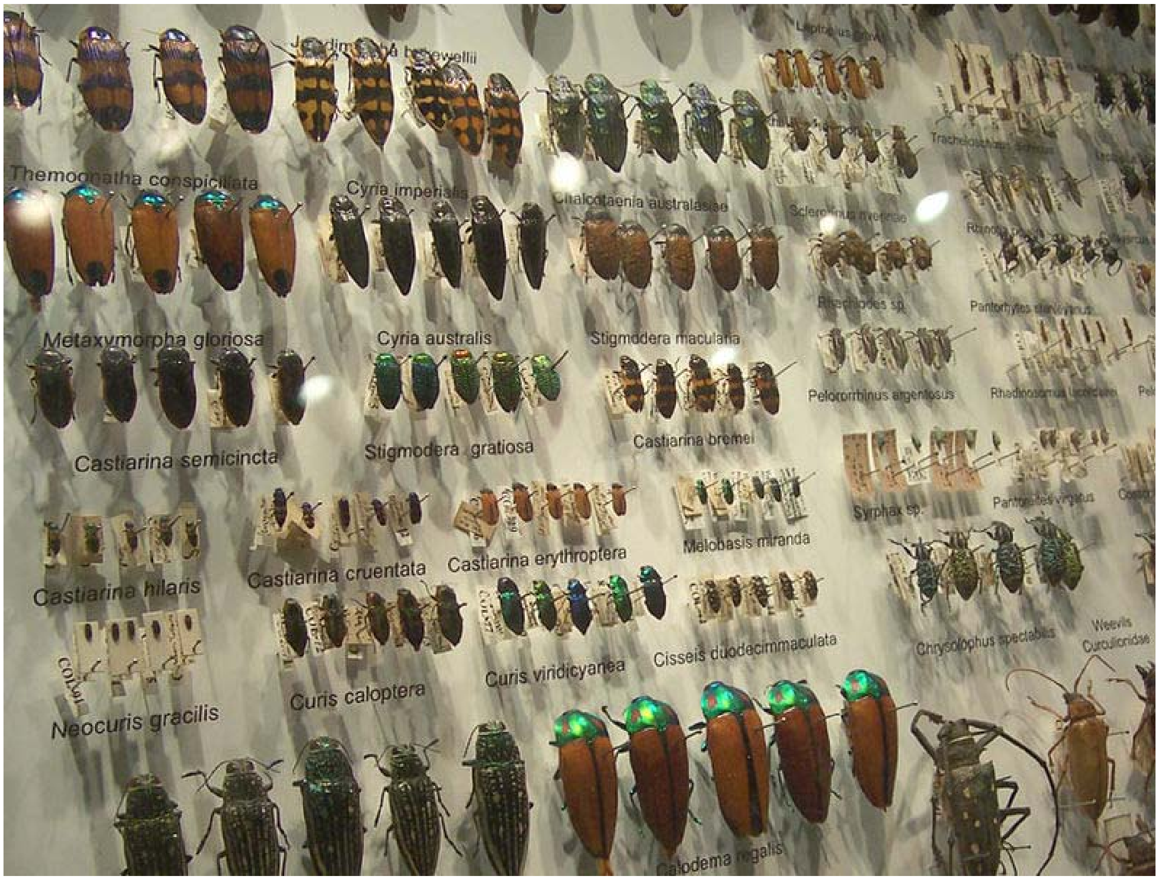
The list of entomologists through recorded history is enormous, and includes such notable figures as Charles Darwin, Jean-Henri Fabre, Vladimir Nabokov, Karl von Frisch (winner of the 1973 Nobel Prize in Physiology or Medicine,) and two-time Pulitzer Prize winner E. O. Wilson.

Identification of insects

Most insects can easily be recognized to order, such as Hymenoptera (bees, wasps, and ants) or Coleoptera (beetles). However, insects other than Lepidoptera (butterflies and moths) are typically identifiable to genus or species only through the use of Identification keys and Monographs. Because the class Insecta contains a very large number of species (over 330,000 species of beetles alone) and the characteristics separating them are unfamiliar, and often subtle (or invisible without a microscope), this is often very difficult even for a specialist.

Insect identification is an increasingly common hobby, with butterflies and dragonflies being the most popular.

Taxonomic specialization



Part of a large beetle collection

Many entomologists specialize in a single order or even a family of insects, and a number of these subspecialties are given their own informal names, typically (but not always) derived from the scientific name of the group:

- Apiology (or melittology) - bees
- Coleopterology - beetles
- Dipterology - flies
- Hemipterology - true bugs
- Lepidopterology - moths and butterflies
- Myrmecology - ants
- Orthopterology - grasshoppers, crickets, etc.
- Trichopterology - caddis flies

Organizations

Like other scientific specialties, entomologists have a number of local, national, and international organizations. There are also many organizations specializing in specific subareas.

- Amateur Entomologists' Society
- Deutsches Entomologisches Institut
- Entomological Society of America
- Entomological Society of Canada
- Entomological Society of Japan
- International Union for the Study of Social Insects
- Netherlands Entomological Society
- Royal Belgian Entomological Society
- Royal Entomological Society of London
- Société Entomologique de France

Museums

Here is a list of selected museums which contain very large insect collections.

Africa

- Natal Museum, Pietermaritzburg, South Africa

Europe

- Natural History Museum, London Natural History Museum
- Natural History Museum, Vienna Naturhistorisches Museum
- Natural History Museum, Paris Muséum national d'histoire naturelle
- Natural History Museum, Berlin Humboldt Museum
- Royal Museum for Central Africa, Brussels Royal Museum for Central Africa
- Natural History Museum, Leiden Natural History Museum, Leiden
- Natural History Museum, Sweden Swedish Museum of Natural History
- Natural History Museum, St. Petersburg Zoological Collection of the Russian Academy of Science
- Natural History Museum, Geneva
- The Bavarian State Collection of Zoology Zoologische Staatssammlung München
- Natural History Museum, Budapest Hungarian Natural History Museum

United States

- Academy of Natural Sciences, Philadelphia, Pennsylvania
- American Museum of Natural History, New York City, New York
- Auburn University Entomological Museum, Auburn University, Auburn, Alabama
- Audubon Insectarium, New Orleans, Louisiana
- Bohart Museum of Entomology,Davis,California
- California Academy of Sciences, San Francisco, California
- Carnegie Museum of Natural History, Pittsburgh, Pennsylvania
- Essig Museum, Berkely, California
- Field Museum of Natural History, Chicago, Illinois

- Florida Museum of Natural History, University of Florida, Gainesville, Florida
- Museum of Comparative Zoology, Cambridge, Massachusetts
- Natural History Museum of Los Angeles County, Los Angeles, California
- National Museum of Natural History, Washington, District of Columbia
- North Carolina State University Insect Museum, Raleigh, North Carolina
- Peabody Museum of Natural History, New Haven, Connecticut
- Texas A&M University, College Station, Texas
- University of Kansas Natural History Museum, Lawrence, Kansas
- University of Nebraska State Museum, Lincoln, Nebraska
- University of Missouri Enns Entomology Museum, University of Missouri, Columbia, Missouri

Canada

- Canadian Museum of Nature, Ottawa, Ontario
- Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, Ontario
- E.H. Strickland Entomological Museum, University of Alberta, Edmonton, Alberta
- Lyman Entomological Museum, Macdonald Campus of McGill University, Sainte-Anne-de-Bellevue, Quebec
- Montreal Insectarium, Montreal, Quebec
- Royal Alberta Museum, Edmonton, Alberta
- Royal Ontario Museum, Toronto, Ontario
- Newfoundland Insectarium, Reidville, Newfoundland
- University of Guelph Insect Collection, University of Guelph, Guelph, Ontario

Chapter- 2

Evolution of Insects

Evolution has produced astonishing variety in insects. Pictured are some of the possible shapes of antennae.

Insects are a highly diverse group of organisms with a worldwide distribution. They have conquered every terrestrial environment and have complex interactions with a wide variety of organisms, including predatory-prey relationships.

Taxonomic Affinities

The relationships of insects to other animal groups remain unclear. Although more traditionally grouped with millipedes and centipedes, evidence has emerged favouring closer evolutionary ties with the crustaceans. In the Pancrustacea theory, insects, together with among others Malacostraca, make up a monophyletic group (sharing a common ancestor): this is today a well accepted hypothesis.

Early evidence

The oldest definitive insect fossil is the Devonian *Rhyniognatha hirsti*, estimated at 396-407 million years old. This species already possessed dicondylic mandibles, a feature associated with winged insects, suggesting that wings may already have evolved at this time. Thus, the first insects probably appeared earlier, in the Silurian period.

The subclass Apterygota (wingless insects) is now considered artificial as the silverfish (order Thysanura) are more closely related to Pterygota (winged insects) than to bristletails (order Archaeognatha). For instance, just like flying insects, Thysanura have so-called dicondylic mandibles, while Archaeognatha have monocondylic mandibles. The reason for their resemblance is not due to a particularly close relationship, but rather because they both have kept a primitive and original anatomy in a much higher degree than the winged insects. The most primitive order of flying insects, the mayflies (Ephemeroptera), are also those who are most morphologically and physiologically similar to these wingless insects. Some mayfly nymphs resemble aquatic thysanurans.

Modern Archaeognatha and Thysanura still have rudimentary appendages on their abdomen called styli, while more primitive and extinct insects known as Monura had much more developed abdominal appendages, as seen here. The abdominal and thoracic segments in the earliest terrestrial ancestor of the insects would have been more similar to each other than they are today, and the head had well developed compound eyes and long antennae. Their body size is not known yet. As the most primitive group today, Archaeognatha, is most abundant near the coasts, it could mean that this was the kind of habitat where the insect ancestors became terrestrial. But this specialization to coastal niches could also have a secondary origin, just as could their jumping locomotion, as it is the crawling Thysanura who are considered to be most original (plesiomorphic). By looking at how primitive cheliceratan book gills (still seen in horseshoe crabs) evolved into book lungs in primitive spiders and finally into tracheae in more advanced spiders (most of them still have a pair of book lungs intact as well), it is possible the trachea of insects was formed in a similar way, modifying gills at the base of their appendages.

So far there is nothing that suggests the insects were a particularly successful group of animals before they got their wings.

Odonata

The Odonata (dragonflies) are also a good candidate as the oldest living member of the Pterygota. Mayflies are morphologically and physiologically more primitive, but the derived and advanced characteristics of dragonflies could have evolved independently in their own direction for a long time. It seems that orders with aquatic nymphs or larvae become evolutionarily conservative once they had adapted to water. If mayflies made it to the water first, this could partly explain why they are more primitive than dragonflies, even if dragonflies have an older origin.

Similarly, stoneflies are the most primitive of the Neoptera, but they were not necessarily the first order to branch off. This also makes it less likely that an aquatic ancestor would have the evolutionary potential to give rise to all the different forms and species of insects that we know today.

Dragonfly nymphs have a unique labial "mask" used for catching prey, and the imago has a unique way of copulating, using a secondary male sex organ on the second abdominal segment. It looks like abdominal appendages modified for sperm transfer and direct insemination have occurred at least twice in insect evolution, once in Odonata and once in the other flying insects. If these two different methods are the original ways of copulating for each group, it is a strong indication that it is the dragonflies who are the oldest, not the mayflies. There is still not agreement about this. Another scenario is that abdominal appendages adapted for direct insemination have evolved three times in insects; once Odonata, once in mayflies and once in the Neoptera, both mayflies and Neoptera choosing the same solution. If so, it is still possible that mayflies are the oldest order among the flying insects. The power of flight is assumed to have evolved only once, suggesting sperm transfer in the earliest flying insects still was done indirectly.

One possible scenario on how direct insemination evolved in insects is seen in scorpions. The male deposits a spermatophore on the ground, locks its claws with the female's claws and then guides her over his packet of sperm, making sure it comes in contact with her genital opening.

When the early (male) insects laid their spermatophores on the ground, it seems likely that some of them used the clasping organs at the end of their body to drag the female over the package. The ancestors of Odonata evolved the habit of grabbing the female behind her head, as they still do today. This action, rather than not grasping the female at all, would have increased the male's chances of spreading its genes. The chances would be further increased if they first attached their spermatophore safely on their own abdomen before they placed their abdominal claspers behind the female's head; the male would then not let the female go before her abdomen had made direct contact with his sperm storage, allowing the transfer of all sperm.

This also meant increased freedom in searching for a female mate because the males could now transport the packet of sperm elsewhere if the first female slipped away. This ability would eliminate the need to either wait for another female at the site of the deposited sperm packet or to produce a new packet, wasting energy. Other advantages include the possibility of mating in other, safer places than flat ground, such as in trees or bushes.

If the ancestors of the other flying insects evolved the same habit of clasping the female and dragging her over their spermathophore, but posterior instead of anterior like the Odonata does, their genitals would come very close to each others. And from there on, it would be a very short step to modify the vestigial appendages near the male genital opening to transfer the sperm directly into the female. The same appendages the male Odonata use to transfer their sperm to their secondary sexual organs at the front of their abdomen.

All insects with an aquatic nymphal or larval stage seem to have adapted to water secondarily from terrestrial ancestors. Of the most primitive insects with no wings at all, Archaeognatha and Thysanura, all members live their entire life cycle in terrestrial environments. As mentioned previously, Archaeognatha were the first to split off from the branch that led to the winged insects (Pterygota), and then the Thysanura branched off. This indicates that these three groups (Archaeognatha, Thysanura and Pterygota) have a common terrestrial ancestor, which probably resembled a primitive model of Apterygota, was an opportunistic generalist and laid spermatophores on the ground instead of copulating, like Thysanura still do today. If it had feeding habits similar to the majority of apterygotes of today, it lived mostly as a decomposer.

One should expect that a gill breathing arthropod would modify its gills to breathe air if it were adapting to terrestrial environments, and not evolve new respiration organs from bottom up next to the original and still functioning ones.

Then comes the fact that insect (larva and nymph) gills are actually a part of a modified, closed trachea system specially adapted for water, called tracheal gills. The arthropod trachea can only arise in an atmosphere and as a consequence of the adaptations of living on land. This too indicates that insects are descended from a terrestrial ancestor.

And finally when looking at the three most primitive insects with aquatic nymphs (called naiads: Ephemeroptera, Odonata and Plecoptera), each order has its own kind of tracheal gills that are so different from one another that they must have separate origins. This would be expected if they evolved from land-dwelling species.

This means that one of the most interesting parts of insect evolution is what happened between the Thysanura-Pterygota split and the first flight.

Evolutionary relationships

Insects have complex evolutionary and ecological relationships with other groups including plants and other animals. For example, insects are prey for a variety of organisms, including terrestrial vertebrates. The earliest vertebrates on land existed 400 million years ago and were large amphibious piscivores, through gradual evolutionary change, insectivory was the next diet type to evolve.

Origin of insect flight

The origin of insect flight remains obscure, since the earliest winged insects currently known appear to have been capable fliers. Some extinct insects (e.g. the Palaeodictyoptera) had an additional pair of winglets attached to the first segment of the thorax, for a total of three pairs.

The wings themselves are thought by many to be highly modified (tracheal) gills. And there is no doubt that the tracheal gills of the mayfly nymph in many species look like wings. By comparing a well developed pair of gill blades in the naiads and a reduced pair of hind wings on the adults, it is not hard to imagine that the mayfly gills (tergaliae) and insect wings have a common origin, and newer research also supports this. The tergaliae are not found in any other order of insects, and they have evolved in different directions with time. In some nymphs/naiads the most anterior pair has become sclerotized and works as a gill cover for the rest of the gills. Others can form a large sucker, be used for swimming or modified into other shapes. But it doesn't have to mean that these structures were originally gills. It could also mean that the tergaliae evolved from the same structures which gave rise to the wings, and that flying insects evolved from a wingless terrestrial species with pairs of plates on its body segments: three on the thorax and nine on the abdomen (mayfly nymphs with nine pairs of tergaliae on the abdomen exist, but so far no living or extinct insects with plates on the last two segments have been found). If these were primary gills, it would be a mystery why they should have waited so long to be modified when we see the different modifications in modern mayfly nymphs.

Theories

When the first forests arose on Earth, new niches for terrestrial animals were created. Spore-feeders and others who depended on plants and/or the animals living around them would have to adapt too to make use of them. In a world with no flying animals, it would probably just be a matter of time before some arthropods who were living in the trees evolved paired structures with muscle attachments from their exoskeleton and used them for gliding, one pair on each segment. Further evolution in this direction would give bigger gliding structures on their thorax and gradually smaller ones on their abdomen. Their bodies would have become stiffer while thysanurans, which didn't evolve flight, kept their flexible abdomen.

Mayfly nymphs must have adapted to water while they still had the "gliders" on their abdomen intact. So far there is no concrete evidence to support this theory either, but it is one that offers an explanation for the problems of why presumably aquatic animals evolved in the direction they did.

Leaping and arboreal insects seems like a good explanation for this evolutionary process for several reasons. Because early winged insects were lacking the sophisticated wing folding mechanism of neopterous insects, they must have lived in the open and not been able to hide or search for food under leaves, in cracks, under rocks and other such confined spaced. In these old forests there weren't many open places where insects with huge structures on their back could have lived without experiencing huge disadvantages. If insects got their wings on land and not in water, which clearly seems to be the case, the tree canopies would be the most obvious place where such gliding structures could have emerged, in a time when the air was a new territory. The question is if the plates used for gliding evolved from "scratch" or by modifying already existing anatomical details. The thorax in Thysanura and Archaeognatha are known to have some structures connected to their trachea which share similarities to the wings of primitive insects. This suggests the origin of both the wings and the spiracles are related.

Gliding requires universal body modifications, as seen in present-day vertebrates such as some rodents and marsupials, which have grown wide, flat expansions of skin for this purpose. The flying dragons (genus *Draco*) of Indonesia has modified its ribs into gliders, and even some snakes can glide through the air by spreading their ribs. The main difference is that while vertebrates have an inner skeleton, primitive insects had a flexible and adaptive exoskeleton.

It is clear that there would have been some animals living in the trees, as animals are always taking advantage of all available niches, both for feeding and protection. At the time, the reproductive organs were by far the most nutritious part of the plant, and these early plants show signs of arthropod consumption and adaptations to protect themselves, for example by placing their reproductive organs as high up as possible. But there will always be some species who will be able to cope with that by following the their food source up the trees.

Knowing that insects were terrestrial at that time and that some arthropods (like primitive insects) were living in the tree crowns, it seems less likely that they would have developed their wings down on the ground or in the water.

In a three dimensional environment such as trees, the ability to glide would increase the insects' chances to survive a fall, as well as saving energy. This trait has repeated itself in modern wingless species such as the gliding ants who are living an arboreal life. When the gliding ability first had originated, gliding and leaping behavior would be a logical next step, which would eventually be reflected in their anatomical design.

The need to navigate through vegetation and to land safely would mean good muscle control over the proto-wings, and further improvements would eventually lead to true (but primitive) wings.

While the thorax got the wings, a long abdomen could have served as a stabilizer in flight.

It is also worth remembering that some of the earliest flying insects were large predators. This isn't surprising since there weren't yet any other predators hunting in the air: it was therefore a totally new ecological niche. Some of the prey were without a doubt other insects, as insects with proto-wings would have radiated into other species even before the wings were fully evolved. From this point onwards, the arms race could continue: the same predator/prey co-evolution which has existed as long as there have been predators and prey on earth; both the hunters and the hunted were in need of improving and extending their flight skills even further to keep up with the other.

Insects that had evolved their proto-wings in a world without flying predators could afford to be exposed openly without risk, but this changed when carnivorous flying insects evolved. It is unknown when they first evolved, but once these predators had emerged they put a strong selection pressure on their victims and themselves. Those of the prey who came up with a good solution about how to fold their wings over their backs in a way that made it possible for them to live in narrow spaces would not only be able to hide from flying predators (and terrestrial predators if they were on the ground) but also to exploit a wide variety of niches that were closed to those who couldn't fold their wings in this way. And today the neopterous insects (those that can fold their wings back over the abdomen) are by far the most dominant group of insects.

The water-skimming theory suggests that skimming on the water surface is the origin of insect flight. This theory is based on the fact that the first fossil insects, the Devonian *Rhyniognatha hirsti*, is thought to have possessed wings, even though the insects closest evolutionary ties are with crustaceans, which are aquatic.

Life cycle

Mayflies

Another primitive trait of the mayflies are the subimago; no other insects have this winged yet sexually immature stage. A few specialized species have females with no subimago, but retain the subimago stage for males.

The reasons the subimago still exists in this order could be that there hasn't been enough selection pressure to get rid of it; it also seems specially adapted to do the transition from water to air.

The male geniatalia are not fully functional at this point. One reason for this could be that the modification of the abdominal appendages into male copulation organs emerged later than the evolution of flight. This is indicated by the fact that dragonflies have a different copulation organ than other insects.

As we know, in mayflies the nymphs and the adults are specialized for two different ways of living; in the water and in the air. The only stage (instar) between these two is the subimago. In more primitive fossil forms, the preadult individuals had not just one instar but numerous ones (while the modern subimago do not eat, older and more primitive species with a subimagos were probably feeding in this phase of life too as the lines between the instars were much more diffuse and gradual than today). Adult form was reached several moults before maturity. They probably didn't have more instars after becoming fully mature. This way of maturing is how Apterygota do it, which moult even when mature, but not winged insects.

Modern mayflies have eliminated all the instars between imago and nymph, except the single instar called subimago, which is still not (at least not in the males) fully sexually mature. The other flying insects with incomplete metamorphosis (Exopterygota) have gone a little further and completed the trend; here all the immature structures of the animal from the last nymphal stage are completed at once in a single final moult. The more advanced insects with larvae and complete metamorphosis (Endopterygota) have gone even further. An interesting theory here is that the pupal stage is actually a strongly modified and extended stage of subimago, but so far it is nothing more than a theory. Interestingly enough there are some insects within the Exopterygota, thrips and whiteflies (Aleyrodidae), who have evolved pupae-like stages too.

Distant ancestors

The distant ancestor of flying insects, a species with primitive proto-wings, had a more or less ametabolous life cycle and instars of basically the same type as thysanurans with no defined nymphal, subimago or adult stages as the individual became older. Individuals developed gradually as they were growing and moulting, but there were probably no big changes in between instars.

Modern mayfly nymphs do not acquire gills until after their first moult. Before this stage they are so small that there is no need for gills to extract oxygen from the water. This could be a trait from the common ancestor all flyers evolved from. An early terrestrial insect would have no need for paired outgrowths from the body before it started to live in the trees (or in the water, for that matter), so it would not have any.

This would also affect the way their offspring looked like in the early instars, resembling earlier ametabolous generations even after they had started to adapt to a new way of living, in a habitat where they actually could have some good use for flaps along their body. Since they matured in the same way as thysanurans with plenty of moultings as they were growing and very little difference between the adults and much younger individuals (unlike modern insects, who are hemimetabolous or holometabolous), there probably wasn't much room for adapting into different niches depending on age and stage. Also, it would have been difficult for an animal already adapted to a niche to make a switch to a new niche later in life based on age or size differences alone when these differences were not significant.

So they had to specialize and focus their whole existence on improving a single lifestyle in a particular niche. The older the species and the single individuals became, the more would they differ from their original form as they adapted to their new lifestyle better than the generations before. The final body design was no longer achieved while still inside the egg, but continued to develop for most of the life, causing a bigger difference between the youngest and oldest individuals. Assuming that mature individuals most likely mastered their new element better than did the nymphs who had the same lifestyle, it would appear to be an advantage if the immatures reached adult shape and form as soon as possible. This may explain why they evolved fewer but more intense instars and a stronger focus on the adult body, and the differences between the adults and the first instars were greater, instead of just gradually growing bigger as earlier generations had done. This evolutionary trend explains how they went from ametabolous to hemimetabolous insects.

Reaching maturity and a fully grown body became only a part of the development process, gradually also a new anatomy and new abilities only possible in the later stages of life, were included. The anatomy they were born and grew up with had limitations the adults who had learned to fly didn't have. If they couldn't live their early life the way adults did, immature individuals had to adapt to the best way of living and surviving despite their limitations till the moment came when they could leave them behind. This would be a starting point in the evolution where imago and nymphs started to live in different niches, some more clearly defined than others. Also, a final anatomy, size and maturity reached at once with a single final nymphal stage meant less waste of time and energy, and also made a more complex adult body structure. These strategies obviously became very successful with time.

Late Carboniferous and Early Permian insect orders include both several current very long-lived groups (mayflies, (Ephemeroptera), dragonflies (Odonata), cockroaches (Blattodea), and Orthoptera (grasshoppers and their relatives)) and a number of Paleozoic forms. During this era, some giant dragonfly-like forms – e.g. *Meganeura* and *Meganeuropsis* (Order Protodonata) and *Mazothairos* (Order Palaeodictyoptera) – reached wingspans of 55 to 70 cm (22 to 28 in), making them far larger than any living insect. Also their nymphs must have had a very impressive size. This gigantism may have been due to higher atmospheric oxygen levels (up to 80% above modern levels during the Carboniferous) that allowed increased respiratory efficiency relative to today. The lack of flying vertebrates could have been another factor.

Most extant orders of insects developed during the Permian period that began around 270 million years ago. Many of the early groups became extinct during the Permian-Triassic extinction event, the largest mass extinction in the history of the Earth, around 252 million years ago.

The remarkably successful Hymenopterans appeared in the Cretaceous but achieved their diversity more recently, in the Cenozoic. A number of highly successful insect groups — especially the Hymenoptera and Lepidoptera (butterflies), as well as many types of Diptera (flies) and Coleoptera (beetles) — evolved in conjunction with flowering plants, a powerful illustration of co-evolution.

Many modern insect genera developed during the Cenozoic; insects from this period on are often found preserved in amber, often in perfect condition. Such specimens are easily compared with modern species. The study of fossilized insects is called paleoentomology.

Chapter- 3

Apiology and Myrmecology

Apiology

Apiology (from Latin *apis*, "bee", and Greek -λογία, *-logia*) is the scientific study of honey bees, a subdiscipline of **melittology**, which is itself a branch of entomology. Honey bees are often chosen as a study group to answer questions on the evolution of social systems.

Related terms

Melittology is the study of all bees, which comprise more than 17,000 species *other* than honey bees. **Apicology** is honey bee ecology. **Apidology** is a variant spelling of *apiology* used outside of the Western Hemisphere, primarily in Europe (e.g.,); it is sometimes used interchangeably with *melittology* (e.g.).

List of notable Apiologists

- Charles Butler, (1560-1647), early English beekeeper and researcher.
- Charles Dadant, (1817-1902), Modernized beekeeping.
- Jan Dzierzon, (1811-1906), Discovered parthenogenesis among bees, proposed first sex determining mechanism for any species.
- Jay Hosler, Professor at Juniata College, Author of the award-winning comic *Clan Apis*.
- Karl Kehrle (aka "Brother Adam") (1898-1996), Benedictine monk, beekeeper, and an authority on bee breeding, developer of the Buckfast bee.
- Warwick Estevam Kerr, (b.1922), Studies genetics and sex determination in honey bees. Responsible for introduction of Africanized bees to America.
- William Kirby, (1759-1850), Author of the first scientific treatise on English bees.
- L. L. Langstroth, (1810-1895), Modernized American beekeeping.
- Martin Lindauer, (1918-2008), studied communication systems in various species of social bees including stingless bees and honey bees.
- Sir John Lubbock (the 1st Lord and Baron Avebury) (1834–1913), wrote on hymenoptera sense organs.
- Robert E. Page, Jr., Studies population genetics and the evolution of complex social behavior at Arizona State University.
- Petro Prokopovych, (1775–1850), Ukrainian beekeeper, founder of commercial beekeeping.
- Moses Quinby, (1810-1875), Early American commercial beekeeper. Invented modern bee smoker.
- Gene E. Robinson, Studies mechanisms of behavior at the University of Illinois.
- Justin O. Schmidt, Studies bee nutrition, chemical communication, physiology, ecology and behavior. Created Schmidt Sting Pain Index.
- Thomas D. Seeley, Studies group organization using the honey bee as a model system at Cornell University.
- Robert Evans Snodgrass, (1875-1962), Author of one of the first comprehensive books on honey bee anatomy and physiology.
- Stephen Taber III, (1924-2008), Innovator in the practice of artificial insemination of queen bees for the purpose of developing disease resistant and gentle bee colonies.
- Mark Winston, Studies life history, caste structure, and reproduction in social insects and pheromones of honey bees at Simon Fraser University.

Myrmecology

Myrmecology is the scientific study of ants, a branch of entomology. Some early myrmecologists considered ant society as the ideal form of society and sought to find solutions to human problems by studying them. Ants continue to be a model of choice for the study of questions on the evolution of social systems because of their complex and varied forms of eusociality. Their diversity and prominence in ecosystems has also made them important components in the study of biodiversity and conservation.

History

The word myrmecology was coined by William Morton Wheeler (1865–1937) although human interest in the life of ants goes back further with numerous ancient folk references. The earliest scientific thinking based on observation of ant life was that of Auguste Forel (1848–1931), a Swiss psychologist who was initially interested in ideas of instinct, learning and society. In 1874 he wrote a book on the ants of Switzerland, *Les fourmis de la Suisse* and he named his home as *La Fourmilière* (the ant colony). Forel's early studies included attempts to mix species of ants in a colony. He noted polydomy and monodomy in ants and compared them with the structure of nations.

Wheeler looked at ants in a new light, in terms of the social organization and in 1910 he delivered a lecture at Woods Hole on the “The Ant-Colony as an Organism,” which pioneered the idea of superorganisms. Wheeler considered trophallaxis or the sharing of food within the colony as the core of ant society. This was studied using a dye in the food and observing how it spread in the colony.

Some like Horace Donisthorpe worked on the systematics of ants. This tradition continued in many parts of the world until advances in other aspects of biology were made. The advent of genetics, ideas in ethology and its evolution led to new thought. This line of enquiry was pioneered by E. O. Wilson who founded the field termed as sociobiology.

List of notable myrmecologists

- Donat Agosti
- E. André (1838–1911)
- Cesari Baroni Urbani
- Murray S. Blum (1929—), Chemical ecologist, and an expert on pheromones.
- Barry Bolton, English ant taxonomist.
- Thomas Borgmeier
- William L. Brown, Jr.
- J. Clark
- Giovanni Cobelli (1849–1937), Italian entomologist. Director of the Rovereto museum.
- A. C. Cole, Jr.
- Cedric Collingwood
- W. C. Crawley
- William Steel Creighton
- Mark A. Deyrup
- Horace Donisthorpe (1870–1951), British myrmecologist. Named several new species.
- Carlos Emery
- Auguste Forel (1848–1931), Swiss myrmecologist, studied brain structure of humans and ants.
- Émil Goeldi
- Deborah Gordon (1955—), Studies ant colony behavior and ecology.
- William H. Gotwald, Jr.
- William Gould (~1715–?), described by Horace Donisthorpe as "the father of British myrmecology".
- Michael Greene Studies interactions between chemical cues and behavior patterns
- Robert E. Gregg
- Bert Hölldobler (1936—), Pulitzer Prize winning German myrmecologist.
- Thomas C. Jerdon (1811–1872)
- Laurent Keller (1961—)
- Walter W. Kempf (- 1976)
- N. Kusnezov
- John E. Lattke
- John T. Longino

- Sir John Lubbock (the 1st Lord and Baron Avebury) (1834–1913), wrote on hymenoptera sense organs.
- William Mann
- Gustav Mayr, Austrian entomologist and professor in Pest and Vienna. He specialised in Hymenoptera.
- Harold Medford - United States Department of Agriculture
- C. Menozzi
- Mark W. Moffett
- Derek Wragge Morley (1920–1969), research included genetics, social behaviour of animals, and the behaviour of agricultural pests.
- Fergus O'Rourke (1923— 2010), Irish zoologist
- Felix Santschi
- Justin O. Schmidt, studies the chemical and behavioral defenses of ants, wasps, and arachnids.
- T. C. Schneirla
- S. O. Shattuck
- Frederick Smith (1805–1879), worked in the zoology department of the British Museum from 1849, specialising in the Hymenoptera.
- Marion R. Smith
- Roy R. Snelling (1934–2008), credited with many important finds of rare or new ant species.
- R. W. Taylor
- Walter Tschinkel
- James C. Trager
- Philip S. Ward
- E. Wasmann
- Neal A. Weber
- John Obadiah Westwood (1805–1893), English entomologist and archaeologist also noted for his artistic talents.
- William Morton Wheeler (1865–1937), curator of invertebrate zoology in the American Museum of Natural History. Described many new species.
- E. O. Wilson (1929—), Pulitzer Prize winning American myrmecologist. Revolutionized the field of sociobiology.

Chapter- 4

Fly

Fly
Fossil range: Middle Triassic - Recent 245–0 Ma

A poster with sixteen different species of flies

Scientific classification

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Superorder:	Panorpida
(unranked):	Antliophora
Order:	**Diptera** Linnaeus, 1758

Suborders

Nematocera (includes Eudiptera)
Brachycera

True **flies** are insects of the order **Diptera** (*di* = two, and *ptera* = wings). They possess a pair of wings on the mesothorax and a pair of halteres, derived from the hind wings, on the metathorax.

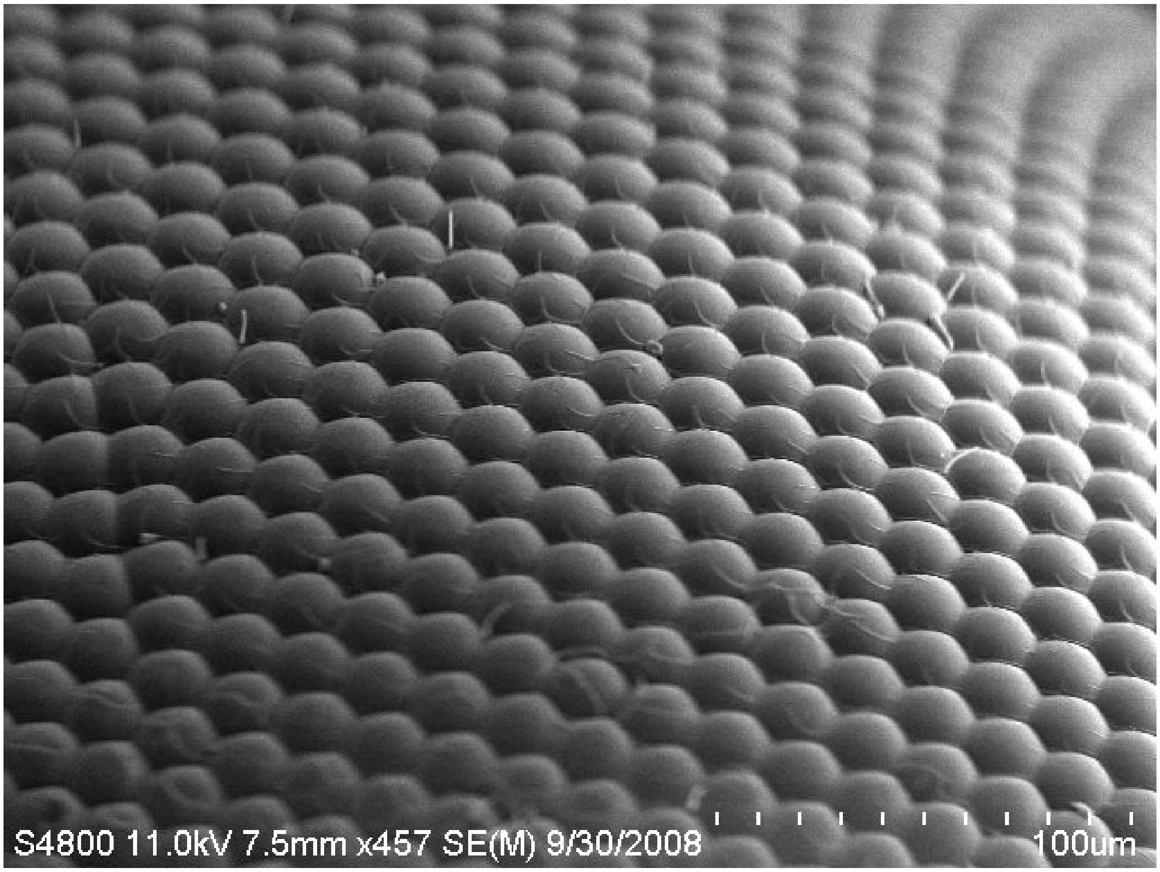
The presence of a single pair of wings distinguishes true flies from other insects with "fly" in their name, such as mayflies, dragonflies, damselflies, stoneflies, whiteflies, fireflies, alderflies, dobsonflies, snakeflies, sawflies, caddisflies, butterflies or scorpionflies. Some true flies have become secondarily wingless, especially in the superfamily Hippoboscoidea, or among those that are inquilines in social insect colonies.

The common names of true flies are written as two words, e.g., crane fly, robber fly, bee fly, moth fly, fruit fly. The common names of non-dipteran insects that have "fly" in their name are written as one word, e.g., butterfly, stonefly, dragonfly, scorpionfly, sawfly, caddisfly, whitefly.

Diptera is a large order, containing an estimated 240,000 species of mosquitoes, gnats, midges and others, although under half of these (about 120,000 species) have been described. It is one of the major insect orders both in terms of ecological and human (medical and economic) importance. The Diptera, in particular the mosquitoes (Culicidae), are of great importance as disease transmitters, acting as vectors for malaria, dengue, West Nile virus, yellow fever, encephalitis and other infectious diseases.

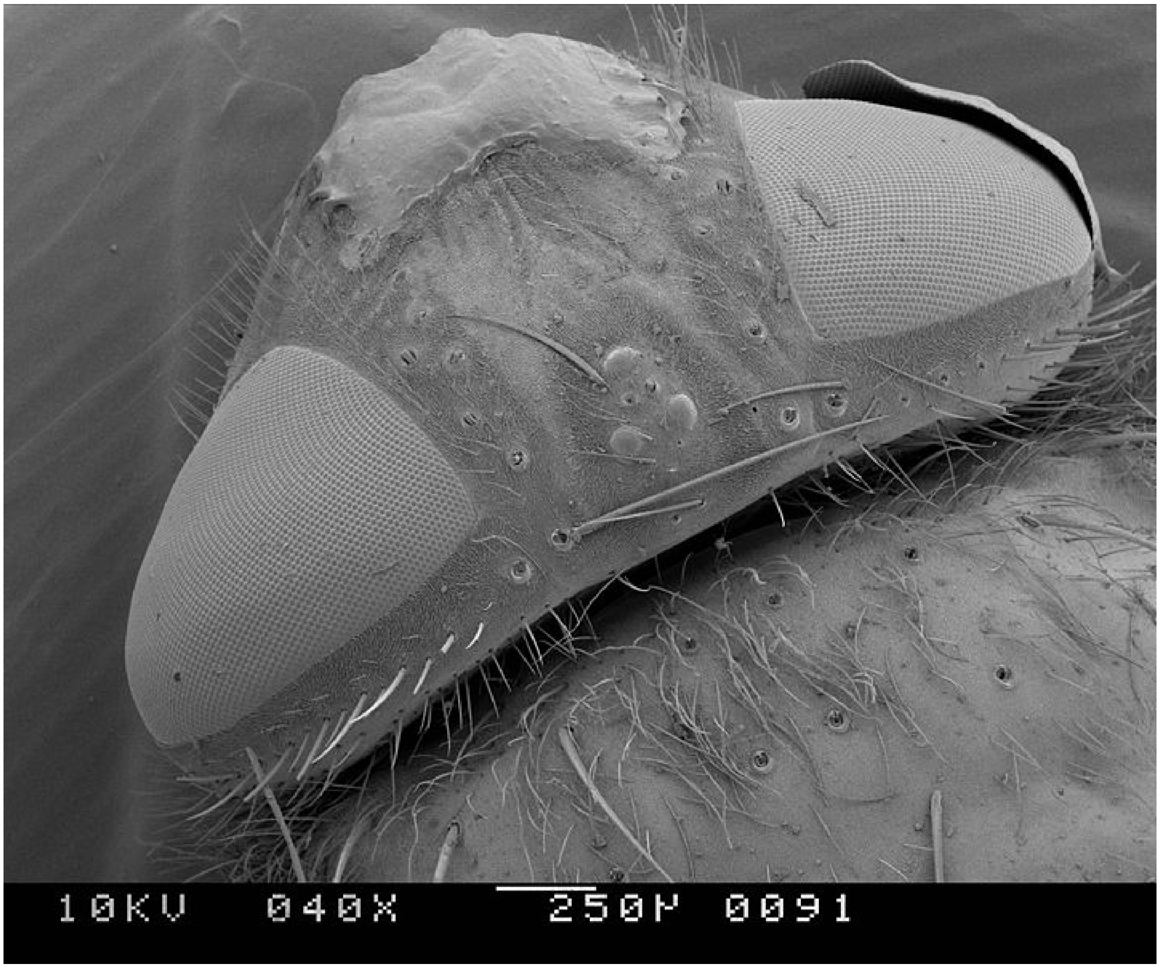
Anatomy and biology

Portrait of a flesh fly (Sarcophagidae)



An image of a house fly eye surface by using scanning electron microscope at 450× magnification

Flies are adapted for aerial movement, and typically have short and streamlined bodies. The first segment of the fly is the head and consists of ocelli, antennae, compound eyes, and the mouth (the labrium, mandible and maxilla make up the mouth). The second segment of the thorax, which bears the wings and contains the flight muscles, is greatly enlarged, with the other two segments being reduced to collar-like structures. The third segment bears the halteres, which help to balance the insect during flight. A further adaptation for flight is the reduction in number of the neural ganglia, and concentration of nerve tissue in the thorax, a feature that is most extreme in the highly derived Muscomorpha infraorder.



A scan of a house fly taken at 40 magnifications under a scanning electron microscope

Flies have a mobile head with eyes, and, in most cases, have large compound eyes on the sides of the head, with five small ocelli on the top. The antennae take a variety of forms, but are often short, to reduce drag while flying.

Because no species of fly have teeth or any other organ or limb that allows them to eat solid foods, flies consume only liquid food, and their mouthparts and digestive tract show various modifications for this diet. The gut includes large diverticulae, allowing the insect to store small quantities of liquid after a meal.

Reproduction and development

Mating anthomyiid flies

The genitalia of female flies are rotated to a varying degree from the position found in other insects. In some flies this is a temporary rotation during mating, but in others it is a permanent torsion of the organs that occurs during the pupal stage. This torsion may lead to the anus being located below the genitals, or, in the case of 360° torsion, to the sperm duct being wrapped around the gut, despite the external organs being in their usual position. When flies mate, the male initially flies on top of the female, facing in the same direction, but then turns round to face in the opposite direction. This forces the male to lie on its back in order for its genitalia to remain engaged with those of the female, or the torsion of the male genitals allows the male to mate while remaining upright. This leads to flies having more reproduction abilities than most insects and at a much quicker rate. Flies come in great populations due to their ability to mate effectively and in a short period of time during the mating season.

The female lays her eggs as close to the food source as possible, and development is rapid, allowing the larva to consume as much food as possible in a short period of time before transforming into the adult. The eggs hatch immediately after being laid, or the flies are ovoviviparous, with the larva hatching inside the mother.

Larval flies, or maggots, have no true legs, and little demarcation between the thorax and abdomen; in the more derived species, the head is not clearly distinguishable from the rest of the body. Maggots are limbless, or else have small prolegs. The eyes and antennae are reduced or absent, and the abdomen also lacks appendages such as cerci. This lack of features is an adaptation to a food-rich environment, such as within rotting organic matter, or as an endoparasite.

The pupae take various forms, and in some cases develop inside a silk cocoon. After emerging from the pupa, the adult fly rarely lives more than a few days, and serves mainly to reproduce and to disperse in search of new food sources.

Classification

Cleaning

The Nematocera are recognized by their elongated bodies and feathery antennae as represented by mosquitoes and crane flies. The Brachycera have a more roundly proportioned body and much shorter antennae. In 1964, B.B. Rohdendorf proposed a classification in which the Nematocera is split into two suborders, the Archidiptera and the Eudiptera.

1. Suborder Nematocera (77 families, 35 of them extinct) – long antennae, pronotum distinct from mesonotum. In Nematocera, larvae are either eucephalic or hemicephalic and often aquatic.

2. Suborder Brachycera (141 families, 8 of them extinct) – short antennae, the pupa is inside a puparium formed from the last larval skin. Brachycera are generally robust flies with larvae having reduced mouthparts.
    1. Infraorders Tabanomorpha and Asilomorpha – these comprise the majority of what was the Orthorrhapha under older classification schemes. The antennae are short, but differ in structure from those of the Muscomorpha.
    2. Infraorder Muscomorpha – (largely the Cyclorrhapha of older schemes). Muscomorpha have 3-segmented, aristate (with a bristle) antennae and larvae with three instars that are acephalic (maggots).

Most of the Muscomorpha are further subdivided into the Acalyptratae and Calyptratae based on whether or not they have a calypter (a wing flap that extends over the halteres).

Beyond that, considerable revision in the taxonomy of the flies has taken place since the introduction of modern cladistic techniques, and much remains uncertain. The secondary ranks between the suborders and the families are out of practical or historical considerations than out of strict respect for phylogenetic classifications (modern cladists spurn the use of Linnaean rank names).

Dipterans belong to the taxon Mecopterida, that also contains Mecoptera, Siphonaptera, Lepidoptera (butterflies and moths) and Trichoptera. Inside it, they are classified closely together with Mecoptera and Siphonaptera in the superorder Antliophora.

Evolution

Diptera derive from Mecoptera or a strictly related group. The first true dipterans are known from the Middle Triassic, becoming widespread during the Middle and Late Triassic.

Chapter- 5

Lepidoptera

Lepidoptera **Temporal range: 199–0 Ma** **Jurassic – Recent**	

A Giant Leopard Moth (*Hypercompe scribonia*)

Scientific classification	
Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Subclass:	Pterygota
Infraclass:	Neoptera
Superorder:	Endopterygota
Order:	**Lepidoptera** Linnaeus, 1758

Suborders

Aglossata
Glossata
Heterobathmiina
Zeugloptera

Lepidoptera is a large order of insects that includes moths and butterflies (called **lepidopterans**). It is one of the most speciose orders in the world, encompassing moths and the three superfamilies of butterflies, skipper butterflies, and moth-butterflies and found virtually everywhere. The name is derived from Ancient Greek λεπίδος (scale) and πτερόν (wing). Comprising over 160,000 described species, in 126 families and 46 superfamilies, the Lepidoptera show many variations of the basic body structure which have evolved to gain advantages in lifestyle and distribution. Recent estimates suggest that the order may have more species, and is among the four largest, most successful orders, along with the Hymenoptera, Diptera, and the Coleoptera.

Species of the order Lepidoptera are commonly characterized as being covered in scales, having two large compound eyes, and a proboscis. Almost all species have membranous wings, except for a few which have crossvein wings. The larvae are called caterpillars and are completely different in form, having a cylindrical body with a well developed head, mandible mouthparts, and from 0–11 (usually 8) pairs of prolegs.

The Lepidoptera have, over millions of years, evolved a wide range of wing patterns and colouration ranging from drab moths akin to the related order Trichoptera to the brightly coloured and complex-patterned butterflies. Accordingly, this is the most recognized and popular of insect orders with many people involved in the observing, study, collecting, rearing and commerce of these insects. A person who collects or studies this order is referred to as a lepidopterist. Many species of the order are of economic interest by virtue of their important natural role through pollination or the silk they produce.

Etymology

The word Lepidoptera comes from the Latin word for "scaly wing", from the Ancient Greek λεπίς (*lepis*) meaning scale and πτερόν (*pteron*) meaning wing. Sometimes the term Rhopalocera is used to group the species that are butterflies, from the Ancient Greek ῥόπαλον (*rhopalon*) and κέρας (*kæras*) meaning *club* and *horn* respectively; coming from the shape of the antennae of butterflies.

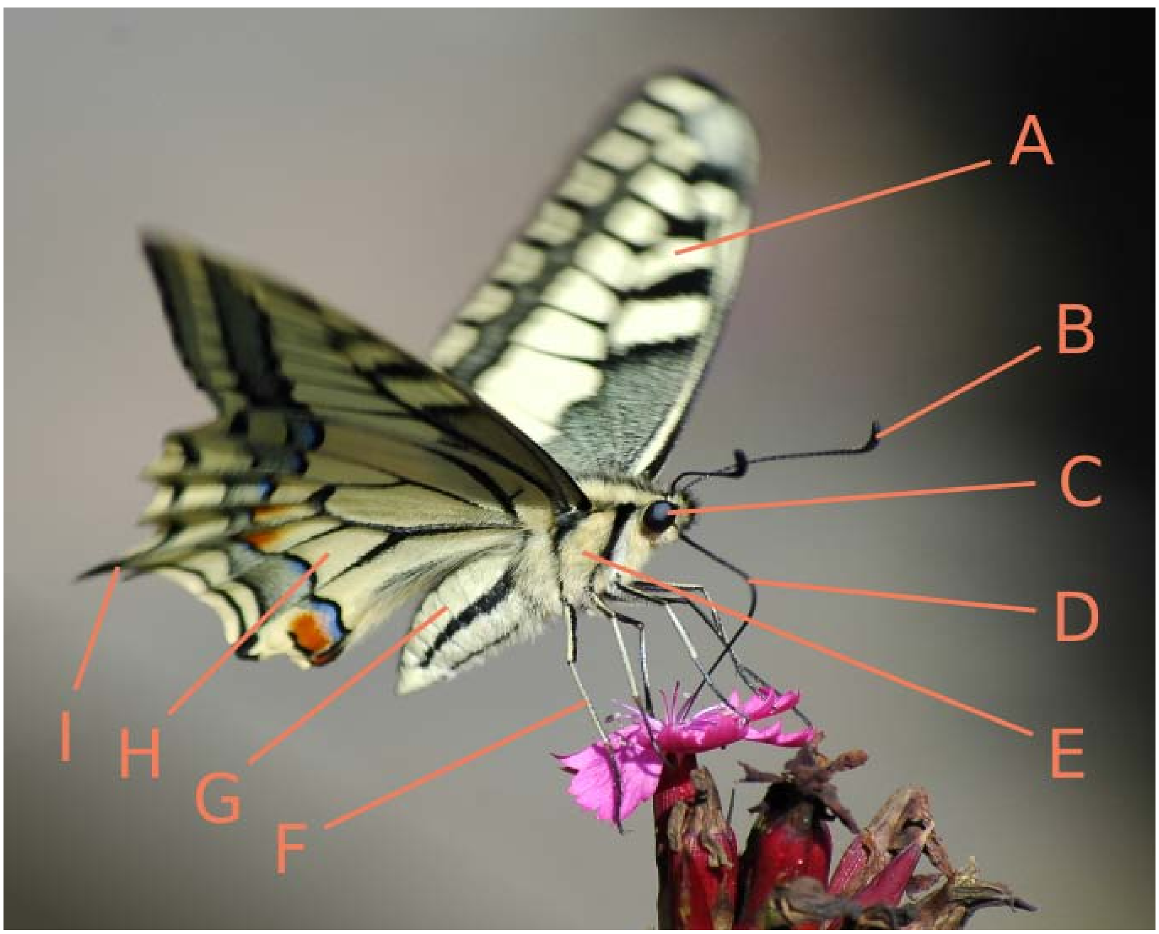
The origins of the common names of many species vary. The English word *butterfly* is from Old English *buttorfleoge*, with many variations in spelling. Other than that, the origin is unknown, although it could be derived from the pale yellow colour of many species' wings suggesting the colour of butter.[butterfly] The species of Heterocera are commonly called moths. The origins of the English word moth are more clear, which comes from Old English *moððe*" (cf. Northumbrian dialect *mohðe*) from Common Germanic (compare Old Norse *motti*, Dutch *mot* and German *Motte* all meaning "moth"). Perhaps its origins are related to Old English *maða* meaning "maggot" or from the root of "midge" which until the 16th century was used mostly to indicate the larva, usually in reference to devouring clothes.[moth]

Distribution and diversity

Lepidoptera are among the most successful groups of insects. They are to be found on all continents, except the Antarctic. Lepidoptera inhabit all terrestrial habitats ranging from desert to rainforest, from lowland grasslands to montane plateaus but almost always associated with higher plants, especially angiosperms (flowering plants). Amongst the northern-most of butterflies and moths is the Arctic Apollo (*Parnassius arcticus*) which is found in the Arctic Circle in northeastern Yakutia, at an altitude of 1500 meters above sea level. In the Himalayas, various Apollo species such as *Parnassius epaphus*, besides others, have been recorded to occur up to an altitude of 6,000 meters above sea level.

Out of the more than 180,000 species described to date, it is estimated that 9% are butterflies and skippers with moths making up the rest. The vast majority of Lepidoptera are to be found in the tropics but a substantial biodiversity occurs on each continent, with some 11,300 species found in North America, and over 10,000 species reported from Australia.

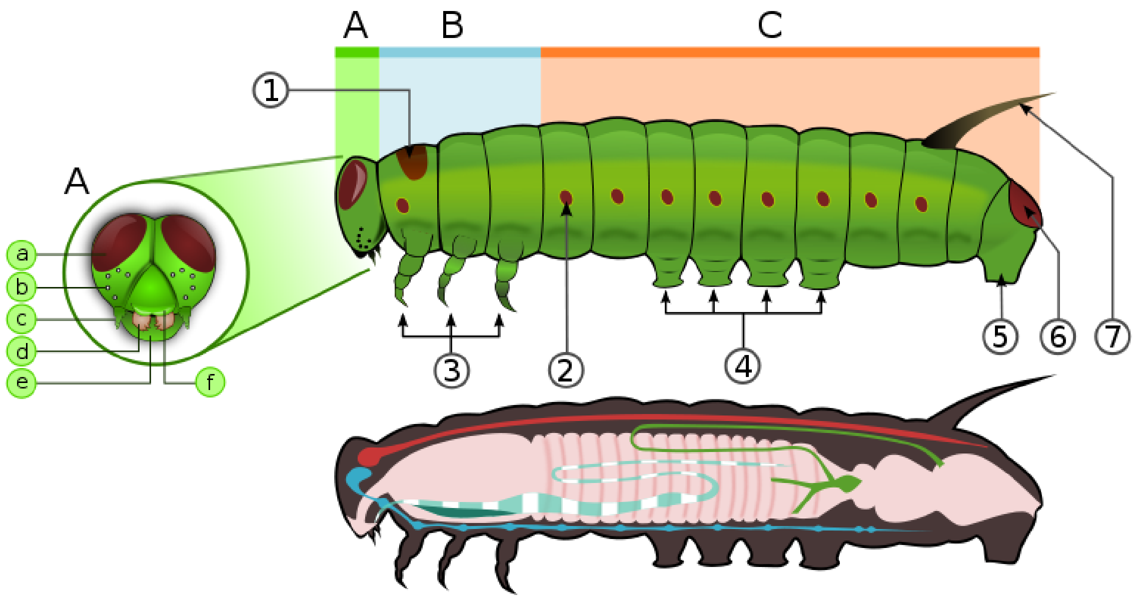
Morphology



A labeled *Papilio machaon*: **A** - Forewing **B** - Antenna **C** - Compound eye **D** - Proboscis **E** - Thorax **F** - Leg **G**- Abdomen **H** - Hindwing **I** -Tail

Lepidoptera are morphologically distinguished from other orders principally by the presence of scales on the external parts of the body and appendages, especially the wings. Butterflies and moths vary in size from microlepidoptera only a few millimetres long, to conspicuous animals with a wingspan of many inches, such as the Monarch butterfly and Atlas moth. The Lepidoptera show many variations of the basic body structure which have evolved to gain advantages in lifestyle and distribution.

Distinguishing characteristics



A – head, B – thorax, C – abdomen, 1 – prothoracic shield, 2 – spiracle, 3 – true legs, 4 – midabdominal prolegs, 5 – anal proleg, 6 – anal plate, 7 – tentacle, a – frontal triangle, b – stemmata (ocelli), c – antenna, d – mandible, e – labrum.

Lepidopterans like all Holometabola, undergo complete metamorphosis, going through a four-stage life cycle: egg; larva / caterpillar; pupa / chrysalis; and imago (plural: *imagines*) / adult. The morphological characteristics which distinguish the order Lepidoptera from other insect orders are:

- *Head*: The lepidopteran head has large compound eyes and mouthparts which are almost always a proboscis.
- *Scales*: Scales cover the external surface of the body and appendages.
- *Thorax*: The prothorax in the case of most species is reduced.
- *Wings*: Two pairs of wings are present in almost the taxa. The wings have very few cross-veins.
- *Abdomen*: The posterior abdominal segments are modified extensively for reproduction. Cerci are absent.

- *Larva*: Lepidoptera larvae are known as caterpillars. They are eruciform with a well developed head and mandibles. They can have anywhere from 0 to 10 prolegs, usually 8.
- *Pupa*: The pupae in most species are adecticous and obtect, while they are decticous in others.

Early stages

The larvae, caterpillars, have a toughened (sclerotised) head capsule, chewing mouthparts,. and a soft body, that may have hair-like or other projections, 3 pairs of true legs, and additional prolegs (up to 5 pairs). Most caterpillars are herbivores, but a few are carnivores (some eat ants or other caterpillars) and detritivores. Larvaes are the feeding and growing stages and periodically undergo hormone-induced ecdysis, developing further with each instar, until they undergo the final larval-pupal moult. Lepidoptera pupa, known as chrysalis, have functional mandibles and with appendages fused or glued to the body in most species, while the pupal mandibles are not functional in others. The larvae of many lepidopteran species will either make a cocoon, a spun casing of silk, and pupate inside them or will pupate in a cell under the ground.

Adult Essex Skipper (*Thymelicus lineola*).

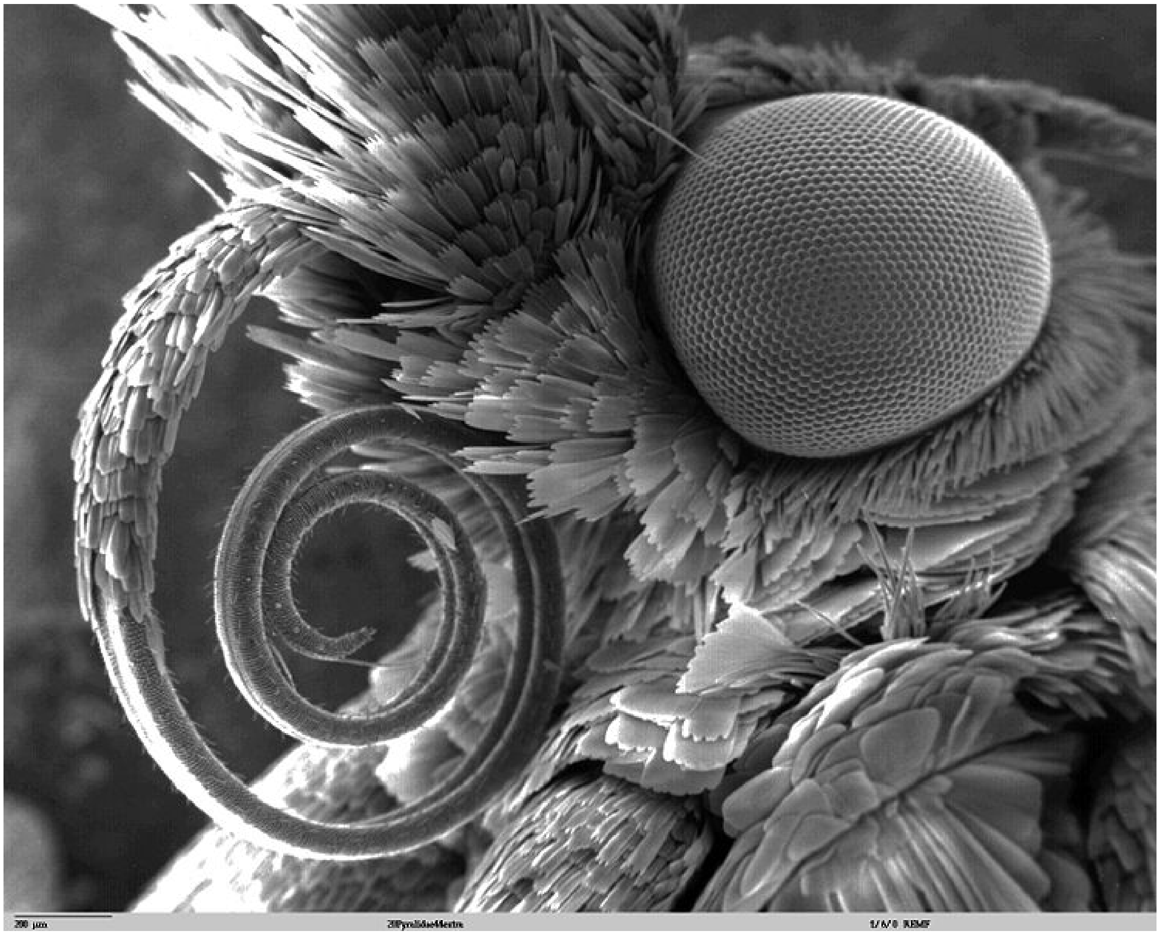
Caterpillar of *Arcitiidae* family

Pupa of a sphingid moth

Eggs of *Phalera bucephala*, the Buff-Tip, a notodontid moth

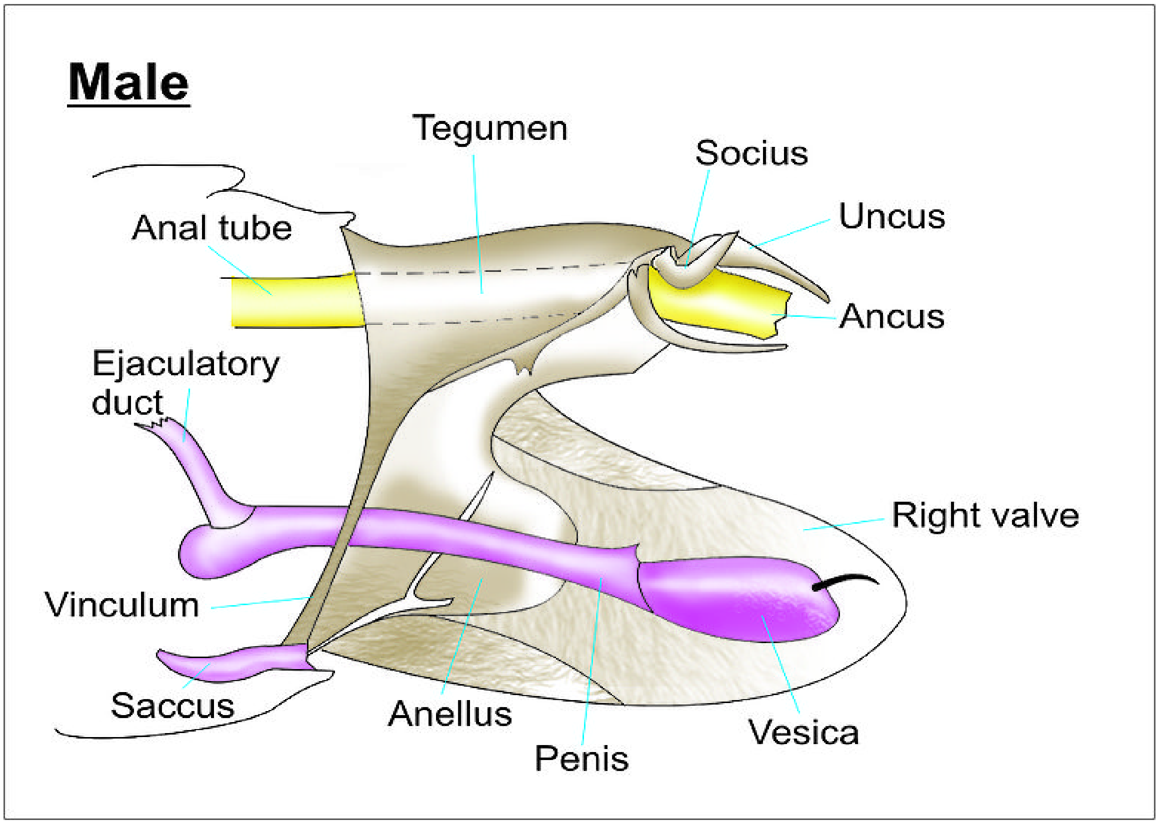
Imago

Adults have two pairs of membranous wings covered, usually completely, by minute scales. In some species, wings are reduced or absent (often in the female but not the male). Antennae are prominent. In moths, males frequently have more feathery antennae than females, for detecting the female pheromones at a distance. Adult mouthparts include a prominent proboscis formed from maxillary galeae, and are adapted for sucking nectar. Some species have reduced mouthparts (some species do not feed as adults), and others have them modified to pierce and suck blood or fruit juices. Mandibles are absent in all except the Micropterigidae which have chewing mouthparts. Adult Lepidoptera have two immobile, multi-facetted, compound eyes, and, only two simple eyes or ocelli, which may be reduced. The three segments of the thorax are fused and consist of non-movable sclerites. The wings arise from the thoracic segments and are functionally dipterous due to a number of wing-locking mechanisms. In some groups, the females are flightless and have reduced wings. The abdominal segments 7–10 or 8–10 form the external genitalia. The genitalia are complex and provide the basis for species discrimination in most families and also in family identification. In more recent families the abdomen is connected to the thorax by muscles connected to projections from the second abdominal sternite. Paired hearing organs at the base of the abdomen occur in the Pyraloidea and Geometroidea. Males have glandular organs that appear as expandable hair brushes or tufts, or as thin-walled, eversible sacs (coremata), from the intersegmental membranes.

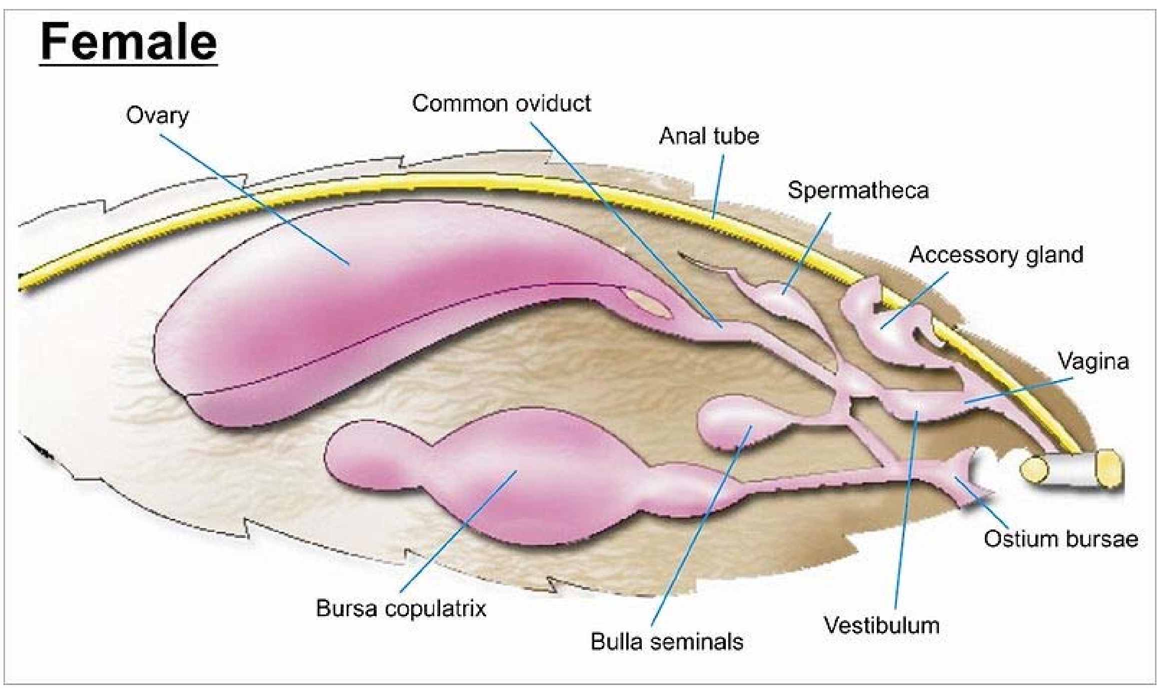


Scanning electron micrograph of proboscis of a moth from family Pyralidae

Wing locking mechanism - *frenulum* (hook) on the rear and the *retinaculum* or socket on forewing



Male genitalia of Lepidoptera



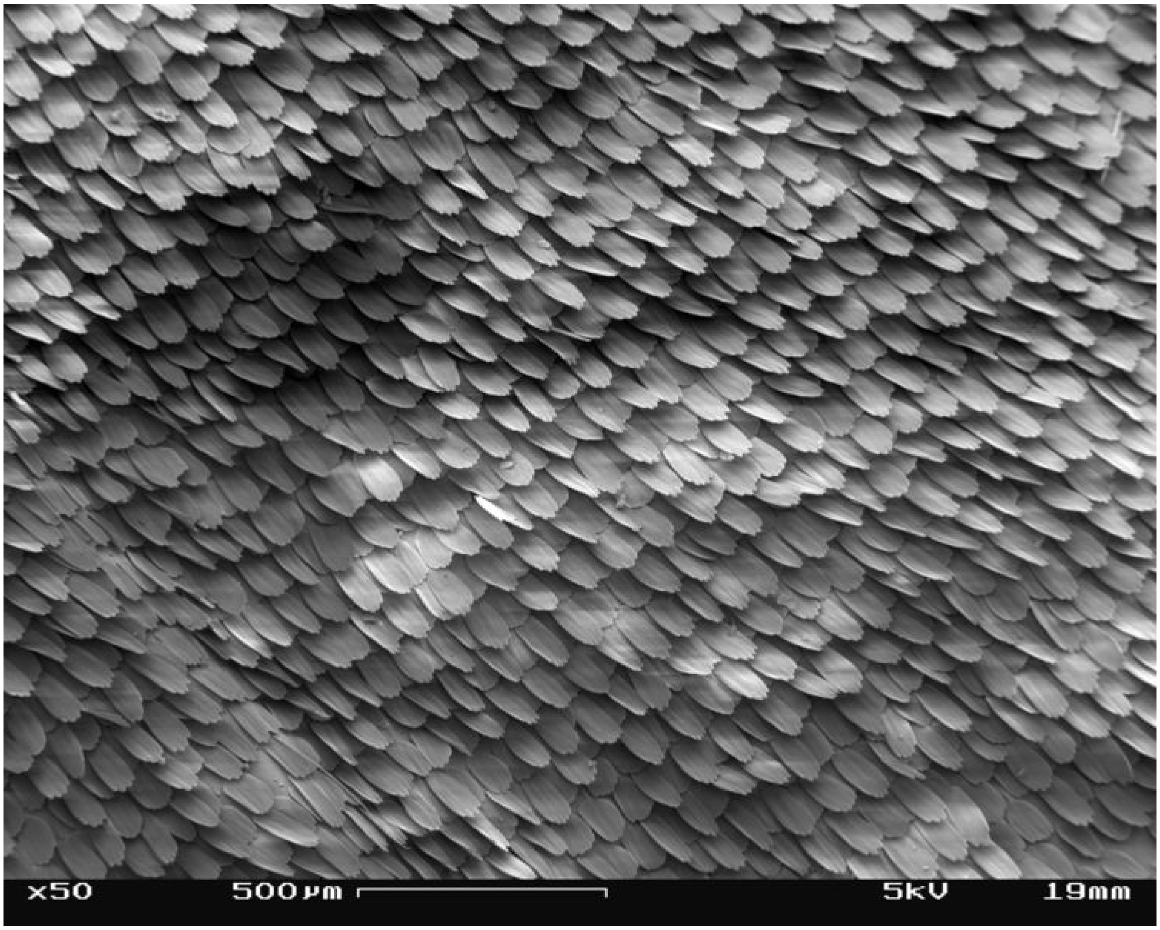
Female genitalia of Lepidoptera

Scales

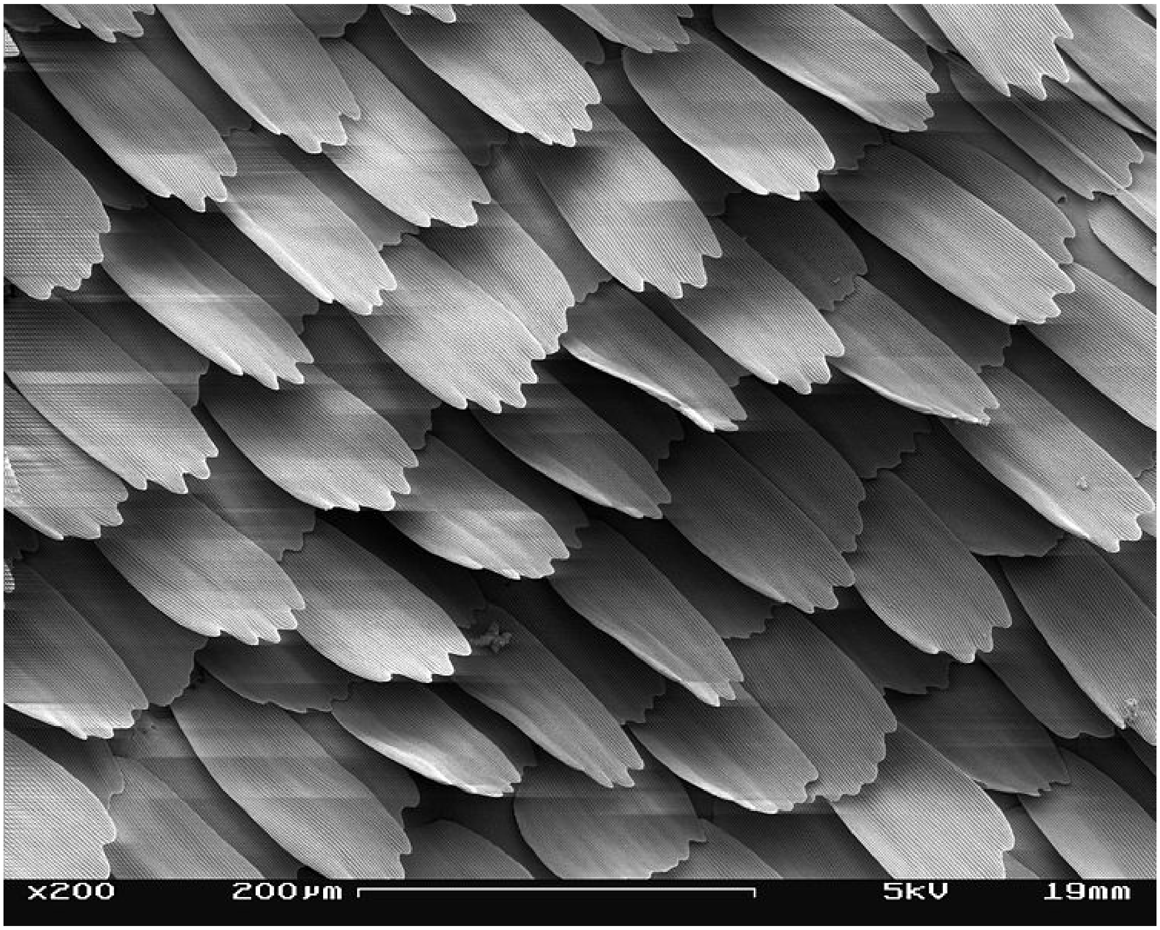
Wing scales form the colour and pattern on wings. The scales shown here are lamellar. The pedicel can be seen attached to a few loose scales.

The wings, head parts of thorax and abdomen of Lepidoptera are covered with minute scales, from which feature the order 'Lepidoptera' derives its names, the word "lepteron" in Ancient Greek meaning 'scale'. Most scales are lamellar, or blade-like and attached with a pedicel, while other forms my be hair-like or specialised as secondary sexual characteristics. The lumen or surface of the lamella, has a complex structure. It gives colour either due to the pigmentary colours contained within or due to its three-dimensional structure. Scales provide a number of functions, which include insulation, thermoregulation, aiding gliding flight, amongst others, the most important of which is the large diversity of vivid or indistinct patterns they provide which help the organism protect itself by camouflage, mimicry and to seek mates.

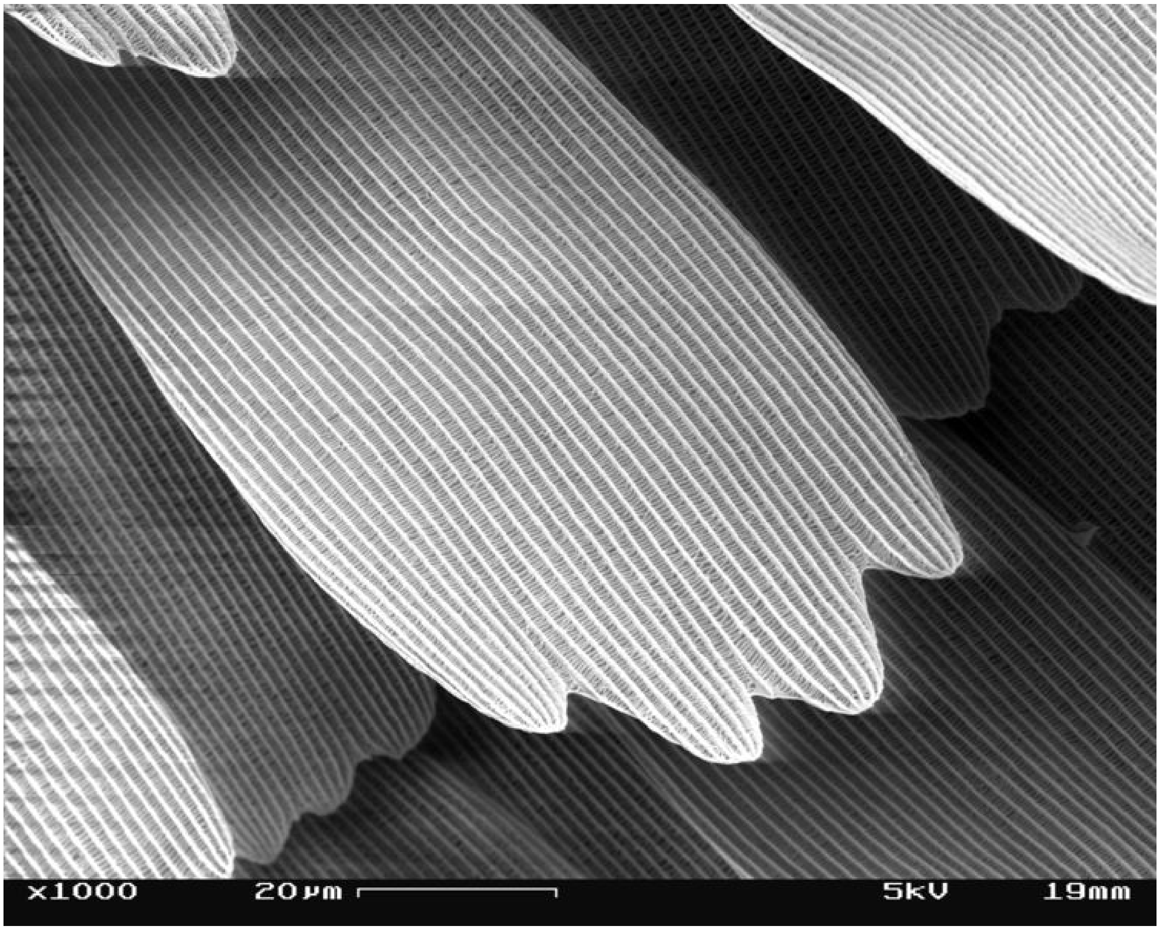
Electron microscopic images of scales



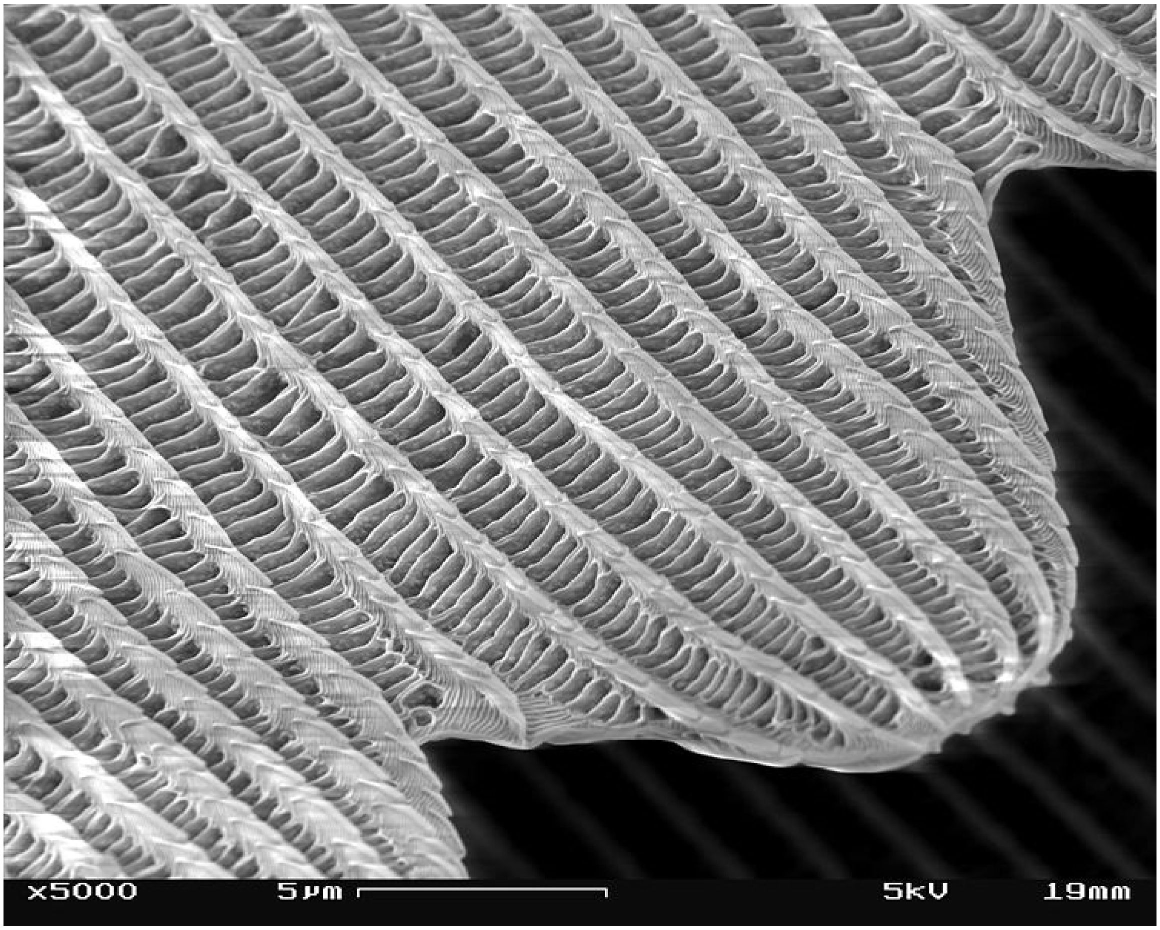
A patch of wing (×50)



Scales close up (×200)



A single scale (x1000)



Microstructure of a scale (x5000)

Reproduction and development

Mating pair of *Laothoe populi* (Poplar Hawk-moth) showing two different colour variants

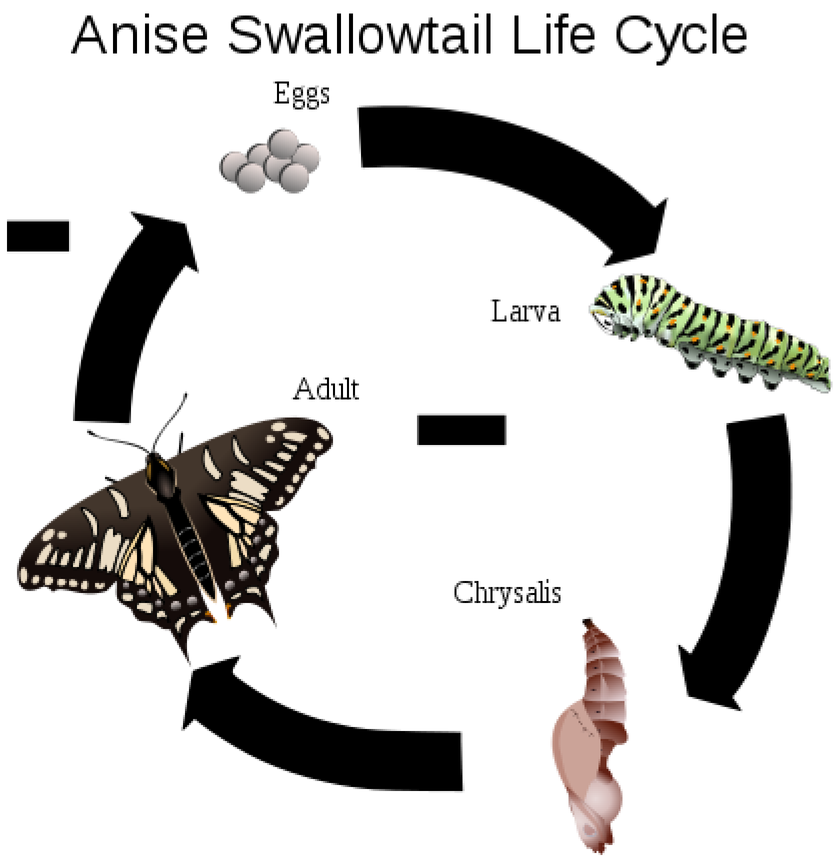
Species of Lepidoptera undergo holometabolism or "complete metamorphosis". Their life cycle normally consists of an egg, larva, pupa, and an imago or adult. The larvae are commonly called caterpillars, and the pupae of moths are called cocoons and that of butterflies are called chrysalids.

Mating

Mating begins with an adult (female or male) attracting a mate, normally using visual stimuli, especially in diurnal species like most butterflies. However, most nocturnal female species, including most moths, use pheromones to attract males, sometimes from long distances. Some species engage in a form of acoustic courtship, or attract mates using sound or vibration such as the polka-dot wasp moth, *Syntomeida epilais*.

Life cycle

The larval form typically lives and feeds on plants



The four stages of the life cycle of an Anise Swallowtail

Lepidopteran usually reproduce sexually and are oviparous (egg-laying), though some species give to live birth in a process called ovoviviparity. There are a variety of differences in egg-laying and the number of eggs laid. Some species simply drop their eggs in flight (these species normally have polyphagous larvae, meaning they eat a variety of plants e.g., Hepialids and some nymphalids) while most Lepidoptera will lay their eggs near or on the host plant that the larvae feed on, normally attracted by its odor. The number of eggs laid may vary from only a few to several thousand.

The larvae, or first stage in their life cycle after hatching, look very different from the adults and come in a variety of shapes and sizes. They are characterized by an elongated body with 0–11 pairs of abdominal legs (usually 8) and hooklets, called apical crochets, and a well developed head with mandibles. The larvae eat every part of the plant, and are normally considered pests to their host plant; species have been found to lay their eggs on the fruit and other species lay their eggs on clothing or fur (e.g., *Tineola bisselliella*, the common clothes moth). Some species are carnivorous and others are even parasitic. A species of Geometridae from Hawaii has carnivorous larvae that catch and eat flies. The larvae develop rapidly with several generations in a year; however, some species may take up to 3 years to develop.

After about 5 to 7 instars, or molts, certain hormones, like prothoracicotropic hormone, stimulate the production of ecdysone, telling the insect to start molting. Then, the larva puparium, a sclerotized or hardened cuticle of the last larval instar, develops into the pupa. Depending on the species, the pupa may be covered in silk and attached with many different types of debris or may be covered with nothing at all. The time it takes for pupae to emerge will vary between species. The adult will emerge from the pupa either by using abdominal hooks or a projection from the head.

While most Lepidoptera are terrestrial, many species of Pyralidae are truly aquatic with all stages except the adult occurring in water. Many species from other families such as Arctiidae, Nepticulidae, Cosmopterygidae, Tortricidae, Olethreutidae, Noctuidae, Cossidae and Sphingidae are aquatic or semi-aquatic.

Behavior and ecology

Flight

The main form of locomotion in most Lepidoptera species is flight. In some species, there is sometimes a gliding component to their flight. Flight occurs either as hovering, or as forward or backward motion.

Navigation

Timelapse of flying moths, attracted to the floodlights

Navigation is important to Lepidoptera species, specially for those that migrate. Butterflies, who have more species that migrate, have been shown to navigate using time compensated sun compasses. They can see polarized light and therefore orient even in cloudy conditions. The polarized light in the region close to the ultraviolet spectrum is suggested to be particularly important. It is suggested that most migratory butterflies are those that belong to semi-arid areas where breeding seasons are short. The life-histories of their host plants also influence the strategies of the butterflies. Other theories include the use of landscapes. Lepidoptera may use coastal lines, mountains, but also man-made roads to orient themselves. Above sea it has been observed that the flight direction is much more accurate if the landscape on the coast is still visible.

Moths also show navigation, as seen in many studies. One study showed that many moths may use Earth's magnetic field to navigate, as a study of the stray Heart and Dart suggests. Another study, this time of the migratory behavior of the Silver Y, showed that this species, even at high altitudes, can correct its course with changing winds, and prefers flying with favourable winds, which suggests a great sense of direction. *Aphrissa statira* in Panama loses its navigational capacity when exposed to a magnetic field, suggesting it uses the Earth’s magnetic field.

Moths exhibit a tendency to circle artificial lights repeatedly. This suggests that these species use a technique of celestial navigation called transverse orientation. By maintaining a constant angular relationship to a bright celestial light, such as the Moon, they can fly in a straight line. Celestial objects are so far away, that even after traveling great distances, the change in angle between the moth and the light source is negligible; further, the moon will always be in the upper part of the visual field or on the horizon. When a moth encounters a much closer artificial light and uses it for navigation, the angle changes noticeably after only a short distance, in addition to being often below the horizon. The moth instinctively attempts to correct by turning toward the light, causing airborne moths to come plummeting downwards, and – at close range – which results in a spiral flight path that gets closer and closer to the light source.

Other explanations have been suggested, such as the idea that moths may be impaired with a visual distortion called a Mach band by Henry Hsiao in 1972. He stated that they fly towards the darkest part of the sky in pursuit of safety and are thus inclined to circle ambient objects in the Mach band region.

Migration

Monarch butterflies cluster in Santa Cruz. Monarch butterflies migrate to Santa Cruz to spend the winter.

Lepidopteran migration is usually seasonal, moving to escape dry seasons or other disadvantageous conditions. Most lepidopteran that migrate are butterflies, varying from short to over long distances. Some butterflies that migrate include the Mourning Cloak, Painted Lady, American Lady, Red Admiral, and the Common Buckeye. Particularly famous migrations are those of the Monarch butterfly from Mexico to northern USA and southern Canada, a distance of about 4,000–4,800 km (2,500–3,000 mi). Other well known migratory species include the Painted Lady and several of the danaine butterflies. Spectacular and large scale migrations associated with the Monsoons are seen in peninsular India. Migrations have been studied in more recent times using wing tags and also using stable hydrogen isotopes.

Moths also undergo migrations, such as the uraniids. *Urania fulgens* undergoes population explosions and massive migrations that may be not surpassed by any other insect in the Neotropics. In Costa Rica and Panama, the first population movements may begin in July and early August and, depending on the year, may be very massive, continuing unabated for as long as five months.

Communication

Pheromones are commonly involved in mating rituals amongst species, especially moths, but pheromones are an important aspect of other forms of communication amongst species as well. Usually only one sex will produce the pheromones and the other would pick them up with its antennae. In many female species, a gland between the eighth and ninth segment under the abdomen produces the pheromones.

Communication can also occur through stridulation, or producing sounds by rubbing various parts of the body together. Some species engage in a form of acoustic courtship, or attract mates using sound or vibration such as the polka-dot wasp moth (*Syntomeida epilais*).

Defense and predation

Papilio machaon caterpillar showing the osmeterium, which emits unpleasant smells to ward off predators

Lepidopterans are soft bodied, fragile and almost defenseless while the immature stages move slowly or are immobile, hence all stages are exposed to predation. Adult Lepidoptera are predated upon by birds, lizards, amphibians, dragonflies and spiders, besides others. Caterpillars and pupa fall prey, not only to birds but invertebrate predators, small mammals, as well as fungi and bacteria. Parasitoid and parasitic wasps and flies may lay eggs in the caterpillar which would eventually kill it as they hatch inside its body and eat its tissues. Insect-eating birds are probably the worst predators. Lepidoptera, especially the immature stages, are an ecologically important food to many insectivorous birds, such as the Great Tit in Europe.

An "evolutionary race" can be seen between predator and prey species. Lepidoptera have developed a number of strategies for defense and protection which include evolution of morphological characters, changes in ecological life-style and in behaviour. These include aposematism, mimicry, camouflage, development of threat patterns and displays and so on.

Only a few birds, such as the nightjars, hunt nocturnal Lepidoptera and their main enemy are bats. Again, an "evolutionary race" exists which has led to numerous evolutionary adaptations of moths to escape from their main predators, such as the ability to hear ultrasonic sounds, or even to emit sounds in some cases. Lepidoptera eggs are also predated upon.

Some caterpillars, such as the zebra swallowtail butterfly larvae, are cannibalistic and may eat other larvae of the same species. Lepidopterans rely on a variety of strategies.

Some species of lepidoptera are poisonous to predators, such as the Monarch butterfly in the Americas, Atrophaneura species (roses, windmills etc.) in Asia, as well as Papilio antimachus and the birdwings, the largest butterflies in Africa and Asia respectively. They obtain their toxicity by sequestering the chemicals from the plants they eat into their own tissues. Some Lepidoptera manufacture their own toxins. Predators that eat poisonous lepidopterans may become sick and vomit violently, learning not to eat those types of lepidopterans. A predator who has previously eaten a poisonous lepidopteran may avoid other species with similar markings in the future, thus saving many other species as well.

Toxic butterflies and larvae tend to develop bright colours, striking patterns as an indicator to predators about their toxicity. This phenomenon is known as aposematism.

Other caterpillars emit bad smells to ward off predators. Some caterpillars, especially members of Papilionidae, contain an osmeterium, a Y-shaped protrusible gland found in the prothoracic segment of the larvae. When threatened, the caterpillar emits unpleasant smells from the organ to ward off the predators.

Camouflage and mimicry are also important defense strategies. Some lepidopterans blend with its surroundings, making them difficult to be spotted by predators. Caterpillars can be shades of green that matches its host plant. Others look like inedible objects, such as twigs or leaves. The larvae of some species, such as the Common Mormon (Papilio polytes) and the Western Tiger Swallowtail look like bird droppings. For example, adult Sesiidae species (also known as *clearwing moths*) have a general appearance that is sufficiently similar to a wasp or hornet to make it likely that the moths gain a reduction in predation by Batesian mimicry.

Eyespots are a type of automimicry used by some lepidopterans. In butterflies, the spots are composed of concentric rings of scales of different colours. The proposed role of the eyespots is to deflect attention to predators. Their resemblance to eyes provokes the predator's instinct to attack these wing patterns.

Polymorphism

Sexually dimorphic bagworm moths (*Tinea ephemeraeformis*) mating. The female is flightless.

The *Heliconius* butterflies from the tropics of the Western Hemisphere are the classical model for Müllerian mimicry.

Seasonal polyphenism in *Eurema hecabe*

Dry-season form

Wet-season form

Polymorphism is appearance of forms or "morphs" differing in colour and number of attributes within a single species. In Lepidoptera, polymorphism can be seen not only between individuals in a population, but also between the sexes as *sexual dimorphism*, between geographically separated populations in *geographical polymorphism* and also between generations flying at different seasons of the year (*seasonal polymorphism*). It also includes the phenomenon of mimicry when mimetic morphs fly alongside non-mimetic morphs in a population of a particular species. Polymorphism occurs both at specific level with heritable variation in the overall morphological design of individuals as well as in certain specific morphological or physiological traits within a species.

Sexual dimorphism is the occurrence of differences between males and females in a species. In Lepidoptera, sexual dimorphism is widespread and almost completely determined by genetic determination. Sexual dimorphism is present in all families of the Papilionoidoea and more prominent in the Lycaenidae, Pieridae and certain taxa of the Nymphalidae. Apart from colour variation which may differ from slight to completely different colour-pattern combinations, secondary sexual characteristics may also be present. Different genotypes maintained by natural selection may also be expressed at the same time. Polymorphic and/or mimetic females occur in the case of some taxa in the Papilionidae primarily to obtain a level of protection not available to the male of their species. The most distinct case of sexual dimorphism is that of adult females of many

Psychidae species who have only vestigial wings, legs, and mouthparts as compared to the adult males who are strong fliers with well-developed wings and feathery antennae.

Geographical polymorphism is where geographical isolation causes a divergence of a species into different morphs. A good example is the Indian White Admiral *Limenitis procris* which has five forms, each geographically separated from the other by large mountain ranges. An even more dramatic showcase of geographical polymorphism is the Apollo butterfly (*Parnassius apollo*). Due to the Apollos living in smal local populations, having no contact with each other, but because of the strong stenotopic species and weak migration ability interbreeding between populations of one species practically does not occur; they form over 600 different morphs, with the size of spots on the wings of which varies greatly.

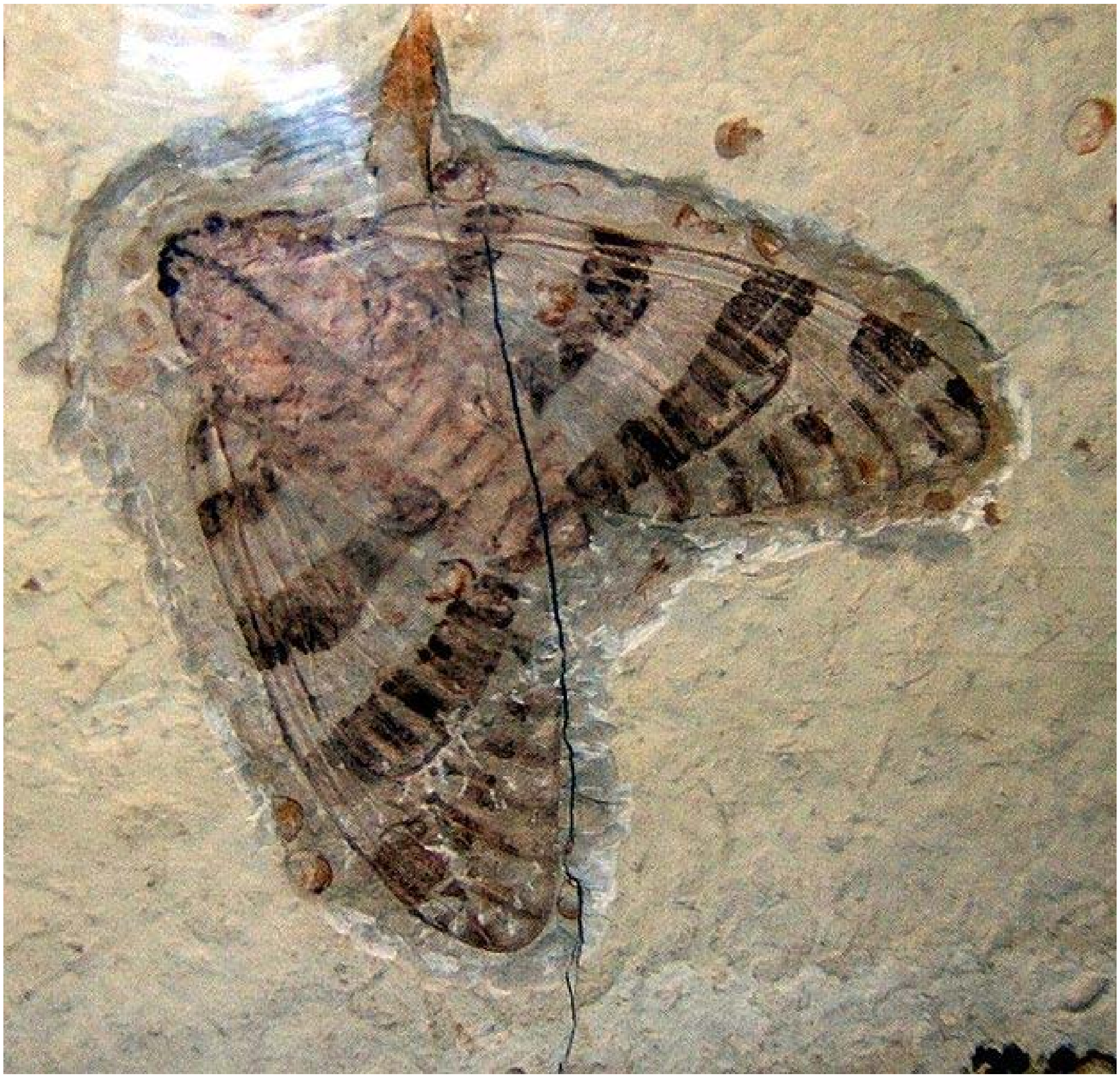
Environmental polymorphism, where genetic heritability plays no role, is often termed as polyphenism. Polyphenism in Lepidoptera is commonly seen in the form of seasonal morphs especially in the butterfly families of Nymphalidae and Pieridae. An Old World pierid butterfly, the Common Grass Yellow (*Eurema hecabe*) has a darker summer adult morph, triggered by a long day exceeding 13 hours in duration, while the shorter diurnal period of 12 hours or less induces a paler morph in the post-monsoon period. Polyphenism also occurs in caterpillars, an example being the Peppered Moth, *Biston betularia*.

Batesian and Müllerian mimicry complexes are commonly found in Lepidoptera. Genetic polymorphism and natural selection give rise to otherwise edible species (the mimic) gaining a survival advantage by resembling inedible species (the model). Such a mimicry complex is referred to as *Batesian* and is most commonly known by the mimicry by the limenitidine Viceroy butterfly of the inedible danaine Monarch. Later research has discovered that the Viceroy is, in fact more toxic than the Monarch and this resemblance should be considered as a case of Müllerian mimicry.

In Müllerian mimicry, inedible species, usually within a taxonomic order, find it advantageous to resemble each other so as to reduce the sampling rate by predators who need to learn about the insects' inedibility. Taxa from the toxic genus *Heliconius* form one of the most well known Müllerian complexes. The adults of the various species now resemble each other so well that the species cannot be distinguished without close morphological observation and, in some cases, dissection or genetic analysis.

Evolution and systematics

Fossil record



A fossil lepidopteran from Russia

Not much is known about ancient Lepidoptera species because so few fossils have been found. The earliest known lepidopteran fossil, *Archaeolepis mane* is from the Jurassic period, about 190 million years ago. The fossil consists of a pair of wings with scales that are characteristically similar to the wing venation pattern found in Trichoptera (caddisflies). 2 other sets of Jurassic Lepidopteran fossils have been found, and 13 sets from the Cretaceous period. The best preserved fossil lepidopteran is the Eocene *Prodryas persephone* from the Florissant Fossil Beds.

Lepidoptera tend not to be as common as some other insects in the habitats that are most conducive to fossilization, such as lakes and ponds, and their juvenile stage has only the head capsule as a hard part that might be preserved. Yet there are fossils, some preserved in amber and some in very fine sediments. Leaf mines are also seen in fossil leaves, although the interpretation of them is tricky. The earliest fossil is *Archaeolepis mane* from the Jurassic, about 190 million years ago in Dorset, UK. It consists of wings and shows scales with parallel grooves under a scanning electron microscope and the characteristic wing venation pattern shared with Trichoptera. Only two more sets of Jurassic lepidopteran fossils have been found, and 13 sets in the Cretaceous. From there, many more fossils are found from the Tertiary, and particularly the Eocene Baltic amber.

Phylogeny

Lepidoptera and Trichoptera (caddisflies) share many similarities that are lacking in other insect orders.

- The females of both orders are heterogametic, meaning they have two different sex chromosomes, whereas in most species the males are heterogametic and the females have two identical sex chromosomes.
- Adults in both orders display a particular wing venation pattern on their forewings.
- The larvae of both orders have mouth structures and gland with which they make and manipulate silk.

Willi Hennig grouped the two sister orders into the Amphiesmenoptera superorder. This group probably evolved in the Jurassic, having split from the now extinct order Necrotaulidae.

Micropterigidae, Agathiphagidae and Heterobathmiidae are the oldest and most basal lineages of Lepidoptera. The adults of these families do not have the curled tongue or proboscis that are found in most members order, but instead have chewing mandibles adapted for a special diet. Micropterigidae larvae feed on leaves, fungi, or liverworts (much like the Trichoptera). Adult Micropterigidae chew the pollen or spores of ferns. In the Agathiphagidae, larvae live inside kauri pines and feed on seeds. In Heterobathmiidae the larvae feed on the leaves of *Nothofagus*, the southern beech tree. These families also have mandibles in the pupal stage, which help the pupa emerge from the seed or cocoon after metamorphosis.

The Eriocraniidae have a short coiled proboscis in the adult stage, and though they retain their pupal mandibles with which they escaped the cocoon, their mandibles are non-functional thereafter. Most of these non-ditrysian families, are primarily leaf miners in the larval stage. In addition to the proboscis, there is a change in the scales among these basal lineages, with later lineages showing more complex perforated scales.

With the evolution of the Ditrysia in the mid-Cretaceous, there was a major reproductive change. The Ditrysia, which comprise 98% of the Lepidoptera, have two separate openings for reproduction in the females (as well as a third opening for excretion), one for mating, and one for laying eggs. The two are linked internally by a seminal duct. (In more basal lineages there is one cloaca, or later, two openings and an external sperm canal.) Of the early lineages of Ditrysia, Gracillarioidea and Gelechioidea are mostly leaf miners, but more recent lineages feed externally. In the Tineoidea, most species feed on plant and animal detritus and fungi, and build shelters in the larval stage.

The Yponomeutoidea is the first group to have significant numbers of species whose larvae feed on herbaceous plants, as opposed to woody plants. They evolved about the time that flowering plants underwent an expansive adaptive radiation in the mid-Cretaceous, and the Gelechioidea that evolved at this time also have great diversity. Whether the processes involved co-evolution or sequential evolution, the diversity of the Lepidoptera and the angiosperms increased together.

In the so-called "Macrolepidoptera", which constitutes about 60% of lepidopteran species, there was a general increase in size, better flying ability (via changes in wing shape and linkage of the forewings and hindwings), reduction in the adult mandibles, and a change in the arrangement of the crochets (hooks) on the larval prolegs, perhaps to improve the grip on the host plant. Many also have tympanal organs, that allow them to hear. These organs evolved eight times, at least, because they occur on different body parts and have structural differences. The main lineages in the Macrolepidoptera are the Noctuoidea, Bombycoidea, Lasiocampidae, Mimallonoidea, Geometroidea and Rhopalocera. Bombycoidea plus Lasiocampidae plus Mimallonoidea may be a monophyletic group. The Rhopalocera, comprising the Papilionoidea (butterflies), Hesperioidea (skippers), and the Hedyloidea (moth-butterflies), are the most recently evolved. There is quite a good fossil record for this group, with the oldest skipper dating from 56 million years ago.

History of study

Engraving of the fossil butterfly *Prodryas* by Samuel Hubbard Scudder

Lepidoptera collection in Cherni Osam Natural Sciences Museum, Troyan, Bulgaria

Linnaeus in *Systema Naturae* (1758) recognized three divisions of the Lepidoptera: *Papilio*, *Sphinx* and *Phalaena*, with seven subgroups in *Phalaena*. These persist today as 9 of the superfamilies of Lepidoptera. Other works on classification followed including those by Michael Denis & Ignaz Schiffermüller (1775), Johan Christian Fabricius (1775) and Pierre André Latreille (1796). Jacob Hübner described many genera, and the Lepidopteran genera were catalogued by Ferdinand Ochsenheimer and Georg Friedrich Treitschke in a series of volumes on the Lepidopteran fauna of Europe published between 1807 and 1835. Gottlieb August Wilhelm Herrich-Schäffer (several volumes, 1843–1856), and Edward Meyrick (1895) based their classifications primarily on wing venation. Sir George Francis Hampson worked on the 'Microlepidoptera' during this period and Philipp Christoph Zeller published *The Natural History of the Tineinae* also on Microlepidoptera (1855).

Among the first entomologists to study fossil insects and their evolution was Samuel Hubbard Scudder (1837–1911), who worked on butterflies. He published a study of the Florissant deposits of Colorado, including the exceptionally preserved *Prodryas persephone*. Andreas V. Martynov (1879–1938) recognized the close relationship between Lepidoptera and Trichoptera in his studies on phylogeny.

Major contributions in the 20th century included the creation of the monotrysia and ditrysia (based on female genital structure) by Borner in 1925 and 1939. Willi Hennig (1913–1976) developed the cladistic methodology and applied it to insect phylogeny. Niels P. Kristensen, E. S. Nielsen and D. R. Davis studied the relationships among monotrysian families and Kristensen worked more generally on insect phylogeny and higher Lepidoptera too. While it is often found that DNA-based phylogenies differ from those based on morphology, this has not been the case for the Lepidoptera; DNA phylogenies correspond to a large extent to morphology-based phylogenies.

Many attempts have been made to group the superfamilies of the Lepidoptera into natural groups, most of which fail because one of the two groups is not monophyletic: Microlepidotera and Macrolepidoptera, Heterocera and Rhopalocera, Jugatae and Frenatae, Monotrysia and Ditrysia.

Relationship to people

In culture

Death's-head Hawkmoth (*Acherontia lachesis*), an old bleached specimen still showing the classical skull-shaped head

A corn earworm (*Helicoverpa zea*) eating a ear of corn

Butterflies such as Sara Longwing (*Heliconius sara*) play an important ecological role in nature as pollination agents

Beondegi, silkworm pupae steamed or boiled and seasoned for taste, for sale by a street vendor in South Korea

Artistic depictions of butterflies have been used in many cultures including as early as 3500 years ago, in Egyptian hieroglyphs. Today, butterflies are widely used in various objects in art and jewelry: mounted in frames, embedded in resin, displayed in bottles, laminated in paper, and in some mixed media artworks and furnishings. Butterflies have also inspired the "butterfly fairy" as an art and fictional character, including in the *Barbie Mariposa* film.

In many cultures the soul of a dead person is associated with the butterfly. As in Ancient Greece, where the word for butterfly ψυχή (psyche) also means *soul* and *breath*. In Latin, as in Ancient Greece, the word for "butterfly" papillio was associated with the soul of the dead.

The skull-like marking on the thorax of the Death's-head Hawkmoth has helped these moths, particularly *A. atropos*, earn a negative reputation, such as associations with the supernatural and evil. The moth has been prominently featured in art and movies such as *Un Chien Andalou* (by Buñuel and Dalí) and *The Silence of the Lambs*, and in the artwork of the Japanese metal band Sigh's album *Hail Horror Hail*.

As pests

The larvae of many Lepidopteran species are major pests in agriculture. Some of the major pests include Tortricidae, Noctuidae, and Pyralidae. The larvae of the Noctuidae genus *Spodoptera* (armyworms) and *Helicoverpa* (corn earworm) can cause extensive damage to certain crops. *Helicoverpa zea* larvae (cotton bollworms or tomato fruitworms) are polyphagous, meaning they eat a variety of crops, including tomatoes and cotton.

As beneficial

Most species of Lepidoptera engage in the pollination of flowers. The adults feed on the nectar inside flowers, using their proboscis to reach the nectar hidden at the base of the petals. In the process, the adult brushes against the flower's stamen, on which the flower's reproductive pollen is made and stored. The pollen is transferred to the adult, who flies to the next flower to feed and unwittingly deposits the pollen on the stigma of the next flower, where the pollen germinates and fertilizes the seeds.

The larvae of *Bombyx mori* are more commonly known as silkworms. They make their cocoons out of silk which can be spun into cloth. Silk is and has been an important economic resource throughout history. The species *Bombyx mori* has been domesticated to the point where it is completely dependent on humans for survival. On the other hand, the species *Bombyx mandarina*, or "Wild Silkmoth," lives and produces silk naturally.

As food

Lepidoptera feature prominently in entomophagy as food items on almost every continent. While in most cases, adults, larvae or pupae are eaten as staples by indigenous people, beondegi or silkworm pupae are eaten as a snack in Korean cuisine while Maguey worm is considered a delicacy in Mexico. In the Carnia region of Italy, children catch and eat *Zygaena* moths in early summer. The ingluvies, despite having a very low cyanogenic content, serves as a convenient, supplementary source of sugar to the children who can include this resource as a seasonal delicacy at minimum risk.

Butterfly ranching

Butterfly ranching in Papua New Guinea permits nationals of that country to 'farm' economically valuable insect species for the collectors market in an ecologically sustainable manner.

Chapter- 6

Moth

Moths	

Emperor Gum Moth, *Opodiphthera eucalypti*

Scientific classification	
Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Lepidoptera
(unranked):	**Heterocera**

A **moth** is an insect closely related to the butterfly, both being of the order Lepidoptera. Moths form the majority of this order; there are thought to be 150,000 to 250,000 different species of moth (about ten times the number of species of butterfly), with thousands of species yet to be described. Most species of moth are nocturnal, but there are crepuscular and diurnal species.

Differences between butterflies and moths

Moths are not easily differentiated from butterflies. Sometimes the name "Heterocera" is used for moths while the term "Rhopalocera" is used for butterflies to formalize the popular distinction; these, however, have no taxonomic validity. Many attempts have been made to subdivide the Lepidoptera into groups such as the Microlepidoptera and Macrolepidoptera, Frenatae and Jugatae, or Monotrysia and Ditrysia. Failure of these names to persist in modern classifications is because none of them represents a pair of "monophyletic groups". The reality is that butterflies are a small group that arose from within the "moths" (being considered as part of *Ditrysia* of the Neolepidoptera). There is thus no way to group all of the remaining taxa in a monophyletic group, as it will always exclude that one descendant lineage.

Etymology

Mating pair of *Laothoe populi*, or Poplar Hawk-moths, showing two different color variants

The Modern English word "*moth*" comes from Old English "*moððe*" (cf. Northumbrian "*mohðe*") from Common Germanic (compare Old Norse "*motti*", Dutch "*Mot*" and German "*Motte*" all meaning "*moth*"). Perhaps its origins are related to the Old English "*maða*" meaning "*maggot*" or from the root of "*midge*" which until the 16th century was used mostly to indicate the larva, usually in reference to devouring clothes.

The study of butterflies and moths is known as lepidoptery, and biologists that specialize in either are called lepidopterists. As a pastime, watching butterflies and moths is known as butterflying and mothing. The latter has given rise to the term "mother" for someone who engages in this activity - sometimes written with a hyphen (moth-er) to distinguish it from its usual meaning.

Caterpillar

Moth larvae, or caterpillars, make cocoons. When it comes out of the cocoon, it is a fully grown moth with wings. Some moth caterpillars dig holes in the ground, and they will live in the hole until they are ready to turn into a fully grown moth.

Economic significance of moths

An adult male Pine Processionary Moth (*Thaumetopoea pityocampa*). This species is a serious forest pest when in larval state. Notice the bristle springing from the underside of the hindwing (frenulum) and running forward to be held in a small catch of the forewing, whose function is to link the wings together.

Poplar hawk-moth caterpillar
Laothoe populi

Moths, and particularly their caterpillars, are a major agricultural pest in many parts of the world. Examples include corn borers and bollworms. The caterpillar of the gypsy moth (*Lymantria dispar*) causes severe damage to forests in the northeast United States, where it is an invasive species. In temperate climates, the codling moth causes extensive damage, especially to fruit farms. In tropical and subtropical climates, the diamondback moth (*Plutella xylostella*) is perhaps the most serious pest of brassicaceous crops.

Several moths in the family Tineidae are commonly regarded as pests because their larvae eat fabric such as clothes and blankets made from natural proteinaceous fibers such as wool or silk. They are less likely to eat mixed materials containing artificial fibers. There are some reports that they can be repelled by the scent of wood from juniper and cedar, by lavender, or by other natural oils. However, many consider this unlikely to prevent infestation. Naphthalene (the chemical used in mothballs) is considered more effective, but there are concerns over its effects on human health. Moth larvae may be killed by freezing the items which they infest for several days at a temperature below −8 °C (17.6 °F).

Protective silk (or similar material) case (cocoon)

Some moths are farmed. The most notable of these is the silkworm, the larva of the domesticated moth *Bombyx mori*. It is farmed for the silk with which it builds its cocoon. As of 2002, the silk industry produces over 130 million kilograms of raw silk, worth about 250 million U.S. dollars, each year. Not all silk is produced by *Bombyx mori*. There are several species of Saturniidae that are also farmed for their silk, such as the Ailanthus moth (*Samia cynthia* group of species), the Chinese Oak Silkmoth (*Antheraea pernyi*), the Assam Silkmoth (*Antheraea assamensis*), and the Japanese Silk Moth (*Antheraea yamamai*).

The mopane worm, the caterpillar of *Gonimbrasia belina*, from the family Saturniidae, is a significant food resource in southern Africa.

Despite being notorious for eating clothing, most moth adults do not eat at all. Most like the Luna, Polyphemus, Atlas, Prometheus, Cercropia, and other large moths do not have mouths. When they do eat, moths will drink nectar.

Attraction to light

Time exposure at floodlight showing moth flight paths

Moths frequently appear to circle artificial lights, although the reason for this behavior remains unknown. One hypothesis advanced to explain this behavior is that moths use a technique of celestial navigation called transverse orientation. By maintaining a constant angular relationship to a bright celestial light, such as the Moon, they can fly in a straight line. Celestial objects are so far away, that even after travelling great distances, the change in angle between the moth and the light source is negligible; further, the moon will always be in the upper part of the visual field or on the horizon. When a moth encounters a much closer artificial light and uses it for navigation, the angle changes noticeably after only a short distance, in addition to being often below the horizon. The moth instinctively attempts to correct by turning toward the light, causing airborne moths to come plummeting downwards, and resulting in a spiral flight path that gets closer and closer to the light source.

It has been suggested that the reason for moths circling lights may have to do with a visual distortion called a Mach band. The theory says that in the pursuit of cover and safety, moths fly towards the dark areas of the sky and are thus inclined to circle ambient objects in the Mach band region. The celestial navigation theory should cause moths to circle lights, not to head directly toward them, as many are seen to do. Mach conjectures that moths, which are nocturnal creatures, must find a place to hide from predators when daylight comes, but cannot do so in darkness. Their instinct when morning comes is to fly toward the light (presumably up) and then down again, with some probability of landing on a surface which matches their camouflage.

A theory which has been advanced in an attempt to explain the attraction male moths have for candles specifically is based on olfaction. There is evidence that olfaction might be, in some cases, mediated by detection of the infra-red spectra of substances. The spiky infrared spectra of a candle flame happens to contain a number of emission lines which coincide with the vibrational frequencies of the female moth's pheromone. The male moth is thereby powerfully attracted to the flame. Other sources with different spike patterns, e.g. hurricane lamps, are less powerful attractants.

Night-blooming flowers usually depend on moths or bats for pollination, and artificial lighting can draw moths away from the flowers, affecting the plant's ability to reproduce. A way to prevent this is to put a cloth or netting around the lamp. Another way is using a colored light bulb (preferably red). This will take the moth's attention away from the light while still providing light to see by.

Predators and parasites of moths

Tomato Hornworm parasitized by braconid wasps

Nocturnal insectivores often feed on moths; these include some bats, some species of owls and other species of birds. Moths are also eaten by some species of lizards, cats, dogs, rodents, and some bears. Moth larvae are vulnerable to being parasitized by Ichneumonidae.

Baculoviruses are parasite double-stranded DNA insect viruses that are used mostly as biological control agents. They are members of the Baculoviridae, a family that is restricted to insects. Most baculovirus isolates have been obtained from insects, in particular from Lepidoptera.

There is evidence that ultrasound in the range emitted by bats causes flying moths to make evasive maneuvers because bats eat moths. Ultrasonic frequencies trigger a reflex action in the noctuid moth that cause it to drop a few inches in its flight to evade attack. Tiger moths also emit clicks which foil bats' echolocation.

Notable moths

- Atlas moth (*Attacus atlas*), the largest moth in the world
- White Witch moth (*Thysania agrippina*), the Lepidopteran with the biggest wingspan
- Madagascan Sunset moth (*Chrysiridia rhipheus*), considered to be one of the most impressive and beautiful Lepidoptera
- Death's-head hawkmoth (*Acherontia* spp.), is associated with the supernatural and evil and has been featured in art and movies
- Peppered moth (*Biston betularia*), the subject of a well-known study in evolution
- Luna moth (*Actias luna*)
- Grease Moth (*Aglossa cuprina*), known to have fed on the rendered fat of humans
- Emperor Gum moth (*Opodiphthera eucalypti*)
- Polyphemus moth (*Antheraea polyphemus*)
- Bogong moth (*Agrotis infusa*), known to have been a food source for Southeastern indigenous Australians

Moths of economic significance:

- Gypsy moth (*Lymantria dispar*), a pest of hardwood trees in North America
- Corn earworm or cotton bollworm (*Helicoverpa zea*), a major agricultural pest
- Indianmeal Moth (*Plodia interpunctella*), a major pest of grain and flour
- Codling moth (*Cydia pomonella*), a pest mostly of apple, pear and walnut trees
- Light brown apple moth (*Epiphyas postvittana*), a highly polyphagous pest
- Silkworm (*Bombyx mori*), for its silk
- Wax moths (*Galleria mellonella*, *Achroia grisella*), pests of bee hives
- *Duponchelia fovealis*, a new invasive pest of vegetable in the United States

Chapter- 7

Grasshopper

Grasshopper Temporal range: Late Permian - Recent	

Immature grasshopper

Scientific classification	
Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Hexapoda

Class:	Insecta
Order:	Orthoptera
Suborder:	**Caelifera** Ander, 1939

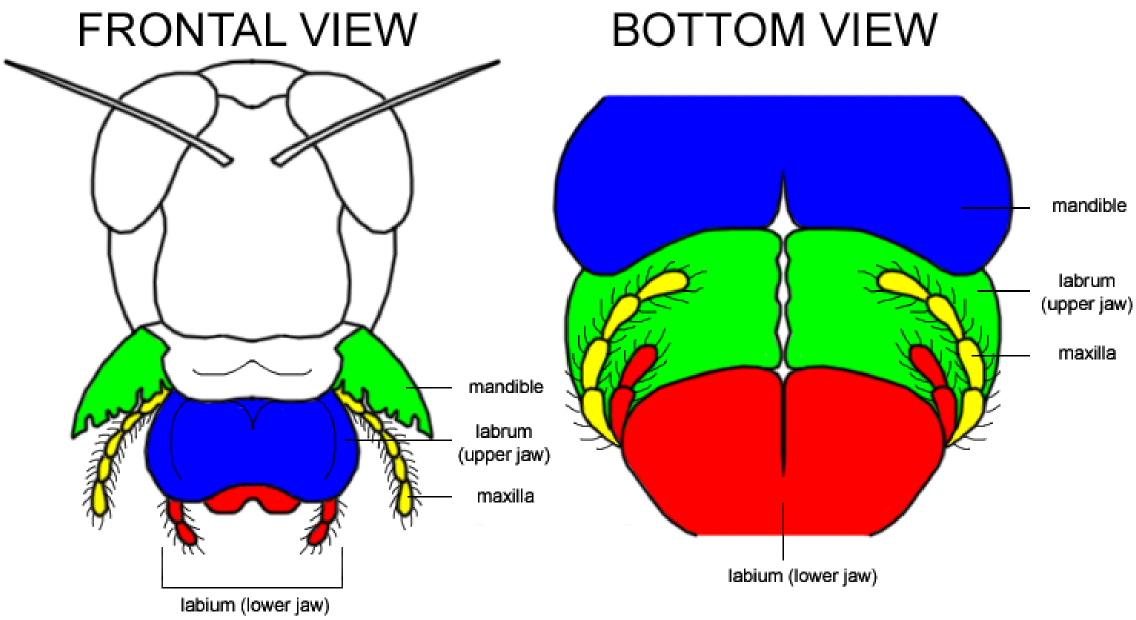
Superfamilies

- Tridactyloidea
- Tetrigoidea
- Eumastacoidea
- Pneumoroidea
- Pyrgomorphoidea
- Acridoidea
- Tanaoceroidea
- Trigonopterygoidea

The **grasshopper** is an insect of the suborder **Caelifera** in the order Orthoptera. To distinguish it from bush crickets or katydids, it is sometimes referred to as the short-horned grasshopper. Species that change colour and behaviour at high population densities are called locusts.

Characteristics

A grasshopper uses camouflage to aid its survival



Grasshopper mouth structure

Grasshoppers have antennae that are almost always shorter than their body), and short ovipositors. They also have pinchers or mandibles that cut and tear off food. Those species that make easily heard noises usually do so by rubbing the hind femurs against the forewings or abdomen (stridulation), or by snapping the wings in flight. Tympana, if present, are on the sides of the first abdominal segment. The hind femora are typically long and strong, fitted for leaping. Generally they are winged, but hind wings are membranous while front wings (tegmina) are coriaceous and not fit for flight. Females are normally larger than males, with short ovipositors. Males have a single unpaired plate at the end of the abdomen. Females have two pairs of valves (triangles) at the end of the abdomen used to dig in sand when egg laying.

They are easily confused with the other sub-order of Orthoptera, Ensifera, but are different in many aspects, such as the number of segments in their antennae and structure of the ovipositor, as well as the location of the tympana and modes of sound production. Ensiferans have antennae with at least 20-24 segments, and caeliferans have fewer. In evolutionary terms, the split between the Caelifera and the Ensifera is no more recent than the Permo-Triassic boundary (Zeuner 1939).

Diversity and range

Recent estimates (Kevan 1982; Günther, 1980, 1992; Otte 1994-1995; subsequent literature) indicate some 2,400 valid Caeliferan genera and about 11,000 valid species described to date. Many undescribed species exist, especially in tropical wet forests. The Caelifera are predominantly tropical.

Biology

Diet and Digestion

Grasshoppers prefer to eat grasses, leaves and cereal crops. Some will tend to eat from a single host plant, while others will eat from a variety of sources throughout the day. Only one of the 8000 species of grasshopper will only eat a single species of plant.

The digestive system of insects includes a foregut (stomodaeum, the mouth region), a midgut (mesenteron), and a hindgut (proctodaeum, the anal region). The mouth is distinct due to the presence of a mandible and salivary glands. The mandible can chew food very slightly and start mechanical digestion. Salivary glands digest the food chemically, though only carbohydrates in the grasses and such they eat. The mouth leads to the muscular pharynx, and through the esophagus to the crop. The crop has the ability to hold food. From the crop, food enters the gizzard, which has teeth like features in it. From there, food enters the stomach. In the stomach, digestive enzymes mix with the food to break it down. These enzymes originate from the gastric caeca surrounding the stomach. This leads to the malpighian tubules. These are the chief excretion organs. The hindgut includes intestine parts (including the ileum and rectum), and exits through the anus. Most food is handled in the midgut, but some food residue as well as waste products from the malpighian tubules are managed in the hindgut. These waste products consist mainly of uric acid, urea and amino acids, and are normally converted into dry pellets before being disposed of.

The salivary glands and midgut secrete digestive enzymes. The midgut secretes protease, lipase, amylase, and invertase, among other enzymes. The particular ones secreted vary with the different diets of grasshoppers.

Nervous system

The grasshopper's nervous system is controlled by ganglia, loose groups of nerve cells which are found in most species more advanced than cnidarians. In grasshoppers, there are ganglia in each segment as well as a larger set in the head, which are considered the brain. There is also a neuropile in the centre, through which all ganglia channel signals. The sense organs (sensory neurons) are found near the exterior of the body and consist of tiny hairs (sensilla), which consist of one sense cell and one nerve fibre, which are each specially calibrated to respond to a certain stimulus. While the sensilla are found all over the body, they are most dense on the antennae, palps (part of the mouth), and cerci (near the posterior). Grasshoppers also have tympanal organs for sound reception. Both these and the sensilla are linked to the brain via the neuropile.

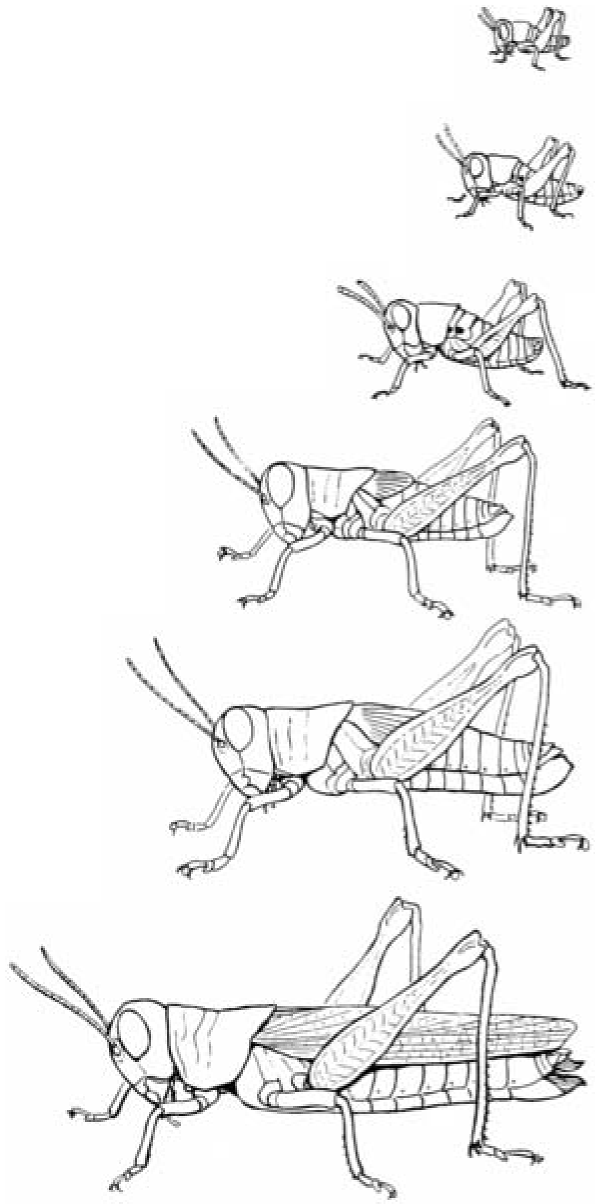
Romalea guttata grasshoppers mating

Common Macrotona (*Macrotona australis*) laying eggs

Reproduction

The grasshopper's reproductive system consists of the gonads, the ducts which carry sexual products to the exterior, and accessory glands. In males, the testes consist of a number of follicles which hold the spermatocytes as they mature and form packets of elongated spermatozoa.

During reproduction, the male grasshopper introduces sperm into the ovipositor through its aedeagus (reproductive organ), and inserts its spermatophore, a package containing the sperm, into the female's ovipositor. The sperm enters the eggs through fine canals called micropyles. The female then lays the fertilized egg pod, using her ovipositor and abdomen to insert the eggs about one to two inches underground, although they can also be laid in plant roots or even manure. The egg pod contains several dozens of tightly packed eggs that look like thin rice grains. The eggs stay there through the winter, and hatch when the weather has warmed sufficiently. In temperate zones, many grasshoppers spend most of their life as eggs through the cooler months (up to 9 months) and the active states (young and adult grasshoppers) live only up to three months. The first nymph to hatch tunnels up through the ground, and the rest follow. Grasshoppers develop through stages and progressively get larger in body and wing size. This development is referred to as hemimetabolous or incomplete metamorphosis since the young are rather similar to the adult.



Six stages of development, from newly hatched nymph to fully winged adult.
(*Melanoplus sanguinipes*)

Circulation and respiration

Grasshoppers have open circulatory systems, with most of the body fluid (hemolymph) filling body cavities and appendages. The one closed organ, the dorsal vessel, extends from the head through the thorax to the hind end. It is a continuous tube with two regions: the heart, which is restricted to the abdomen; and the aorta, which extends from the heart to the head through the thorax. Haemolymph is pumped forward from the hind end and the sides of the body through a series of valved chambers, each of which contains a pair of lateral openings (ostia). The haemolymph continues to the aorta and is discharged through the front of the head. Accessory pumps carry haemolymph through the wing veins and along the legs and antennae before it flows back to the abdomen. This haemolymph circulates nutrients through the body and carries metabolic wastes to the malphighian tubes to be excreted. Because it does not carry oxygen, grasshopper "blood" is green.

Respiration is performed using tracheae, air-filled tubes, which open at the surfaces of the thorax and abdomen through pairs of spiracles. The spiracle valves only open to allow oxygen and carbon dioxide exchange. The tracheoles, found at the end of the tracheal tubes, are insinuated between cells and carry oxygen throughout the body.

Other information

As food

In certain countries, grasshoppers are eaten as a good source of protein. In Mexico for example, *chapulines* are regarded for their high content of protein, minerals and vitamins. They are usually collected at dusk, using lamps or electric lighting, in sweep nets. Sometimes they are placed in water for 24 hours, after which they can be boiled or eaten raw, sun-dried, fried, flavoured with spices, such as garlic, onions, chile, drenched in lime, and used in soup or as a filling for various dishes. They are abundant in Mexican food and street markets, particularly in the central regions.

They are served on skewers in some Chinese food markets, like the Donghuamen Night Market.

Raw grasshoppers should be eaten with caution, as they may contain tapeworms.

In some countries in Africa, grasshoppers are an important food source, as are other insects, adding proteins and fats to the daily diet, especially in times of food crisis. They are often used in soup. The "grasshoppers" eaten in Uganda and neighbouring areas are called *nsenene*, but they are in fact bush crickets, also called katydids.

In some countries in the Middle East, grasshoppers are boiled in hot water with salt, left in the sun to dry then eaten as snacks.

Locusts

Locusts are several species of short-horned grasshoppers of the family Acrididae that sometimes form very large groups (swarms); these can be highly destructive and migrate in a more or less coordinated way. Thus, these grasshoppers have solitary and gregarious (swarm) phases. Locust swarms can cause massive damage to crops. Important locust species include *Schistocerca gregaria* and *Locusta migratoria* in Africa and the Middle East, and *Schistocerca piceifrons* in tropical Mexico and Central America (Mesoamerica). Other grasshoppers important as pests (which, unlike true locusts, do not change colour when they form swarms) include *Melanoplus* species (like *M. bivittatus*, *M. femurrubrum* and *M. differentialis*) and *Camnula pellucida* in North America; the

Romalea guttata (lubber grasshopper), *Brachystola magna*, and *Sphenarium purpurascens* in northern and central Mexico; species of *Rhammatocerus* in South America; and the *Oedaleus senegalensis* (Senegalese grasshopper) and the *Zonocerus variegatus* (variegated grasshopper) in Africa.

Grasshopper hidden in the grass

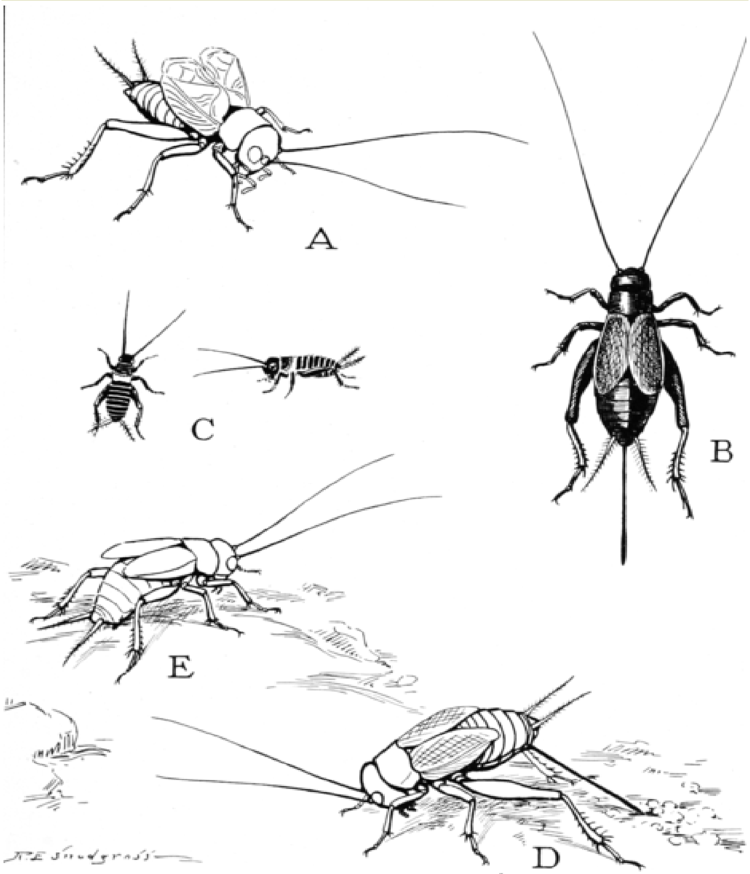
Camouflage

The coloring of different species of grasshopper are often dependent on environment. Many species are adapted to green fields and forests, and blend in well there to avoid predators. Others have adapted to drier, sandy environments and blend in well with the colors of dry dirt and sand.

Chapter- 8

Cricket (Insect)

Cricket



Common black cricket, *Gryllus assimilis*

Scientific classification	
Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Orthoptera
Superfamily:	Grylloidea
Family:	**Gryllidae** Bolívar, 1878

Crickets, family **Gryllidae** (also known as "true crickets"), are insects somewhat related to grasshoppers, and more closely related to katydids or bush crickets (family Tettigoniidae). They have somewhat flattened bodies and long antennae. There are about 900 species of crickets. They tend to be nocturnal and are often confused with grasshoppers because they have a similar body structure including jumping hind legs. Crickets are harmless to humans.

Cricket chirping

Only the male crickets chirp. A large vein running along the bottom of each wing has "teeth," much like a comb does. The chirping sound is created by running the top of one wing along the teeth at the bottom of the other wing. As he does this, the cricket also holds the wings up and open, so that the wing membranes can act as acoustical sails. It is a popular myth that the cricket chirps by rubbing its legs together.

There are four types of cricket song: The calling song attracts females and repels other males, and is fairly loud. The courting song is used when a female cricket is near, and is a very quiet song. An aggressive song is triggered by chemoreceptors on the antennae that detect the near presence of another male cricket and a copulatory song is produced for a brief period after a successful mating.

Crickets chirp at different rates depending on their species and the temperature of their environment. Most species chirp at higher rates the higher the temperature is (approximately 62 chirps a minute at 13°C in one common species; each species has its own rate). The relationship between temperature and the rate of chirping is known as Dolbear's Law. Using this law it is possible to calculate the temperature in Fahrenheit by adding 40 to the number of chirps produced in 14 seconds by the snowy tree cricket common in the United States.

Crickets, like all other insects, are cold-blooded. They take on the temperature of their surroundings. Many characteristics of cold-blooded animals, like the rate at which crickets chirp, or the speed at which ants walk, follow an equation called the Arrhenius equation. This equation describes the activation energy or threshold energy required to induce a chemical reaction. For instance, crickets, like all other organisms, have many chemical reactions occurring within their bodies. As the temperature rises, it becomes easier to reach a certain activation or threshold energy, and chemical reactions, like those that occur during the muscle contractions used to produce chirping, happen more rapidly. As the temperature falls, the rate of chemical reactions inside the crickets' bodies slow down, causing characteristics, such as chirping, to also slow down.

Crickets have tympanic membranes located just below the middle joint of each front leg (or knee). This enables them to hear another cricket's song.

In 1975, Dr. William H. Cade discovered that the parasitic tachinid fly *Ormia ochracea* is attracted to the song of the male cricket, and uses it to locate the male in order to deposit her larvae on him. It was the first example of a natural enemy that locates its host or prey using the mating signal. Since then, many species of crickets have been found to be carrying the same parasitic fly, or related species. In response to this selective pressure, a mutation leaving males unable to chirp was observed amongst a population of field crickets on the Hawaiian island of Kauai, giving these crickets the obvious advantage of eluding their parasitoid opponents.

Diet and life cycle

Crickets are omnivorous scavengers who feed on organic materials, as well as decaying plant material, fungi, and some seedling plants. Crickets eat their own dead when there are no other sources of food available, and exhibit predatorial behavior upon weakened, crippled crickets.

Crickets have relatively powerful jaws, and have been known to bite humans, mostly without breaking the skin. The bite can, however, be painful when inflicted on sensitive skin such as the webbing between fingers.

Crickets mate in late summer and lay their eggs in the fall. The eggs hatch in the spring and have been estimated to number as high as 200 per fertile female. Subspecies *Acheta Domestica* however lays eggs almost continually, with the females capable of laying at least twice a month. Female crickets have a long needlelike egg-laying organ called an ovipositor.

Crickets are popular as a live food source for carnivorous pets like frogs, lizards, tortoises, salamanders, and spiders. Feeding crickets with nutritious food in order to pass the nutrition onto animals that eat them is known as gut loading. In addition to this, the crickets are often dusted with a mineral supplement powder to ensure complete nutrition to the pet.

Taxonomy

African field cricket *Gryllus bimaculatus*

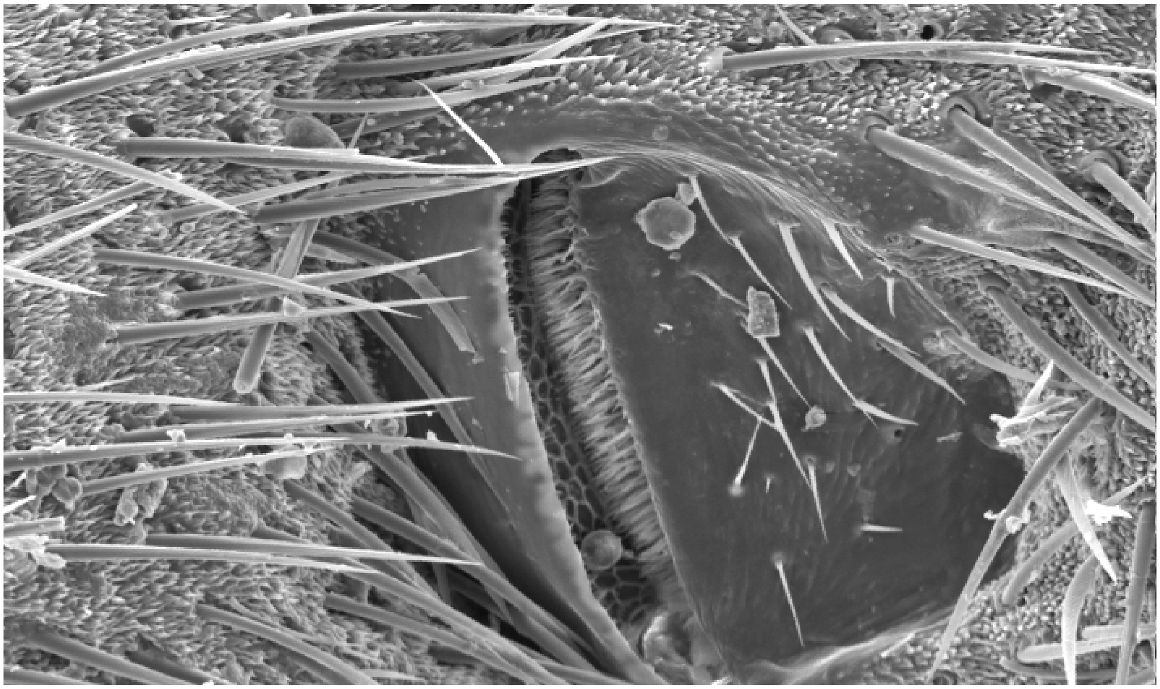
Subfamilies of the family Gryllidae:

- Eneopterinae – (true) bush crickets
- Gryllinae – common or field crickets; brown or black; despite the name, some of them enter houses (e.g. *Acheta domesticus*, the house cricket). This family includes the genera Gryllus, Platygryllus, Acheta and Gryllodes.
- Nemobiinae – ground crickets
- Oecanthinae – tree crickets; usually green with broad, transparent wings; frequent trees and shrubs.
- Phalangopsinae - spider crickets
- Podoscirtinae – anomalous crickets
- Pteroplistinae
- Trigonidiinae – sword-tail crickets

In addition to the above subfamilies in the family Gryllidae, several other orthopteran groups outside of this family also may be called crickets:

- Cave crickets - also called camel crickets
- Jerusalem crickets / Sand crickets
- Mogoplistidae – scaly crickets
- Mole crickets
- Mormon crickets
- Myrmecophilidae – ant crickets
- Parktown prawns
- Tettigoniidae – katydids or bush crickets

Australian brown field cricket



Scanning electron micrograph of a spiracle valve—the organ that allows fresh air to pass into the cricket's respiratory system

A cricket

Chapter- 9

Caddisfly

Caddisflies Temporal range: Triassic–Recent	
	
Scientific classification	
Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Superorder:	Amphiesmenoptera
Order:	**Trichoptera**
Suborders	
Annulipalpia Spicipalpia Integripalpia	

The **caddisflies** are an order, **Trichoptera**, of insects with approximately 12,000 described species. Also called **sedge-flies** or **rail-flies**, they are small moth-like insects having two pairs of hairy membranous wings. They are closely related to Lepidoptera (moths and butterflies) which have scales on their wings, and the two orders together form the superorder Amphiesmenoptera. Caddisflies have aquatic larvae and are found in a wide variety of habitats such as streams, rivers, lakes, ponds, spring seeps, and temporary waters (vernal pools). The larvae of many species make protective cases of silk decorated with gravel, sand, twigs or other debris. The name "Trichoptera" comes from Greek: *trich*, "hair" + *ptera*, "wings".

Ecology

Although caddisflies may be found in waterbodies of varying qualities, species-rich caddisfly assemblages are generally thought to indicate clean water. Together with stoneflies and mayflies, caddisflies feature importantly in bioassessment surveys of streams and other water bodies. Caddisfly species can be found in all feeding guilds in stream habitats, with some species being predators, leaf shredders, algal grazers, and collectors of particles from the watercolumn and benthos.

Underwater architects

Caddisfly larva with portable case of rock fragments

Caddisfly larva emerging from case made of plant material

Close-up of spun case of caddisfly larva. BC, Canada

A "net" made by caddisfly larva. Texas, United States

Caddisflies are considered underwater architects because many species use silk for building throughout their larval life. Caddisflies can be loosely divided into three behavioral groups based on this use of silk: retreat-making caddisflies, case-making caddisflies, and free-living caddisflies. Those that build retreats build a net or retreat from silk and other materials and use it to catch food items such as algae, aquatic invertebrates and zooplankton from the flowing stream. Case-making caddisflies make portable cases using silk along with substrate materials such as small fragments of rock, sand, small pieces of twig, aquatic plants, or sometimes silk alone. Many use the retreats or cases throughout their larval life, adding to, or enlarging them as they grow. These may look very much like bagworm cases, which are constructed by various moth species that are not aquatic. Free-living caddisflies do not build retreats or carry portable cases until they are ready to pupate.

Development

Many species of caddisfly larvae enter a stage of inactivity called the pupa stage for weeks or months after they mature but prior to emergence. Their emergence is then triggered by cooling water temperatures in the fall, effectively synchronizing the adult activity to make mate-finding easier. In the Northwestern US, caddisfly larvae within their gravel cases are called 'periwinkles.'

Caddisfly pupation occurs much like pupation of Lepidoptera. That is, caddisflies pupate in a cocoon spun from silk. Caddisflies which build the portable cases attach their case to some underwater object, seal the front and back apertures against predation though still allowing water flow, and pupate within it. Once fully developed, most pupal caddisflies cut through their cases with a special pair of mandibles, swim up to the water surface, cast off skin and the now-obsolete gills and mandibles, and emerge as fully formed adults. In a minority of species, the pupae swim to shore (either below the water - see figure - or across the surface) and crawl out to emerge. Many of them are able to fly immediately after breaking from their pupal skin.

The adult stage of caddisflies, in most cases, is very short-lived, usually only 1–2 weeks, but can sometimes last for 2 months. Most adults are non-feeding and are equipped mainly to mate. Once mated, the female caddisfly will often lay eggs (enclosed in a gelatinous mass) by attaching them above or below the water surface. Eggs hatch in as little as three weeks.

Caddisflies in most temperate areas complete their lifecycles in a single year. The general temperate-zone lifecycle pattern is one of larval feeding and growth in autumn, winter, and spring, with adult emergence between late spring and early fall, although the adult activity of a few species peaks in the winter. Larvae are active in very cold water and can frequently be observed feeding under ice. In common with many aquatic insect species, many caddisfly adults emerge synchronously *en masse*. Such emergence patterns ensure that most caddisflies will encounter a member of the opposite sex in a timely fashion. Mass emergences of this nature are called 'hatches' by salmon and trout anglers, and salmonid fish species will frequently 'switch' to whatever species is emerging on a particular day. Anglers take advantage of this behavior by matching their artificial flies to the appropriate fly.

Chapter- 10

Butterfly

Butterflies	

Charaxes brutus natalensis in Dar es Salaam, Tanzania

Scientific classification	
Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Lepidoptera
(unranked):	**Rhopalocera**

Subgroups

- Superfamily Hedyloidea:
    - Hedylidae
- Superfamily Hesperioidea:
    - Hesperiidae
- Superfamily Papilionoidea:
    - Papilionidae
    - Pieridae
    - Nymphalidae
    - Lycaenidae
    - Riodinidae

Spider lily and butterfly Papilio xuthus Linnaeus 1767

A **butterfly** is a mainly day-flying insect of the order Lepidoptera, the butterflies and moths. Like other holometabolous insects, the butterfly's life cycle consists of four parts, egg, larva, pupa and adult. Most species are diurnal. Butterflies have large, often brightly coloured wings, and conspicuous, fluttering flight. Butterflies comprise the *true butterflies* (superfamily Papilionoidea), the *skippers* (superfamily Hesperioidea) and the *moth-butterflies* (superfamily Hedyloidea). All the many other families within the Lepidoptera are referred to as moths.

Butterflies exhibit polymorphism, mimicry and aposematism. Some, like the Monarch, will migrate over long distances. Some butterflies have evolved symbiotic and parasitic relationships with social insects such as ants. Some species are pests because in their larval stages they can damage domestic crops or trees; however, some species are agents of pollination of some plants, and caterpillars of a few butterflies (e.g., Harvesters) eat harmful insects. Culturally, butterflies are a popular motif in the visual and literary arts.

Life cycle

Mating Common Buckeye Butterflies

It is a popular belief that butterflies have very short life spans. However, butterflies in their adult stage can live from a week to nearly a year depending on the species. Many species have long larval life stages while others can remain dormant in their pupal or egg stages and thereby survive winters.

Butterflies may have one or more broods per year. The number of generations per year varies from temperate to tropical regions with tropical regions showing a trend towards multivoltinism.

Egg

Egg of *Ariadne merione*

Butterfly eggs are protected by a hard-ridged outer layer of shell, called the *chorion*. This is lined with a thin coating of wax which prevents the egg from drying out before the larva has had time to fully develop. Each egg contains a number of tiny funnel-shaped openings at one end, called *micropyles*; the purpose of these holes is to allow sperm to enter and fertilize the egg. Butterfly and moth eggs vary greatly in size between species, but they are all either spherical or ovate.

Butterfly eggs are fixed to a leaf with a special glue which hardens rapidly. As it hardens it contracts, deforming the shape of the egg. This glue is easily seen surrounding the base of every egg forming a meniscus. The nature of the glue is unknown and is a suitable subject for research. The same glue is produced by a pupa to secure the setae of the cremaster. This glue is so hard that the silk pad, to which the setae are glued, cannot be separated.

Eggs are usually laid on plants. Each species of butterfly has its own hostplant range and while some species of butterfly are restricted to just one species of plant, others use a range of plant species, often including members of a common family.

The egg stage lasts a few weeks in most butterflies but eggs laid close to winter, especially in temperate regions, go through a *diapause* (resting) stage, and the hatching may take place only in spring. Other butterflies may lay their eggs in the spring and have them hatch in the summer. These butterflies are usually northern species, such as the Mourning Cloak (Camberwell Beauty) and the Large and Small Tortoiseshell butterflies.

Caterpillars

Caterpillars of *Junonia coenia*

Butterfly larvae, or caterpillars, consume plant leaves and spend practically all of their time in search of food. Although most caterpillars are herbivorous, a few species such as *Spalgis epius* and *Liphyra brassolis* are entomophagous (insect eating).

Some larvae, especially those of the Lycaenidae, form mutual associations with ants. They communicate with the ants using vibrations that are transmitted through the substrate as well as using chemical signals. The ants provide some degree of protection to these larvae and they in turn gather honeydew secretions.

Caterpillars mature through a series of stages called instars. Near the end of each instar, the larva undergoes a process called apolysis, in which the cuticle, a tough outer layer made of a mixture of chitin and specialized proteins, is released from the softer epidermis beneath, and the epidermis begins to form a new cuticle beneath. At the end of each instar, the larva moults the old cuticle, and the new cuticle expands, before rapidly hardening and developing pigment. Development of butterfly wing patterns begins by the last larval instar.

Butterfly caterpillars have three pairs of true legs from the thoracic segments and up to 6 pairs of prolegs arising from the abdominal segments. These prolegs have rings of tiny hooks called crochets that help them grip the substrate.

Some caterpillars have the ability to inflate parts of their head to appear snake-like. Many have false eye-spots to enhance this effect. Some caterpillars have special structures called osmeteria which are everted to produce smelly chemicals. These are used in defense.

Host plants often have toxic substances in them and caterpillars are able to sequester these substances and retain them into the adult stage. This helps making them unpalatable to birds and other predators. Such unpalatibility is advertised using bright red, orange, black or white warning colours. The toxic chemicals in plants are often evolved specifically to prevent them from being eaten by insects. Insects in turn develop countermeasures or make use of these toxins for their own survival. This "arms race" has led to the coevolution of insects and their host plants.

Wing development

Last instar wing disk, *Junonia coenia*

Detail of a butterfly wing

Wings or wing pads are not visible on the outside of the larva, but when larvae are dissected, tiny developing *wing disks* can be found on the second and third thoracic segments, in place of the spiracles that are apparent on abdominal segments. Wing disks develop in association with a trachea that runs along the base of the wing, and are surrounded by a thin *peripodial membrane*, which is linked to the outer epidermis of the larva by a tiny duct.

Wing disks are very small until the last larval instar, when they increase dramatically in size, are invaded by branching tracheae from the wing base that precede the formation of the wing veins, and begin to develop patterns associated with several landmarks of the wing.

Near pupation, the wings are forced outside the epidermis under pressure from the hemolymph, and although they are initially quite flexible and fragile, by the time the pupa breaks free of the larval cuticle they have adhered tightly to the outer cuticle of the pupa (in obtect pupae). Within hours, the wings form a cuticle so hard and well-joined to the body that pupae can be picked up and handled without damage to the wings.

Pupa

Chrysalis of Gulf Fritillary

When the larva is fully grown, hormones such as prothoracicotropic hormone (PTTH) are produced. At this point the larva stops feeding and begins "wandering" in the quest of a suitable pupation site, often the underside of a leaf.

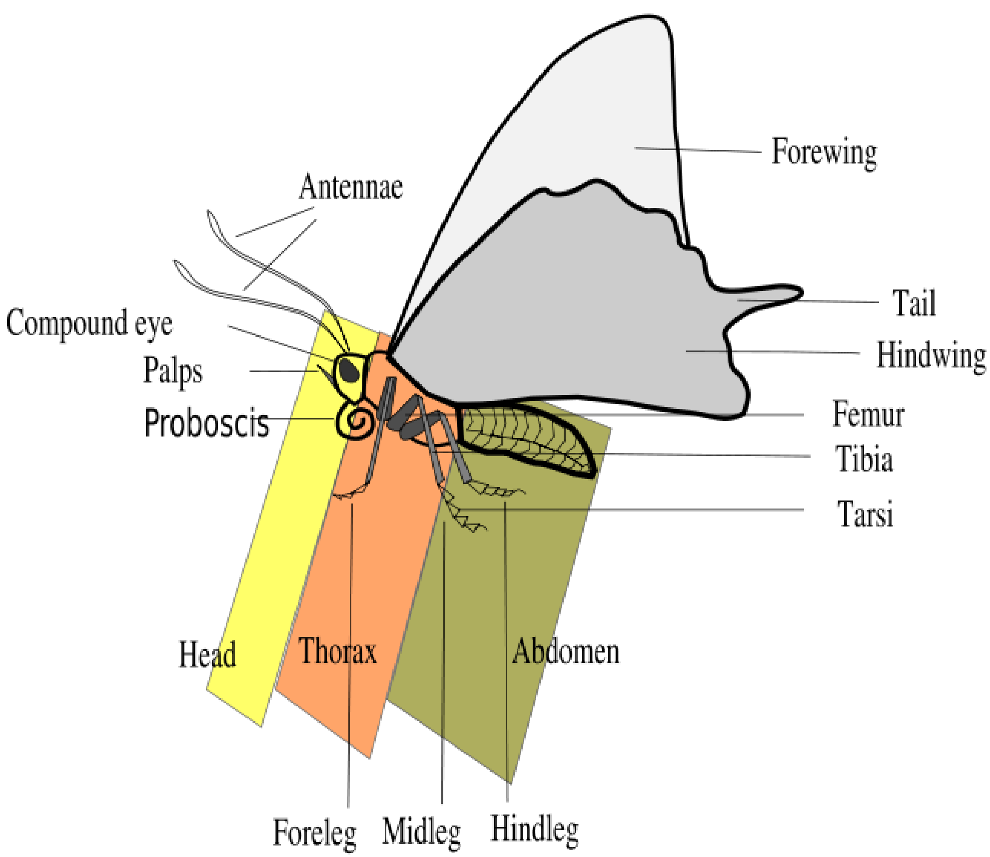
The larva transforms into a pupa (or chrysalis) by anchoring itself to a substrate and moulting for the last time. The chrysalis is usually incapable of movement, although some species can rapidly move the abdominal segments or produce sounds to scare potential predators.

The pupal transformation into a butterfly through metamorphosis has held great appeal to mankind. To transform from the miniature wings visible on the outside of the pupa into large structures usable for flight, the pupal wings undergo rapid mitosis and absorb a great deal of nutrients. If one wing is surgically removed early on, the other three will grow to a larger size. In the pupa, the wing forms a structure that becomes compressed from top to bottom and pleated from proximal to distal ends as it grows, so that it can rapidly be unfolded to its full adult size. Several boundaries seen in the adult color pattern are marked by changes in the expression of particular transcription factors in the early pupa.

Adult or imago

The adult, sexually mature, stage of the insect is known as the imago. As Lepidoptera, butterflies have four wings that are covered with tiny scales. The fore and hindwings are not hooked together, permitting a more graceful flight. An adult butterfly has six legs, but in the nymphalids, the first pair is reduced. After it emerges from its pupal stage, a butterfly cannot fly until the wings are unfolded. A newly emerged butterfly needs to spend some time inflating its wings with blood and letting them dry, during which time it is extremely vulnerable to predators. Some butterflies' wings may take up to three hours to dry while others take about one hour. Most butterflies and moths will excrete excess dye after hatching. This fluid may be white, red, orange, or in rare cases, blue.

External morphology



Parts of an adult butterfly

Butterflies have two antennae, two compound eyes, and a proboscis

Adult butterflies have four wings: a forewing and hindwing on both the left and the right side of the body. The body is divided into three segments: the head, thorax, and the abdomen. They have two antennae, two compound eyes, and a proboscis.

Polymorphism

Many adult butterflies exhibit polymorphism, showing differences in appearance. These variations include geographic variants and seasonal forms. In addition many species have females in multiple forms, often with mimetic forms. Sexual dimorphism in coloration and appearance is widespread in butterflies. In addition many species show sexual dimorphism in the patterns of ultraviolet reflectivity, while otherwise appearing identical to the unaided human eye. Most of the butterflies have a sex-determination system that is represented as ZW with females being the heterogametic sex (ZW) and males homogametic (ZZ).

Genetic abnormalities such as gynandromorphy also occur from time to time. In addition many butterflies are infected by *Wolbachia* and infection by the bacteria can lead to the conversion of males into females or the selective killing of males in the egg stage.

Mimicry

The Heliconius butterflies from the tropics of the Western Hemisphere are the classical model for Müllerian mimicry.

Batesian and Mullerian mimicry in butterflies is common. Batesian mimics imitate other species to enjoy the protection of an attribute they do not share, aposematism in this case. The Common Mormon of India has female morphs which imitate the unpalatable red-bodied swallowtails, the Common Rose and the Crimson Rose. Mullerian mimicry occurs when aposematic species evolve to resemble each other, presumably to reduce predator sampling rates, the Heliconius butterflies from the Americas being a good example.

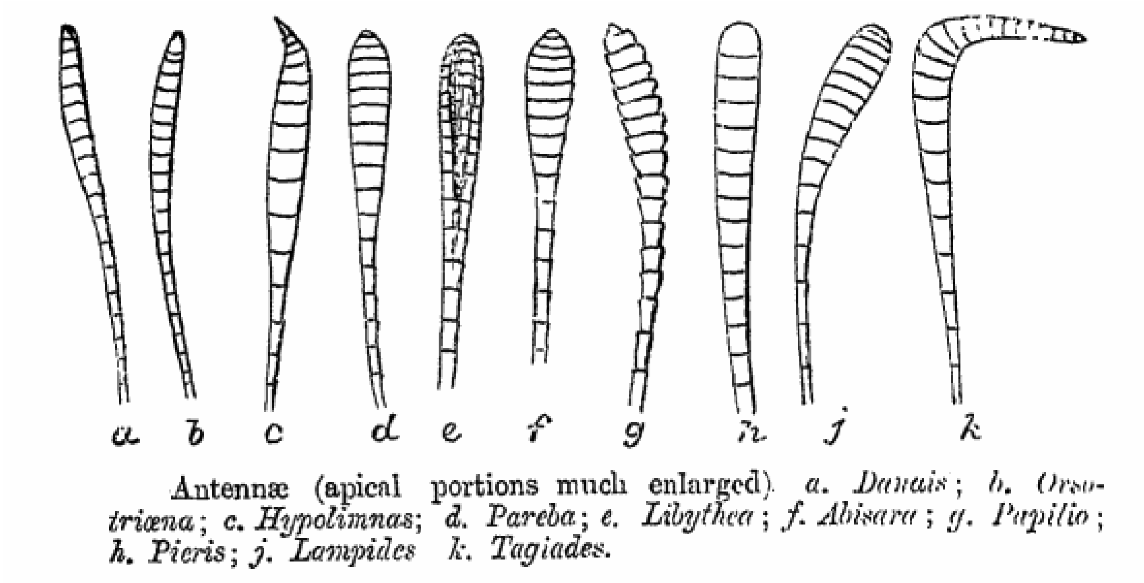
Wing markings called eyespots are present in some species; these may have an automimicry role for some species. In others, the function may be intraspecies communication, such as mate attraction. In several cases, however, the function of butterfly eyespots is not clear, and may be an evolutionary anomaly related to the relative elasticity of the genes that encode the spots.

Seasonal polyphenism

Many of the tropical butterflies have distinctive seasonal forms. This phenomenon is termed seasonal polyphenism and the seasonal forms of the butterflies are called the dry-season and wet-season forms. How the season affects the genetic expression of patterns is still a subject of research. Experimental modification by ecdysone hormone treatment has demonstrated that it is possible to control the continuum of expression of variation between the wet and dry-season forms. The dry-season forms are usually more cryptic and it has been suggested that the protection offered may be an adaptation. Some also show greater dark colours in the wet-season form which may have thermoregulatory advantages by increasing ability to absorb solar radiation.

Bicyclus anynana is a species of butterfly that exhibits a clear example of seasonal polyphenism. These butterflies, endemic to Africa, have two distinct phenotypic forms that alternate according to the season. The wet-season forms have large, very apparent ventral eyespots whereas the dry-season forms have very reduced, oftentimes nonexistent, ventral eyespots. Larvae that develop in hot, wet conditions develop into wet-season adults where as those growing in the transition from the wet to the dry season, when the temperature is declining, develop into dry-season adults. This polyphenism has an adaptive role in *B. anynana*. In the dry-season it is disadvantageous to have conspicuous eyespots because *B. anynana* blend in with the brown vegetation better without eyespots. By not developing eyespots in the dry-season they can more easily camouflage themselves in the brown brush. This minimizes the risk of visually mediated predation. In the wet-season, these brown butterflies cannot as easily rely on cryptic coloration for protection because the background vegetation is green. Thus, eyespots, which may function to decrease predation, are beneficial for *B. anynana* to express.

Habits



Antennal shape in the Lepidoptera from C. T. Bingham (1905)

The Australian painted lady feeding on a flowering shrub

Butterflies feed primarily on nectar from flowers. Some also derive nourishment from pollen, tree sap, rotting fruit, dung, decaying flesh, and dissolved minerals in wet sand or dirt. Butterflies are important as pollinators for some species of plants although in general they do not carry as much pollen load as bees. They are however capable of moving pollen over greater distances. Flower constancy has been observed for at least one species of butterfly.

As adults, butterflies consume only liquids and these are sucked by means of their proboscis. They feed on nectar from flowers and also sip water from damp patches. This they do for water, for energy from sugars in nectar and for sodium and other minerals which are vital for their reproduction. Several species of butterflies need more sodium than provided by nectar. They are attracted to sodium in salt and they sometimes land on people, attracted by human sweat. Besides damp patches, some butterflies also visit dung, rotting fruit or carcasses to obtain minerals and nutrients. In many species, this mud-puddling behaviour is restricted to the males, and studies have suggested that the nutrients collected are provided as a nuptial gift along with the spermatophore during mating.

Butterflies sense the air for scents, wind and nectar using their antennae. The antennae come in various shapes and colours. The hesperids have a pointed angle or hook to the antennae, while most other families show knobbed antennae. The antennae are richly covered with sensillae. A butterfly's sense of taste is coordinated by chemoreceptors on the tarsi, or feet, which work only on contact, and are used to determine whether an egg-laying insect's offspring will be able to feed on a leaf before eggs are laid on it. Many butterflies use chemical signals, pheromones, and specialized scent scales (androconia) and other structures (coremata or 'Hair pencils' in the Danaidae) are developed in some species.

Vision is well developed in butterflies and most species are sensitive to the ultraviolet spectrum. Many species show sexual dimorphism in the patterns of UV reflective patches. Color vision may be widespread but has been demonstrated in only a few species.

Some butterflies have organs of hearing and some species are also known to make stridulatory and clicking sounds.

Monarch butterflies

Many butterflies, such as the Monarch butterfly, are migratory and capable of long distance flights. They migrate during the day and use the sun to orient themselves. They also perceive polarized light and use it for orientation when the sun is hidden.

Many species of butterfly maintain territories and actively chase other species or individuals that may stray into them. Some species will bask or perch on chosen perches. The flight styles of butterflies are often characteristic and some species have courtship flight displays. Basking is an activity which is more common in the cooler hours of the morning. Many species will orient themselves to gather heat from the sun. Some species have evolved dark wingbases to help in gathering more heat and this is especially evident in alpine forms.

Flight

Heteronympha merope taking off

Like many other members of the insect world, the lift generated by butterflies is more than what can be accounted for by steady-state, non-transitory aerodynamics. Studies using *Vanessa atalanta* in a windtunnel show that they use a wide variety of aerodynamic mechanisms to generate force. These include wake capture, vortices at the wing edge, rotational mechanisms and Weis-Fogh 'clap-and-fling' mechanisms. The butterflies were also able to change from one mode to another rapidly.

Migration

The Monarch butterfly migrates large distances

Many butterflies migrate over long distances. Particularly famous migrations are those of the Monarch butterfly from Mexico to northern USA and southern Canada, a distance of about 4000 to 4800 km (2500–3000 miles). Other well known migratory species include the Painted Lady and several of the Danaine butterflies. Spectacular and large scale migrations associated with the Monsoons are seen in peninsular India. Migrations have been studied in more recent times using wing tags and also using stable hydrogen isotopes.

Butterflies have been shown to navigate using time compensated sun compasses. They can see polarized light and therefore orient even in cloudy conditions. The polarized light in the region close to the ultraviolet spectrum is suggested to be particularly important.

It is suggested that most migratory butterflies are those that belong to semi-arid areas where breeding seasons are short. The life-histories of their host plants also influence the strategies of the butterflies.

Defense

The wings of a butterfly (Leopard Lacewing *Cethosia cyane*) become increasingly damaged as it ages, and do not repair

Butterflies are threatened in their early stages by parasitoids and in all stages by predators, diseases and environmental factors. They protect themselves by a variety of means.

Chemical defenses are widespread and are mostly based on chemicals of plant origin. In many cases the plants themselves evolved these toxic substances as protection against herbivores. Butterflies have evolved mechanisms to sequester these plant toxins and use them instead in their own defense. These defense mechanisms are effective only if they are also well advertised and this has led to the evolution of bright colours in unpalatable butterflies. This signal may be mimicked by other butterflies. These mimetic forms are usually restricted to the females.

Eyespots on the wings of this butterfly are part of the animal's defense

Cryptic coloration is found in many butterflies. Some like the oakleaf butterfly are remarkable imitations of leaves. As caterpillars, many defend themselves by freezing and appearing like sticks or branches. Some papilionid caterpillars resemble bird dropping in their early instars. Some caterpillars have hairs and bristly structures that provide protection while others are gregarious and form dense aggregations. Some species also form associations with ants and gain their protection.

Behavioural defenses include perching and wing positions to avoid being conspicuous. Some female Nymphalid butterflies are known to guard their eggs from parasitoid wasps.

Eyespots and tails are found in many lycaenid butterflies and these divert the attention of predators from the more vital head region. An alternative theory is that these cause ambush predators such as spiders to approach from the wrong end and allow for early visual detection.

A butterfly's hind wings are thought to allow the butterfly to take swift, tight turns to evade predators.

Notable species

Rusty-tipped Page (*Siproeta epaphus*), Butterfly World (Florida)

There are between 15,000 and 20,000 species of butterflies worldwide. Some well-known species from around the world include:

- Swallowtails and Birdwings, Family **Papilionidae**
  - Common Yellow Swallowtail, *Papilio machaon*
  - Spicebush Swallowtail, *Papilio troilus*
  - Lime Butterfly, *Papilio demoleus*
  - *Ornithoptera* genus (Birdwings; the largest butterflies)
- Whites and Yellows, Family **Pieridae**
  - Small White, *Pieris rapae*
  - Green-veined White, *Pieris napi*
  - Common Jezebel, *Delias eucharis*
- Blues and Coppers or Gossamer-Winged Butterflies, Family **Lycaenidae**
  - Xerces Blue, *Glaucopsyche xerces* (extinct)
  - Karner Blue, *Lycaeides melissa samuelis* (endangered)

    - Red Pierrot, *Talicada nyseus*
- Metalmark butterflies, Family **Riodinidae**
    - Duke of Burgundy, *Hamearis lucina*
    - Plum Judy, *Abisara echerius*
- Brush-footed butterflies, Family **Nymphalidae**
    - Painted Lady, or Cosmopolitan, *Vanessa cardui*
    - Monarch butterfly, *Danaus plexippus*
    - *Morpho* genus
    - Speckled Wood, *Pararge aegeria*
- Skippers, Family **Hesperiidae**
    - Mallow Skipper, *Carcharodus alceae*
    - Zabulon Skipper, *Poanes zabulon*

Chapter- 11

Entomology Equipment

Bottle trap for insects

Bottle trap is a name used for several different objects. Among these are a piece of material used in bathroom plumbing, as well as various traps that are made out of discarded bottles and which are used to trap animals as different as beetles, mice, fish and octopuses.

In this context, a **bottle trap** is a type of baited arboreal (placed in a tree) insect trap widely used for collecting either prized or harmful fruit-eating beetles, especially *flower beetles*., *leaf chafers* and *longhorn beetles* as well as wasps and other unwanted flying insects.

Structure

A bottle trap is an insect trap made out of a plastic bottle. Most collectors use bottles of 1.5 or 2 liters to make these traps but smaller bottles are sometimes used as well. There are basically two types:

- Funnel type. These bottle traps are made by cutting off the neck of the bottle as well as the complete tapering part of the top. The neck and cap are discarded. For catching wasps only the cap is removed, while leaving the neck in place. The tapering part is placed upside down on top of the rest of the bottle, thereby effectively forming a funnel. This funnel is then fixed to the bottle by piercing both bottle and funnel at two opposing sides. A wire fitted through these holes ensures the funnel solidly fits on the bottle, while the trap can easily be opened when required. After putting the bait in the bottle the trap is placed at the desired location.
    - Advantages:
        - Insects can't escape from this type of trap, since they fly up along the side of the bottle, not finding the exit, which is in the middle.
        - Bats and large moths can't enter the trap, since they are too large to fit through the funnel.
        - This type can, unlike the other kind, also be used to collect troublesome wasps

    - Disadvantages:
        - Not only insects but also rain will funnel into the trap. This trap is therefore normally only used in dry seasons.
        - This construction requires a bit more work than the side door type.

- Side-door type. A side-door bottle trap consists of a bottle with cap of which the higher end of one upright side is cut open. A simple rectangular shape is cut out, taking care that it stays attached to the bottle on its upside. This plastic flap is then bend upward, effectively forming a rain shield over the entrance. After adding some bait the trap is put in its place.
    - Advantages:
        - Because of its opening with rain shield very little rain enters the trap, making it effective in wet seasons too.
        - Construction is very simple and requires no additional materials.
    - Disadvantages:
        - The wider opening allows for small bats and large moths to enter. These may die in the trap and pollute it, as well as forming, with their wings, a bridge to the exit.
        - Captured beetles may escape again since they may simply fly upward along the side of the bottle.

Bait

Many different types of bait are used. Since this kind of trap is mainly used for beetles that are attracted to (over)ripe fruits, baits with a certain amount of alcohol are usually very effective. Types of bait which are commonly used are:

- For beetles:
    - Banana with or without beer or rum (and sometimes with added sugar).
    - A mixture of (cheap) red wine, vinegar and sugar.
- For wasps (funnel type bottle trap only):
    - Syrup, soft drink or sugar water.

Other fruits are sometimes used as well, but banana is most often used since it is widely available, normally inexpensive and contains suffient sugar to start a fermentation process by itself. The different ingredients are usually kept apart and mixed in the trap itself, but some collectors prefer to mix their bait before going into the field.

Placement

Bottle traps (like all traps) yield best in places where more of the desired insects are to be expected. For beetles, in general this means high up in trees, especially flowering or fruiting trees. Other places in which traps are often placed with good results include forest borders. Traps placed inside forests usually yield smaller numbers of beetles, but also different species. Traps for luring wasps are usually set up a short distance (several meters) from the place where they are bothersome.

There are various methods used for placing bottle traps:

- After a hole is made in the top of the trap, a branch is bent down and its top fitted through the hole.
- A thin cord is attached to the trap, after which the cord is thrown over a high branch and the trap pulled up, the rope then being fixed to some lower branch.
- After a wire hook is fixed to it, the trap is either manually or with the aid of a long stick hung over a branch.
- The trap is just placed on the ground.

The first three methods are used most often for collecting beetles, while the latter two are more commonly in use for catching wasps.

Bycatch

Next to the desired beetles, many other insects may find the bait attractive. Sap beetles (a group of small fruit-eating beetles), moths like the large white witch moth, various butterflies, cockroaches, flies, stingless bees, wasps and even small fruit eating bats may enter the bottle traps as bycatch while the collector aims for beetles. Such unwanted animals in the trap may cause the collector several problems:

- These unwanted insects pollute the trap. Because they cannot escape the trap, they will, like the beetles, eventually die in it. Fragile insects such as moths and butterflies will live only for a short time in these traps, and after they die their bodies will quickly start rotting, and their intestines as well as the scales on their wings will pollute the bait. Although this will not necessarily alter the attractiveness of the bait to other insects, the remains of the unwanted specimen will make it more difficult for the collector to check the bait for desired beetles. Unwanted animals which are still alive usually need some time to get over the effects of alcohol, after which they will fly away.
- They may create an escape route for trapped beetles. Especially the very long wings of the neotropical white witch moth may form an effective bridge from the bait to the opening of the trap.
- Protected species such as bats may enter the trap and not be able to leave it again. When they are still alive, bats are often able to fly away directly after being flushed with clean water.

Flight interception trap

The **Flight Interception Trap** or FIT is a widely used trapping system for flying insects. It is especially well-suited for collecting beetles, since these animals usually drop themselves after flying into an object, rather than flying upward (in which case a Malaise trap is a better option). Flight Interception Traps are mainly used to collect flying species which are not likely to be attracted to bait or light.

Construction

The basis of any Flight Interception Trap consists of an upright placed see-through barrier under which one or more small basins are placed. The barrier may consist of such materials as plastic mesh, a transparent plastic sheet or even plexiglass, although the latter works not for day-active insects since it is visible to them due to its specific refraction. The basins are filled with a preserving fluid such as ethanol (which should be mixed with something bad-tasting (like denatonium) to prevent wild animals drinking it), propylene glycol, salt-saturated water or even plain water. The best preservative to keep internal organs in good condtion is FAACC, a solution of formaldehyde. A small amount of detergent is added to break the surface tension, causing the insects to sink.

Location

Depending on either the desired information (for research) or desired species (for trade) the construction can be put in open land or in the forest. It is important to place the barrier in a straight angle with the most likely flying route for insects (e.g. blocking a forest corridor), such as to maximize results.

Checking

The basins can be checked daily (when it is e.g. important to check the activity of the desired insects under different weather conditions), weekly or even less often. Maximum time between two checks depends on the used preservatives, since not all preservatives are equally suited for preserving insects for a longer time.

Cover

To prevent the basins from filling up with litter, most researchers place some kind of roof over the trap. This keeps leaves from falling in while it also keeps the rain out (which could otherwise dilute the preservative or cause an overflow).

Insect trap

A sticky insect trap used to monitor pest populations

Insect traps are used to monitor or directly reduce insect populations. They typically use food, visual lures, chemical attractants and pheromones as bait and are installed so that they do not injure other animals or humans or result in residues in foods or feeds. Visual lures use light, bright colors and shapes to attract pests. Chemical attractants or pheromones may attract only a specific sex. Insect traps are sometimes used in pest management programs instead of pesticides but are more often used to look at seasonal and distributional patterns of pest occurrence. This information may then be used in other pest management approaches.

The trap mechanism or bait can vary widely. Light traps with ultraviolet attract certain insects. Designs differ according to the behaviour of the insects being studied. Grasshoppers and some beetles are attracted to lights at a long range but are repelled by it at short range. Farrow's light trap has a large base so that it captures insects that may otherwise fly away from regular light traps. Flies and wasps are attracted by proteins. Mosquitoes and many other insects are attracted by bright colors, carbon dioxide, lactic acid, floral or fruity fragrances, warmth, moisture and pheromones. Synthetic attractants like Methyl eugenol are very effective with Tephritid flies. Yellow pan traps are used to monitor aphids and some other sap sucking insects. Pitfall traps are used for ground foraging and flightless insects such as beetles of the family Carabidae.

Insect traps in practice

At present,

Examples of food traps

Following traps are used extensively by gardeners:

- eggshells: strewn on the ground; protects plants against snails
- carrot disks: against click beetles and crane flies
- sawdust: against onion fly, carrot fly and cabbage flies
- flour grains: made from 3 parts flour, 2 parts chalc, and 1 part sugar, knid to a grain; against mice
- beer and regular pot traps: small pots, filled with 2 cm beer or without anything at all, dug into the soil; against snails and other insects

Killing jar

A killing jar in use. Notice the insect in the right side of the jar

A **killing jar** is a device used by entomologists to kill captured insects quickly and with minimum damage. The jar, typically glass, must be hermetically sealable and usually has a thin layer of hardened plaster of paris on the bottom to absorb the insecticide. The insecticide will then slowly evaporate, allowing the jar to be used many times without the need to refresh the insecticide. The absorbent plaster of paris layer also prevents the insecticide from sticking to and damaging insects.

The most common insecticides used today in killing jar are ether, chloroform and ethyl acetate. The crushed leaves of the shrub cherry laurel are very effective, though only for a few hours after fresh collection. In the past, potassium cyanide or other cyanide compounds were used, but is no longer used due to its extreme toxicity. The potassium cyanide would slowly decompose, releasing hydrogen cyanide.

Malaise trap

A Malaise trap

A **Malaise trap** is a large, tent-like structure used for trapping flying insects particularly Hymenoptera and Diptera. The trap is made of a material such as terylene netting and can be various colours. Insects fly into the tent wall and are funnelled into a collecting vessel attached to highest point. It was invented by René Malaise in 1934.

Structure

There are many versions of the malaise trap, but the basic structure consists of a tent with a large opening at the bottom for insects to fly into and a tall central wall that directs the flying insects upwards to a cylinder containing a killing agent. The chemicals vary according to purpose and access. Conventionally, cyanide was used inside the jar with an absorbent material. However, due to restrictions, many people use ethanol. Ethanol will damage some flying insects like Lepidopterans, but most people use the malaise trap primarily for Hymenopterans and Dipterans. In addition, the ethanol will keep the specimens preserved for a longer period of time. Other dry killing agents include no-pest strips (vapona) and ethyl acetate and need to be checked more regularly.

Design details

Cylinder

When choosing a malaise trap design, it is important to consider the types of insects you want to catch. The opening to the cylinder is of key importance. Typically, the opening is around 12-15mm, but can vary according to the size of insect you are trying to catch. If using a dry agent, a smaller hole will result in a faster death, limiting the amount of damage a newly caught insect will inflict on older, fragile specimens. In ethanol, this is less of a concern. Larger holes also allow in more butterflies, moths, and dragonflies potentially.

Location

Placement of the trap is very important. The trap should be positioned to maximize the number of flying insects that pass through the opening. This is determined by the natural features of the site. One should evaluate topography, vegetation, wind, and water. For example, if there is a wide corridor in a forest such as a trail, the trap should be oriented with its opening to the corridor. Also, places where vegetation is growing high around the opening will limit the number of flying insects that enter the trap. Other ideal places may be above small streams or on edges of forests.

A well placed trap in ideal seasonal conditions can catch over 1,000 insects a day. Even in less ideal conditions, like rain, the trap is still effective.

Other uses

The malaise trap can also function as a light trap. If a lamp is placed at the end opposite of the opening, the light will attract insects into the trap. For those who want to know what insects they are catching in the day versus the night, the specimens should be collected and removed at dawn and dusk. For others, specimens should be removed from the trap at least once a week if using ethanol, or more often if using a dry killing agent.

The design of the trap catches insects that naturally fly upwards when they hit a barrier. However, some insects drop when met with a barrier. An addition of a pan with ethanol at the bottom of the main wall will catch specimens like beetles that fall before reaching the top. A trap without the netting on top but with just a preservative-filled basin under the barrier is commonly named a Flight Interception Trap or FIT.

Pooter

A USAF Colonel using a powered aspirator, or pooter, to collect mosquitoes in northern Thailand

A **pooter** (sometimes, usually by Americans, referred to as an **aspirator** or **aspirator gun**) is a device used in the collection of insects, crustaceans or other small, fragile organisms, usually for scientific purposes.

Such devices are most commonly used by entomologists for field and lab work. One of the most common designs consists of a small resealable jar or vial, the lid or stopper of which is penetrated by two tubes. On the inner end of one tube, fine mesh or another type of filter is attached, and this tube leads to the user's mouth (usually connected by a long, flexible piece of tubing). The end of the second tube projects into the collecting chamber, and its far end can then be placed over an insect or other small organism; the user sucks on the first tube, and the insect is drawn into the collecting chamber through the other.

The other common design (the more traditional "pooter") consists of a length of flexible tubing, of which one end is held in the mouth, and the other end which holds the tip. The tip is usually a glass or plastic pipette inserted into the plastic tubing, with a piece of gauze as a filter at the inner end to prevent accidental ingestion. Small insects (e.g., *Drosophila*) may be gently collected and held against the filter by steady inhalation, and transferred into a container by then blowing the insect(s) out. A skilled lab worker, for instance, may be able to sequentially inhale and then transfer a pooter-full of *Drosophila* flies singly into vials, thus facilitating rapid setup of fly experiments with a minimum of pain caused to the researcher, or the researched. Larger, motor-powered variants of this design exist (typically, a leaf blower working in reverse), where the insects are sucked into a mesh collecting bag in a long plastic tube, and held there by the powerful suction.