Medical entomology for students

Second edition

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CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK   www.cup.cam.ac.uk
40 West 20th Street, New York, NY 10011–4211, USA   www.cup.org
10 Stamford Road, Oakleigh, Melbourne 3166, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain

First edition published by Chapman and Hall 1996
Second edition published 2000

Printed in the United Kingdom at the University Press, Cambridge

Typeface Palatino 10/12.5pt. *System* QuarkXPress™ [SE]

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication data

Service, M. W.
Medical entomology for students / Mike W. Service. – 2nd ed.
p.   cm.
Includes bibliography references and index.
ISBN 0 521 66659 7
1. Insects as carriers of disease.   I. Title.
RA639.5.S47   2000
614.4′32–dc21   99-16231   CIP

ISBN 0 521 66659 7 paperback

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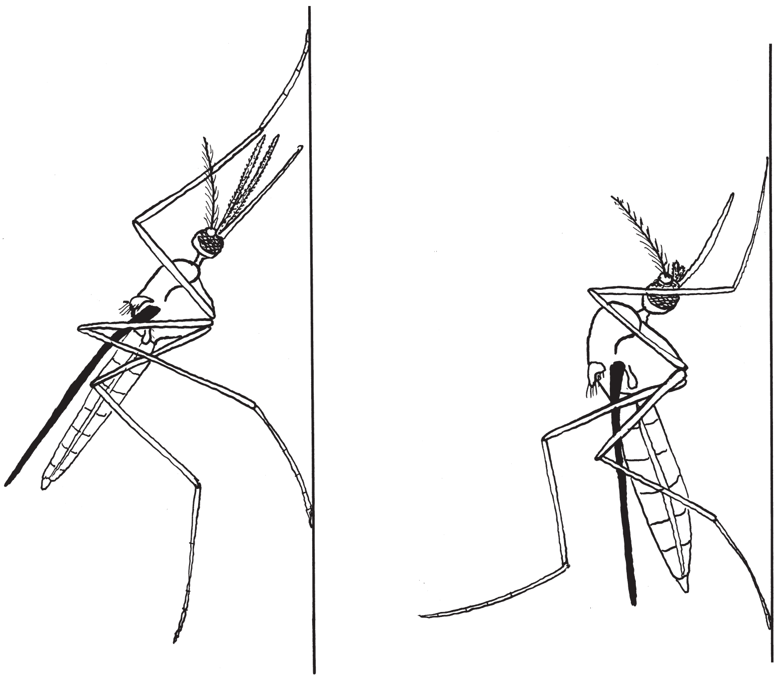
Introduction to mosquitoes (Culicidae)



There are some 3200 species and subspecies of mosquitoes belonging to 37 genera, all contained in the family Culicidae. This family is divided into three subfamilies: Toxorhynchitinae, Anophelinae (anophelines) and Culicinae (culicines). Mosquitoes have a world-wide distribution; they occur throughout the tropical and temperate regions and extend their range northwards into the Arctic Circle. The only areas from which they are absent are Antarctica, and a few islands. They are found at elevations of 5500 m and down mines at depths of 1250 m below sea level.

The most important pest and vector species belong to the genera *Anopheles*, *Culex*, *Aedes*, *Psorophora*, *Haemagogus* and *Sabethes*.

Anopheles species, as well as transmitting malaria, are also vectors of filariasis (*Wuchereria bancrofti*, *Brugia malayi* and *Brugia timori*) and a few arboviruses. Certain *Culex* species transmit *Wuchereria bancrofti* and a variety of arboviruses. The genus *Aedes* contains important vectors of yellow fever, dengue, encephalitis viruses and many other arboviruses, and in a few restricted areas they are also vectors of *Wuchereria bancrofti* and *Brugia malayi*, whereas *Mansonia* species transmit *Brugia malayi* and sometimes *Wuchereria bancrofti* and a few arboviruses. *Haemagogus* and *Sabethes* mosquitoes are vectors of yellow fever and a few other arboviruses in Central and South America, while the genus *Psorophora* contains some troublesome pest species in North and South America.

Several mosquitoes in other genera have also been incriminated as vectors of various arboviruses. Moreover, many species, although not carriers of any disease, can nevertheless be troublesome because of the serious biting nuisances they cause.

1.1 EXTERNAL MORPHOLOGY OF MOSQUITOES

Mosquitoes possess only one pair of functional wings, the fore-wings. The hind-wings are represented by a pair of small, knob-like halteres. Mosquitoes are distinguished from other flies of a somewhat similar shape and size by: (i) the possession of a conspicuous forward-projecting proboscis; (ii) the presence of numerous appressed scales on the thorax, legs, abdomen and wing veins; and (iii) a fringe of scales along the posterior margin of the wings.

Mosquitoes are slender and relatively small insects, usually measuring about 3–6 mm in length. Some species, however, can be as small as 2 mm while others may be as long as 19 mm. The body is distinctly divided into a head, thorax and abdomen.

The head has a conspicuous pair of kidney-shaped compound eyes. Between the eyes arises a pair of filamentous and segmented antennae. In females the antennae have whorls of short hairs (that is pilose antennae), but in males, with a few exceptions in genera of no medical importance, the antennae have many long hairs giving them a feathery or plumose appearance. Mosquitoes can thus be conveniently sexed by examination of the antennae: individuals with feathery antennae are males, whereas those

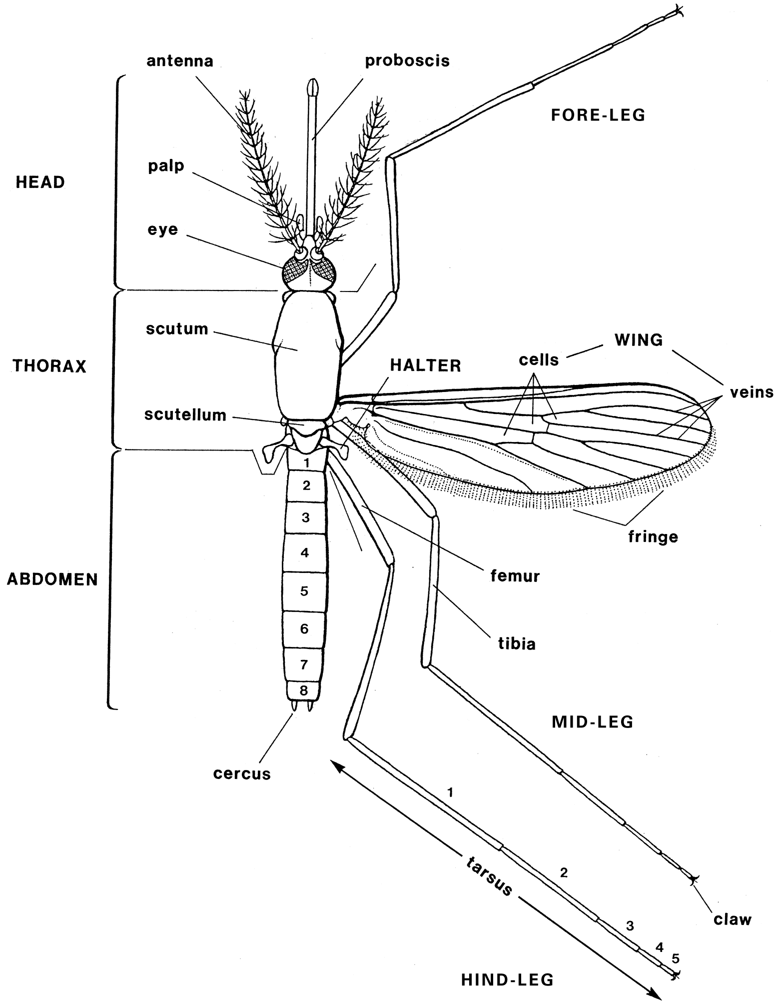


Figure 1.1 Diagrammatic representation of a female adult mosquito.

with only short and rather inconspicuous antennal hairs are females (Figs. 1.1, 1.13). Just below the antennae are a pair of palps which may be long or short and dilated or pointed at their tips, depending on the sex of the adults and whether adults are anophelines or culicines (Fig. 1.13). Arising between the palps is the single elongated proboscis, which contains the piercing mouthparts of the mosquito. In mosquitoes the proboscis characteristically projects forwards (Fig. 1.1).

The thorax is covered, dorsally and laterally, with scales which may be dull or shiny, white, brown, black or almost any colour. It is the arrangement of black and white, or coloured, scales on the dorsal surface of the thorax that gives many species (especially those of the genus *Aedes*) distinctive patterns (Fig. 3.3).

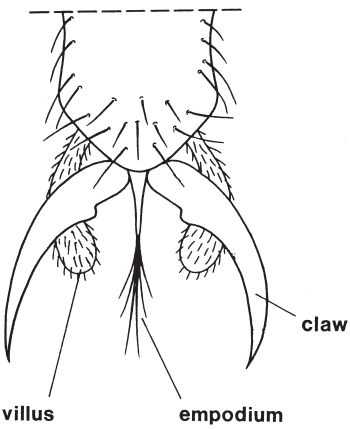


Figure 1.2 Tip of the last segment of the tarsus of a *Culex* mosquito showing claws, hair-like empodium and two large pulvilli.

The wings are long and relatively narrow and the number and arrangement of the wing veins is virtually the same for all mosquito species (Fig. 1.1). The veins are covered with scales which are usually brown, black, white or creamy yellow, but more brightly coloured scales may occasionally be present. The shape of the scales and the pattern they form differs considerably between both genera and species of mosquitoes. Scales also project as a fringe along the posterior border of the wings. In life the wings of resting mosquitoes are placed across each other over the abdomen in the fashion of a closed pair of scissors. The legs of the mosquito are long and slender and are covered with scales which are usually brown, black or white and may be arranged in patterns, often in the form of rings (Fig. 3.4). The tarsus terminates in, usually, a pair of toothed or simple claws. Some genera, such as *Culex*, have a pair of small fleshy pulvilli (Fig. 1.2) at the end of the tarsus.

The abdomen is composed of 10 segments but only the first seven or eight are visible. In mosquitoes of the subfamily Culicinae, the abdomen is usually covered dorsally and ventrally with mostly brown, blackish or whitish, scales. In the Anophelinae, however, the abdomen is almost, or entirely, devoid of these scales. The last abdominal segment of the female mosquito terminates in a pair of small finger-like cerci, whereas in the males a pair of prominent claspers, comprising part of the male external genitalia, are present.

In unfed mosquitoes the abdomen is thin and slender, but after females have bitten a suitable host and taken a blood-meal (only females bite) the abdomen becomes greatly distended and resembles a red oval balloon. When the abdomen is full of developing eggs it is also dilated, but is whitish and not red in appearance.

1.1.1 Mouthparts and salivary glands

The mouthparts are collectively known as the proboscis. In mosquitoes the proboscis is elongate and projects conspicuously forwards in both sexes – although males do not bite. The largest component of the mouthparts is the long and flexible gutter-shaped labium which terminates in a pair of small flap-like structures called the labella. In cross-section the labium is seen to almost encircle all the other components of the mouthparts (Fig. 1.3) and serves as a protective sheath. The individual components are held close together in life and only become partially separated during blood-feeding, or when they are teased apart for examination as illustrated in Fig. 1.4.

The uppermost structure, the labrum, is slender, pointed and grooved along its ventral surface. In between this 'upper roof' (labrum) and 'lower gutter' (labium) are five needle-like structures, namely, a lower pair of toothed maxillae, an upper pair of mandibles, which are more finely toothed, and finally a single untoothed, hollow stylet called the hypopharynx. When a female mosquito bites a host the labella, at the tip of the fleshy labium, are placed on the skin and the labium, which cannot pierce the skin, curves backwards. This allows the paired mandibles, paired maxillae, labrum and hypopharynx to penetrate the host's skin. Saliva from a pair of trilobed salivary glands, situated ventrally in the anterior part of the thorax, is pumped down the hypopharynx. Saliva, in at least some species, contains anticoagulants which prevent the blood from clotting and obstructing the mouthparts as it is sucked up into the space formed by the apposition of the labrum and other piercing mouthparts. Saliva also contains antihaemostatic enzymes that produce haematomas in the skin and facilitate the location and uptake of blood, and anaesthetic substances that help reduce the pain inflicted by the mosquito's bite, so reducing the host's defensive reactions.

Although male mosquitoes have a proboscis, the maxillae and mandibles are usually reduced in size or the mandibles are absent, so males cannot bite.

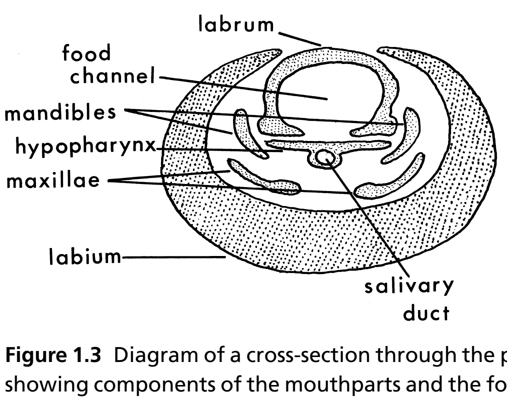


Figure 1.3 Diagram of a cross-section through the proboscis of a mosquito showing components of the mouthparts and the food channel.

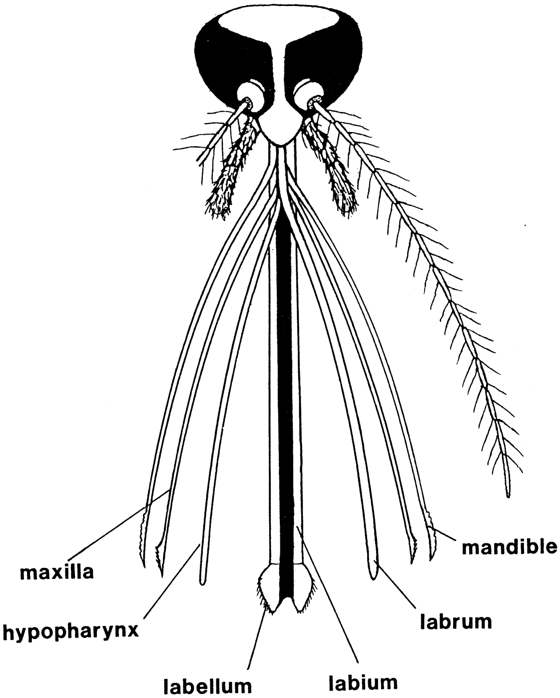


Figure 1.4 Diagram of the head of a female culicine mosquito showing the components of the mouthparts spread out from the labium.

1.2 LIFE CYCLE

1.2.1 Blood-feeding and the gonotrophic cycle

Most mosquitoes mate shortly after emergence from the pupa. Spermatozoa, passed by the male into the spermatheca of the female, usually serve to fertilize all eggs laid during her lifetime; thus only one mating and insemination per female is required. With a few exceptions, a female mosquito must bite a host and take a blood-meal to obtain the necessary nutrients for the development of the eggs in the ovaries. This is the normal procedure and is referred to as anautogenous development. A few species, however, can develop the first batch of eggs without a blood-meal. This process is called autogenous development. The speed of digestion of the blood-meal depends on temperature and in most tropical species takes only 2–3 days, but in colder, temperate countries blood digestion may take as long as 7–14 days.

After a blood-meal the mosquito's abdomen is dilated and bright red in colour, but some hours later the abdomen becomes a much darker red. As the blood is digested and the white eggs in the ovaries enlarge, the abdomen becomes whitish posteriorly and dark reddish anteriorly. This

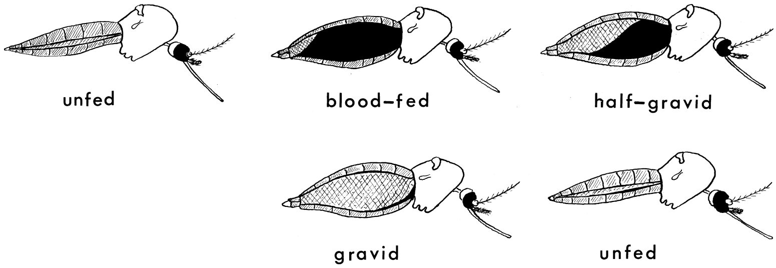


Figure 1.5 Diagrammatic representation of the gonotrophic cycle of a female mosquito. Each cycle starts with an unfed adult which passes through a blood-fed, half-gravid and gravid condition. After oviposition the female is again unfed and seeks another blood-meal.

condition represents a mid-point in blood digestion and ovarian development, and the mosquito is referred to as being half-gravid (Fig. 1.5). Eventually all blood is digested and the abdomen becomes dilated and whitish due to the formation of fully developed eggs (Fig. 1.5). The female is now said to be gravid and she searches for suitable larval habitats in which to lay her eggs. After oviposition the female mosquito takes another blood-meal and after 2–3 days (in the tropics) a further batch of eggs is matured. This process of blood-feeding and egg maturation, followed by oviposition, is repeated several times throughout the female's life and is referred to as the gonotrophic cycle.

Although male mosquitoes have a conspicuous proboscis, their mandibles and maxillae are insufficiently developed for piercing the skin and blood-feeding; instead they feed on the nectar of flowers, and other naturally occurring sugary secretions. Males are consequently unable to transmit any diseases. Sugar feeding is not, however, restricted to males; females may also feed on sugary substances to obtain energy for flight and dispersal, but only in a few species (the autogenous ones) is this type of food sufficient for egg development.

1.2.2 Oviposition and biology of the eggs

Depending on the species, female mosquitoes lay about 30–300 eggs at any one oviposition. Eggs are brown or blackish and 1 mm or less long. In many Culicinae they are elongate or approximately ovoid in shape, but eggs of *Mansonia* are drawn out into a terminal filament (Fig. 3.8). In the Anophelinae eggs are usually boat-shaped (Fig. 1.8). Many mosquitoes, such as species of *Anopheles* and *Culex*, lay their eggs directly on the water surface. In *Anopheles* the eggs are laid singly and float on the water, whereas those of *Culex* are laid vertically in several rows held together by surface tension to form an egg raft which floats on the water (Fig. 1.15). *Mansonia* species lay their eggs in a sticky mass that is glued to the underside of floating plants. None of the eggs of these mosquitoes can survive desiccation and consequently they die if they become dry. In the tropics eggs hatch within 2–3 days, but in cooler temperate countries they may not hatch until after 7–14 days, or longer.

Other mosquitoes, such as those belonging to the genera *Aedes*, *Psorophora* and *Haemagogus*, do not lay eggs on the water surface but deposit them just above the water line on damp substrates, such as mud and leaf litter, or on the inside walls of tree-holes and clay water-storage pots. Eggs of these genera can withstand desiccation, especially those of *Aedes* and *Psorophora* which can remain dry for months or even years but still remain viable and hatch when soaked in water. Because such eggs are laid above the water line of breeding places it may be many weeks or months before they become flooded with water, and thus have the opportunity to hatch. However, even when flooded, hatching may extend over long periods because the eggs hatch in instalments. Moreover, eggs of *Aedes* and *Psorophora* may require repeated immersions in water followed by short periods of desiccation before they will hatch. *Aedes* and *Psorophora* eggs may also enter a state of either quiescence, hatching when suitable conditions occur, or diapause and will not hatch until some specific stimulus terminates the state of diapause. Environmental stimuli such as changes in daylength and/or temperature often break diapause and cause eggs to hatch. In temperate regions many *Aedes* and *Psorphora* species overwinter as diapausing eggs.

1.2.3 Larval biology

Mosquito larvae can be distinguished from all other aquatic insects by being legless and having a bulbous thorax that is wider than both the head and abdomen. There are four active larval instars. All mosquito larvae require water in which to develop; no mosquito has larvae that can withstand desiccation although they may be able to survive short periods among, for example, wet mud.

Mosquito larvae have a well-developed head, bearing a pair of antennae and a pair of compound eyes. Prominent mouthbrushes are present in most species and serve to sweep water containing minute food particles into the mouth. The thorax is roundish in outline and has various simple and branched hairs which are usually long and conspicuous. The 10-segmented abdomen has nine visible segments, most of which have simple or branched hairs (Figs. 1.9, 1.16). The last segment, which differs in shape from the preceding eight segments, has two paired groups of long hairs forming the caudal setae, and a larger fan-like group comprising the ventral brush (Figs. 1.10, 1.16), and ends in two pairs of transparent, sausage-shaped anal papillae. Although often called gills they are not concerned with respiration but with osmoregulation.

Mosquito larvae, with the exception of *Mansonia* and *Coquillettidia* species (and a few other mosquito species), must come to the water surface to breathe. Atmospheric air is taken in through a pair of spiracles situated dorsally on the tenth abdominal segment. In the subfamilies Toxorhynchitinae and Culicinae these spiracles are situated at the end of a single dark-coloured and heavily sclerotized tube termed the siphon (Fig. 1.16). *Mansonia* and *Coquillettidia* larvae possess a specialized siphon that is more or less conical, pointed at the tip and supplied with prehensile hairs and serrated cutting structures (Fig. 3.9). These enable the siphon to be inserted into the roots or stems of aquatic plants and thus oxygen for larval respiration is obtained from the plants. In contrast larvae of the Anophelinae do not have a siphon (Figs. 1.10, 1.13).

Mosquito larvae feed on yeasts, bacteria, protozoans and numerous other plant and animal micro-organisms found in the water. Some, such as *Anopheles* species, are surface-feeders, whereas many others browse over the bottoms of habitats. A few mosquitoes are carnivorous or cannibalistic. There are four larval instars and in tropical countries larval development, that is the time from egg hatching to pupation, can be as short as 5–7 days, but many species require about 7–14 days. In temperate areas the larval period may last several weeks or months, and several species overwinter as larvae.

1.2.4 Larval habitats

Mosquito larval habitats vary from large and usually permanent collections of water, such as freshwater swamps, marshes, ricefields and borrow pits, to smaller collections of temporary water such as pools, puddles, water-filled car tracks, ditches, drains and gulleys. A variety of 'natural container-habitats' also provide breeding places, such as water-filled tree-holes, rock-pools, water-filled bamboo stumps, bromeliads, pitcher plants, leaf axils in banana, pineapple and other plants, water-filled split coconut husks and snail shells. Larvae also occur in wells and 'man made container-habitats', such as clay pots, water-storage jars, tin cans, discarded kitchen utensils and motor vehicle tyres. Some species prefer shaded larval habitats whereas others like sunlit habitats. Many species cannot survive in water polluted with organic debris whereas others can breed prolifically in water contaminated with excreta or rotting vegetation. A few mosquitoes breed almost exclusively in brackish or salt water, such as in salt-water marshes and mangrove swamps, and are consequently restricted to mostly coastal areas. Some species are less specific in their requirements and can tolerate a wide range of different types of breeding places.

Almost any collection of permanent or temporary water can constitute a mosquito larval habitat, but larvae are usually absent from large expanses of uninterrupted water such as lakes, especially if they have large numbers of fish and other predators which are likely to eat mosquito larvae. They are also usually absent from large rivers and fast-flowing waters, except that they may occur in marshy areas and isolated pools and puddles formed at the edges of flowing water.

1.2.5 Pupal biology

All mosquito pupae are aquatic and comma-shaped. The head and thorax are combined to form the cephalothorax, which has a pair of respiratory trumpets dorsally (Fig. 1.6). The abdomen is 10-segmented although only eight segments are visible. Each segment has numerous short hairs and the last segment terminates in a pair of oval and flattened structures termed paddles (Figs. 1.11, 1.18). Some of the developing structures of the adult mosquito can be seen through the integument of the cephalothorax, the most conspicuous features being a pair of dark compound eyes, folded wings, legs and the proboscis (Fig. 1.6).

Pupae do not feed but spend most of their time at the water surface taking in air through the respiratory trumpets. If disturbed they swim up and down in the water in a jerky fashion.

Pupae of *Mansonia* and *Coquillettidia* differ in that they have relatively long breathing trumpets, which are modified to enable them to pierce aquatic vegetation and obtain their oxygen in a similar fashion to the larvae (Fig. 3.9). As a consequence their pupae remain submerged and rarely come to the water surface.

In the tropics the pupal period in mosquitoes lasts only 2–3 days but in cooler temperate regions pupal development may be extended over 9–12

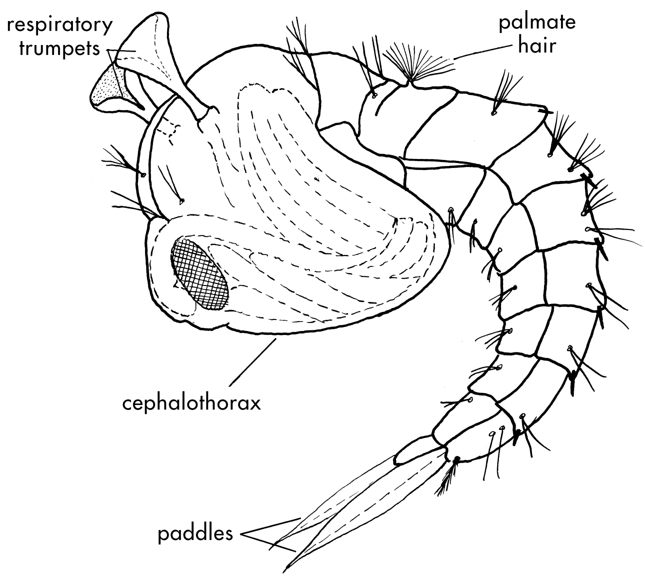


Figure 1.6 *Anopheles* pupa.