

Melophagus
(insect: dipteran)

Overview

Arthropods are coelomate metameric invertebrate animals with a chitinous exoskeleton and jointed limbs. They undergo protostomial embryonic development and grow by cuticular moulting (ecdysis). Three main subphyla are recognized: Chelicerata, Crustacea and Hexapoda. Insects are hexapods with three pairs of uniramous legs, three tagmata (head, thorax, abdomen), ectognathous mouthparts with whole-limb mandibles, and one pair of antennae. Diptera (true flies) have two pairs of wings, but the hindwings are reduced to stabilizing halteres. All species are holometabolans and exhibit complete metamorphosis whereby vermiform larval stages undergo pupation and transform into free-flying adults. Several major parasitic groups are recognized: nematocerans (small slender bodies, long filamentous antennae, narrow wings) and brachycerans (larger bodies, short stout antennae, broad wings); the latter being divided into the Tabanomorpha (larval head capsule sclerotized) and the Muscomorpha (larval head not sclerotized, circular-seamed (cyclorrhaphous) pupae). Muscomorphans include the glossinids (tsetse flies), hippoboscids (louse flies), muscids (house flies), calliphorids (blow flies), sarcophagids (flesh flies) and oestrids (bot flies); all with sponging or biting mouthparts. These flies are either ectoparasitic with adults biting hosts (former three groups) or endoparasitic with vermiform larvae developing in host tissues (latter three groups). Hippoboscids (louse flies) are unusual in being dorsoventrally flattened with a soft leathery abdomen. Both sexes have piercing mouthparts and suck blood from mammals and birds. Most are permanent ectoparasites using strong claws on their feet to cling to hairs or feathers. Females are larviparous and pupiparous, depositing developed larvae on the host to attach and undergo pupation. Infestations by *Melophagus* and *Hippobosca* spp. have been associated with unthriftiness in sheep and other mammals.

Classification:

Domain: Eukaryota (membrane-bound nucleus)
Supergroup: Amorphea (unikonts with single flagellum, or nonflagellated amoebae)
Kingdom: Metazoa (multicellular eukaryotes, heterotrophs, notably animals)
Group: Protostomia (triploblastic, spiral cleavage)
Subgroup: Ecdysozoa (cuticle moulted = ecdysis)
Phylum: Arthropoda (chitinous exoskeleton, segmented body, jointed limbs, haemocoel)
Subphylum: Hexapoda (three tagmata, three pairs uniramous legs, whole-limb mandibles, Malpighian tubules)
Class: Insecta (ectognathous mouthparts (bases lie outside head capsule), single pair antennae, many with wings)
Superorder: Holometabola (Endopterygota) (young do not resemble adults, pupae, with internally developing wings)
Order: Diptera (true flies, single pair of forewings, hindwings modified into halteres, vermiform larvae)
Suborder: Brachycera (tabanid/March flies, short stout antennae often with aristae, telmophagy)
Infraorder: Muscomorpha (Cyclorrhapha) (flies, cyclorrhaphous (circular-seamed) pupae, larval head not sclerotized)
Division: Schizophora (head with frontal suture (lunule))
Section: Calyptratae (calypters cover halteres)
Superfamily: Hippoboscoidea (pupa-bearers)
Family: Hippoboscidae (flat/louse flies, leathery abdomen, piercing mouthparts, strong claws on feet)
Genus: *Melophagus* (parasitic on skin/fleece of sheep)
Species: various species cause anaemia, reduced productivity

Parasite biodiversity and host range: Most Metazoa are multicellular triploblastic animals with differentiated tissues, many being bilaterally symmetrical with a body cavity. Most invertebrate animals are protostomes as their embryonic development involves spiral determinate cleavage. Those that moult their external cuticles during their life-cycles (process known as ecdysis) are grouped together in the unique clade Ecdysozoa, including the nematodes (roundworms), onychophorans (velvet worms), tardigrades (water bears) and arthropods (myriapods, chelicerates, crustaceans and hexapods). Arthropods have small segmented bodies encased in chitinous exoskeletons with articulated limbs. Most species are free-living in terrestrial and aquatic habitats, although a small range are ectoparasitic on other animals, some feeding on the blood or skin of vertebrates. Five subphyla are recognized: Chelicerata, Crustacea, Hexapoda, Myriapoda and Trilobita. Insects are hexapods with six legs, three distinct body parts, two antennae and mouthparts with whole-limb mandibles. Insects are the most biodiverse group on the planet, with millions of species described in numerous taxa. Notorious ectoparasitic species belong to four orders in two superorders: the Hemipteroidea (Exopterygota) containing the orders Hemiptera (bugs) and Phthiraptera (lice); and the Holometabola (Endopterygota) containing the orders Siphonaptera (fleas) and Diptera ('true' flies). Flies are small winged holometabolans that undergo complete (holometabolous) metamorphosis with vermiform larvae undergoing pupation in silk cocoons. Thousands of dipteran species have been described throughout the world, most being free-living saprophages (detritivores) but some being parasitic either as adults biting and feeding on hosts (often haematophagous) or producing larvae that invade host tissues (condition known as myiasis). Two major suborders are recognized: the Nematocera (with small bodies, long filamentous antennae, narrow wings and aquatic larvae and pupae); and the Brachycera (with large bodies, short stout antennae often with aristae and broad wings).

Major parasitic dipteran families	Biodiversity	Parasitic stages	Status	Pathogenesis*	Disease transmission
Suborder: Nematocera (small midges/mosquitoes, thread-horned with long filamentous segmented antennae (= nemato-cera), aquatic life-cycles (larval/pupal stages associated with water), female adults require blood meal before they can lay eggs) (34 families)					
Culicidae (mosquitoes)	3 subfamilies, 70 genera, 3,500 species	adult ♀	obligate	blood-sucking	viral, protozoal, helminth
Psychodidae (moth flies, sand flies)	5 subfamilies, 150 genera, 3,000 species	adult ♀	obligate	blood-feeding	viral, bacterial, protozoal
Simuliidae (black flies)	3 subfamilies, 30 genera, 2,000 species	adult ♀	obligate	blood-feeding	protozoal, helminth
Ceratopogonidae (biting midges)	4 subfamilies, 110 genera, 6,000 species	adult ♀	obligate	blood-feeding	viral, protozoal, helminth
Suborder: Brachycera (large tabanid/March flies, with stout and fewer antennal segments (= brachy-cera), antennae often with arista, females with slashing-sponging mouthparts to pierce skin and feed on pool of blood (telmophagy)) (120 families)					
Infraorder: Tabanomorpha (larval head capsule incomplete posteriorly (only anterior parts sclerotized))					
Tabanidae (horse flies, deer flies)	3-5 subfamilies, 133 genera, 4,300 species	adult ♀ [+ larvae]	obligate [accidental]	blood-feeding [GI, UG, TR myiasis]	viral, bacterial, protozoal, helminth
Infraorder: Muscomorpha (Cyclorrhapha) (aristate antennae, setose bodies, cyclorrhaphous pupa)					
Section: Calyptratae (calypters cover halteres)					
Superfamily: Muscoidea (synanthropic flies)					
Muscidae (house flies, stable flies)	9-10 subfamilies, 190 genera, 4,200 species	adult ♀, ♂ [+ larvae]	obligate [accidental]	biting, blood-feeding [CU, GI, TR myiasis]	bacterial, helminth
Superfamily: Oestroidea (cause larval myiasis) (6 families)					
Calliphoridae (blow flies)	11 subfamilies, 75 genera, 1,100 species	larvae	facultative, obligate	CU, GI, NP, AU, UG TR, myiasis	-
Sarcophagidae (flesh flies)	3 subfamilies, 108 genera, 2,500 species	larvae	facultative, obligate	TR, GI, CU myiasis	-
Oestridae (bot flies, warble flies)	5 subfamilies, 25 genera, 150 species	larvae	obligate	CU, GI, NP, OC myiasis	-
Superfamily: Hippoboscoidea (pupa-bearers)					
Glossinidae (tsetse flies)	1 genus, 3 species-groups, 25 species	adult ♀, ♂	obligate	blood	protozoal
Hippoboscidae (louse flies, keds)	1-3 subfamilies, 21 genera, 212 species	adult ♀, ♂	obligate	blood	viral, protozoal, helminth

*type of myiasis: AU = auricular; CU = cutaneous; GI = gastro-intestinal; NP = naso-pharyngeal; OC = ocular; TR = traumatic; UG = uro-genital.

The suborder Brachycera contains 6 infraorders: Asilomorpha (bee flies, robber flies, spider flies), Muscomorpha (previously suborder Cyclorrhapha) (house flies, blow flies, fruit flies), Stratiomyomorpha (soldier flies), Tabanomorpha (horse, deer and snipe flies), Vermileonomorpha (wormlions) and Xylophagomorpha (awl flies); all of which vary considerably in their morphological and biological characteristics. Members of the infraorder Muscomorpha differ from the others in that they form cyclorrhaphous (circular-seamed) pupae (adults eclose through a circular cap rather than a longitudinal slit), larvae without sclerotized heads, and adults with short pendulous 3-segmented antennae (the third segment often bearing feather-like arista), palps with a single segment, and feet with 2 pads. Collectively, 15 superfamilies have been classified into 2 Divisions: the Schizophora (containing flies whose heads bear a frontal ptilinal suture and sclerotized lunule); and the Aschiza (hover flies lacking a frontal suture and lunule). Within the Schizophora, 2 sections are recognized: the Calyptratae (comprising flies with calypters covering the halteres, large squamae, a strong thoracic suture and well-defined grooves on the antennal pedicels); and the Acalyptratae (without covering calypters, small squamae, a weak thoracic suture and no pedicel grooves). Calyptratae flies are divided into 3

superfamilies: Muscoidea (synanthropic flies with well-developed sponging mouthparts for feeding on decaying organic material or biting mouthparts for blood-feeding, most females being oviparous (egg-layers)); Hippoboscoidea (louse flies and tsetse flies with elongate biting mouthparts for blood-feeding, female flies formerly regarded as pupa-bearers and placed in group Pupipara (now defunct) as they have since been shown to birth mature larvae (considered to be prepupae)); and Oestroidea (blow flies, bot flies and flesh flies whose larvae are endoparasitic and cause myiasis).

The superfamily Hippoboscoidea contains 4 families: Glossinidae (tsetse flies); Hippoboscidae (louse flies); Nycteribiidae (bat flies); and Streblidae (bat flies). The family Hippoboscidae contains dorsoventrally flattened flies with piercing mouthparts, leathery abdomens and strong claws on their feet. These 'flat' flies may be wingless or have wings with veins crowded into the leading half of wing. Members are often found as ectoparasites on many species on wild birds, although some infest ungulates, including domestic livestock. Over 200 species have been described in over 20 genera classified into 1-3 subfamilies. Usually, one subfamily is recognized (Hippoboscinae) albeit with 4 tribes: Hippoboscini with 2 genera (including *Hippobosca*), Lipoptenini with 2 genera (including *Melophagus*), Olfersiini with 3 genera, and Ornithomyini with 6 genera, with another 10 unplaced genera. Alternatively, some authorities have placed parasites of birds into the separate subfamily Ornithomyiinae, and melophagine parasites of artiodactyls into the subfamily Melophaginae (or Lipopteninae).

Tribe	Genera	Hosts	Site	Transmission
Hippoboscini	<i>Hippobosca</i>	equids, bovids	skin	direct
Lipoptenini	<i>Melophagus</i>	bovids, cervids	skin	direct

The genus *Melophagus* (syn. *Mellophagus*, *Melophaga*) contains 8 species that mainly parasitize artiodactyls (cloven-hoofed animals), particularly in temperate zones around the world. Early workers recognized 2 'species groups' (elevated tentatively to subgenera *M. (Melophagus)* and *M. (Dorcadophagus)*) on the basis of morphological differences in adult sclerotization, setation and palpi, but it is not yet known whether they are supported by molecular characterization studies. These dipteran ectoparasites are unusual in that they are wingless and have leathery integuments (somewhat resembling ticks). They spend their entire lives on their hosts whereby viviparous females produce mature larvae which almost immediately undergo pupation. Transmission between hosts is by close body contact. Keds have been introduced to most parts of the world where domestic sheep are kept. Infestations were previously more widespread and abundant but contemporary treatment and control programs have proven particularly effective.

<i>Melophagus</i> species	Hosts	Location	Clinical signs	Distribution
Species group 'a' (tentatively subgenus <i>M. (Dorcadophagus)</i>)				
<i>M. antilopes</i>	Artiodactyla: bovid (goitered gazelle)	skin		Asia
<i>M. rupicaprinus</i>	Artiodactyla: bovid (chamois, alpine ibex)	skin		Europe
Species group 'b' (tentatively subgenus <i>M. (Melophagus)</i>)				
<i>M. ovinus</i> (sheep ked) (syn. <i>Hippobosca bolivianus</i> , <i>fera</i> , <i>montanus</i> , <i>ovinus</i>) (incl. subspp. <i>ovinus</i> , <i>himalayae</i>)	Artiodactyla: bovid (cattle, European bison, yak, sheep, bighorn sheep, Dall sheep, argali, goat, alpine ibex, chamois, Mongolian gazelle), cervid (hog deer); Lagomorpha: leporid (rabbit); Carnivora: canid (dog, red fox); Primates: hominid (human)	skin (neck, shoulders, belly)	irritation, anaemia, wool loss, cockle (vector for ovine trypanosomiasis, eperythrozoonosis)	worldwide, esp. temperate zones
Ungrouped				
<i>M. dyspnoetus</i>	Artiodactyla: bovid (Siberian ibex)	skin		Russia
<i>M. grunini</i>	?	skin		Kazakhstan
<i>M. kamshaticus</i>	Artiodactyla: bovid (bighorn sheep)	skin		Russia
<i>M. kaukasikus</i>	?	skin		Russia
<i>M. pantholopsus</i>	Artiodactyla: bovid (Tibetan antelope)	skin		China

Parasite morphology: *Melophagus* spp. form 4 different types of developmental stages (eggs, larvae, pupae and adults) but only the latter 2 are found on hosts as the eggs and larvae develop *in utero* within female keds. Developing eggs appear as single cream-coloured inclusions measuring around 1.1 x 0.3 mm. Developing larvae appear as ovoid stages that are nourished by maternal milk gland secretions and grow through 3 instars (L1-3) to measure up to 4 mm long. Mature L3 (sometimes called prepupa) are laid by females and immediately harden forming barrel-shaped puparia 3-4 mm long that are initially creamy-yellow with a dark posterior respiratory plate, but they darken uniformly to red-brown within hours. The enclosed stage forms a pupa which appears as an amorphous gel-like blob while undergoing metamorphosis into an adult fly. Adult keds are readily identifiable as wingless louse flies with dorsoventrally-flattened bodies measuring 4-8 mm long. They are grey-reddish brown in colour, covered with many setae (short bristly hairs), have a soft leathery abdomen and 6 long clawed legs. The body has 3 conspicuous tagma: a short head fixed to the broad flattened thorax; and a large ovoid abdomen with inconspicuous segments. The head is short and broad with 2 small lateral

brown compound eyes (more setae on inner orbit in species group 'b' than 'a'), broad interantennal frons lacking ocelli, small immovable antennae located in deep rimmed pits and bearing few setae, and a forward-projecting proboscis flanked by long palps (longer in species group 'b' than 'a'). The proboscis strongly sclerotized and its base is partly retracted into a ventral head pouch when not in use while the distal portion is concealed within the palpal sheath. The proboscis contains piercing-sucking stylet-like mouthparts well adapted for feeding from blood vessels (process known as solenophagy) using the long thin labium (with terminal dentate labella) to cut the skin and the labrum and hypopharynx coming together to form a food channel for sucking. Blood is sucked up using strong pharyngeal muscles and passes through a tubular oesophagus to a globular proventriculus with an associated saccular crop. The digestive midgut apparently does not possess a peritrophic matrix but does contain endosymbiotic enterobacteria within bacteriocytes and a small granular bacteriome. Waste is passed through the hindgut (with excretory Malpighian tubules) to the rectum and terminal anus. The thorax has a shield-like dorsal scutum but completely lacks wings (apterous), as both the forewings and halteres are absent (unique to the genus *Melophagus* as other hippoboscids taxa have forewings, albeit some transiently, and stumpy halteres). The ventral thorax is the point of attachment for 3 pairs of long stout legs, each composed of 5 segments (coxa, trochanter, robust femur, flattened tibia, and tarsus), with the tarsi terminating in a pair of large toothed and recurved claws with prominent basal heels. The abdomen is bulbous, soft and leathery without distinct segments, although some species may have 1-2 tergal plates (species group 'a') while they are absent in others (species group 'b'). The abdomen is highly setate and contains pairs of lateral respiratory spiracles. The posterior end of female keds often appears flattened with a terminal asetate plate, while hind-end of male keds is rounded. Males have 2 testes connected to a seminal vesicle leading to a tubular ejaculatory duct and terminal copulatory apparatus (with retractable phallosome and claspers). Females have 2 ovaries connected by oviducts to a common duct expanding posteriorly to form a uterus that accommodates one embryo at a time. The uterus, with associated spermatheca (for sperm storage) and branched accessory (milk) glands, leads to the vulva in the terminal genital plate.

Site of infection: Adult keds and their pupae occur in the pelage (fleece, coat) of their mammalian hosts, principally sheep and related bovid artiodactyls. They are most commonly found under the neck, shoulders and ventral belly (ribs to breech), and contrary to popular belief, they do not undertake daily or seasonal migration between sites. Keds may occasionally be found in other closely-attending mammals, notably the ears of sheep-dogs (herding or guardian dogs) and on human skin (especially shepherds).

Pathogenesis: *Melophagus* spp. are sedentary wingless flies that feed on vertebrate hosts by piercing the skin with their mouthparts and sucking blood. Both male and female flies feeding every 24-36 hours, engorging over 5-10 minutes from blood vessels near bases of wool/hair follicles. Ked bites cause irritation, inflammation and pruritus, resulting in animals seeking relief by biting, scratching or rubbing afflicted areas, usually leading to self-trauma with loss and damage of wool (depilation, broken fibres). The fleece becomes thin, ragged and dirty with permanent brown discolouration caused by ked faeces leading to down-graded value. Blemishes at bite sites may be exacerbated by allergic dermatitis reactions leading to ridged defects in sheepskins (called cockle or rib cockle) evident as scattered dense brown nodules that significantly reduces hide value for both grain and suede leather production. Host immune responses to persistent attack include cellular infiltration and vasoconstriction to reduce dermal capillary flow, but these responses may also contribute to poorer wool growth and reduced quality. Infested animals suffer biting-stress and do not feed well with resultant unthriftiness, loss of condition, weight loss and reduced wool growth, particularly in lambs and pregnant ewes. Heavy infestations may also result in blood loss severe enough to manifest as anaemia, especially in lambs. *Melophagus* spp. are traditionally not renowned for the transmission of infectious diseases, as they are generally confined to the same individual hosts for multiple generations. Biological studies have shown that they may transmit the nonpathogenic haemoprotozoan *Trypanosoma melophagium* via stercorarian transmission, and experimental studies found they may carry blue-tongue virus although there is little evidence to suggest they are natural vectors. More recently, molecular studies have detected gene sequences from various bacteria (*Acinetobacter*, *Rickettsia* (spotted fever group), *Bartonella*, *Anaplasma* and even *Borrelia burgdorferi sensu lato*), protozoa (*Theileria ovis*) and viruses (Border disease virus) in keds from around the world, but their involvement in disease transmission remains speculative.

Developmental cycle and mode of transmission: Like all dipteran flies, keds undergo complete metamorphosis whereby grub-like larvae form pupae in which they transform into adult flies. However, unlike most Diptera, larval development occurs *in utero* (rather than in aquatic or terrestrial habitats), and all stages occur on vertebrate hosts (adults are wingless and stay on hosts). Female keds do not lay eggs but produce them one at a time and retain them in the reproductive tract where they embryonate using yolk reserves. After 1-2 days, larvae emerge from the eggs and are retained in the uterus where they are nourished by secretions from special milk glands over 7-8 days. These secretions also facilitate the vertical transmission of endosymbiotic bacteria, some being ubiquitous and obligate (essential) for ked survival (*Arsenophonus*) while others appear to be facultative (including *Sodalis*, *Bartonella* and *Wolbachia* spp.). The larvae develop through 3 instars (L1-3) before mature L3 which have ceased to feed (also called prepupae) are birthed. This type of reproduction is known as adenotrophic viviparity and the female flies are larviparous (not pupiparous as suggested by early works). Prepupae are deposited (larviposited) on the fleece covered with a secretion that hardens on drying and glues the puparium to wool above the skin (*Melophagus* is the only hippoboscids to glue puparia to their hosts, as those of other hippoboscids are deposited, or drop, on bedding or the ground). The prepupa forms a true pupa within 6-12 hours or parturition, and complete pupation takes 19-23 days in summer, 20-36 days in winter, but up to 45 days in more adverse conditions. Young adult keds then emerge and both sexes begin feeding on host blood. Teneral females (whose cuticles have not yet hardened) may mate within several days of eclosion, and a single mating may provide enough sperm for her lifetime (stored internally in spermathecae), but

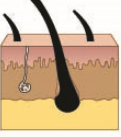
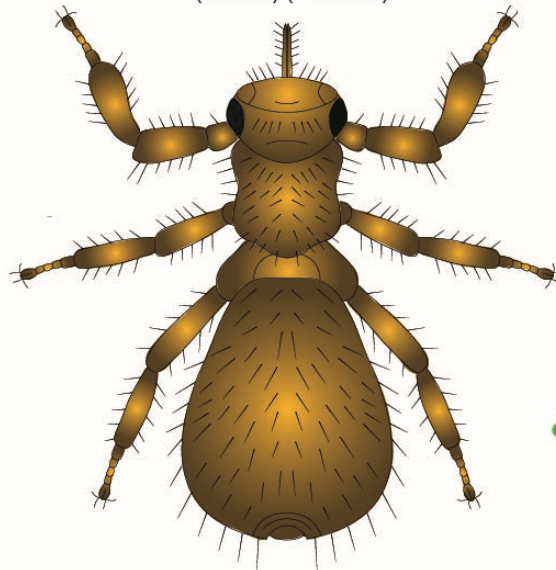
most mate several times when multiple males are present. Gravid females may produce their first larvae after 12-14 days, and then subsequent larvae every 7-8 days. Male keds live for 2-3 months while females live for 4-6 months and may produce 10-12 larvae (sometimes up to 20) in their lifetime. The whole life-cycle may be completed in as little as 5 weeks, but generally takes longer, especially in cooler months. Transmission from host-to-host occurs by direct body contact and the transfer of adult keds, rather than by contamination of the surrounding environment. Indeed, keds that fall from hosts only live only a few days and are not highly mobile. Most transmission occurs during periods on intimate host contact, particularly from ewes to suckling lambs. Keds have been observed to move to the surface of the fleece in response to increasing temperatures, possibly aided by increased host motility accompanying flocking behaviour. In temperate regions, ked numbers and transmission peaks around winter, particularly when sheep are gathered together for feeding or shelter.

Differential diagnosis: Infestations may be suspected in animals exhibiting irritability, unthriftiness and damaged wool, but dermal lesions indicative of feeding sites are cryptic and hidden beneath the fleece. Subsequent physical examination may reveal patchy discolouration of the wool (due to ked faeces) and occasional small red-brown 'dirt' granules (pupae). Definitive diagnosis, however, is afforded by the direct detection of adult keds on the skin or in the fleece, particularly around the ribs. Specimens should be collected for microscopic examination and identification, particularly since keds are often erroneously referred to as tick-like or louse-like. Adult keds are identified by their unique appearance as flat hairy 6-legged wingless flies. Recent studies have applied molecular biological techniques to the characterization of ked species following the polymerase chain reaction (PCR) amplification of nuclear (ribosomal DNA) gene sequences as well as mitochondrial genome analyses.

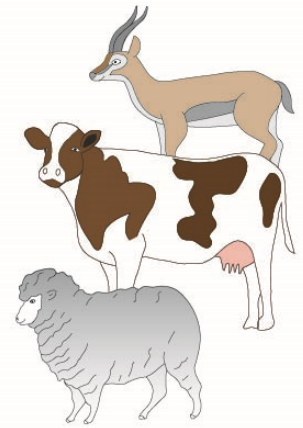
Treatment and control: A wide range of insecticides have been used to treat infestations in livestock, including inorganic metal-based pesticides, organophosphates (such as coumaphos, malathion, diazinon), chloronicotinyles (imidacloprid), pyrethroids (pyrethrin), and macrocyclic lactones (ivermectin). Treatment is highly effective against adult keds, but not against encased pupae, so treatment needs to be repeated 24-28 days later, or the insecticide used needs to have residual activity of several weeks. Most modern treatments used to control sheep lice are also effective against ked infestations, especially those containing ivermectin or pyrethrin. Shearing sheep has been found to remove many adults and pupae (up to 75%), so it is highly beneficial to shear sheep before treatment, particularly before lambing. Insecticides may be applied as topical or systemic preparations, such as dips, sprays, dusts or spot-ons, and care should be taken to ensure topical applications penetrate the fleece. Many countries have developed highly successful control programmes for sheep ked and have eradicated, or almost eradicated, infestations in commercial sheep flocks. Routine monitoring, annual treatments, stock movement restrictions and quarantine measures have been used in many programmes, but are now often no longer considered necessary.

Melophagus

adult female
(dorsal) (~ 6 mm)

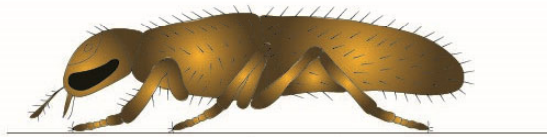


skin
(blood loss, irritation,
allergy, unthriftiness)
(vectors for infectious
microbial diseases)



Definitive Hosts
(mammals)

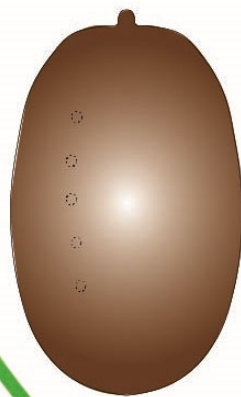
wingless adults permanent ectoparasites
(cling to pelage and feed on blood)
(transmission by adults crawling between hosts in close contact)



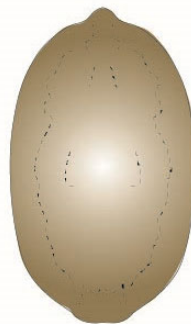
resting posture

eclosion

complete
(holometabolous)
metamorphosis



pupa
(~ 4 mm)



larva *in utero*
(~ 3 mm)



egg *in utero*
(~ 1 mm)

eggs
in utero
larvate

adult females larviparous, deposit larvae
with glue that hardens immediately attaching puparium to pelage



Melophagus adult female



Melophagus adult male



Melophagus pupa