MOSQUITOES

OF

PUBLIC HEALTH IMPORTANCE

AND

THEIR CONTROL

Training Guide - Insect Control Series

Harry D. Pratt, Ralph C. Barnes, and Kent S. Littig

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
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INTRODUCTION

Mosquitoes cause great suffering and economic loss because of their blood sucking habits. They are vectors of *malaria, yellow fever, dengue,* and *filariasis,* four of the most important diseases of the tropical and subtropical parts of the world today. Fortunately control programs and climate have now reduced these diseases to a minor or historical importance in the United States. On the other hand, epidemics of three types of *encephalitis* continue to occur in many parts of this country and are the most important mosquito-borne diseases in the United States today.

Because mosquitoes play an important role in the transmission of encephalitis, and cause great discomfort and misery by their bites, there has been a great expansion recently in mosquito control activities. The Surgeons General of the U.S. Army and Public Health Service have emphasized the point that pest mosquitoes are important to human health as their continued annoyance affects physical efficiency and comfort, mental equanimity, and the enjoyment of life (Bradley, 1951).

In this training guide the importance of mosquitoes to human health will be considered as well as their biology, habits, identification and control. Survey and evaluation measures are also discussed, as well as training aids for supporting a program. A list of "Selected References" is included to permit the reader to delve deeper into the subject matter in the very extensive literature.

EFFECTS ON HUMAN HEALTH

Mosquitoes have probably had a greater influence on human health and well-being throughout the world than any other insects. This is not due wholly to the important human diseases they transmit, but also to the severe annoyance they cause.

DIRECT EFFECTS

Mosquito bites may itch for days, some people suffering restlessness, loss of sleep and serious nervous irritation. Burnet (1953) states that the saliva of mosquitoes contains protein (antigen), foreign to the human body, capable of stimulating antibody production. Sensitivity to the protein develops after repeated bites induce a sufficient production of antibody. Then, after each bite, the introduction of more antigen (or protein) into the skin cells causes liberation of histamine and a skin or systemic reaction. Hess and Quinby (1956) have shown that mosquitoes often cause serious economic loss through restriction of man's outdoor activities. The cost may be measured in loss of recreation, milk and beef production, and the production of crops. In extreme cases mosquitoes have caused the death of domestic animals, apparently due to the loss of blood, or as a result of anaphylactic shock.

DISEASE TRANSMISSION

MALARIA

On a worldwide basis the various types of malaria are the most important of the human diseases (table 6.1) transmitted by mosquitoes and have probably had a more profound influence on world development than any other diseases. Malaria was introduced into the United States in colonial days and spread throughout the country as it was settled, being prevalent in the eastern, middle western, and particularly the southern states. Over 100,000 cases were reported annually in the early 1930's but the number dropped to about 60,000 by 1942. During World War II malaria control work (largely drainage and larviciding) was conducted on military bases by the Army, Navy, and Air

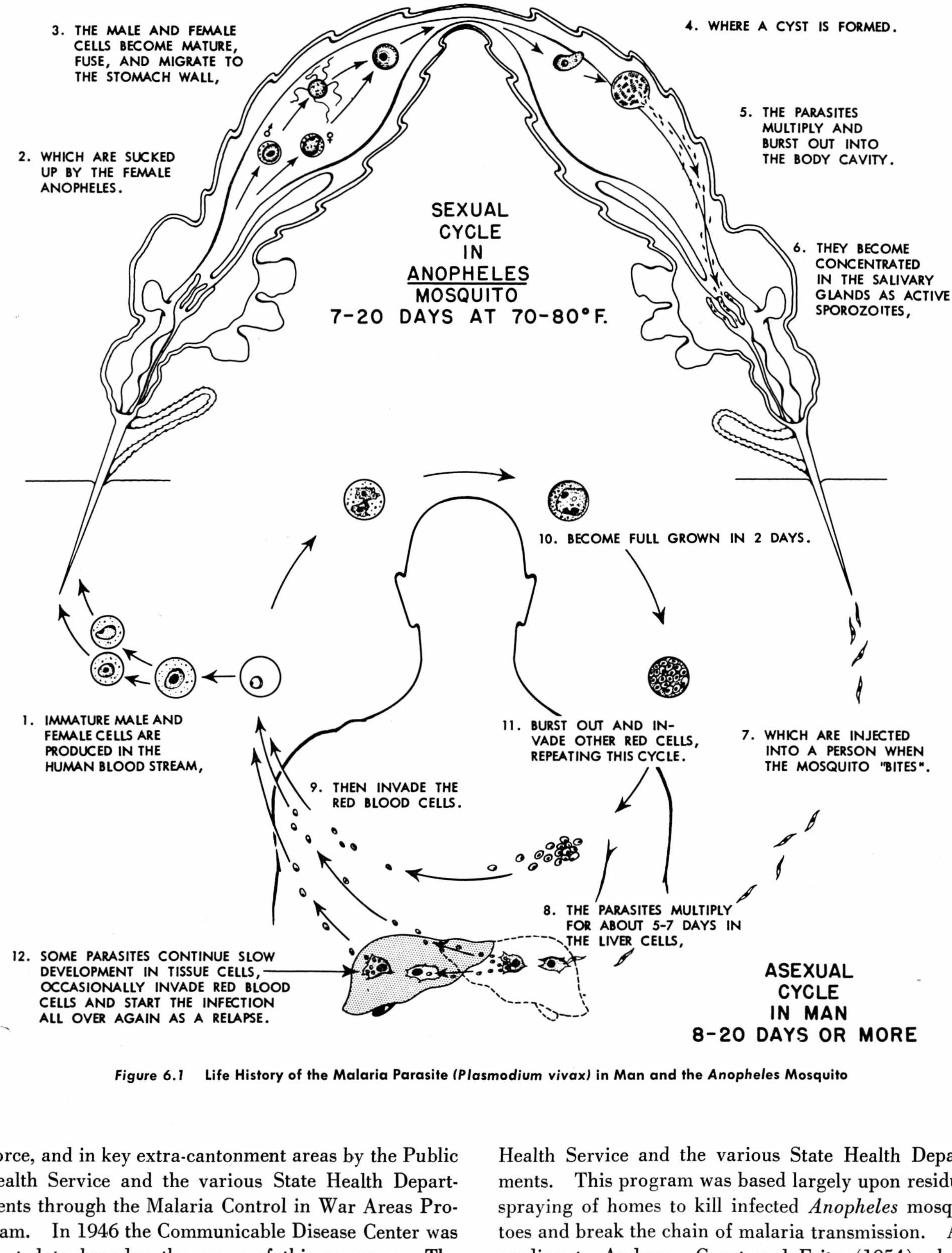


Figure 6.1 **Life History of the Malaria Parasite (*Plasmodium vivax*) in Man and the *Anopheles* Mosquito**

Force, and in key extra-cantonment areas by the Public Health Service and the various State Health Departments through the Malaria Control in War Areas Program. In 1946 the Communicable Disease Center was created to broaden the scope of this program. The National Malaria Eradication Program was begun in 1946–47 as a cooperative enterprise of the Public Health Service and the various State Health Departments. This program was based largely upon residual spraying of homes to kill infected *Anopheles* mosquitoes and break the chain of malaria transmission. According to Andrews, Grant and Fritz (1954) about 1,365,000 homes were sprayed with DDT in 1948 when about 9797 cases of malaria were reported. By

1952 the number of cases reported had dropped to 7023, of which approximately 50 were contracted in the United States. The residual spray program was greatly reduced after 1950, but surveillance continues to the present time. Beginning in 1958 less than 100 cases of malaria have been reported each year for the entire United States, most of them contracted overseas, with only 3 or 4 primary indigenous cases reported in 1961 and 1962.

The various types of malaria are acute or chronic diseases caused by tiny protozoan parasites of the genus *Plasmodium*, which are transmitted from person to person by the bite of *Anopheles* mosquitoes. Although there are 15 *Anopheles* species in the United States only two seem to be important in malaria transmission: *A. quadrimaculatus* east of the Rockies and *A. freeborni* west of the Rockies. (See table 6.1.)

According to Russell (1952), the malaria parasites have four phases of development, in two cycles (fig. 6.1):

The Sexual Cycle

The Sexual Cycle starts with the production of immature male and female gametocytes in the red blood corpuscles of man. These are sucked into the stomach of the female mosquito where the male and female cells unite, forming the fertilized zygote. The zygote becomes motile and is then known as the ookinete which penetrates the stomach wall producing oocysts. Hundreds of spindle-shaped sporozoites are produced, escaping into the mosquito's body fluid when the cysts rupture. The sporozoites penetrate the salivary glands, remaining there until the mosquito bites again, transferring them to a new host. The sexual cycle takes 7 to 10 days under favorable conditions, longer in cooler weather.

The Asexual Cycle

The Asexual Cycle in man has three phases. See figure 6.1.

a. **Development and multiplication of plasmodia in liver cells** and perhaps the reticulo-endothelial systems of other organs for about a week followed by:

b. **Invasion of the red blood cells** where the parasites divide asexually and multiply until infection is great enough to produce a paroxysm. In benign tertian malaria caused by *Plasmodium vivax* fever occurs when parasites are liberated from the red blood cells into the blood stream every 48 hours (fig. 6.2) whereas in quartan malaria (*P. malariae*)

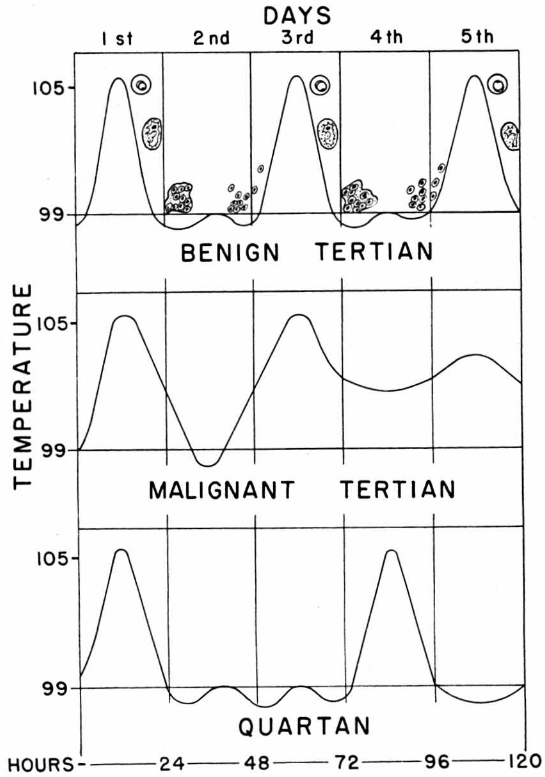


Figure 6.2 **Typical Fever Charts of 3 Types of Malaria**

the period is 72 hours and in malignant tertian (*P. falciparum*) malaria the cycle takes from 40 to 48 hours. The paroxysms may be due to the release of toxins, although there is no clear evidence on this point. Soon some of the parasites develop into immature sexual forms (gametocytes) and the patient may infect mosquitoes and initiate the sexual cycle again. In malaria caused by *P. vivax* and *P. malariae* other asexual parasites (merozoites) may have:

c. **Continued slow asexual development** in tissue cells and escape to the blood stream to initiate relapses when a falling off in immunity or drug treatment makes it possible for the parasites successfully to invade the blood stream. Relapses may occur many months or years after the original attack. Other persons may have chronic attacks until successfully treated, or until moving from a malarious area and possible reinfection, in which case infection may cease due to senescence of the plasmodia.

YELLOW FEVER

This viral disease may be acute and highly fatal or so mild that infections are inapparent. It probably originated in Africa and was brought in the slave ships to the New World. The two epidemiological types,

TABLE 61.—*Some important mosquito-borne diseases*

DISEASE	*CAUSATIVE ORGANISM*	*IMPORTANT VECTORS*
MALARIA	Protozoa:	*Anopheles* mosquitoes:
Benign Tertian	*Plasmodium vivax*	*A. quadrimaculatus* east of the Rockies
Malignant Tertian	*Plasmodium falciparum*	
Quartan	*Plasmodium malariae*	*A. freeborni* west of the Rockies
Ovale	*Plasmodium ovale*	
YELLOW FEVER	Yellow Fever Virus	Many mosquitoes, especially
Urban Type		Yellow fever mosquito (*Aedes aegypti*)
Jungle Type		Jungle mosquitoes, such as *Haemagogus* or *Sabethes* in tropical America and *Aedes* spp. in Africa
DENGUE	Dengue Virus	Primarily *Aedes aegypti* and *Aedes albopictus*
ENCEPHALITIS	Viruses	Many mosquitoes including
Eastern	EE Virus	*Culiseta melanura*
Western	WE Virus	*Culex tarsalis*
St. Louis	SLE Virus	*Culex pipiens* complex and *Culex tarsalis*
FILARIASIS	Worm (Nemathelminthes)	Many mosquitoes, especially
Bancroftian Type	*Wuchereria bancrofti*	*Culex quinquefasciatus*
Malayan Type	*Brugia malayi*	*Mansonia* species
HEARTWORM OF DOGS	Worm (Nemathelminthes)	Many mosquitoes such as
	Dirofilaria immitis	*Aedes taeniorhynchus, Aedes aegypti*

NOTE.—People may contract malaria, yellow fever, dengue, or encephalitis after being bitten by one infected mosquito. It requires the bites of many infected mosquitoes and the injection of many filarial worms to cause a clinical case of filariasis.

urban and **jungle yellow fever,** are caused by the same virus, and protection is given by the same vaccine, but the mosquito vectors and vertebrate hosts are quite different, according to Strode (1951).

Classical Urban Yellow Fever

Classical urban yellow fever is transmitted from man to man by the yellow fever mosquito, *Aedes aegypti* (fig. 6.3), see Christophers 1960. Although no epidemics have occurred in the United States since the outbreak at New Orleans in 1905 and no major epidemic has occurred in the Americas since 1942, epidemics were once reported from most of the larger seaports in southern United States, even as far north as Philadelphia, New York and Boston. Formerly this malady occurred over wide areas of South and Central America and was introduced repeatedly into the United States. *Aedes aegypti* has been eradicated from most of the Americas south of the Rio Grande and these efforts are being continued in Mexico and other countries to the south of the United States.

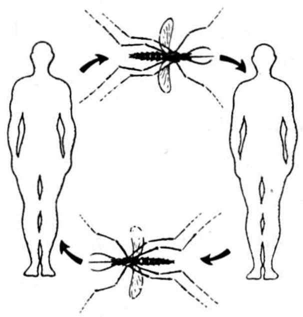


Figure 6.3 **Infection Chain of Urban Yellow Fever and Dengue**

Jungle Yellow Fever

Jungle yellow fever (fig 6.4) also called sylvan or sylvatic yellow fever, is normally a disease of monkeys and perhaps other wild animals, transmitted most frequently by species of treetop-frequenting *Haemagogus* and *Aedes* and possibly by *Sabethes.* The occasional human cases are contracted when people in the forest are bitten by infected mosquitoes. *Haemagogus spegazzinii falco,* a tree hole breeder, appears to be the major vector in South America, being replaced by *Aedes leucocelaenus clarki* and other species in Central America and parts of South America.

According to Soper (1958) a wave of jungle yellow fever started northward from Panama in 1948 and reached the various countries as listed below:

Panama	1948
Costa Rica	1951–2
Nicaragua	1952
Honduras	1953–4
Guatemala	1955–7
Mexico	1957(?)

DENGUE

Dengue, known also as breakbone fever, is an acute, rarely fatal disease caused by a virus. It is charac-

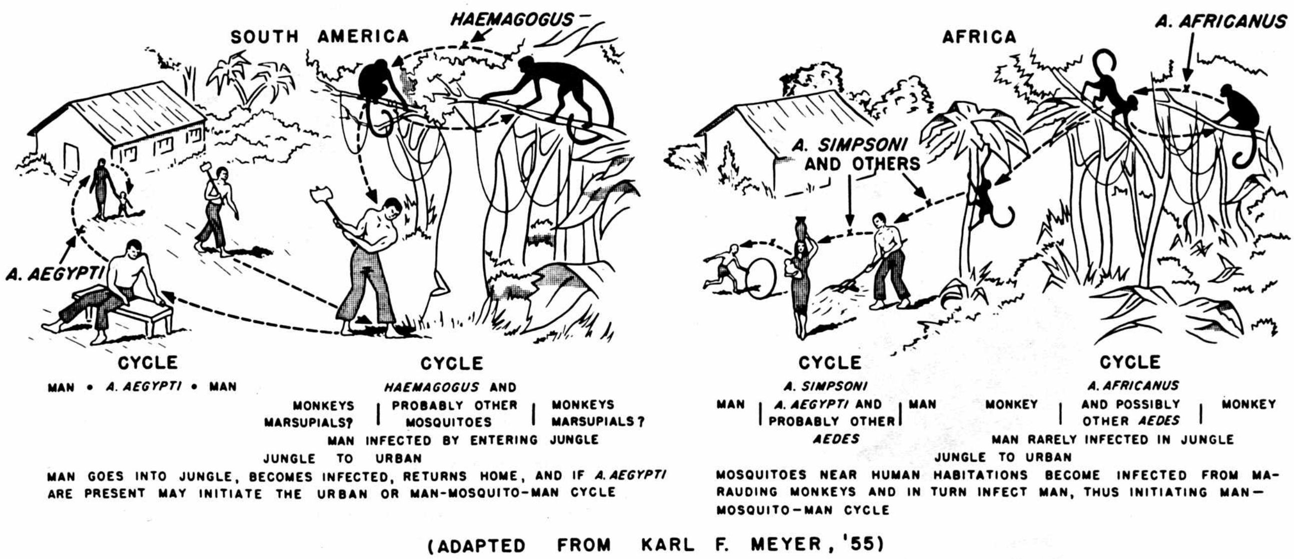


Figure 6.4 **Epidemiology of Jungle Yellow Fever (Adapted from Karl F. Meyer, 1955)**

terized by sudden onset, high fever, severe headache, backache, and joint pain, and a rash appearing the third or fourth day, particularly on the hands and feet.

Dengue fever is transmitted from person to person by the yellow fever mosquito, *Aedes aegypti.* The cycle therefore is similar to that of urban yellow fever. *Aedes albopictus* is also an important vector in Hawaii, the Philippines and Southeast Asia. Mosquitoes obtain the virus from the blood of infected persons during the period from the day before the initial fever to the third or fourth day of the disease. The virus multiplies in the mosquito, which becomes infective in from 8 to 14 days after the infected blood meal. Under favorable temperature conditions, the mosquitoes remain infective for the rest of their lives, which may be one to two months or more.

Dengue may occur in epidemic form in almost any part of the tropics or subtropics. It has been prevalent in the Mediterranean, Africa, South America, Southeast Asia, and the Pacific Islands. The Public Health Service has been concerned with 5 outbreaks in the past 40 years as follows:

- 1922 Florida to Texas—perhaps 2 million cases, estimated about a million cases in Texas by Chandler and Read (1961).
- 1934 Florida to Georgia—estimated 15,000 cases
- 1943 Hawaii—estimated 1400 cases
- 1945 Louisiana—several hundred cases
- 1963 Puerto Rico—many thousands of cases

ENCEPHALITIS

A number of arthropod-borne viral (arbovirus) diseases affect the central nervous system, causing an encephalitis, or inflammation of the brain (encephalon). Three major types in the United States: Eastern, Western, and St. Louis encephalitis are caused by different viruses (Ferguson, 1954; Schaeffer, *et al.*, 1958). These are transmitted normally from bird to bird, and less commonly from bird to man or his domestic animals, by a number of species of mosquitoes as listed in Table 6.1. The distribution of these three major types of encephalitis in the United States is shown in figure 6.5.

Eastern Encephalitis

Eastern encephalitis is found along the Atlantic and Gulf coasts and inland in the Mississippi Valley in limited areas. According to Chamberlain (1958), "the foci of eastern encephalitis infection are fresh water swamps." There have been four important epidemics as listed below:

State	*Year*	*Cases*	*Human Deaths*
Massachusetts	1938	34	25
Louisiana	1947	15	9
Massachusetts	1956	12	8
New Jersey	1959	32	22

Eastern encephalitis occurs commonly in horses and pheasants. *Culiseta melanura* is a suspect vector along with *Aedes sollicitans* and *vexans* and *Mansonia perturbans.*

Western Encephalitis

Western encephalitis is found in all of the states west of the Mississippi and in Wisconsin and Illinois. It has been found in limited areas further east in birds

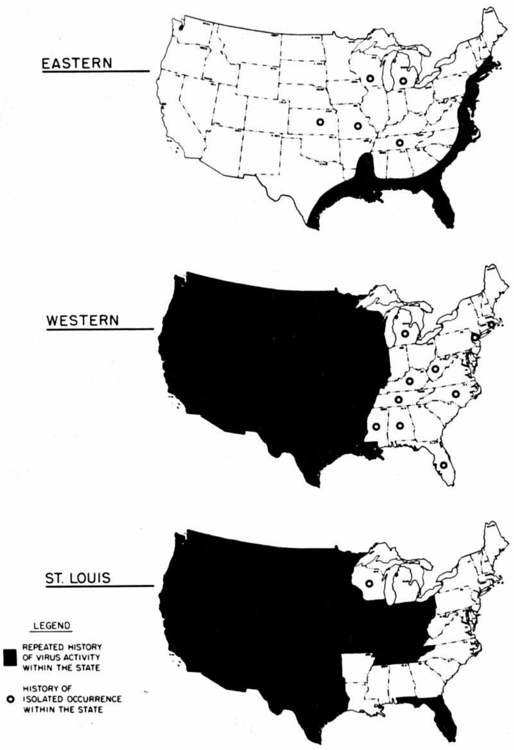


Figure 6.5 **The Geographical Distribution of the Arthropod-Borne Encephalitides in the United States. Total Virus Activity in Man and Animals**

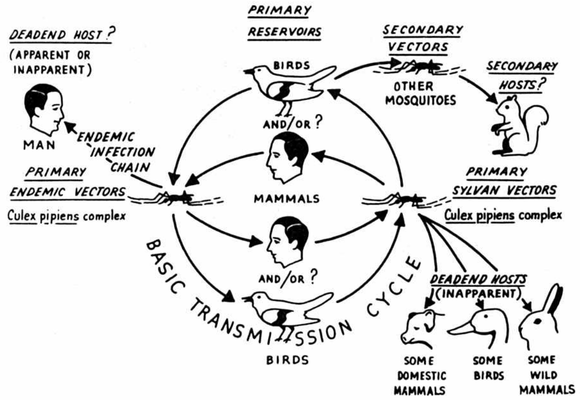


Figure 6.6 **Summer Infection Chains for Urban St. Louis Encephalitis (Chains for Rural SLE Are Similar to Those for WE) (from Hess and Holden, 1958)**

and mosquitoes. There were many noteworthy outbreaks in horses in the 1930's. The largest human outbreak involving over 3,000 persons occurred in 1941. Another large epidemic occurred in California in 1952. In 1958 there were about 140 cases, 47 reported in Utah. *Culex tarsalis* is the most important vector.

St. Louis Encephalitis

St. Louis encephalitis has been found in all of the states west of the Mississippi and in the Ohio river valley. Noteworthy outbreaks occurred in St. Louis in 1933 with about 1000 cases and 200 deaths and in 1937 with some 500 cases, in California in 1952, in the Rio Grande valley in 1954 and 1957, in the Ohio valley including Calvert City, Kentucky in 1955, and in Louisville, Kentucky in 1956. Members of the *Culex pipiens-quinquefasciatus* complex are the chief urban vectors. *Culex tarsalis* is the chief vector in some western states, particularly on the Pacific coast. Epidemics occurred in the Tampa Bay area of Florida in 1959, 1961, and 1962. In the 1962 outbreak about 500 cases, with approximately 50 deaths, were reported. *Culex nigripalpus* was probably the vector in Florida.

Donaldson (1958) reported that "taking all three types together, a distribution map would involve essentially the entire country with the exception of northern New England."

These three types of encephalitis are generally considered to be viral diseases in which birds serve as natural hosts and mosquitoes as the most important vectors. Human cases vary from mild inapparent infections to very severe sickness with permanent damage to the nervous system or even death. Horses may have similar mild or severe infections with the eastern and western types of encephalitis, whereas the St. Louis virus causes only inapparent infections. Birds may die from encephalitis, particularly red-winged blackbirds and pheasants infected with eastern encephalitis. According to Hess and Holden (1958) the basic transmission cycle from bird to bird is maintained by mosquitoes with the human and horse cases considered as accidents and dead-end hosts in the chain of infection, see figure 6.6. Studies by R. Kissling and coworkers (1954) indicated that small birds such as the English sparrow, grackle, or red-winged blackbird develop a very high level of viremia for a few days during which time mosquitoes can become infected whereas the level of virus (titer) is usually lower in many of the larger birds and horses and man. Mosquitoes are therefore less likely to become infected from these hosts and transmit the encephalitis virus to new uninfected hosts.

Donaldson (1958) listed the following needs as most important toward a definitive program for the control of arthopod-borne encephalitides.

1. Continuing appraisal of the true public health importance of the arthropod-borne encephalitides.
2. Comprehensive understanding of the epidemiology.
3. Improved diagnostic tools, procedures and resources.
4. Development of effective and practical methods of control.

FILARIASIS

Human cases of filariasis are caused by the nematodes, *Wuchereria bancrofti* and *Brugia malayi*, hence the names *Bancroftian* and *Malayan filariasis*. The adult worms live in various parts of the lymphatic system. People may harbor the parasites with no apparent symptoms or the filarial worms may cause inflammation and other complications. In some people who have had prolonged and repeated infections, there may be extreme enlargement of the external genitalia, breasts, or legs, hence the clinical term elephantiasis for pronounced enlargement of parts of the body, often with a thickened and rough skin.

Filariasis is rather widespread in many tropical and subtropical regions throughout the world. In the Western Hemisphere it occurs in the West Indies, Colombia, Venezuela, Panama, and the coastal portions of the Guianas and Brazil.

A small endemic center existed for many years near Charleston, S.C., but this has now disappeared. In many parts of United States, Puerto Ricans and other people who have recently left the tropics may have the microfilariae circulating in their blood. However, the disease is not now known to be naturally acquired in the United States.

During World War II great concern was expressed about the possibility of filariasis becoming established in the United States. Coggeshall (1946) reported that about 10,000 of some 38,000 Marines and U.S. Navy personnel sent to the South Pacific became infected with *Wuchereria bancrofti*, and that at one time there were about 2,600 men with these filarial infections at Klamath Falls, Oreg. He stated that, "It is now almost four years since the first servicemen were infected and not a single case of elephantiasis has been seen in the 2,595 men at this station."

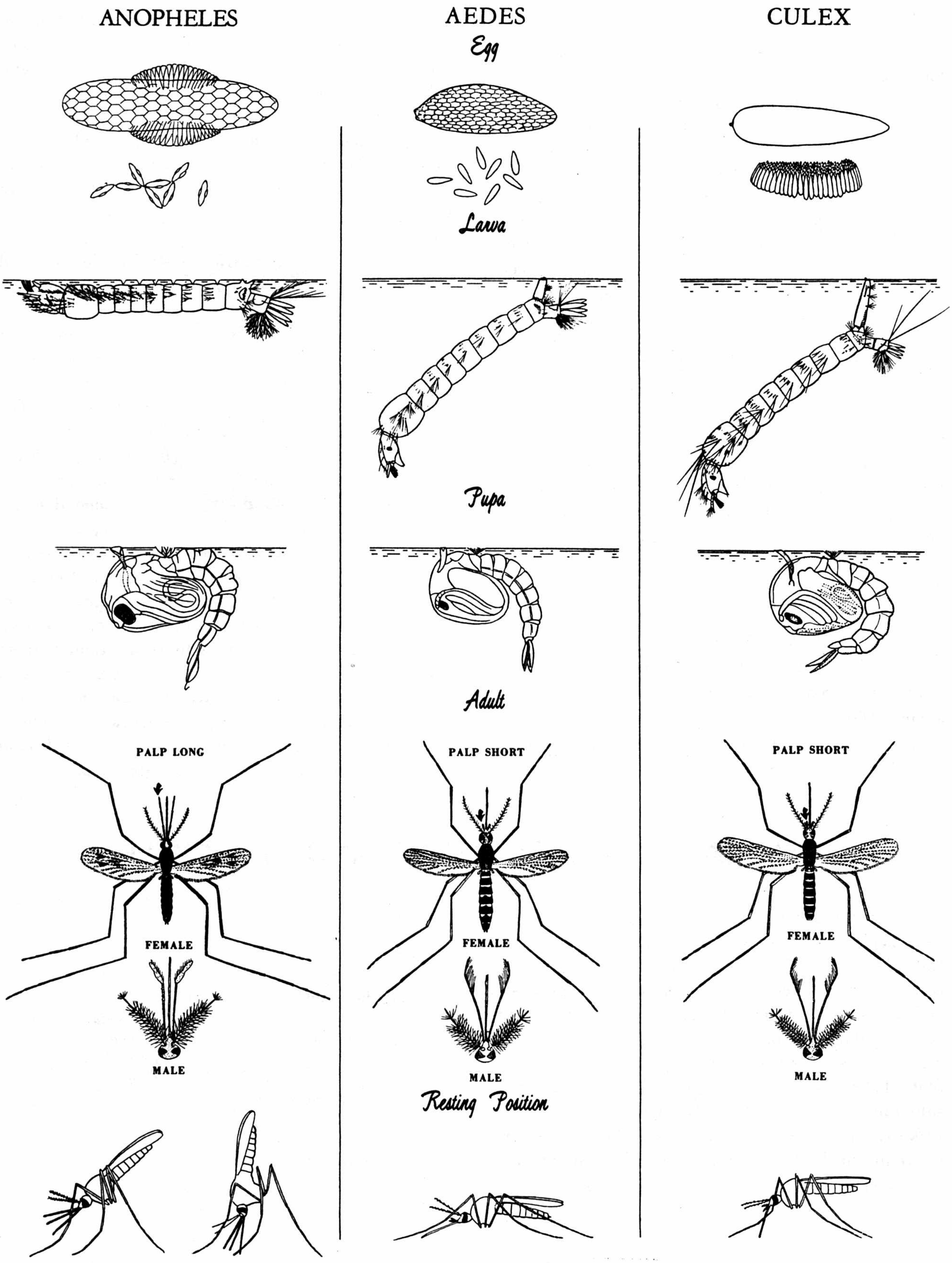
Napier and other Indian workers believed that the filarial worms would develop in the mosquito only in areas where the mean temperature is 80° F. or above with a relative humidity of 60 percent. If this is true, only a relatively small area of the United States—those states bordering the Gulf of Mexico, Georgia, and South Carolina—is favorable for the establishment of filariasis.

The young filarial worms are transmitted from person to person by various species of mosquitoes. They undergo developmental changes in the mosquito, which is an essential link in the cycle of transmission. The microfilariae occur in the human blood stream during certain stages of an infection. Here they are picked up by mosquitoes as they feed. A minimum period of 10 to 11 days is required for the developmental stages in the mosquito from which point they reach the new host at the next feeding. They are not injected into the new host by the mosquito but actively penetrate the skin, perhaps at the site where the mosquito punctured the skin. Many species of mosquitoes are known to be capable of transmitting filariasis, though these may not all be important in nature. Some important known vectors of *W. bancrofti* are *Culex quinquefasciatus*, *C. pipiens*, *Aedes polynesiensis*, and *Anopheles gambiae*. The generally accepted vectors of *Brugia malayi* are mosquitoes in the genus *Mansonia*.

GENERAL CHARACTERISTICS AND LIFE CYCLE

Mosquitoes are small, long-legged, two-winged insects belonging to the order Diptera and the family Culicidae. The adults differ from other flies in having two characters in combination: an elongate proboscis and scales on the wing veins and wing margin. This is a very large group, containing over 2,600 species. There are approximately 150 species in the United States belonging to 12 genera distributed among three subfamilies according to Stone, Knight, and Starcke (1959). Their general classification of the mosquitoes occurring in the United States is outlined at right:

Order Diptera
- Family Culicidae
  - Subfamily Anophelinae (anophelines)
    - Genus *Anopheles*
  - Subfamily Culicinae (culicines)
    - Genus *Aedes*, *Culex*, *Culiseta*, *Deinocerites*, *Haemagogus*, *Mansonia*, *Orthopodomyia*, *Psorophora*, *Uranotaenia*, *Wyeomyia*
  - Subfamily Toxorhynchitinae
    - Genus *Toxorhynchites* (formerly *Megarhinus*)



Kent S. Littig and Chester J. Stojanovich

Figure 6.7 **Characteristics of Anophelines and Culicines**

LIFE HISTORY

Mosquitoes have four distinct stages in their life history, the *egg, larva, pupa,* and *adult* (fig. 6.7). The first three stages occur in water, but the adult is an active flying insect, feeding on the blood of man and animals or upon plant juices.

EGGS

Eggs are white when first deposited, becoming dark within an hour or two. In general, mosquito eggs fall into three distinct groups: (1) Those that are laid singly on the water surface; (2) those that are glued together to form rafts which float on the water surface; and (3) those which are laid singly out of the water. These differences are reflected in the structure of the egg.

Anopheline eggs are typical of those which are laid singly on the water surface. These eggs are elongate oval, usually pointed at one end and provided with a pair of lateral floats, see figure 6.7. They average about one-half millimeter in length. Eggs of anophelines are laid on the water forming specific patterns. Hatching takes place within 2 or 3 days. The eggs of *Toxorhynchites* are also laid singly on the water surface where they are kept afloat by means of air bubbles which form among the spines on the egg shell.

The eggs of several genera are laid side by side so as to form a raft. This raft, which may contain 100 eggs or more, remains afloat on the surface of the water until hatching occurs. This usually requires only a few days. Egg rafts are characteristic of the genera *Culex, Culiseta, Mansonia,* and *Uranotaenia.*

Eggs which are laid out of water must be placed so the larvae can readily reach the water or they must be able to survive long periods of drying until such time as they may be flooded. The eggs of *Orthopodomyia, Aedes triseriatus,* and *Ae. aegypti* are laid on the sides of tree holes or containers just above the water level so that with a rise in the water the eggs hatch. Other species of *Aedes* and all species of *Psorophora* lay their eggs on the ground where they remain until flooding occurs. Some species may survive in the egg stage for three or four years if flooding does not occur. In some cases hatching occurs as soon as the eggs are flooded; thus several generations per year may occur. This is typical of the *Psorophora* group and of *Ae. vexans* and *Ae. sollicitans.* Others must be subjected to freezing before they will develop; thus, there is only one generation per year. Many species of *Aedes* belong in this group, examples being *Ae. stimulans* and *Ae. abserratus.*

LARVAE

The **larvae** of all mosquitoes live in water. Some species live in permanent ponds and marshes, some in temporary flood waters, or woodland pools, some in water contained in tree holes or leaves of plants, and others in artificial containers. Mosquitoes have adapted themselves to almost all kinds of aquatic situations except flowing streams and the open waters of large streams, lakes, and seas. Although mosquito larvae get their food from the water in which they live, they must come to the surface for air or, as in the case of *Mansonia,* obtain air from the under-water portions of plants, see Horsfall (1955).

The larval period includes four developmental instars which usually require at least 4 to 10 days for completion. At the end of each instar the larva sheds its skin or molts. The fourth instar is the mature larva and with the fourth molt the pupa appears (fig. 6.7).

Mosquito larvae move about in two ways; by jerks of the body, and by propulsion with the mouth brushes. Movements of anopheline larvae at the surface are generally of the first type. The "crawling" movements of culicine larvae over the bottom and the slow movement at the water surface are probably due to propulsive action of the mouth brushes. Mosquito larvae assume characteristic positions in the water. Anopheline larvae lie parallel to the surface, while most other groups hang head down with only the tip of the air tube penetrating the surface film. Although larvae are heavier than water, they can rest just beneath the surface without muscular effort. Certain nonwetting structures, such as the air tube in the culicines and the spiracular plate and palmate hairs in the anophelines, serve to suspend them from the surface film.

There are many physical, chemical, and biological characteristics of water which affect mosquito larvae. These include temperature, light, movement, dissolved gases and salts, and other living organisms present. Vegetation is important as protection for the larvae. Predators such as fish and insects destroy great numbers of mosquito larvae.

The three body regions, head, thorax, and abdomen are distinct.

Head

The head is broad, and somewhat flattened (fig. 6.8). The antennae are located on each side toward the front. Behind the antennae near the hind margin of the head are the eyes. The mouthparts are at the under side of the head near the front. They consist of a series of brushes in addition to the grinding and grasping structures. Thus, the larva is able to strain out small aquatic

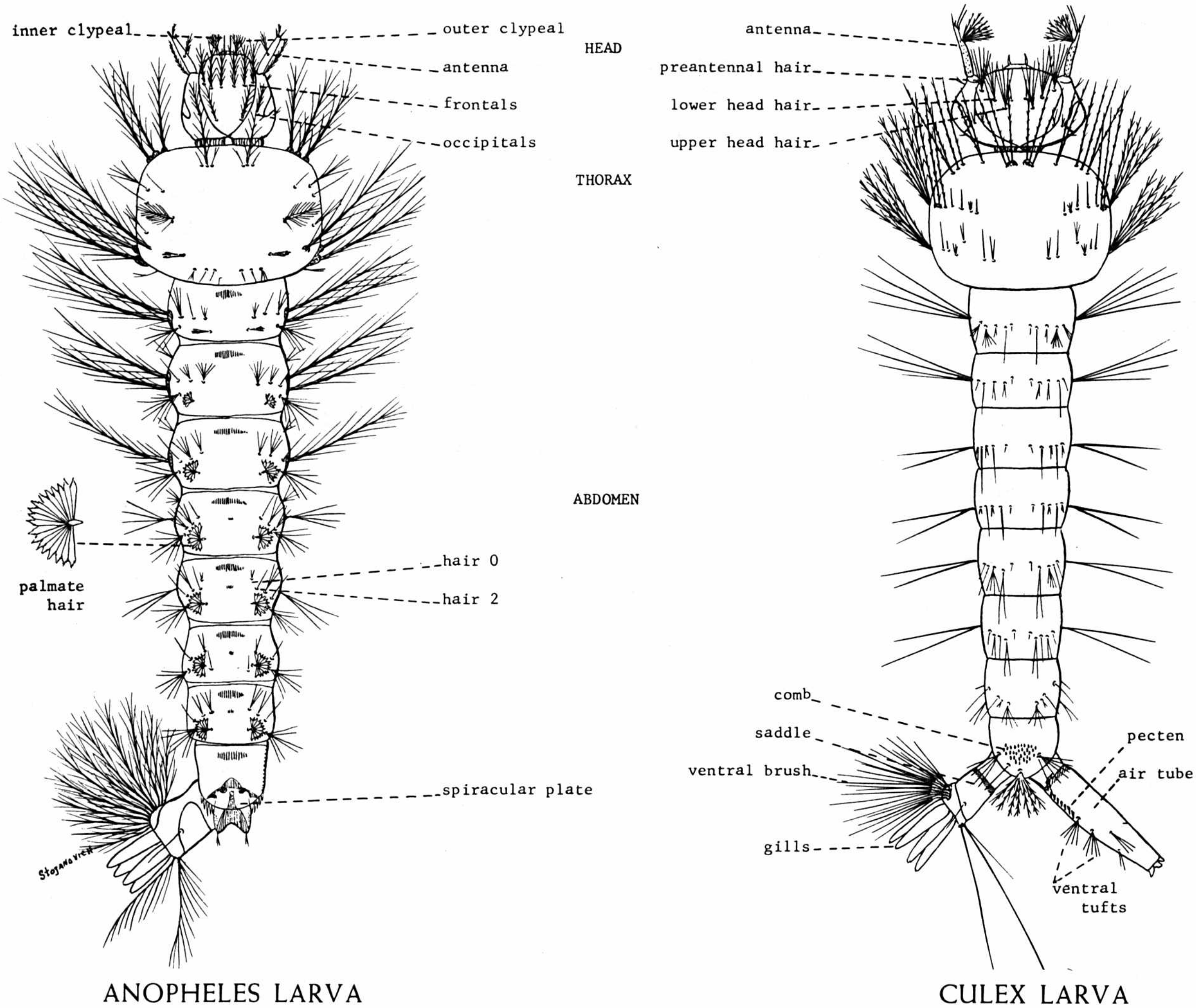


Figure 6.8 **Fourth Stage *Anopheles* and *Culex* Larvae**

organisms and particles of plant and animal material present in the water. A few predaceous species have mouthparts adapted for grasping and swallowing their prey.

Thorax

The thorax is broader than head or abdomen and somewhat flattened. It has several groups of hairs which are useful in identification of species, but there are no other special structures.

Abdomen

The abdomen is long and subcylindrical, consisting of nine well-defined segments. The first seven segments are similar, but the eighth and ninth are considerably modified. The eighth segment bears the respiratory apparatus. In the anophelines this consists of paired spiracular openings while in the other groups a prominent air tube is present. The ninth segment is out of line with the other segments and bears two to four membranous tapering appendages commonly known as anal gills. These anal gills seem to serve more for the regulation of osmotic pressure than for respiration. See Figure 6.8.

PUPAE

The mosquito pupa also lives in water and is very active. It does not feed, but must come to the surface for air except in the case of *Mansonia* spp. The pupa differs greatly from the larva in shape and appearance, the front part, consisting of the head and thorax, being greatly enlarged and enclosed in a sheath. On the upper surface is a pair of respiratory trumpets. The abdomen consists of eight freely movable segments with a pair of paddles at the tip.

Mosquito pupae are undoubtedly the most active of all insect pupae. Most species are lighter than water, their buoyancy being due to an air space between the wing cases on the underside of the combined head and thorax. By vigorous movement of the abdomen the pupae move about with considerable speed, rising directly to the surface when movement stops.

The pupal stage lasts from one day to a few weeks, no species being known to pass the winter as pupae. At the end of the pupal stage, the pupal skin is broken and the adult works its way out, crawls onto the surface of the water, and is soon ready to fly away.

ADULTS

The adult mosquito (fig 6.7) is a small fragile insect with a slender abdomen, one pair of narrow wings, and three pairs of long, slender legs. It varies in length from slightly over $\frac{1}{16}$ inch to about $\frac{1}{2}$ inch. The three body regions, head, thorax, and abdomen are distinct.

Head

The head of a mosquito (fig. 6.9) is almost spherical and is joined to the thorax by a narrow membranous connection. It bears a pair of large compound eyes, a pair of antennae, a pair of palpi and the proboscis. The antennae arise on the front of the head between the eyes. They are long, slender structures consisting of 15 segments only 14 of which are ordinarily visible. Each of the last segments bears a whorl of hairs which are short and sparse in the females, but long and bushy in the males. The antennae are believed to serve as organs of hearing and smell. The palpi are five-segmented structures originating at the lower front margin of the head near the proboscis. In female anophelines the palpi are straight and about the same length as the proboscis. The palpi of the male anopheline differ from those of the female in being enlarged at the tip (fig. 6.7). The palpi of female culicines are very short, while in the male they are usually long and densely haired, with the last two segments turned upward. The proboscis projects downward and forward from the lower front margin of the head. It consists of a labium or sheath-like structure enclosing a group of six stylets. The labium serves as a protective sheath for the stylets but does not enter the wound when the mosquito is biting. The stylets serve to penetrate the skin of the host animal and also form a small duct through which saliva is injected into the wound as well as a canal through which liquid food is drawn. The mouthparts of the male are incapable of piercing the skin of human or animal hosts.

Thorax

The thorax, or middle region of the body, bears the wings and legs. The upper surface of the thorax or mesonotum is covered with coarse hairs or scales which are variously colored. These color patterns are often useful in identification of species. The sides of the thorax may be covered with scales and bear several groups of hairs or bristles used for identification purposes. The long, slender legs arise from the lower sides of the thorax. Each leg consists of a short conical **coxa,** a small hinge-like **trochanter,** a long **femur,** a slender **tibia,** and a 5-segmented **tarsus.** The first segment of the tarsus is the longest and is often equal to the tibia in length. The fifth tarsal segment bears a pair of small **claws.** The legs are covered with scales of varying colors, forming patterns which are often useful in separation of species. The wings are long and narrow with characteristic venation. The veins are clothed with scales often of varying colors which may be distributed to form definite patterns. The hind margin of the wing also bears a close-set row of long, slender, fringe scales. A pair of small knobbed structures known as **halteres** is found behind and slightly below the wings. They vibrate rapidly when the mosquito is in flight and serve as organs of equilibrium.

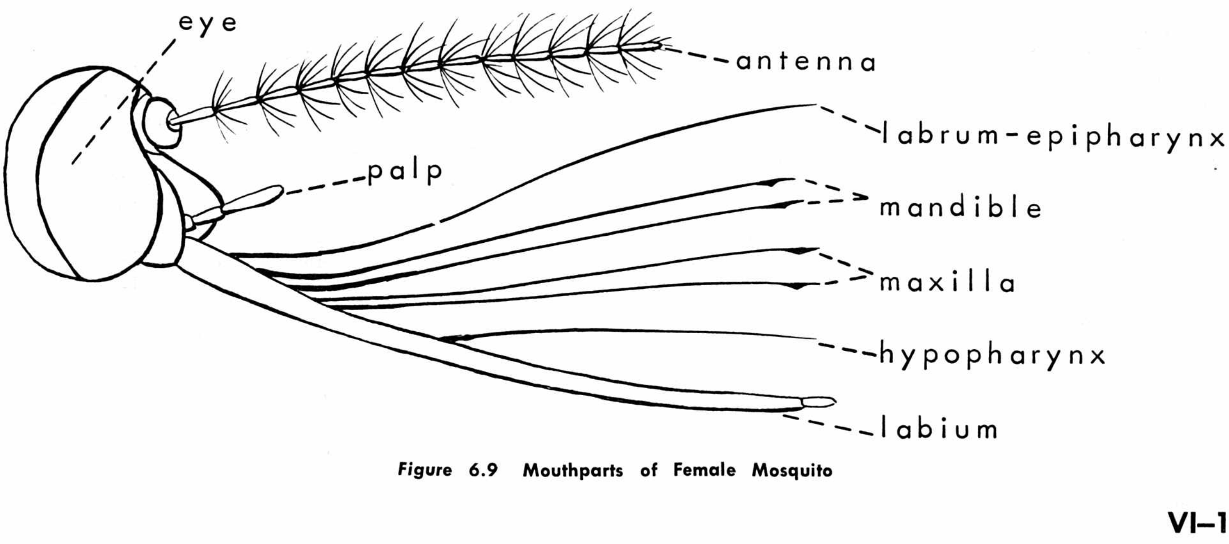
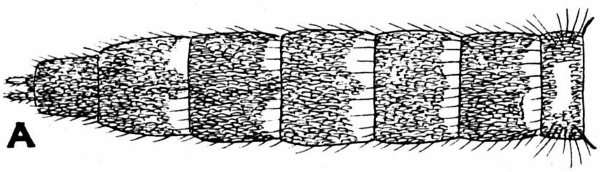


***Figure* 6.9 Mouthparts of Female Mosquito**

Abdomen

The elongate abdomen is nearly cylindrical consisting of ten segments, only eight of which are readily visible. The 9th and 10th segments are greatly modified for sexual functions. In the culicines, the abdomen is covered with scales which often form characteristic markings. In *Aedes* and *Psorophora,* the female abdomen is tapered apically, with the eighth segment withdrawn into the seventh. See figure 6.10. In other genera in the United States the abdomen is bluntly rounded at the apex. The terminal segments of the male abdomen are greatly modified for copulation, the structures often being of value in identification of the species.



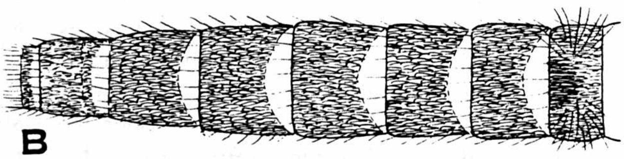


Figure 6.10 A. Pointed Abdomen of *Aedes*. B. Blunt Abdomen of *Culex*

HABITS OF THE ADULT MOSQUITOES

Adult mosquitoes are usually about half males and half females. The males ordinarily emerge first and remain near the breeding places, mating with the females soon after their emergence. Only the females bite and most (but not all) species require a blood meal before they can lay fertile eggs. The female tends to travel greater distances and appears to live longer than the male.

Flight habits vary considerably. *Aedes aegypti,* probably the most highly domesticated mosquito of the United States, breeds only in and around human habitations and flies very short distances. Most anophelines have a maximum flight range of about 1 mile. However, other species such as *Aedes vexans,* and *A. sollicitans* may fly 10 to 20 miles or more.

Mosquitoes also show considerable variation as to their preferred hosts, some species feeding on cattle, horses, or other domestic animals, while others prefer man. A few species feed only on cold-blooded animals and some subsist entirely on nectar or plant juices. Some are active during the daytime and others only at night.

The life span of adult mosquitoes is not well known. Some species apparently live one or two months during the summer, although under unfavorable conditions this may be greatly reduced. Adults that hibernate may live for six months or more.

TABLE 6.2—*Biological data on some important U.S. species of mosquitoes*

Mosquito species	Eggs	Broods per year	Overwinter
Anopheles quadrimaculatus	Singly on water	Many	As adult female.
freeborni	do	do	Do.
Culex pipiens	Rafts on water	do	Do.
quinquefasciatus	do	do	Do.
tarsalis	do	do	Do.
Culiseta melanura	do	do	As adult female and larvae.
Mansonia perturbans	do	One	As larvae.
Aedes aegypti	(Singly on sides of containers or tree holes.)	Many	As eggs.
triseriatus	do	do	Do.
sollicitans	Singly on ground	do	Do.
taeniorhynchus	do	do	Do.
dorsalis	do	do	Do.
nigromaculis	do	do	Do.
vexans	do	do	Do.
Psorophora ciliata	do	do	Do.
confinnis	do	do	Do.

TABLE 6.2—*Biological data on some important U.S. species of mosquitoes*—Continued

Mosquito species	Preferred larval habitat	Effective flight range
Anopheles quadrimaculatus	Clean, partially shaded water; some vegetation	1 mile.
freeborni	.....do	1–2 miles or more.
Culex pipiens and *quinquefasciatus*	Permanent water with organic matter or pollution	1 mile or more.
tarsalis	Almost any collection of water, usually waste water	2–10 miles.
Culiseta melanura	Permanent, shaded pools in swamps	100–1,000 yards.
Mansonia perturbans	Permanent water with some aquatic vegetation	1–5 miles or more.
Aedes aegypti	Artificial containers	1 block (usually less than ½ mile).
triseriatus	Tree holes, artificial containers	½–1 mile.
sollicitans	Temporary pools, usually brackish or with sulphates	5–20 miles.
taeniorhynchus	Temporary pools, usually brackish	Do.
dorsalis	Temporary pools, pastures, etc	10–20 miles or more.
nigromaculis	.....do	2–5 miles
vexans	Temporary pools	5–20 miles.
Psorophora confinnis	Temporary pools, rice fields	5 miles or more.
ciliata	Temporary pools	Do.

TYPES OF MOSQUITO LIFE HISTORIES

The life histories of North American mosquitoes have been divided by Pratt (1959) into eleven basic types, based on three simple criteria: stage in which the winter is passed, place where eggs are laid, and the number of generations per year.

1. *CULEX PIPIENS* TYPE

Culex, Anopheles, Uranotaenia.

Overwinter as adults; eggs laid on water surface; several generations a year.

2. NORTHERN *AEDES* TYPE

Aedes stimulans, excrucians, fitchii, communis, abserratus and many other *Aedes, Culiseta morsitans.*

Overwinter as eggs; eggs laid on damp earth or mud; one generation a year.

3. TEMPORARY POOL MOSQUITO TYPE

Aedes, Psorophora, perhaps *Culex pilosus.*

Overwinter as eggs; eggs laid on damp earth or mud, or on the edge of a "container"; several generations a year.

a. Salt Marsh Group

Aedes sollicitans, taeniorhynchus, cantator, squamiger

b. Temporary Pools Group

Aedes vexans, sticticus, dorsalis, nigromaculis, atlanticus

c. Artificial Container Group

Aedes aegypti and *triseriatus.*

d. Tree Hole Group

Aedes triseriatus, varipalpus, sierrensis, Orthopodomyia

e. Rock Pool Group

Aedes atropalpus

4. *MANSONIA PERTURBANS* TYPE

Overwinter as larvae attached to roots of plants; one irregular generation a year; eggs laid on water surface.

5. *ANOPHELES WALKERI* TYPE

Overwinter as eggs; several generations a year; eggs laid on water surface.

6. *CULISETA MELANURA* TYPE

Overwinter as larvae which may be frozen in blocks of ice; eggs laid on water surface; several generations a year.

7. *WYEOMYIA SMITHII* TYPE

Overwinter as larvae, often frozen in ice for some time; eggs laid on leaves; several generations a year.

8. *CULISETA IMPATIENS* TYPE

Also *Culiseta alaskaensis, Culex territans* and *Anopheles earlei* in Alaska.

Overwinter as mated females; feed and lay eggs on water surface following spring; one generation a year.

9. TROPICAL *ANOPHELES* AND *CULEX* TYPE

Breeding continuously; eggs laid on water surface; many generations a year. Includes *Anopheles albimanus, A. atropos,* and *A. quadrimaculatus* along the Florida and Gulf coasts; also *Uranotaenia* and *Deinocerites cancer*.

10. TROPICAL *AEDES* AND *PSOROPHORA* TYPE

Breeding continuously, new broods appearing after flooding of temporary pools; eggs laid on damp earth or mud; several generations a year. *Culex pilosus* may fall in this group.

11. *MANSONIA INDUBITANS* TYPE

Overwinter as larvae; eggs laid on underside of leaves; one or more generations a year. *Mansonia titillans* may also fall in this group.

NOTES ON IMPORTANT SPECIES OF MOSQUITOES

THE *ANOPHELES* GROUP

Anopheline mosquitoes are distributed throughout the United States, one or more species being present in every state. The females are easily distinguished from the culicines by having palpi which are about the same length as the proboscis. They can usually be distinguished also by their resting position, the anophelines with the head, thorax, and abdomen in a straight line normally assuming an angle of from 40° to 90° while the culicines rest nearly parallel to the surface.

The eggs of anophelines are always laid singly on the water surface and are provided with lateral floats which keep them at the surface. They are laid in batches of 100 or more with each female laying an average of 400–500 eggs. Hatching usually occurs within one to three days and breeding is continuous during the warm seasons of the year.

Anopheline larvae are found in many different types of water although the larger permanent bodies of fresh water are most often utilized. Two species, *A. atropos* and *A. bradleyi* breed in salt or brackish waters but all other species breed in fresh water. The larval stage requires from 4 to 5 days to several weeks depending upon the species and environmental conditions, especially the water temperature. The larvae feed just beneath the water surface where they ingest all forms of microscopic animal and plant life as well as other floating particles that come within range of their mouth brushes. Anopheline larvae probably also utilize food materials in solution in the water. In general, it seems that microorganisms, particularly bacteria and yeasts are the basic food materials. These materials are usually present in natural waters and the food supply is not believed to be an important limiting factor. Most anopheline species breed in water where the higher aquatic plants are present. These plants may serve as indicators of physical and chemical conditions which are suitable for anopheline breeding. Plants also exert a direct influence on mosquitoes through their effects on the egg-laying of the females and the protection they offer to the larvae. Some plants such as the bladderwort actually capture and destroy larvae.

Adult anopheline mosquitoes are usually active only at night, spending the daytime resting in dark, damp shelters. The peak of activity comes just after dark and again just before daylight. The flight range of most species is short, usually less than one mile. All anophelines apparently require a blood meal before they can lay fertile eggs. The species in the United States more commonly feed on the blood of domestic animals than on man. Most species overwinter by hibernation of the fertilized female. One species, *A. walkeri,* may also overwinter in the egg stage.

(1) *ANOPHELES QUADRIMACULATUS* (The common malaria mosquito)

This fairly large dark brown mosquito has four dark spots near the center of each wing. The palpi and tarsi are entirely dark. See figure 6.11.

This species is the most important vector of malaria in the United States. It is the anopheline most frequently found in houses, and is more likely to attack humans than any other anopheline of the United States

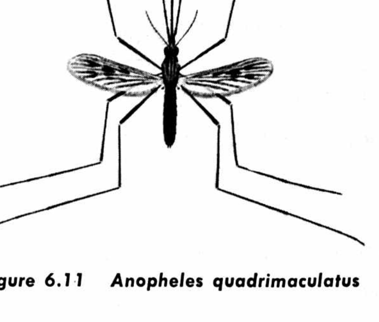


Figure 6.11 Anopheles quadrimaculatus

with the possible exception of *A. freeborni*. Careful studies have shown that approximately 5 percent of the blood meals are human blood. *A. quadrimaculatus* has probably been responsible for the transmission of almost all human malaria which has occurred east of the Rocky Mountains. The bites are less painful than those of many other species of mosquitoes and often go unnoticed.

This species is distributed from the southeastern United States northward to southern Quebec and Ontario and westward to the Dakotas, central Nebraska, Kansas, Oklahoma, and Texas. It also occurs in eastern Mexico as far south as Vera Cruz. It has been of greatest importance in the South Atlantic and Gulf Coastal Plains and the lower Mississippi River Valley. It may also become abundant at times in areas as far north as Minnesota, Michigan, New York, and New England.

A. quadrimaculatus breeds chiefly in permanent fresh water pools, ponds, and swamps which contain aquatic vegetation or floating debris. It is most abundant in shallow waters. In some areas it appears to favor open sunlit waters while in others it is found in densely shaded swamps. This species shows a preference for clear, quiet waters which are neutral to alkaline and does not usually occur where the pH is lower than 6. Breeding seldom occurs in stagnant waters heavily polluted with plant or animal matter. Some of the common habitats are lime-sink ponds, borrow pits, sloughs, bayous, sluggish streams and shallow margins and backwater areas of reservoirs and lakes (King, Bradley, and others, 1960). Production is greatest in waters with low aquatic vegetation or flotage of twigs, barks and leaves.

A. quadrimaculatus larvae can withstand rather low temperatures, but do not complete their development at temperatures below 50 to 55° F. and no appreciable development takes place until the water temperature reaches 65 to 70° F. Even at these temperatures, from 30 to 35 days may be required for development of the aquatic stages. The most favorable temperature for the development of *A. quadrimaculatus* is between 85 to 90° F. at which temperatures only about 8 to 14 days are required. Larvae may often be found where water surface temperature exceeds 100° F. during the afternoons, although they probably cannot survive constant water temperatures much above 95° F.

The females mate soon after emergence, often during their first day, either before or after the first blood meal. The males emerge first, remaining near the breeding places. A female may mate repeatedly, although one mating is sufficient to insure the production of fertile eggs during her entire life. Egg laying begins from 2 to 3 days after the first blood meal. A single female may lay as many as 12 batches of eggs and a total of over 3,000 eggs.

During the daytime adults remain inactive, resting in cool, damp, dark shelters, such as buildings, caves, and under bridges. Feeding and other activity occurs almost entirely at night. They enter houses readily to feed upon humans but they feed more frequently on other warm-blooded animals such as cows, horses, mules, pigs, and chickens. Normally most adults fly no more than one half mile from their breeding place and only a small percentage fly farther than one mile. *A. quadrimaculatus* is not ordinarily taken in light traps in great numbers.

In the most southern part of the country, *A. quadrimaculatus* breeds continuously through the year. Over most of its range, however, it spends the winters as fertilized adult females in caves, hollow trees, basements, and other protected places. In all but the most northern areas it may emerge from hibernation and move about and take blood meals on warm days during the winter. In the spring, the females emerge, take a blood meal and deposit their eggs. There may be as many as 9 or 10 generations each season. Populations often reach a peak during July or August and decline rapidly in September and October. Hibernating females may survive for 4 or 5 months.

ANOPHELES FREEBORNI (The Western Malaria Mosquito)

The western malaria mosquito is similar in appearance to *A. quadrimaculatus*. It is the most important vector of malaria in western United States. It enters homes and animal shelters readily and bites avidly at dusk and at dawn. This species occurs over most of the area west of the Continental Divide, from southern British Columbia to Lower California. East of the Divide it is found in southern Colorado, New Mexico and extreme western Texas, according to Carpenter and LaCasse (1955).

A. freeborni breeds in permanent or semipermanent waters which are at least partially exposed to the sunlight, and contain vegetation or flotage. Clear, clean, slightly alkaline water is preferred. Larvae may also be found in slightly brackish water near the ocean or in desert pools. It normally avoids water polluted with sewage or other organic materials. Breeding may take place in habitats very similar to those in which *A. quadrimaculatus* is found, but it has for the most part adapted itself to seepage areas, borrow pits, hoof prints, improperly irrigated fields and the edges of streams and irrigation canals. Rice fields are a particularly favorable breeding place for this species. This mosquito is well adapted to the semiarid region in which it occurs.

In California, *A. freeborni* leave their hibernating places in February, obtain a blood meal, and lay eggs for the first generation. Because of the abundance of breeding places at this time of year and the scarcity of predators, large broods develop. Succeeding generations are greatly reduced in range and size by the recession of waters, except where irrigation waters maintain their breeding places. In late fall at the end of the dry season, females from the last generation migrate long distances, sometimes 10 to 12 miles to seek shelter in outbuildings, homes, and cellars. During the winter season they are in a state of semihibernation from which they emerge on warm days and nights for feeding. The winter biting is sometimes referred to as "nibbling." They move about nervously, often attacking at the ankles and seldom feeding to repletion. These winter feedings usually do not result in development of eggs. They may, however, result in the transmission of malaria.

The midseason flight range of *A. freeborni* is generally restricted to a one-mile radius. In cases of very heavily infested rice fields, longer flights up to 2½ miles have been noted. Males are seldom found more than one-quarter mile from their breeding places.

ANOPHELES PUNCTIPENNIS

This mosquito has the wings conspicuously marked with spots of pale and dark scales (fig. 6.12). The palpi are entirely dark. It probably occurs in every State although definite records are still lacking for Arizona, Nevada, and Utah. This species is not known

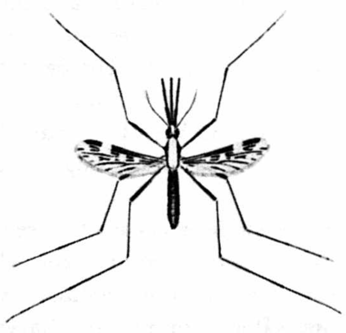


Figure 6.12 Anopheles punctipennis

to be a natural vector of malaria although it may be infected in the laboratory. It is a rather vicious biter out-of-doors, but apparently does not enter homes as readily as do *A. quadrimaculatus* and *A. freeborni* (King, Bradley, et. al., 1960).

A. punctipennis breeds in a very wide variety of habitats. Larvae may be found along with *A. quadrimaculatus* or they may occur in rain barrels, hog wallows, grassy bogs, spring pools, swamps, and margins of streams. They seem to prefer cool water and are the first anophelines to appear in the spring. They are most abundant during the spring and fall in the southern States but are found more uniformly throughout the summer in the northern States.

3 ANOPHELES CRUCIANS

This anopheline has areas of pale and dark scales on the wings and three prominent black spots on the last wing vein. The palpi are banded with white. It is probably not of importance in the transmission of malaria although it is susceptible to infection in the laboratory. It bites man readily, but is not ordinarily of much significance as a pest. It occurs throughout the southeastern United States extending northward along the coastal plain to Massachusetts. The western limit of its range is in Kansas, Oklahoma, and Texas. It is apparently most abundant along the Atlantic and Gulf Coastal Plains.

A. crucians breeds extensively in acid waters such as those of the cypress swamps and ponds in coastal Florida and Georgia. It may also be found in many other habitats such as lake margins, wheel ruts, sluggish shelters of the same type utilized by *A. quadrimaculatus*, and is often taken in great numbers in light traps. The flight range may be somewhat greater than one mile, especially in areas where they are usually abundant. Two other species in the *Anopheles crucians* complex are *A. bradleyi*, typically a salt-marsh breeder, and *A. georgianus*, whose larvae occur in fresh water seepage areas.

4 ANOPHELES WALKERI

This species resembles *A. quadrimaculatus* though it is somewhat darker and has narrow white rings on the palpi. It is widely distributed in eastern United States extending from southern Canada southward to Vera Cruz, Mexico. It is known to occur as far west as Minnesota, Nebraska, Kansas, and Texas. *A. walkeri* quite readily bites man and is a good laboratory vector of malaria. Its epidemiological importance in relation to malaria is not known.

A. walkeri commonly breeds in sunny marshes or along lake margins among thick growths of aquatic vegetation such as cattails and sawgrass. It may also be found along the grassy edges of slow-flowing swamp streams and in bordering pools. In the northern States it produces a distinctive type of egg known as the "winter egg" in which stage it may spend the winter. The adults commonly rest during the day on the lower part of the stems of sedges, grasses and other emergent vegetation of their breeding places. *A. walkeri* is often taken in great numbers in light traps.

ANOPHELES PSEUDOPUNCTIPENNIS

This species is similar in appearance to *A. punctipennis* except that the palpi are banded with white. It occurs in south central United States extending on into Mexico, Central and South America. It is not considered to be of any importance in the United States, though in certain countries to the south it is an important malaria vector (MacDonald, 1957).

A. pseudopunctipennis breeds in pools in shallow or receding streams especially those in full sunlight containing luxuriant growth of green algae. They also breed in other ground pools and ponds and occasionally in artificial containers such as fountains and tanks. They are often found in water that is warm to the touch, much too warm for other anophelines. Their flight range is generally a mile or less.

ANOPHELES FRANCISCANUS

Anopheles franciscanus is similar to *A. pseudopunctipennis* in appearance and habits. It occurs along the Pacific Coast from southern Oregon into Mexico and eastward into Nevada, Arizona, and New Mexico. It is often present in great numbers in certain localities but it is not believed to be of any importance as a malaria vector. *A. franciscanus* is commonly found at the mouths of rivers entering the Pacific, the larvae occurring in abundance in the shallow pools of sandy arroyos. Their breeding habits are generally similar to those of *A. pseudopunctipennis*.

5 ANOPHELES ALBIMANUS

This major vector of malaria in the Caribbean Region occurs only in southern Texas and the Florida Keys in the United States and is apparently of no importance in these areas. It is the only anopheline in continental United States having white rings on the tarsal segments.

THE *AEDES* GROUP

The genus *Aedes* contains more than 500 species distributed from the Polar regions to the Tropics. Almost one-half of all North American mosquitoes belong to this genus which includes many of our major pest species as well as important disease vectors. There are some 60 species of *Aedes* known from the United States of which about 40 may be rather common at least in certain regions. In general the *Aedes* mosquitoes assume greater importance as one goes from the tropics northward. In northern United States, as well as in Canada and Alaska, many species of *Aedes* occur and these are often present in astronomical numbers.

All species of *Aedes* lay their eggs singly on the ground or above the water line in tree holes or containers. They hatch only after flooding and in some species the eggs are able to survive long periods of drying. Many of the northern species have only one brood a year, hatching not occurring until the eggs have been subjected to periods of drying and cold. Other species are intermittent breeders, having several generations per year depending upon the rainfall or irrigation practices. According to Bates (1949) all species occurring in regions having cold winters pass the winter in the egg stage.

Breeding places for species of *Aedes* are extremely variable. In general they breed in temporary pools formed by rains or melting snows. Some species breed in the coastal salt marshes which are flooded at intervals by unusually high tides. Others have become adapted to irrigation practices. A few species breed in tree holes, rock pools, and artificial containers.

Practically all species of *Aedes* are blood sucking in habit, many species being vicious biters of great economic importance. Their biting habits are variable but they most frequently attack during the evening hours. Some species, however, bite only during the day and others will bite either during the day or night.

6a AEDES AEGYPTI (The Yellow Fever Mosquito)

The yellow fever mosquito is a small dark species that can be recognized by the lyre-shaped silvery-white lines on the thorax and the white bands on the tarsal segments. It is the vector of urban yellow fever and dengue, and a pest of some significance when it occurs in large numbers.

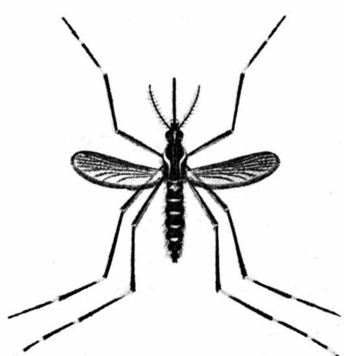


Figure 6.13 Aedes aegypti

Ae. aegypti is essentially a tropical species, thought to have been introduced into the Western World from Africa. In the United States it has a limited distribution in the southeastern and southern States extending northward to Virginia, Kentucky, and Missouri. Formerly an abundant species in most southern cities, *Ae. aegypti* appears to have become less common during recent years. This is probably due to large scale use of insecticides such as DDT, and to the improved urban sanitation. See Hayes and Tinker (1958).

Ae. aegypti is thoroughly domesticated, breeding almost exclusively in artificial containers in and around human habitations. The eggs are laid singly on the water just at the margin or on the sides of the container above the water line. They are able to withstand drying for several months, and hatch quickly when the container is again filled with water. Hatching may take place in two days or less if temperatures are high. Typical breeding places are flower vases, tin cans, jars, discarded automobile tires, unused water closets, cisterns, rain barrels, and sagging roof gutters. The larvae complete their development in about 6 to 10 days or in much longer periods in cool weather. The pupal period is not over 2 days under normal conditions. The life cycle may be completed in ten days, although it may vary up to three weeks. It breeds throughout the year in the tropics with generations succeeding each other rapidly. In southern United States, the reproduction rate slows down during the winter and the eggs may remain dormant for several weeks or months. This species is very susceptible to cold and does not survive the winter except in southern United States.

The adults apparently prefer the blood of man to that of other animals, entering houses readily, often those that are well screened. *Ae. aegypti* bites principally during the morning and late afternoon. It attacks quietly, preferring to bite about the ankles, under coat sleeves, or at the back of the neck, often becoming a troublesome pest. The adults appear to be rather long-lived as they will live 4 months or more in the laboratory. Their flight range is from several hundred feet to half a mile.

AEDES ATLANTICUS-TORMENTOR-INFIRMATUS

These species are almost identical in appearance and can be separated only in the larval stage or by a study of the male genitalia. They are distributed throughout the southeastern States. The females are vicious biters attacking readily during the daytime in or near wooded areas. They have been reported driving cattle from woodlands by their attacks.

AEDES CANADENSIS

This dark mosquito has the tarsi banded with white at both ends of the segments. It is widely distributed in the United States, being particularly common in the northern States. It is often a serious pest in woodland situations but rarely migrates far from its breeding places.

Ae. canadensis is one of the first mosquitoes to appear in early spring. The larvae breed in woodland pools filled by melting snows or by spring rains. It shows preference for pools with a bottom of dead and decaying leaves, although it may also be found in roadside puddles, sink holes, wooded swamps and isolated oxbows of small woodland streams. There may be more than one generation per year and the adults live for several months. In New York they may be found from March until October, although they become less common in late summer and early fall, according to Carpenter and LaCasse (1955).

AEDES CANTATOR (The Brown Salt-Marsh Mosquito)

The brown salt-marsh mosquito is a rather large, brown species with indistinct white bands on the abdomen and tarsi. It is an important salt marsh mosquito along the North Atlantic Coast from Maine to Virginia. *Ae. cantator* is an abundant and severe pest in the coastal marshes of Massachusetts, Rhode Island, Connecticut, New York, and New Jersey. Its habits are generally similar to those of *Ae. sollicitans,* though it is not as active during the day, being essentially an evening mosquito. Broods frequently migrate considerable distances, invading shore towns and summer resorts. It is often the dominant species on the salt marshes early in the season, yielding this position to *Ae. sollicitans* later in the summer.

AEDES CINEREUS

This small brown species occurs sparingly throughout most of the United States, occasionally assuming importance as a pest mosquito in some of the northern States. The flight range of *Ae. cinereus* seems to be limited and it is usually found in the woods near the larval habitat. It is usually single-brooded, the larvae occuring in shallow woodland pools.

6b

AEDES DORSALIS

This is a medium-sized mosquito varying in coloration from dark brown to a whitish straw color. The upper surface of the abdomen is marked with a longitudinal stripe of pale scales and the hind tarsi are banded with yellowish scales at both ends of the segments. *Ae. dorsalis* is a severe pest of man and cattle throughout the arid and semiarid regions of western United States. It occurs over most of the country, but is rare and unimportant in the eastern and southern States. *Ae. melanimon* is very similar to *dorsalis* in the West. See figure 6.14.

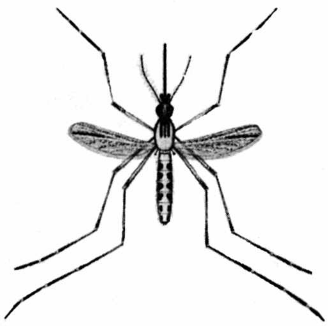


Figure 6.14 Aedes dorsalis

The larvae develop in the salt marshes of the Pacific Coast and in irrigation and flood waters of the interior. It is a common breeder in irrigated pastures and waste water pools. Several broods are produced each year in irrigated areas, a brood following each flooding.

The females of *Ae. dorsalis* are vicious biters, attacking in either day or night, being particularly active in the evening or on calm, cloudy days. They are strong fliers, occasionally migrating in large broods. They are commonly found 10 miles from their breeding places and a flight of 22 miles has been recorded in Utah. The females, and at times, the males, may be taken in great numbers in light traps. Over-wintering takes place in the egg stage and the eggs may remain viable for several years.

AEDES NIGROMACULIS

This medium-sized dark mosquito has a longitudinal line of yellowish-white scales on the upper surface of the abdomen. It has bands of white scales at the base of the tarsi segments but not at the apex. This species is an important pest mosquito throughout the western plains extending from Minnesota west to Washington and south to Texas and Mexico. During recent years it has assumed great prominence in the irrigated pastures of the West especially in the Central Valley of California. The remarkable spread of this species is indicated by the fact that it was not known from the State of California until 1937. It now occurs over most of the State at the lower elevations and is rapidly replacing *Ae. dorsalis* in open sunlit pools of waste irrigation and other intermittent water, according to Carpenter and LaCasse (1955).

This species has proved to be extremely well adapted to pasture irrigation. The eggs will hatch within 2 to 6 days after they are deposited, if flooding occurs. It is able to produce a brood following each irrigation which is usually at intervals of 8 to 12 days in the Central Valley of California. Under favorable conditions, a brood may be produced within 5 days, and as many as 20 broods can be produced in one season. In most areas of the San Joaquin Valley, *Ae. nigromaculis* is now the number one pest problem and is present in astronomical numbers. For example, a light trap operating for three nights near an irrigated pasture collected almost a gallon of mosquitoes, predominantly *Ae. nigromaculis*. As many as 20 million eggs of this species may be found in a single acre of irrigated pasture.

The adult is a severe pest of man and animals, attacking readily and inflicting a painful bite. It will bite during the daytime but is most active during the evening hours. It is a strong flier and may migrate several miles from its breeding ground. The winter is passed in the egg stage.

AEDES PUNCTOR (and related species)

This group of dark-legged *Aedes* includes also *Ae. abserratus*, *Ae. pullatus*, *Ae. communis*, *Ae. hexodontus*, and *Ae. cataphylla*. They are important woodland pests in the Northeastern States and in the mountainous regions of the West. The females of these species are very difficult to separate but the group is well represented throughout northern United States, Canada, and Alaska, see Horsfall (1955).

All species of this group are single-brooded. The larvae develop in temporary pools formed by melting snows as well as in the grassy margins of lakes, ponds, and streams. They have a flight range of probably less than one mile. They often cause great annoyance in recreational areas near their breeding places.

AEDES SOLLICITANS (The Salt-Marsh Mosquito)

The salt-marsh mosquito, *Aedes sollicitans* is the most important of the salt marsh species and one of the most severe mosquito pests known. It occurs along the Atlantic and Gulf Coastal Plains from Maine to Texas and has been reported from many inland areas where brackish waters are available. Such inland records include New York, Indiana, Kentucky, Illinois, Oklahoma, Arkansas, and New Mexico. Adults can be recognized by the golden color of the upper side of the thorax and a longitudinal stripe of white or yellowish-white scales on the abdomen. The proboscis and tarsi also have wide pale bands.

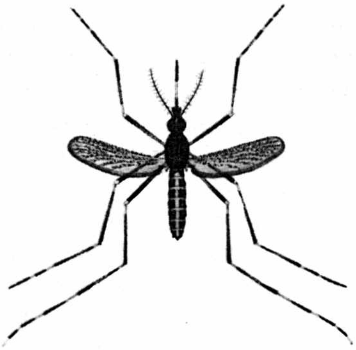


Figure 6.15 *Aedes sollicitans*

The eggs of this species are laid on the mud of marshes where they remain until flooded by high tides or rains. Breeding generally occurs on the parts of the marsh not covered by daily tides; usually pot holes and depressions of various size are utilized, but sometimes they occur over rather extensive level areas. The eggs must remain dry for at least 24 hours before they will hatch. After having been dry for a week or two, they hatch within a few minutes when covered with water. Development of the larval and pupal stages requires 7 to 10 days during warm weather. Several generations are produced each year in the northern States, while in South Florida breeding is continuous throughout the year, according to Carpenter and LaCasse (1955).

The adults of *Ae. sollicitans* are strong fliers often migrating in large swarms from the marshes to cities and towns many miles away. They very commonly fly 5 to 10 miles and may travel up to 40 miles or more. The migratory flights begin just before dark and may consist of tremendous numbers of mosquitoes. During the day they rest among the grasses though they will readily attack anyone who disturbs them, even in full sunlight. They are fierce biters and may literally drive one from the marsh areas. Fortunately, they do not often come indoors. They have been a very severe deterrent to the development of some of the coastal resort areas. They are often collected in light traps in great numbers.

AEDES SPENCERII

This important pest mosquito of the prairie regions of Minnesota, North Dakota, Montana, and northward into Canada occurs southward to Illinois, Iowa, Nebraska, Colorado, and Utah. The females are fierce biters, attacking during the day, even in bright sunlight. They are serious pests of man and livestock. They often migrate into cities and towns, but the extent of their flight range has not been determined. There is probably only one generation a year. The larvae are found in surface pools filled by melting snow or spring rains.

AEDES STICTICUS

Aedes sticticus is a medium-sized species having the thorax clothed with pale scales and the legs speckled with white scales but not banded. It is a flood-water species which occurs throughout most of the United States but is most abundant in the northern States. It has assumed great importance as a pest mosquito in such widely separated areas as central New York and the Columbia River Valley of Washington and Oregon.

Ae. sticticus usually has only one brood annually. The eggs are laid on the ground particularly in the valleys of rivers and smaller streams. A loam soil with either dead or live vegetation or both, is preferred to bare areas exposed to the sun and wind. Eggs do not hatch until the spring or summer following the season during which they were deposited. If flooding does not occur they will survive 2 or 3 years. Larval development requires 10 days to three weeks depending upon temperature.

Adults are often very abundant following floods. The females are ferocious biters during the evening, and also during the day in cloudy or shaded situations. The flight range is extensive, possibly up to 25 or 30 miles. They may live as long as 3 months.

AEDES STIMULANS GROUP

This group includes four common and rather widely distributed woodland species: *Ae. stimulans, Ae. excrucians, Ae. fitchii,* and *Ae. increpitus*. Their habits are generally similar and the adult females are difficult to separate. They occur throughout most of the northern States from New England to the Pacific Coast, although *Ae. increpitus* apparently does not occur east of the Rocky Mountains. These species are among the most abundant and annoying of the woodland mosquitoes in many of our Northern States. They bite readily in the daytime. There is only one generation a year but the adults may live most of the summer. The winter is passed in the egg stage, hatching with the melting of the ice and snow in early spring.

9

AEDES TAENIORHYNCHUS (The Black Salt-Marsh Mosquito)

The black salt-marsh mosquito has cross bands of white scales on the upper side of the abdomen and white rings on the proboscis and tarsi. It occurs on the coastal plains from Massachusetts to Texas and on the Pacific Coast in southern California. It has also been reported from certain inland areas around salt pools in oil fields. *Ae. taeniorhynchus* is the most abundant and troublesome salt marsh species along the south Florida coasts and may be a severe pest as far north as New Jersey.

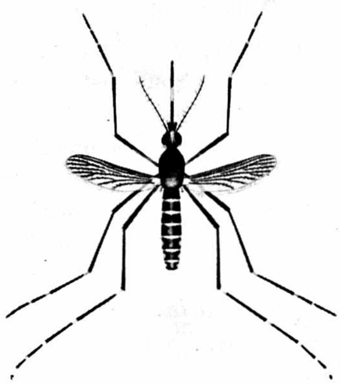


Figure 6.16 Aedes taeniorhynchus

The breeding habits are similar to those of *Ae. sollicitans*, though it also breeds in fresh water pools near the salt marshes. The adults are strong fliers and fierce biters, being active principally at night. They may be very annoying in the shade during the day, but are less likely than *Ae. sollicitans* to attack in bright sunlight. According to Bidlingmayer and Schoof (1957) 90 percent of the females in one release study were recovered within 4 miles of the release point, but some females were collected as far away as 18 to 21 miles.

10 **AEDES TRISERIATUS (The Tree-Hole Mosquito)**

The tree-hole mosquito is blue-black in appearance with silvery white scales at the sides of the thorax. It occurs throughout most of eastern United States and has been reported as far west as Montana, Idaho, and Texas. It breeds principally in tree holes and to some extent in water barrels and other artificial containers. The bite is painful and sometimes this species is troublesome in the woods. Adults apparently do not wander far from their breeding places. Larval development appears to be rather slow with nearly a month being required to reach maturity.

AEDES TRIVITTATUS

Aedes trivittatus is widely distributed in northern United States from Maine west to Idaho. It has been taken as far south as Georgia, Louisiana, and Arizona. It is a fierce biter and an extremely annoying pest in some of the northern States. The upper surface of the thorax is marked with two conspicuous whitish stripes.

The larvae occur mostly in flood-water pools and temporary rain pools. The young larvae feed at the surface of the water but the later instars spend most of their time concealed in the vegetation at the bottom of the pool. Perhaps it is for this reason that larvae are seldom encountered even though adults may be present in large numbers. Emergence of adults begins about 8 days after hatching. The adults rest among grasses and other vegetation during the daytime. They will bite when disturbed, but are especialy active in the evening. They apparently do not migrate very far.

AEDES "VARIPALPUS" COMPLEX (The Western Tree-Hole Mosquito)

The western tree-hole mosquitoes are a complex of small, dark mosquitoes with brilliant white bands at both ends of the tarsal segments, restricted to western North America from Arizona to British Columbia. They assume considerable importance as pest species in some parts of California. At present *Aedes sierrensis* is considered the correct name for the species on the Pacific Coast and *Ae. varipalpus* and *Ae. monticola* occur in Arizona. These species ordinarily breed in tree holes, but may also occur in rain barrels that contain a heavy sediment of decaying leaves. The adults are often so small that they can pass through ordinary window screens. However, they seem to bite less readily indoors than outdoors.

11 **AEDES VEXANS (The Flood-Water Mosquito)**

Aedes vexans is a medium-size, brown mosquito with narrow rings of white scales on the hind tarsi and with a V-shaped notch at the middle of each band of white scales on the upper surface of the abdomen. This is probably the most widespread species of *Aedes* in the United States and the most abundant and troublesome mosquito in many areas. It has been reported from every State, and is a major pest in most of the

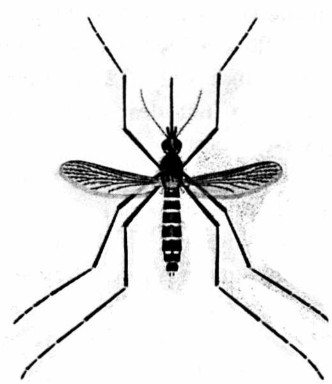


Figure 6.17 Aedes vexans

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Northern States from New England to the Pacific Coast. It is less abundant in the extreme South.

Ae. vexans breeds in rain pools, flood waters, roadside puddles, hog wallows and practically all temporary bodies of fresh water. Eggs are laid on the ground, hatching when flooding occurs. In receding waters larvae may frequently be concentrated so that 500 or more are found to each pint of water. Development of the aquatic stages requires 10 to 21 days, depending on temperature. They are single-brooded in some areas in the Western States where flooding occurs only in the spring. In most of the *Ae. vexans* range there are several broods each year, see Stage *et al.* (1952).

Adults migrate long distances from their breeding places, 5 to 10 miles being rather common. The adults are vicious biters and are especially annoying at dusk and after dark. Studies in Oregon have shown that the adults live for nearly 2 months. They are attracted to light and both males and females are frequently taken in light trap collections. They rest during the day in grass and other vegetation, and only rarely are found in shelters of the type used for evaluation of anopheline populations.

OTHER SPECIES OF *AEDES*

A number of other species of this group may be of importance in restricted areas in the United States. These include *Ae. squamiger*, a salt-marsh species of the California Coast; *Ae. mitchellae* of the Southeastern States; *Ae. aurifer* in the Northeastern States; *Ae. atropalpus*, a rock-hole breeder, of the Eastern and Southern States; *Ae. campestris* in the northern Great Plains; *Ae. increpitus* of the Western States; *Ae. niphadopsis* of Utah, Nevada, and Idaho; and *Ae. intrudens*, a woodland species of northern United States and Canada.

THE *CULEX* GROUP

The genus *Culex* includes about 300 species most of which occur in the tropical and subtropical regions of the world. Some 26 species have been reported in the United States although only 12 of these are at all common. The group includes several important pest species and disease vectors.

Culex mosquitoes breed in quiet waters of almost all types from that in artificial containers to large bodies of permanent water. Water in which there is considerable organic material including sewage is often a favored breeding place. The eggs are deposited in rafts of 100 or more each. They remain afloat on the water surface until hatching occurs some 2 or 3 days later. Breeding continues throughout the warm season with several generations a year in the Southern States. The adult females hibernate during the winter in protected places. The females are generally inactive during the day, biting at night.

CULEX ERRATICUS (and related species)

Three closely related species of the subgenus *Melanoconion* are found in the Southeastern States. These are *C. erraticus*, *C. peccator*, and *C. pilosus*, rather small dark species, the females being almost indistinguishable. *C. erraticus*, the most common species of this group, breeds in grassy permanent pools and ponds often in association with anophelines (King, Bradley, *et al*, 1960). They have been reported breeding in great numbers in the rice fields of Arkansas. The adults are persistent and painful biters, though they are said to prefer the blood of fowls. They bite principally in the evening.

12 *CULEX NIGRIPALPUS*

This is principally a tropical mosquito but occurs as far north as Tennessee and North Carolina. It is quite common in Florida becoming an important pest species in flooded fields. Larvae are also found in ditches and grassy pools. *Culex nigripalpus* is the proven vector of St. Louis encephalitis virus in the Tampa Bay outbreak in 1962 (Chamberlain, unpublished data).

13 *CULEX PIPIENS-QUINQUEFASCIATUS* (Northern and Southern House Mosquitoes)

The northern and southern house mosquitoes are closely related and difficult to separate. They are brown mosquitoes of medium size with cross bands of white scales on the abdominal segments but without other prominent markings. *C. pipiens*, the northern house mosquito, occurs throughout northern United States extending as far south as Georgia and Oklahoma. *C. quinquefasciatus*, the southern house mosquito, occurs in all the Southern States from coast to coast and extends northward to Nebraska, Iowa, Illinois, and Ohio. One or both of these species will probably be found in every one of the States.

The house mosquitoes are the most common species in many of our urban communities and rural premises, commonly entering houses where their habit of "singing" is very annoying. *Culex quinquefasciatus* is a severe pest. *Culex pipiens pipiens* or *Culex pipiens molestus* may also feed on man. Members of the *Culex pipiens-quinquefasciatus* complex are important vectors in urban epidemics of St. Louis encephalitis, particularly in the Midwest.

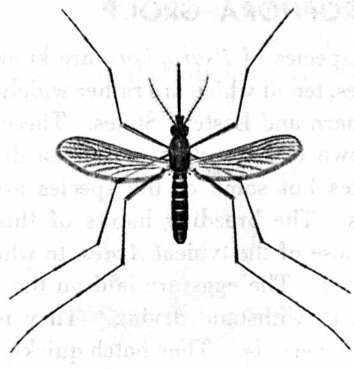


Figure 6.18 Culex quinquefasciatus

C. pipiens and *C. quinquefasciatus* breed prolifically in rain barrels, tanks, tin cans, and practically all types of artificial containers. Other important sources of these mosquitoes are storm-sewer catch basins, poorly drained street gutters, polluted ground pools, cesspools, open septic tanks, and effluent drains from sewage disposal plants. A heavy production of house mosquitoes is often associated with insanitary conditions.

C. pipiens and *C. quinquefasciatus* lay their eggs in clusters of from 50 to 400 eggs. These clusters, known as egg rafts, float on the surface of the water. Hatching occurs within a day or two in warm weather and from 8 to 10 days are required for completion of the larval and pupal stages. In somewhat cooler weather of early spring or late fall this may require two weeks or more. Breeding continues throughout the warmer months of the year. Some races can survive and produce fertile eggs without a blood meal, see Horsfall (1955).

These species do not migrate far except when great numbers are being produced. Ordinarily, when adults are present, larvae will be found nearby. They are active only at night and may be found resting during the day in and around houses, chicken houses, outbuildings, and various shelters near their breeding places. They are readily attracted to light traps.

15 **CULEX PEUS (Formerly Known as *Culex stigmatosoma*)**

This is a western species similar in appearance to *C. tarsalis.* It breeds in almost all types of ground pools and artificial containers. In California it is reported breeding in tremendous numbers in oxidation ponds. *C. peus* rivals *C. tarsalis* in abundance in the Pacific Coast States, but apparently it does not bite man. It has been found infected with western encephalitis virus.

CULEX RESTUANS

This species is widely distributed east of the Rocky Mountains from the Gulf of Mexico into Canada. Some observers report that it is often an abundant and annoying mosquito in the Eastern States, while others say that it rarely bites man. It is similar in appearance and habits to *C. pipiens* although it is not usually as important a pest.

C. restuans ordinarily breeds in rather foul water such as that containing decaying grass or leaves. Favored breeding places are rain barrels, tin cans, woodland pools, ditches, and pools in streams. It appears early in the season and continues breeding throughout the summer.

16 **CULEX SALINARIUS**

Culex salinarius occurs throughout most of eastern United States, being especially common along the Atlantic and Gulf Coasts. It bites readily out of doors at night and is at times a fairly important pest. Larvae are found in grassy pools of both fresh and brackish water, in lake margins, marshes, cattail bogs, ponds, and ditches.

17 **CULEX TARSALIS**

This mosquito (fig. 6.19) is a medium-sized, dark species with a broad, white band at the middle of the proboscis and white bands at each end of the tarsal segments. It is a fairly important pest species in some parts of its range. It is most active soon after dusk and may enter buildings in search of blood. *C. tarsalis* has been found naturally infected with the virus of both St. Louis and western encephalitis. Laboratory experiments have also demonstrated its ability to transmit both diseases. Epidemiological studies carried on in several western States indicate that it is much more frequently infected with these viruses than are other mosquitoes. The infection is apparently acquired from feeding upon birds, later transmitting it to other birds

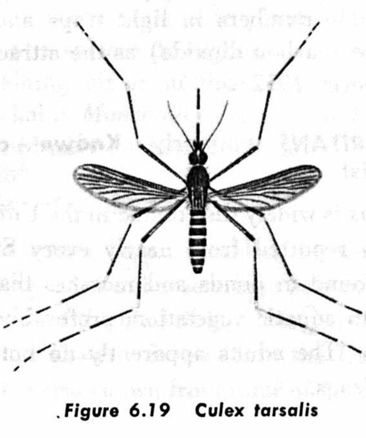


Figure 6.19 Culex tarsalis

or to horses or man. It is believed to be the most important vector of encephalitis to man and horses in the Western States, according to Ferguson (1954).

C. tarsalis is widely distributed west of the Mississippi River including southern Canada and northern Mexico. It is also known from Wisconsin and is most abundant along the Pacific Coast. In California, it occurs from sea level up to 7,600 feet in the Sierra Nevada. It is essentially a rural mosquito.

C. tarsalis larvae develop in a rather wide variety of aquatic situations. In the arid and semiarid regions, they utilize almost all types of water being most frequently found in temporary to semi-permanent bodies of water associated with irrigation. These include canals, ditches, borrow pits, impoundments, ground pools, and hoof prints. They breed in effluent from cesspools and other waters containing large quantities of organic material from human wastes; also, in artificial containers of various types such as cans, jars, barrels, drinking troughs, ornamental ponds, and catch basins. Females deposit at least two rafts of eggs usually containing from 100 to 150 eggs each. Hatching normally occurs within 48 hours. The larval and pupal stages develop rapidly and breeding continues from early spring until late fall. Adult females hibernate in the more northern areas (Horsfall, 1955).

Adults are active chiefly from dusk to dawn. During daylight hours the adults remain quietly at rest in secluded spots. They can frequently be found on porches, on shaded sides of buildings, in privies, or under bridges. The majority, however, rest in grass and shrubs, or along cut banks of streams. *C. tarsalis* apparently must have a blood meal in order to produce fertile eggs. It has a wide range of hosts showing some preference for birds, though it also commonly feeds on cows, horses, and humans. Dispersion studies have shown that *C. tarsalis* will fly at least 10 miles, although the majority of individuals probably remain within a mile of their breeding places. They are taken in considerable numbers in light traps and in traps using dry ice (carbon dioxide) as the attractant (Bellamy and Reeves, 1952).

CULEX TERRITANS (Formerly Known as *Culex apicalis*)

C. territans is widely distributed in the United States, having been reported from nearly every State. The larvae are found in ponds and marshes that are well supplied with aquatic vegetation, preferably in rather cool waters. The adults apparently do not bite man but feed on frogs.

THE *PSOROPHORA* GROUP

Thirteen species of *Psorophora* are known from the United States, ten of which are rather widely distributed in the Southern and Eastern States. These mosquitoes are not known to be vectors of human disease in the United States but some of the species are extremely severe pests. The breeding habits of this group are similar to those of the typical *Aedes*, to which they are closely related. The eggs are laid on the ground and are adapted to withstand drying. They may lie dormant for long periods. They hatch quickly upon being flooded and development of the larvae is very rapid.

PSOROPHORA CILIATA

This is a very large, yellowish-brown mosquito with shaggy legs, which is commonly known as the gallinipper. It is a vicious biter and because of its large size presents a rather terrifying appearance. *P. ciliata* is widespread through eastern United States from Mexico to Canada, being abundant locally in the South and Middle West. When present in numbers it is a severe pest, attacking readily during the daytime as well as in the evening.

P. ciliata is one of the few species whose larvae feed on other aquatic insects including mosquito larvae. It breeds in temporary pools, often in association with *P. confinnis* and *Ae. vexans* upon which it feeds. The fourth instar larvae may consume three or four other larvae in 1 day. *P. ciliata* larvae are easily recognized in the field as they are two or more times as long as most other species. They hang almost straight down from the water surface. The larval and pupal life is short as is characteristic of this group of mosquitoes. The eggs are laid on the surface of drying soil, hatching when flooded as with *Psorophora confinnis*. Hibernation takes place in the egg stage (Horsfall, 1955).

PSOROPHORA CONFINNIS

This species is known as the glades mosquito in Florida and the dark rice field mosquito in Arkansas and adjacent rice-producing areas. It is a medium to large dark species having a narrow ring of white scales near the apex of the hind femur. *P. confinnis* is the most widespread and important species of *Psorophora* in the United States. It occurs throughout southern United States, extending westward to south California and northward to Nebraska and Iowa, New York, and Massachusetts. It reaches its greatest abundance in the Florida Everglades and in the rice fields of Arkansas and Mississippi. The females are fierce biters, attacking anytime during the day or night.

When present in great numbers they occasionally kill livestock and make it almost unbearable for people to remain outdoors in the infested areas (King, Bradley, *et al.*; 1960).

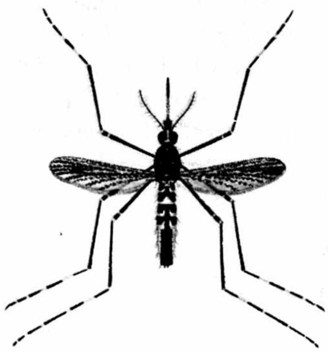


Figure 6.20 Psorophora confinnis

P. confinnis breeds in temporary rain pools, irrigation waters, and seepage pools. Eggs are not laid on water surfaces but on ground that is subject to flooding from rainfall, overflow, or irrigation. Soil with low, rank vegetation seems to be ideal for egg deposition. Drained rice fields are among the most favorable sites. Eggs will hatch after 4 or 5 days if they are submerged at that time. If they remain on the surface of the soil for 2 or 3 weeks or longer and are then flooded, hatching may begin within a few minutes. Overwintering is in the egg stage. The larval period for *P. confinnis* is very short. During midsummer in Arkansas, it may be completed in as little as 4 days. The average time at a mean temperature of 79° F., is slightly over 5 days. The pupal stage is completed in 1 or 2 days. The number of generations per season varies from one to many, depending upon how often suitable hatching conditions occur. Areas which dry up and are then flooded a few days later may produce a brood with each flooding. Such conditions are provided with certain types of irrigation, particularly rice culture. Adults live from 1 to 2 months. They have a flight range of up to at least 10 miles.

PSOROPHORA CYANESCENS

This species has a metallic, blue appearance with the tarsal segments entirely dark. It is abundant in Oklahoma and Arkansas as well as certain areas of Alabama, Mississippi, and Louisiana. It has been reported from all the Southeastern States north to Illinois and Indiana. *P. cyanescens* is a severe pest attacking either during the day or night. In Arkansas and Oklahoma, it may become so numerous after rains in July and August as to drive people indoors or to a different locality. It breeds in temporary rain pools and its life history is similar to that of *P. confinnis*.

PSOROPHORA FEROX

This species, known as the white-footed woods mosquito, is frequently encountered in woodland areas throughout the South and East. It occurs in most of the States from Texas to Nebraska and eastward. It is a persistent and painful biter, attacking readily during the day. The larvae develop in temporary rain pools.

PSOROPHORA SIGNIPENNIS

This is a common species in central United States from Montana and North Dakota to Texas. It is very abundant in Oklahoma, Nebraska, and Kansas. This species inflicts a painful bite, but does not appear to be as serious a pest as the numbers taken in light traps might indicate. *P. signipennis* is well adapted to breeding in temporary ground pools in arid regions. Its development from egg to adult stage may be completed in 5 days under favorable conditions.

OTHER SPECIES OF *PSOROPHORA*

A number of other species of *Psorophora* may be pests at times, particularly in the Southern States. These include *P. discolor*, *P. horrida*, *P. varipes*, and *P. howardii*. The latter is very similar to *P. ciliata* in both the larval and adult habits. The other three species have breeding habits similar to *P. confinnis* but are rarely as abundant.

THE *MANSONIA* GROUP

This group includes three species in the United States, one of which is very widespread and common. They are troublesome biters and severe pests in many areas. *Mansonia* eggs are laid in rafts on marshes or lakes. After hatching, the larvae descend below the surface of the water and insert their air tubes into the stems or roots of aquatic plants. They remain below the water surface throughout the larval and pupal stages obtaining air from these plants. Because of this unique habit, *Mansonia* larvae cannot be controlled by use of ordinary surface larvicides.

19

MANSONIA PERTURBANS

This is a rather large, speckled, brown and white mosquito which has a characteristic pale band at about the outer third of the hind tibia. It is distributed in the Southern and Eastern States from the Gulf Coast to Canada. It is also known from some of the Great Plains and Rocky Mountain States and from the four Pacific Coast States. This species has recently been found naturally infected with the virus of eastern encephalitis in Georgia. Its role in the epidemiology of this disease has not been established.

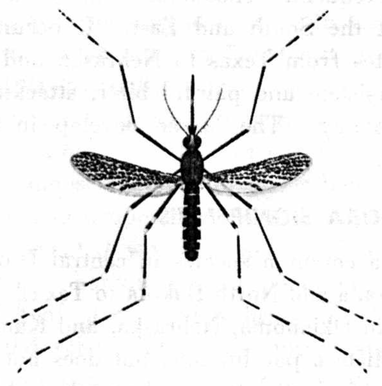


Figure 6.21 Mansonia perturbans

Breeding of *M. perturbans* takes place in marshes, ponds, and lakes having a thick growth of aquatic vegetation. Larval development is unusually slow, requiring several months. The larvae which hatch one season do not ordinarily complete their development until the following spring. They remain below the water surface throughout this period though they may detach from their host plants and move about. The pupae also have breathing tubes adapted for penetrating plant tissues and they too attach to plants from which they get their air. The pupal stage requires 5 or 6 days. The adults emerge in late spring or early summer. There appears to be only one generation per year throughout most of the range of this species. It is possible that a partial second brood may be produced in Florida. Larvae have been found associated with a number of plants. Some of the more important ones are pickerel weed, cattail, water lettuce, arrowhead, aquatic sedges, and swamp-loose-strife.

The females will bite during the daytime in shady, humid places, but are principally active in the evening and early part of the night. They readily enter houses and bite viciously. These strong fliers are frequently taken in light trap collections.

20

MANSONIA TITILLANS

This tropical species is fairly common in Florida and has also been reported from South Texas. The adults are severe biters and fairly important pests in Florida. The eggs of *M. titillans* are laid on the under surface of the leaves of water lettuce. The larvae and pupae attach to the roots of this plant, developing in the same manner as described for *M. perturbans*. The adults are frequently taken in light traps. *M. indubitans* occurs in Southern Florida.

THE *CULISETA* GROUP

Members of this genus are somewhat similar in appearance and habits to *Culex*. There are 10 species in the United States of which 5 are fairly widespread. They are relatively unimportant as pests. Two species have been found naturally infected with encephalitis virus but their relation to the epidemiology of these diseases is not known.

CULISETA INCIDENS

This species is principally western in its distribution. It is reported from Texas, Oklahoma, Nebraska, and all States to the west. In some areas it is a troublesome pest while in others it seems timid about biting man. It is reported as feeding more frequently on domestic animals. *C. incidens* breeds in a wide variety of habitats from the brackish water pools on the Pacific Coast to spring water and snow pools in the mountains. It has also been taken in reservoirs, ornamental ponds, hoof prints, rain barrels, and discarded automobile tires.

21

CULISETA INORNATA

This is a large, grayish-brown mosquito with broad, lightly scaled wings. It has been reported from almost all the States except in upper New England. In the Northern and Western States it breeds throughout the spring and summer, while in the South it is more common during the winter. They do not readily attack man, but attack domesticated animals and may be of considerable annoyance to livestock. *C. inornata* has been found naturally infected with the virus of western encephalitis and in laboratory experiments it has been shown capable of transmitting the virus. Its habits indicate that it is unlikely to be an important vector of this disease to man.

Larvae of *C. inornata* are frequently found in cold water. The hibernating females come out during warm spells of the winter and early spring even while snow is still on the ground. They are sometimes referred to locally as snow mosquitoes.

22

CULISETA MELANURA

Culiseta melanura is a small dark species which resembles members of the *Culex* group more closely than do other species of this genus. It occurs throughout most of eastern United States from the Gulf States to Canada. The larvae develop in small permanent collections of water. Adults may be taken in considerable numbers in light traps and to a lesser extent in daytime resting stations. It has on numerous occasions been found naturally infected with the viruses of eastern and western encephalitis. It rarely bites man.

CULISETA MORSITANS

Culiseta morsitans has been reported from most of the Northern States from coast to coast and is fairly common in some parts of New York and New England. It breeds in spring-fed pools and is single-brooded. The adults are not known to bite man.

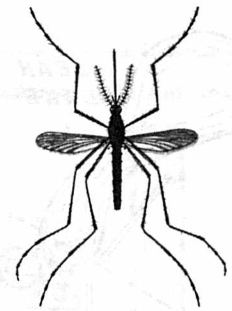


Figure 6.22 Culiseta melanura

MOSQUITO SURVEYS

INTRODUCTION

Surveys are essential for the planning, operation, and evaluation of any effective mosquito-control program, whether for the prevention of mosquito-borne diseases or the lowering of populations of these biting insects to a level permitting normal activities without undue discomfort.

Two types of surveys are widely used:

1. **The original basic survey** to determine the species of mosquitoes, source, location, densities, and flight range. It may also include information on life cycles, feeding preferences, larval habitats, adult resting places, and recommendations for a control program, setting up immediate aims and long-term objectives.
2. **The operational survey,** a continuing evaluation which is extremely valuable in the daily operation of a mosquito-control program, furnishing information on the effectiveness of control operations and data for comparison throughout a season or from year to year.

Such surveys do not determine the absolute population of mosquitoes as is done in the human population census. Rather, an index of population is obtained to show fluctuations in mosquito abundance throughout the period of the survey or in different areas in the control zone.

MOSQUITO CONTROL MAPS

Reasonably accurate and comprehensive maps are essential in planning a mosquito control operation, in field survey and control operations, in program evaluation, and in reporting for informational and budgeting purposes. A map is used for orientation and for locating larval breeding places and adult sampling stations. A contour map should show streets, roads, railroads, as well as ponds, lakes, streams, and other water areas.

The schematic map (fig. 6.23) illustrates the type of information required for a small project. When greater areas are involved it is best to have a master map such as this and area maps of greater scale and detail for planning drainage and other control operations in the field. The master map will indicate the protected area, the possible flight range of mosquitoes from different breeding sites, and the degree of penetration into the protected areas. All larval and adult sampling stations are indicated by symbols and numbers. Counts made at these stations at weekly or biweekly intervals permit immediate evaluation of the mosquito problem at any time, indicating the abundance of mosquitoes, the species involved, the flight range, and the areas requiring high priority for treatment.

ADULT MOSQUITO SURVEYS

PURPOSE

The adult survey permits evaluation of the incidence of mosquitoes in a community where they may bite people, and shows the relative abundance of the various species present at any time. Using this information and reference material on the breeding sites and habits of mosquito species, the vector control specialist can determine the need for a control program and conduct an effective search for the larval breeding places. The adult mosquito survey furnishes data for utilization of space spraying equipment at the best time and place, and for reporting to supervisors and to the public the extent of the problem and results of control operations. Interpreting of adult mosquito survey reports and translating this information to action will save manpower, materials and equipment and furnish justification for the entire operation.

EQUIPMENT

The required equipment is simple and inexpensive, consisting of a collecting tube or aspirator (fig. 6.24),

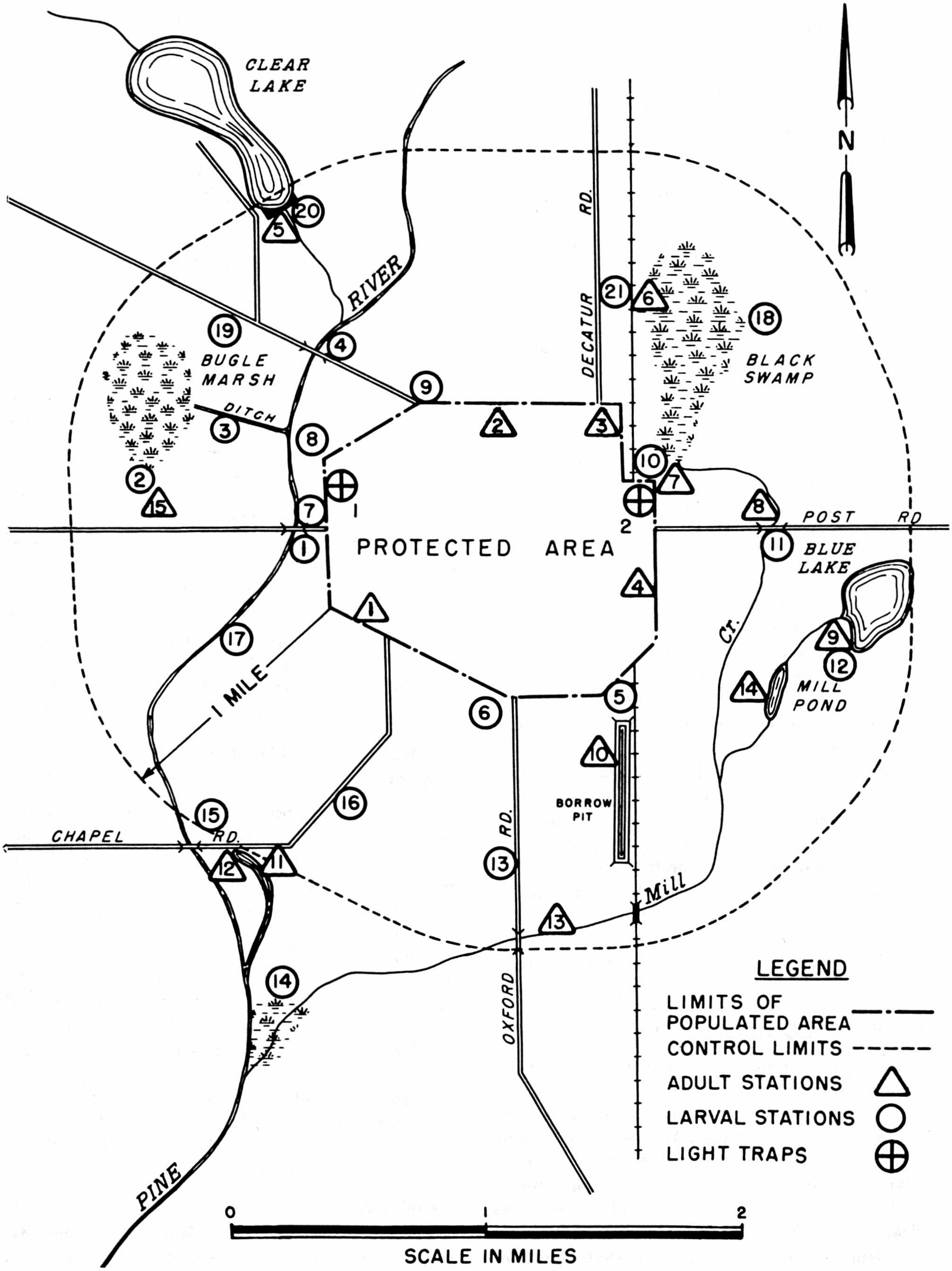


Figure 6.23 Schematic Map Showing Mosquito Sampling Stations

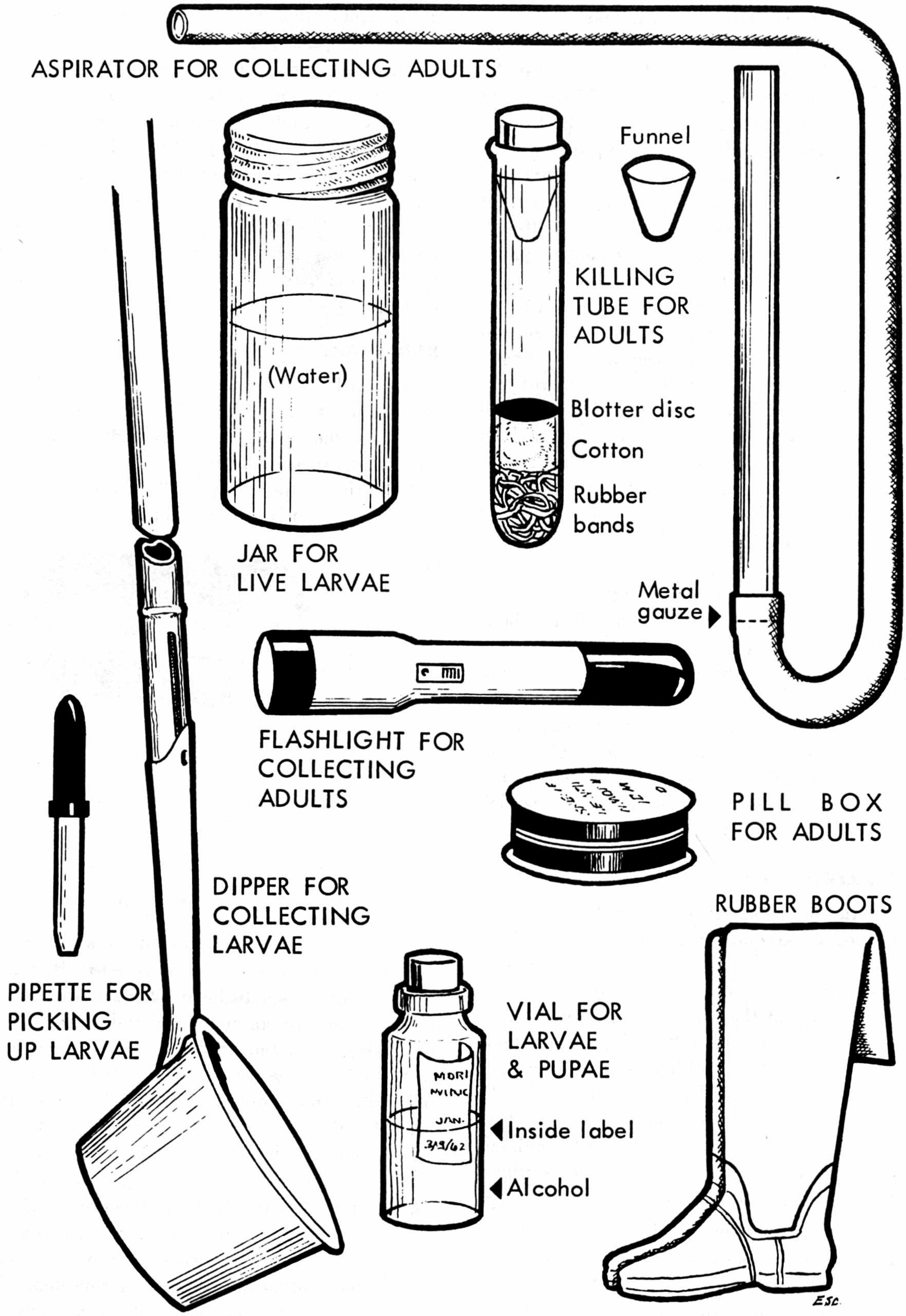


Figure 6.24 **Equipment For Mosquito Surveys**

pill boxes, cages (for live collections), field record forms or notebook, pencil, flashlight, and map.

The collecting tube may be made from a glass or plastic tube of any convenient size (fig. 6.24), usually large test tubes about 1-inch diameter by 7 inches long being preferred. The tube is filled to a depth of about one inch with finely cut rubber bands, art gum, or other available rubber. Sufficient chloroform or ethyl acetate is then added to saturate the rubber. A disc of blotting paper is placed over the rubber, a half-inch of cotton, and then two or three discs of blotting paper cut slightly larger than the tube pressed down over the cotton. The tube is closed with a cork (never a rubber) stopper. Collecting tubes remain effective for several weeks and can be recharged when necessary by removing the discs and cotton and adding more chloroform. Some workers wrap the base of the collecting tube with adhesive tape to lessen breakage, and others add an inverted paper cone inside the mouth of the tube to trap specimens more easily. The addition of crinkled tissue paper to the tubes helps keep specimens dry and prevents breakage, making identification easier.

A simple aspirator is prepared from a section of plastic (or glass) tubing 12 inches long with an inside diameter of about 3/8 of an inch. One end of the tube is covered with bobbinet or fine wire screening and then inserted into a piece of rubber tubing 2 to 3 feet long (fig. 6.24).

Small pill boxes or salve boxes are convenient for holding dead mosquitoes until they can be identified. A wisp of cotton, or preferably soft tissue or lens paper, will prevent damage to the specimens as they are carried about or shipped to a laboratory for identification.

BITING COLLECTIONS

The collection of mosquitoes as they bite is a convenient method of sampling populations. In making biting collections or counts, the subject should expose part of his body by rolling up his sleeves or trouser legs, or by removal of the shirt, and sit quietly for a designated period of time (usually 10 or 15 minutes). The mosquitoes are collected with an aspirator or chloroform tube, either by the collector or a coworker. In many parts of the tropics it is customary to make biting collections about sundown from a domestic animal, such as a white horse. If collections are made at night, a flashlight is required. Whether counts are made from human beings or animals, it should be recognized that certain individuals are more attractive to mosquitoes than others. It is, therefore, desirable for the same person or animal to be used throughout a given survey. Collections must be made at regular intervals and at approximately the same time of day, so that biting rates at different stations may be compared to show trends in mosquito populations.

With day-biting species, the index may be based upon the number of mosquitoes alighting upon one's clothing in a given time interval (the landing rate), rather than those actually in biting position. This is more practical when populations are very high, and is useful for a rapid check of mosquito abundance before and after treatment. The landing-rate method has been used especially with certain species of *Aedes* or *Psorophora* found in salt marshes, rice fields, or the arctic and subarctic tundras.

BAIT TRAPS

Animal bait traps, or stable traps (fig 6.25), have been used extensively in the West Indies, South America, and other parts of the world. Bait traps are somewhat expensive to build, transport and maintain, but a series of these traps will collect live mosquitoes over a wide area for a whole night, without large

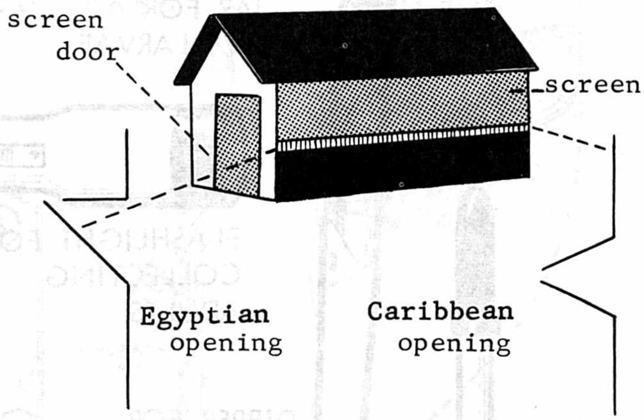


Figure 6.25 **Animal Bait Trap**

numbers of other insects, and in areas where electric power is not available (Pratt, 1948; Bates, 1949). Animal bait traps must be of sufficient size and strength to hold the bait animal comfortably and permit its convenient entry and removal. A considerable portion of the sides of the trap is covered with screen wire in order that mosquitoes may be attracted to the bait animal. V-shaped entrances make it easy for mosquitoes to enter and bite but difficult for them to find their way out after feeding. Two types of openings, the Egyptian and Caribbean, are widely used. The animal is generally placed in the trap in the evening and left overnight. The trap is inspected early in the morning and the mosquitoes counted and/or collected. Horses, calves, mules, donkeys and sheep have been used as attractants.

WINDOW TRAPS

Window traps (fig. 6.26) employing the same principle as the animal bait trap are sometimes used, the humans sleeping inside serving as bait animals. The baffles can be mounted in the windows of the buildings with the screen cages inside to catch mosquitoes as

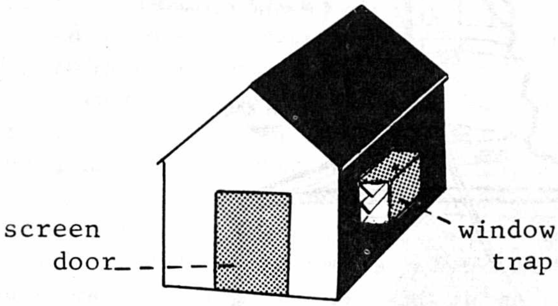


Figure 6.26 **Window Trap**

they enter. More frequently, on malaria control programs, the cages are placed outside, for mosquitoes which have rested on a surface sprayed with DDT often have a positive phototropic reaction and attempt to fly out of a treated house.

CARBON DIOXIDE TRAPS

Solidified carbon dioxide (dry ice) will attract large numbers of some mosquito species. An economical portable mosquito bait trap utilizing dry ice as an attractant has been developed in California (Bellamy and Reeves, 1952). This trap (fig. 6.27) made from a

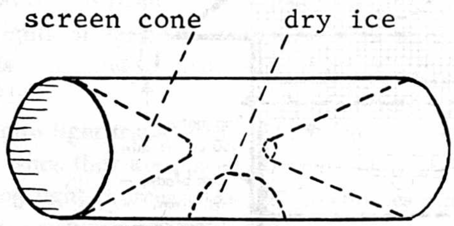


Figure 6.27 **Carbon Dioxide Trap**

12-inch lard can with two inwardly directed screen funnels is baited with about 3 pounds of dry ice wrapped in newspaper. It is effective in capturing large numbers of *Culex tarsalis.*

INSECT NETS

Insect nets are utilized for collecting mosquitoes from grass and other vegetation. This type of collection is of value in determining the adundance of those species which rest in these habitats during the daytime, such as *Aedes vexans, Ae. sollicitans, Ae. taeniorhynchus,* and *Ae. nigromaculis.*

DAYTIME RESTING PLACES

Adults of many species are inactive during the day, resting quitely in dark, cool, humid places. Careful inspection of daytime shelters gives an index to the population density of these mosquitoes. This method is especially useful for anopheline mosquitoes and is commonly used for *Anopheles quadrimaculatus.* It is also of value in estimating populations of some culicines such as *Culex quinquefasciatus* and *C. tarsalis.* Mosquito resting stations may be divided into two general types: natural and artificial.

Natural Resting Stations

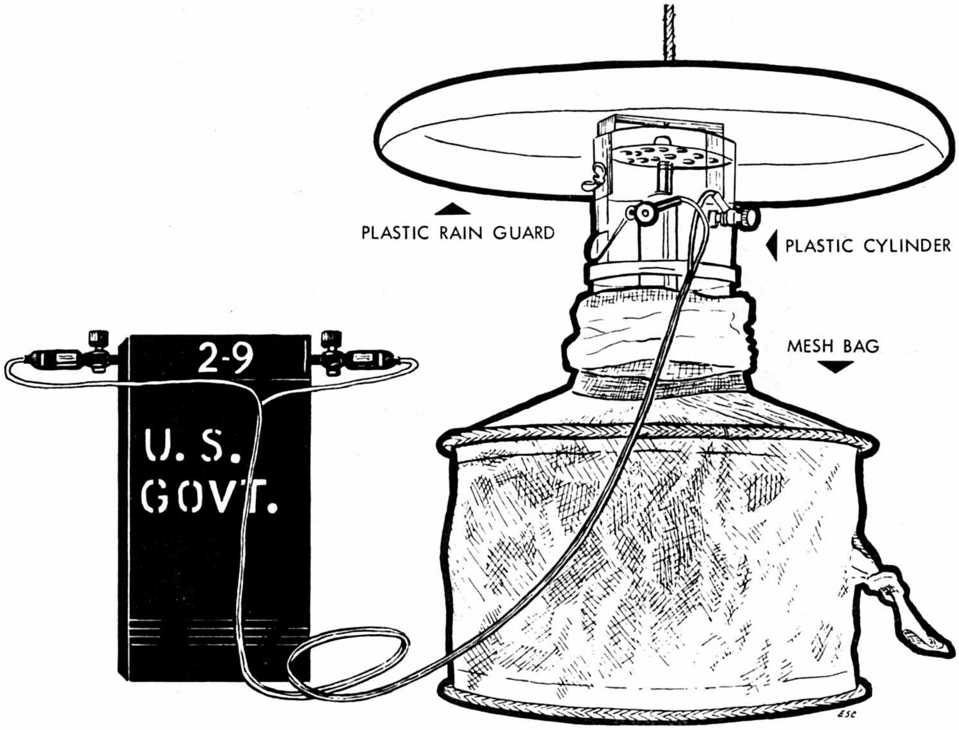
These resting stations are places normally present in an area, such as houses, stables, chickenhouses, privies, culverts, bridges, caves, hollow trees, and overhanging banks along streams. With experience one is able to evaluate the suitability of shelters by casual inspection. Dwellings, especially when unscreened, often prove to be satisfactory resting stations, being especially important when mosquito-borne diseases are being investigated. Under such conditions they furnish an index to the number of mosquitoes which may bite man and transmit encephalitis or other diseases. In the evaluation of DDT residual spray programs it is essential that both treated and untreated houses be checked periodically.

Artificial Resting Stations

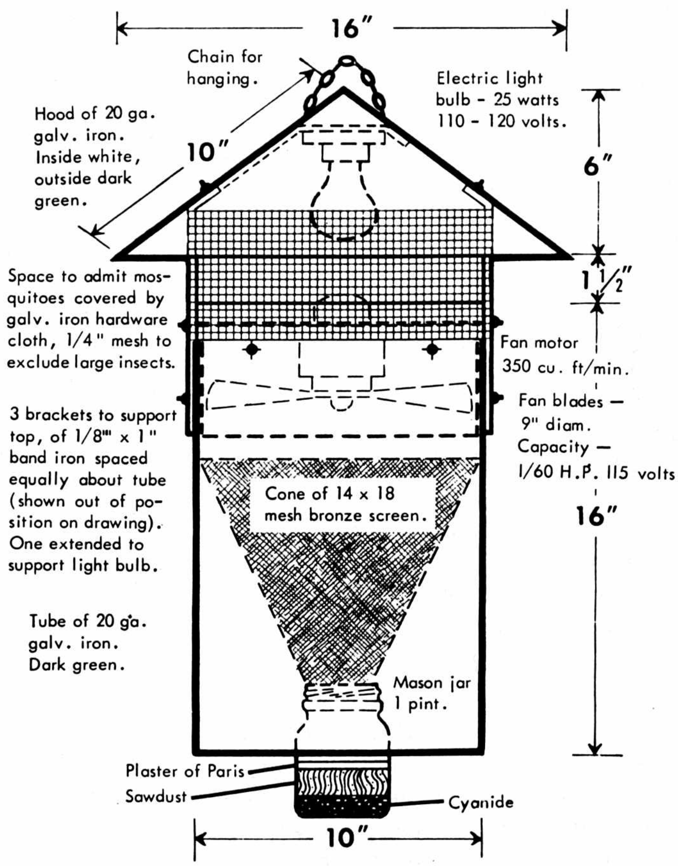
Suitable resting stations may not be available in sufficient numbers to give a satisfactory evaluation of the mosquito population. It may be necessary to construct special shelters or to use boxes, barrels, kegs, etc., as artificial resting stations. Many different types of artificial shelters have been used. They should always be placed near the suspected breeding places in shaded, humid locations. Mosquitoes enter such shelters at dawn, probably in response to changes in light intensity and humidity and ordinarily do not leave until dusk. Artificial shelters built in the form of an outdoor privy 4 feet square and 6 to 7 feet high have been used successfully in the United States.

LIGHT TRAPS

Many mosquito species are attracted to light, making it possible to utilize this response in sampling adult populations between dusk and dawn. The New Jersey Mosquito Light Trap developed in the 1930's (Provost, 1959) has been used widely in obtaining data on the intensity and species composition of mosquito populations.



A. CDC MINIATURE LIGHT TRAP



B. AMERICAN LIGHT TRAP

***Figure 6.28* Mosquito Light Trap**

The "American" model mosquito light trap (fig. 6.28B) has been developed by the Bureau of Vector Control, California Department of Public Health as a modification of the New Jersey light trap. It was redesigned to reduce intake of moths and other "trash insects" and to permit construction by the individual utilizing available parts (Mulhern, 1953).

The CDC Miniature Light Trap (fig. 6.28A) was developed for greater portability in making live mosquito catches in remote areas which could not otherwise be sampled (Sudia and Chamberlain, 1962). This small plastic trap has been field tested for one year, resulting in catches of about one half as many mosquitoes as the New Jersey trap, or its modification the American Light Trap (fig. 6.28B) used in California. In one instance the miniature trap collected 25,000 *Psorophora confinnis* in a single night. It has been used with success in collecting *Culicoides* and *Phlebotomus*. It collects a high percentage of mosquitoes in proportion to "trash insects" and many more females than male specimens, a desirable feature in collecting mosquitoes for virus studies. Both new traps exclude many moths, beetles, and other large insects.

The CDC Miniature Light Trap weighs only 1¾ pounds, is demountable for easy transport, and has a collapsible catching bag. The large plastic overhang protects the operating mechanism, even in the heaviest rainstorms. It can be operated on any 6 volt d.c. source, but the use of a 30 ampere-hour motorcycle battery weighing about 10 pounds gives up to 5 nights' operation without recharging. The Aristo-Rev No. 1 motor, available from hobby shops, will give from 15 to 25 nights of service before wearing out. Cost of materials, exclusive of battery and labor, is approximately $10.

Mosquito light traps attract adults from a considerable area when they are placed in locations remote from competing light sources. As the mosquitoes reach the light they are blown downward through a screen funnel into a killing jar or a mesh bag suspended below the trap. The light and fan are powered from alternating current ordinarily, but batteries are used for remote locations. The killing jar is made from a pint or quart fruit jar or plastic container. A layer of sodium or potassium cyanide is placed in the bottom, covered with a layer of sawdust or cotton and a layer of plaster of Paris or cardboard. For safety reasons rubber bands or chunks may be used instead of cyanide and saturated with chloroform. Some workers use only paradichlorobenzene in the killing jar. Frequently a perforated paper cup is placed in the mouth of the jar to hold the specimens, keeping them dry, clean, and easy to remove.

The mosquito light trap is mounted on a post, or hung from a tree, with the light 5½ or 6 feet above the ground. It should be located 30 or more feet from buildings in open areas near trees and shrubs. It should not be placed near other lights, in areas open to strong winds, or near industrial plants giving off smoke or gas. The traps are operated on a regular schedule from 1 to 7 nights per week. They are turned on just before dark and turned off after daylight. An automatic time clock may be utilized to start and stop the trap, or it may be turned on and off by hand. The collection should be removed each morning and placed in a properly labelled box until it can be sorted and identified.

Wide differences have been noted in the reactions of different species of mosquitoes to light. Light trap collections must therefore be used in conjunction with other methods of sampling mosquito populations. They have proven very useful in measuring densities of some of the culicine mosquitoes, such as *Aedes sollicitans*, *Aedes vexans*, *Aedes nigromaculis*, *Culex pipiens* and *Mansonia perturbans*. Some anophelines especially *Anopheles albimanus*, *Anopheles crucians*, *Anopheles atropos*, and *Anopheles walkeri*, are also readily taken in light traps. The common malaria mosquito, *Anopheles quadrimaculatus*, however, is seldom taken in significant numbers. Pratt (1948) and Provost (1959) have reported that light trap collections of many species of mosquitoes show fluctuations on a 4-week cycle correlated with the dark and bright phases of the moon, being greatest during the darker phases.

LARVAL MOSQUITO SURVEYS

Mosquito larvae are found only in water from warm, brackish, seaside marshes to the pure cold water of melted snows. They are found in such diverse locations as rivers, lakes and ponds, and crab holes, pitcher plants, eaves troughs, funerary urns, bottles, cans, reservoirs, tree holes, old tires, and vases.

The inspector must assume that mosquitoes have adapted themselves to almost every conceivable type of aquatic situation. It is necessary to obtain information regarding the general breeding habits of the species known or suspected to be present in the area prior to initiation of larval surveys. An experienced person may be able to spot the probable mosquito-breeding places in a specific area by means of a rapid reconnaissance survey. These places should be carefully numbered and marked on the map. More detailed inspection is then required to determine the specific breeding sites and establish permanent larval sampling stations. Larval surveys show the exact areas in which mosquitoes breed and their relative abundance. For this reason they are of special value in control operations.

EQUIPMENT FOR LARVAL MOSQUITO SURVEYS

A white enamel dipper about 4 inches in diameter is most used for collecting mosquito larvae (fig. 6.24). The handle of such a dipper may be extended to a convenient length by inserting a suitable piece of cane or wood. Many special dippers are used for specific purposes, being designed so that their capacity can be directly related to the water surface area examined. Thus, the number of larvae per square foot or square meter may be computed with reasonable accuracy.

White enamel pans are used in preference to dippers by some inspectors. A convenient-sized pan is about 14 inches long, 9 inches wide, and 2 inches deep. This pan is used to sweep an area of water until the pan is half full. It may then be floated on the water surface while the larvae are removed.

Inspection of small artificial containers or cisterns may require the use of a flashlight or a mirror with which to reflect light into the breeding place. Large bulb pipettes or siphons made of rubber tubing are sometimes used to remove water from small obscure areas such as tree holes. The water may then be put in a dipper or pan where the larvae are counted and collected. Wide-mouthed pipettes (eye droppers) are used for removing larvae from the dipper or pan; and small vials, preferably with screw caps, serve to hold the larvae until they can be identified or mounted on slides. Screened-bottom spoons may be substituted for pipettes if the larvae are to be transferred to wide-mouth bottles. Alcohol of 95-percent strength is a most satisfactory preservative but 70-percent alcohol is in common use. An extensive account of equipment for collecting mosquito larvae is given in Boyd (1949).

INSPECTION PROCEDURES

Mosquito larvae are usually found where surface vegetation or debris are present. Thus, in the larger ponds and lakes, larvae are ordinarily confined to the marginal areas. It is necessary to proceed slowly and carefully in searching for mosquito larvae as disturbance of the water or casting shadows may cause the larvae to dive to the bottom. Anopheline larvae are collected by a skimming movement of the dipper with one side pressed just below the surface. The stroke is ended just before the dipper is full since larvae will be lost if the dipper is filled to the point that it runs over . Where clumps of erect vegetation are present, it is best to press the dipper into such clumps with one edge depressed so that the water flows from the vegetation into the dipper. Culicine larvae such as *Aedes vexans, sollicitans* or *taeniorhynchhus* or the species of *Psorophora* require a quicker motion of the dipper as they are more likely to dive below the surface when disturbed.

The inspector should always record the number of dips made, and the number of larvae found (see report form, fig. 6.29). The larvae are transferred to small vials by a wide-mouth pipette and preserved in alcohol for later identification. It is possible to get a rough idea of the breeding rates by computing the number of larvae of each species per dip. The number of dips required will depend upon the size of the area, but for convenience they should be made in multiples of 10. Inspections should be made at intervals of one to two weeks during the breeding season, as areas which are entirely negative at one time may be found breeding heavily at other times. Laboratory identifications of specimens are tabulated on the record form figure 6.30.

Variations in the procedure described above are required when inspecting for certain species. For example, *Mansonia* larvae remain below the water surface throughout their development. These larvae are found by pulling up aquatic plants (cattail, sedges, pickerelweed, etc.) and washing them in a pan of water. A search of the bottom muck and trash from the area where the host plants have been uprooted may be productive. This material should be scooped up and examined in pans of clear water. Other methods for collecting *Mansonia* larvae are described by Bidlingmayer (1954).

Inspection for *Aedes aegypti* involves a careful search for artificial containers in which these domestic mosquitoes breed. Such inspections are usually made on a premise-by-premise basis where bottles, tin cans, vases, automobile tires, and all other containers of water are examined. The *Ae. aegypti* index is obtained by dividing the total number of premises inspected into those in which breeding is found. Collection of the larvae may require a dipper but is more frequently accomplished directly by means of a wide-mouth pipette.

Inspection for *Aedes triseriatus* and *Ae. sierrensis* involves searching for tree holes and artificial containers in which these species breed. These are often too small to admit an ordinary dipper, but water may be siphoned into a dipper or pan where the larvae can be seen.

MOSQUITO EGG SURVEYS

Egg surveys are carried out primarily to determine the breeding places of salt-marsh, flood-water, and irrigated-field mosquitoes in the genera *Aedes* and *Psorophora*. These mosquitoes lay their eggs on damp soil in places subject to intermittent flooding, not on the surface of watered areas where the water stands for a week or more as do *Anopheles* and *Culex*. Therefore, two entirely different types of egg surveys have been carried out with these temporary pool mosquitoes: sod sampling, and egg separation.

SOD SAMPLING

Sod sampling was carefully studied and reported by Bradley and Travis (1942). They cut samples containing 8 square inches of soil and vegetation, trimmed to a thickness of about an inch, and stored them for a week or more to allow the embryos time to develop within the eggs. The sod samples were then placed in glass jars and flooded with water, the larvae being identified as they hatched. The use of sod sampling as an adjunct to larval surveys in delimiting breeding areas has led to important economies in larvicidal and ditching operations. Frequently sod sampling has revealed much heavier concentrations of salt-marsh mosquito eggs in higher areas of the marshes subject to intermittent flooding overgrown with salt marsh bermuda (*Distichlis spicata*) and rush-grass (*Sporobolus virginicus*) than in the lower areas where water stands for longer periods of time characterized by growths of black rush (*Juncus Roemerianus*) and marsh grass (*Spartina* spp.). These results have been confirmed by later research of many workers including Elmore and Fay (1958) who have worked out characters for identifying first stage larvae of the salt-marsh mosquitoes (*Aedes sollicitans* and *Ae. taeniorhynchus*).

EGG SEPARATION MACHINES

Egg separation machines were developed as early as 1938 by C. M. Gjullin for separating eggs of *Aedes vexans, Ae. sticticus,* and *Ae. dorsalis* from soil and debris. Horsfall (1956) developed an entirely different technique which involves mechanical agitation, washing, screening out, or sedimentation of debris and flotation of the eggs in saturated salt solution. The samples are cut in the field with a sharp trowel around a board 6 inches square (one-quarter of a square foot), placed in plastic bags and stored sometimes for months in a cool room. The various species of *Aedes* and *Psorophora* can be identified by microscopic examination of live or preserved eggs using literature published by Prof. Horsfall and his students. This egg-separating technique has been used by many mosquito abatement districts to locate prolific breeding places of *Aedes* and *Psorophora* pest mosquitoes. These areas are then treated with insecticides, often by prehatch treatment.

UTILIZATION OF SURVEY DATA

Data from preliminary reconnaissance surveys are correlated with reported disease prevalence or complaints of pest mosquitoes. It is only after reviewing all of this information that the health officer or mosquito control supervisor can make an intelligent decision as to the need for a control program and the type of control operations which will be most effective and economical. Such informaton can then be presented to appropriate officials in the community together with a request for the necessary funds to carry out the project.

Inspections must be continued routinely once a mosquito-control project is under way. Information from such inspections serves to show the progress of the control operations. The success or failure of a mosquito-control project cannot be measured in terms of the number of feet of ditches constructed or the number of gallons of insecticides used. While these are useful statistics, it is the actual population of mosquitoes that is significant. If the mosquito population is reduced to a satisfactory level, there should be accurate data showing this reduction in order that full credit may be claimed for the accomplishment. On the other hand, if mosquito populations remain high, these facts should be known so that efforts may be intensified to obtain control. It is always advisable to inspect some comparable breeding areas beyond the control zone at regular intervals in order to learn the normal fluctuation of various species throughout the season.

In some of the malaria-control programs arbitrary limits have been set as to the number of *Anopheles quadrimaculatus* that may be tolerated in resting stations. Counts ranging from 10 to 20 females per station within the ¼-mile zone have been used as indicating the lower limit of significance. Control measures are applied when one or more stations exceed this limit. Such a rule of thumb is a useful means of encouraging good control and inspection procedures, but it must not be followed blindly without consideration of other factors involved (Federal Security Agency, *et al.*, 1947).

Some localities have worked out the correlation between mosquito annoyance and the numbers captured in light traps. In New Jersey, for example, it was determined that general annoyance did not ordinarily occur until the number of female mosquitoes of all species exceeded 24 per trap per night. Similar criteria

NAME OF INSTALLATION: ____________________ MAILING DATE: ____________________

NAME OF COLLECTOR: ____________________ NAME OF SUPERVISOR: ____________________

(Directions for completing this form are given in Section A on reverse side of this form.)

(1) COLLECTION STATION	(2) COLLECTION DATE	(3) MOSQUITOES				(4) OTHER ANIMAL LIFE	(5) DESCRIPTION OF LOCALE IN WHICH SPECIMENS WERE COLLECTED (See symbols on reverse side.)
			LARVAE				
		TOTAL ADULTS	POSITIVE DIPS	NUMBER DIPS	NUMBER LARVAE		

SAMPLE SURVEY FORM

SECTION A: This form will be forwarded in duplicate. Entries will be typewritten or clearly printed in ink. Complete names of installation, collector and supervisor will be entered in the appropriate spaces provided.

(1) Collection Station: The appropriate symbol and number of each collection station will be entered, consecutively, in column 1, such as: Larval Station 1 = L1; Light Trap Station 2 = T2; Resting Station 1 = R1; Biting Station 2 = B2, etc.

(2) Collection Date: The actual day on which each collection is made will be entered in column 2.

(3) Mosquitoes: The number of adult and larval mosquitoes submitted from each collection station will be entered in their appropriate spaces in column 3.

(4) Other animal life: Number of specimens which are not readily taken to be mosquitoes, will be entered in column 4.

(5) Description of Locale: A short pertinent description of the surroundings from which specimens are collected should be entered for each collection. If specimens are obtained from the bodies of other animals or plants (host organisms) such information should be included. The following symbols may be found helpful:

WATER		VEGETATION	
L - Lake	SW - Salt Water	T - Trees	LV - Leaves
R - River	TP - Temporary Pool	SH - Shrubs	B - Bark
P - Pond	AC - Artificial Container	WP - Water Plants	
S - Stream	TH - Tree Hole Water	ST - Stems	

Adapted from U. S. Army

Figure 6.29 **Mosquito Collection Record**

MOSQUITO IDENTIFICATION RECORD

NAME OF INSTALLATION:

DETERMINATIONS BY: DATE:

NOTE: Animals other than mosquitoes are listed on reverse side of form.

STATION #

DATE		MALES	LARVAE	TOTAL FEMALES

SECTION A: Forward form in duplicate. Typewrite or print in ink.

SECTION B: ANIMALS OTHER THAN MOSQUITOES

STATION #	DATE	HOST	IDENTITY	TOTAL
				TOTAL

Figure 6.30 **Mosquito Identification Record**

690-826 O—63——6

can be worked out for other areas and also for various species.

Standards for biting- or landing-rate collections as well as for other sampling methods for adult mosquitoes may also be readily established.

Numbers of mosquito larvae found are a bit more difficult to correlate with pest problems or disease hazards. However, larval surveys reveal the specific sources of mosquito production. This information is invaluable to the control supervisor as it enables him to apply effective larvicides to the right places at the right times. Data over a period of time may also serve to justify the use of permanent control measures. The more expensive operations, such as filling and draining, should be undertaken only when careful inspection of each area has shown its role in the production of the vector or pest species of mosquitoes which are important in the locality.

THE CONTROL OF MOSQUITO LARVAE

NATURALISTIC METHODS

No information is available concerning a virus disease harmful to mosquitoes and thus of potential value as a biological control agent. Studies of bacteria, such as *Bacillus thuringiensis*, have not revealed effective control with these pathogens. In California serious research is continuing on the use of blue-green algae and protozoa, particularly Microsporidia, as control agents. Laird (1960) has summarized much of the literature concerning the use of mermithid nematodes to control northern *Aedes* larvae, and the various protozoal, mycotic, bacterial, and rickettsial infections of mosquito larvae.

In Hawaii and the South Pacific not-too-successful control has been attempted using the larvae of *Toxorhynchites* (formerly *Megarhinus*) to devour the larvae of *Aedes aegypti* and *Ae. albopictus*. In Canada and Alaska careful observations have been made of the predaceous larvae of *Chaoborus, Mochlonyx,* and *Eucorethra* in the biological control of *Aedes* larvae.

Much has been written about the role of plants in mosquito control, including bladderwort (*Utricularia*), stonewort (*Chara*), and duckweeds (*Lemna* and allies). There is also considerable literature on the use of vegetation to shade out important anopheline vectors of malaria and of decaying vegetation to foul water and make it unattractive to mosquitoes (Boyd, 1949).

Mosquito-eating fish offer the greatest opportunities in biological control for the average non-research mosquito control organization. Many mosquito abatement districts raise and distribute top minnows (such as *Gambusia*) and other small fish to control mosquitoes in cisterns, water tanks, garden pools and marshes. One of the most important reasons for the construction of miles of ditches in salt marshes is to allow the circulation of water throughout the marsh and the dispersal of mosquito-eating fish as widely as possible.

FILLING AND DRAINING

FILLING

The filling of mosquito breeding places with soil, rock, or rubbish is the most permanent of mosquito control operations, being of particular value in elimination of small depressions that do not require a great deal of material. This type of mosquito control is often ideal for unskilled, prisoner-type labor. Small filling projects with hand labor usually cost much in excess of $1 per cubic yard. Large filling operations therefore use heavy earth-moving equipment, usually at a cost of a few cents per cubic yard.

SANITARY LANDFILLS

Sanitary Landfills (fig. 6.31) are used because they (1) eliminate mosquito breeding sites, (2) provide for economical disposal of refuse, and (3) improve land values. The daily cover should be 6 inches. The final cover should have at least 2 feet of compacted earth and a slope of 0.1–0.5 foot per hundred feet for drainage.

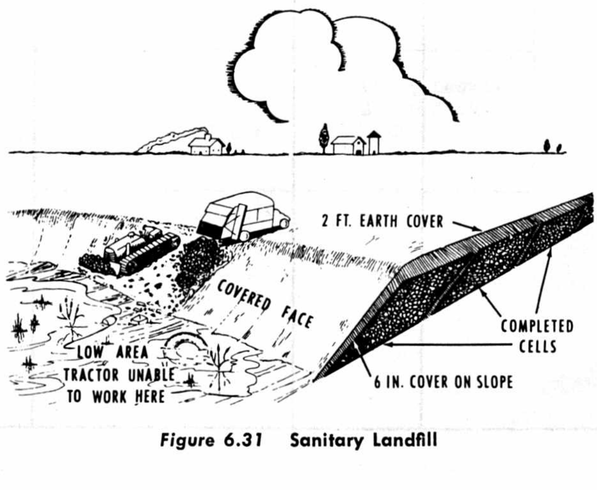


Figure 6.31 **Sanitary Landfill**

HYDRAULIC LANDFILLS

Hydraulic landfills are often used for spoil disposal purposes by dredges used to deepen rivers and harbors. Sanitary and hydraulic landfills often settle unevenly, form large deep cracks and produce mosquito breeding places. Therefore, these areas must be inspected regularly and the proper control measures carried out, such as grading, ditching, or larviciding.

Low places, including old quarries, and brick pits, have been eliminated by diverting soil-laden streams, allowing them to deposit silt in these depressions. In many situations, a combination of filling and drainage is the most economical method of preventing mosquito production.

DRAINING

Mosquito control may be accomplished by open ditching, subsoil drainage, pumping and diking with use of tide gates. The choice of these methods depends upon many factors, such as relative cost, terrain, soil type, and extent of mosquito breeding area. Good discussions of mosquito control drainage are included in Boyd (1949) and Federal Security Agency, *et al.* (1947).

Open Ditching

Surface drains vary from simple dirt ditches to elaborate concrete channels.

Lines should be as straight as possible to prevent erosion and to shorten the length of ditches.

Grade of a drainage ditch should be sufficient to give cleansing velocity, but not enough to erode the bottom or sides. It is desirable to provide a *fall of 0.1 to 0.5 foot per 100* feet. If the slope is steeper, spillways of concrete, masonry, rocks, or wood may be constructed as a series of steps to decrease water velocity and prevent undue erosion.

Shape is determined by many factors. *Mosquito control ditches should have the bottom rounded,* not flat or V-shaped (fig. 6.32A). Wide ditches should not have flat bottoms, but should be U-shaped, or with an invert in the center (fig. 6.32B) so that the water will be confined to a small self-cleaning channel. These ditches are usually not as large as storm-water drains designed to remove water within a few hours after heavy rainfall. *Mosquito control ditches must drain an area in two or three days,* before larvae and pupae have had time to develop into adult mosquitoes.

Side slope will vary from vertical in stiff clay or the peat-like soil of salt marshes (fig. 6.33A) to as much as 4:1 in sandy soils. Ordinarily, the sides of a ditch should not have an angle greater than 45°, or a 1:1

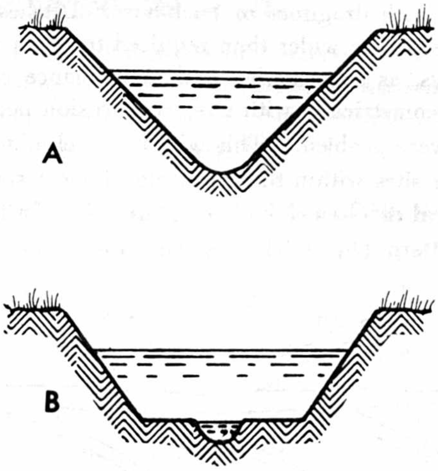


Figure 6.32 **Steps in Construction of Mosquito Drainage Ditch**

slope, that is 1 foot horizontally for each foot vertically. A ditch that is two feet wide at the bottom and two feet deep would be six feet wide at the top (fig. 6.33B).

The berm is the area along each side of a ditch itself, and the *spoilbanks* are formed by the excavated soil. It is best to level the *spoil,* or dirt, into low places rather than to leave spoilbanks. If spoilbanks are left, they should be at least 6 to 8 feet from the ditch to prevent the dirt from washing into the ditch and cut at frequent intervals to permit drainage into the ditch.

Bank stabilization is accomplished with masonry, rip-rap, poles, or sod. Bermuda grass grows well in full sunlight, requires little water, and does not grow tall enough to impede drainage. Banks should be stabilized in areas where water is turbulent, such as at the lower end of a culvert, a bend in the ditch, or the area where a lateral enters a ditch.

Depth of ditches must be determined by surveying before excavation begins. Hand labor is expensive but continues to be used for small jobs or maintenance work. Shallow ditches may be made with road grading equipment, while large deep channels may be con-

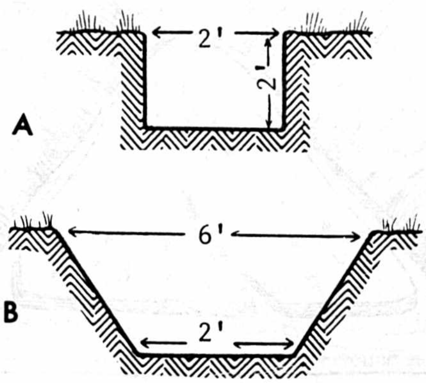


Figure 6.33 **Side Slope of Ditches**

structed with draglines or back-hoes. Ditches should be no deeper or wider than required to drain an area in 3 days, as construction and maintenance costs increase geometrically with size, and erosion becomes a more severe problem. This will assure elimination of breeding sites within the life cycle of most species.

Lateral ditches should be constructed in a herringbone pattern (fig. 6.34), entering the main ditch in

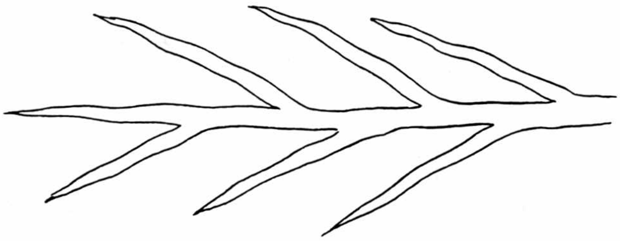


Figure 6.34 **Herringbone Ditch Pattern**

the downstream direction. If possible, the lateral should enter the main ditch at an elevation slightly above the grade of the main channel.

Interceptor ditches (fig. 6.35) may be necessary in some swampy areas to drain both surface and subsurface water by lowering the water table.

Permanent ditch linings are installed in cities, parks, or other permanent installations to reduce maintenance costs and prevent mosquito breeding in ditches. These may be constructed of rip-rap, masonry, or concrete. Precast inverts, sometimes known as *Panama Inverts* (fig. 6.36) have been widely used. These are usually made of concrete in 3-foot sections, with a rounded bottom and a joint to facilitate laying the inverts in a prepared ditch. In large ditches with considerable flow, side slabs of concrete may be laid

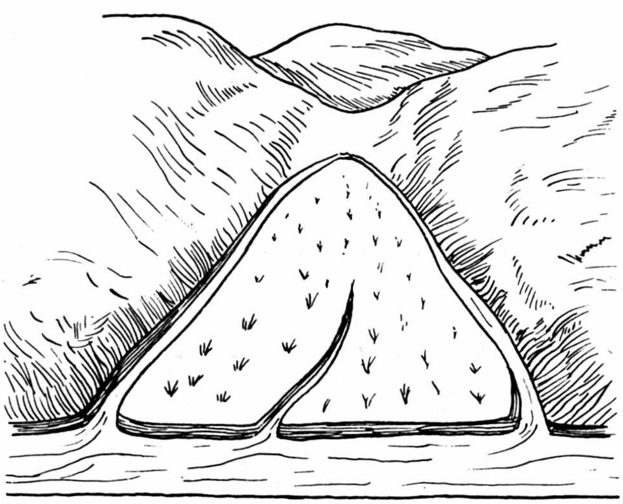


Figure 6.35 **Interceptor Ditch**

above the inverts to minimize erosion of the ditch banks. Plastic ditch linings have been tested in California and are reported to have a service life of several years.

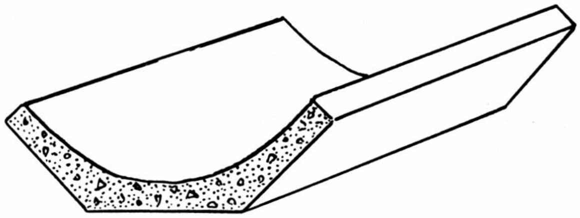


Figure 6.36 **Panama Invert**

Subsoil Drainage

Underground drains of stone or pipe which are used for draining fields and improving agricultural yield also decrease mosquito production. Subsoil drainage is expensive but requires little maintenance and has the great advantage that the land may be used productively for farming without the ditches becoming choked with weeds or dammed up by refuse, creating mosquito breeding places. Large ditches may be filled with stones and covered with leaves, pine needles or gravel to serve as a filter draining off water rapidly.

Concrete or ceramic farm tiles (fig. 6.37), usually 6 inches in diameter and a foot long, are laid in ditches 4 to 6 feet below the surface so that they will not be damaged by plowing or heavy equipment. Subsoil drainage systems should have a gradient of at least 1 foot vertically for each 200 to 400 feet horizontally. Tiles are laid butt-to-butt, wedged in place by stones or dirt, and covered on the side and top with trash, leaves or felt paper. Then the ditches are backfilled with gravel and earth.

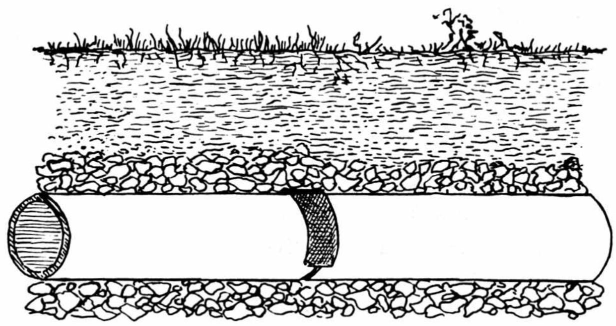


Figure 6.37 **Subsoil Tile Drainage**

Pumping

In many areas, swampy lands are so extensive and the gradient is so small, that simple runoff ditches are not effective in draining mosquito-breeding areas. Therefore, water is collected from open ditch or subsoil drainage systems into a pit, or *sump*, from which

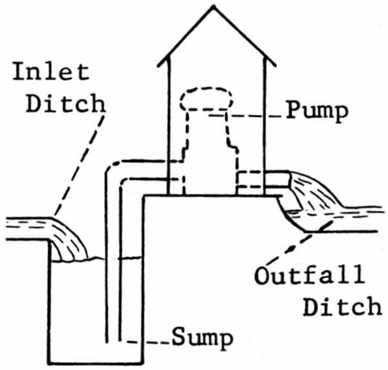


Figure 6.38 Pump Station

the water is lifted by pumping into outfall ditches, a nearby stream, or other body of water. See figure 6.38.

Diking

A combination of diking and pumping is often used to dewater marshes and to prevent production of salt-marsh mosquitoes along the Atlantic coast or fresh-water mosquitoes along impoundments of the Tennessee Valley Authority. Experiments have been conducted in New Jersey and Florida using dikes to hold in water and to flood marshes. This procedure changes the habitat, replacing the temporary pools producing hordes of *Aedes* mosquitoes which are severe biters and fly long distances with permanent water preferred by *Culex* and *Anopheles* which usually do not bite in the daytime and have a shorter flight range.

Tide Gates

Marshes near the ocean may be partially drained by constructing open ditches which discharge through a culvert equipped with a gravity-operated tide gate (fig. 6.39). At low tide, the pressure of water in the drainage system opens the tide gate and allows water to drain out. As the tide rises, the gate is closed, thus preventing water from re-entering the marshy area.

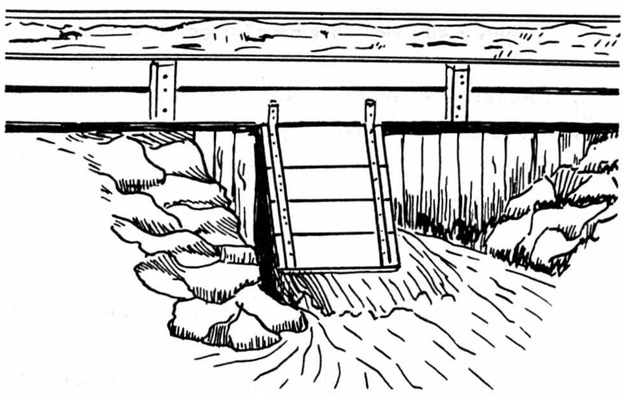


Figure 6.39 Tide Gate

MANAGEMENT OF WATER

Management of water is of tremendous importance in controlling mosquito production on man-made impoundments, farm ponds, sewage stabilization ponds, salt marshes, and irrigated land.

MOSQUITO CONTROL ON IMPOUNDED WATER

"Malaria Control on Impounded Water" by the Federal Security Agency, *et al.* (1947) deals with mosquito control in detail. Some of the important factors are:

1. Proper reservoir preparation, including
   a. Clearing of major vegetation on the shoreline between the high and low water elevations,
   b. Deepening or filling low places, and
   c. Diking and dewatering low places, usually by pumping.
2. Water level management, including
   a. Initial filling of the reservoirs.
   b. Annual surcharge to strand flotage which would provide protection for larvae, and
   c. Constant level, or fluctuation with recession of about 0.1 foot per week, during the mosquito-breeding season.

MOSQUITO CONTROL ON FARM PONDS, SEWAGE STABILIZATION PONDS, AND BORROW PITS

The most important feature in all these man-made reservoirs is a steep, clean shoreline with little or no vegetation to provide protection for mosquito larvae. Many States recommend that one side of a farm pond be shallow and gently sloping to provide easy access for cattle, but that the other sides have steep clean shorelines so that any mosquito larvae are exposed to fish or wave action. Sewage stabilization ponds may produce large numbers of *Culex* mosquitoes which prefer water with a high organic content. Proper shoreline maintenance is of great importance in limiting mosquito breeding. The borrow pits along highways should be constructed so that they are either (1) self-draining to prevent the production of temporary pool mosquitoes such as *Aedes vexans* and *Psorophora confinnis*, or (2) deep enough so that they will hold water at least two feet deep with a steep, clean shoreline to minimize the breeding of such permanent water mosquitoes as *Culex*, *Anopheles*, and *Mansonia*.

MOSQUITO CONTROL ON SALT MARSHES

The vast marshlands along the Atlantic, Gulf, and Pacific coasts are major producing areas for important man-biting *Aedes* mosquitoes. Experience has shown that it is not practical or economical to drain all these marshlands, and that such a procedure would conflict with interests of farmers growing salt-marsh hay, and of wildlife management workers. Research by many workers including Ferrigino (1959) and Florschutz (1959) indicates that the bulk of the pestiferous *Aedes* are produced in the higher portions of the marshes subject to recurrent flooding which are less important from the game-management viewpoint. There is less *Aedes* production in the lower portions of the marshes with the salt grass and wild rice, which are very important in game bird production. Future research should encourage (1) more surveys to delimit the actual areas producing mosquitoes, (2) the effects of diking and flooding to change the marshes so that they do not produce as many of the strong-flying, man-biting *Aedes* which breed in temporary pools, and (3) mutual cooperation between mosquito control and wildlife management organizations.

MOSQUITO CONTROL IN IRRIGATED AREAS

Billions of mosquitoes are produced every year in the irrigated lands of the United States. Some species, such as *Culex tarsalis,* seriously affect the health of man and his animals by transmitting encephalitis viruses. Other mosquitoes, particularly *Aedes vexans, Ae. dorsalis, Ae. nigromaculis* and *Psorophore confinnis,* are vicious blood-sucking insects affecting the comfort and economic welfare of the people, even hindering the planting and harvesting of crops and the industrial development in infested areas. These problems are particularly acute in the 22 Western States where some 30 million acres are already under irrigation and in the Eastern States where irrigated acreage is increasing. The mosquito problems arise in four distinct areas in the irrigation project: storage reservoir, project distribution system, irrigated farms, and project drainage system (fig. 6.40). The main points listed below follow the excellent review by Henderson (1952) and the recommendations of the American Society of Agricultural Engineers (1958).

I. Storage Reservoir

Where mosquito production occurs in vegetation and flotage, borrow pits, and seepage areas unless

1. The impoundment is cleared of vegetation in the construction stage;
2. Borrow pits and low areas are built so that they hold water continuously and have steep sides, *or* are ditched and made self-draining;

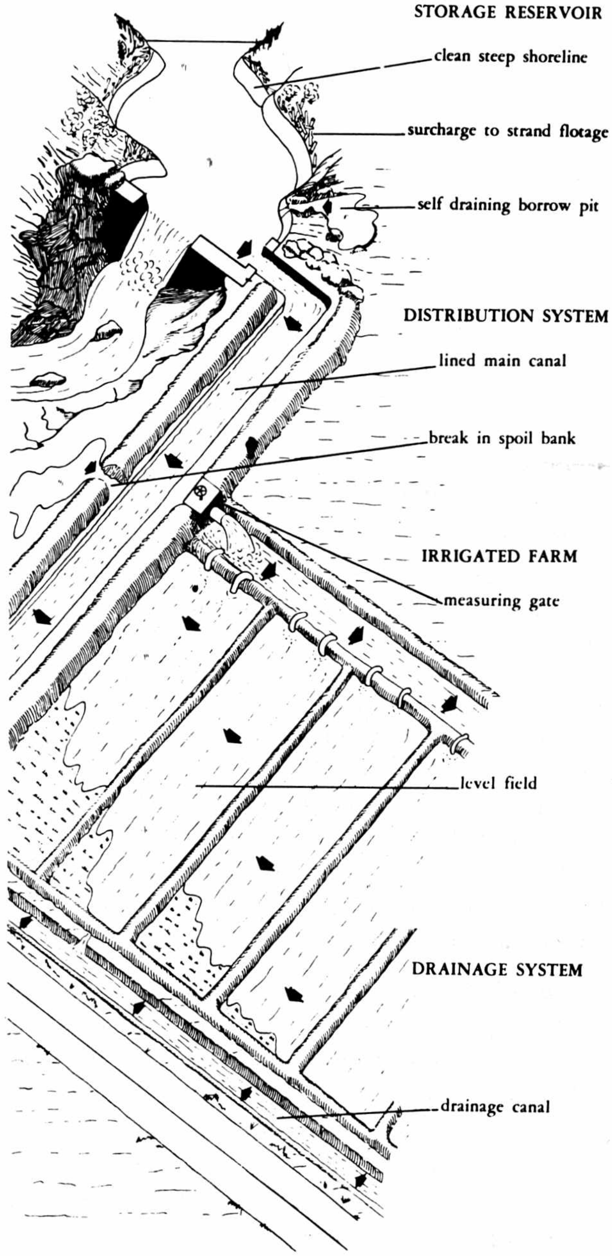


Figure 6.40 **Flow Diagram of Irrigation System**

3. Flotage is stranded by the spring surcharge; and
4. There is a planned program for cyclical fluctuation and seasonal withdrawal of water from the reservoir.

II. Project Distribution System

Where the main problems are seepage, blocking of natural drains, and impounding waste water, unless

1. Main canals and laterals are built in impervious soil or are lined;

2. Drains are installed to prevent ponding, and borrow areas are constructed to be self-draining;
3. Delivery schedules provide adequate, but not excessive, water; and
4. The distribution system is periodically cleaned and maintained.

III. Irrigated Farms

Where the man-made, "on-field" mosquito-breeding problem is most acute, unless

1. There is proper layout of the farm supply system, drainage system, and field layout;
2. All surface-irrigated fields are properly graded;
3. Only the necessary amount of irrigation water is used; and
4. An adequate drainage system is provided for removal of excess water.

IV. Project Drainage System

Where "off-field" mosquito breeding may be a serious problem in roadside ditches, borrow pits, and wasteland, unless

1. Main drainage systems are installed to remove waste and natural water in irrigated and non-irrigable land;
2. Drainage ditches are built and maintained to prevent ponding in the canals;
3. Ditches are constructed so that there will be no ponding outside the canals due to seepage or improper construction of spoil banks; and
4. The drainage system is periodically cleaned and maintained.

MOSQUITO LARVICIDING

INTRODUCTION

Mosquito larviciding is the practice of killing mosquito larvae with stomach poisons or contact poisons. Materials such as paris green are used as stomach poisons, which must be ingested by the larvae as they feed on treated waters. DDT, BHC, and some of the organic phosphorus insecticides may act as stomach poisons, but their primary action is as contact poisons which penetrate the body wall or the respiratory tract. Diesel oil and kerosene are also important as contact insecticides.

If areas cannot be drained or filled at reasonable cost and control by fish, salinification, or other naturalistic methods is not possible, larvicidal control is often the method of choice. Larvicidal control is of primary importance in areas where immediate control of pest or disease-carrying mosquitoes is necessary particularly in cases of extensive flooding following natural disasters such as hurricanes or prolonged rainy seasons.

TYPES OF FORMULATIONS

DDT and other insecticides may be applied as dusts, pellets or granular formulations, wettable powders, solutions, or emulsions to control mosquito larvae. *Dusts* have been widely used as mosquito larvicides, but they are light, are subject to air currents and spotty application, and may stick to leaves. *Pellets or granular formulations* have a larger particle size permitting them to slip through leaves or dense vegetation reaching the water surface to kill mosquito larvae. *Wettable powders* are frequently used in the prehatch treatment of areas for control of mosquito larvae. These wettable powders may be applied on snow and ice or on earth in dried-up mosquito breeding areas seeded with eggs of temporary pool mosquitoes. *Oil solutions* may be sprayed on water surfaces to kill both anopheline and culicine larvae and pupae, particularly in waters with high organic content. Most mosquito-control organizations continue to use some petroleum oil to kill mosquito larvae which are resistant to the organic insecticides. *Emulsions* have been employed rather extensively in treating irrigated waters, such as rice fields, where oil solutions would be toxic to cultivated plants. The water in the emulsion serves as a carrier for the minute oil droplets containing insecticides, facilitating treatment of large areas with hydraulic equipment. The emulsion breaks almost immediately after the spraying operation, producing an oil film upon the surface of the breeding area.

TEMPORARY LARVICIDES

Petroleum Oils

Petroleum oils were the first of the larvicides to be widely used, following the pioneer research of L. O. Howard in 1892, on the use of kerosene to kill mosquito larvae. Petroleum oils are toxic to the eggs, larvae and pupae of both anopheline and culicine mosquitoes. According to Ginsburg (1959) there are two lethal fractions in petroleum oils used for mosquito control: a toxic fraction, with low boiling range and high volatility, which penetrates the tracheae of larvae and pupae and produces an anesthetic effect; and a lasting fraction which acts much slower and generally does not have any direct toxic action but suffocates by mechanical interference with breathing.

Although much has been written concerning desirable specifications for larvicidal oils, in actual practice the user is limited to those materials obtainable in large volumes, at moderate prices, and of uniform composition. No. 2 fuel oil (or diesel oil No. 2) and kerosene are generally available and appear equally toxic to larvae. Fuel oil apparently has the more lasting qualities. Control of both anopheline and culicine larvae has been obtained by applying 15 to 50 gallons of No. 2 fuel oil per acre making this method expensive both as to materials and labor. The amount of oil necessary for control depends primarily on the amount of vegetation and other flotage on the water surface. The addition of 2 to 5 percent of a spreading agent such as cresylic acid or castor oil aids in penetration into vegetation, scum, and pollution. In recent years new agents such as sodium lauryl sulfate (Gardinol), alkyl aryl polyether alcohol (Triton X–100), B–1956, and others have made it possible to obtain control with 5 to 10, instead of the usual 15 to 50, gallons of oil per acre. Some workers add a small amount (up to 10 percent) of black oil to serve as a marker and help prevent retreatment of areas already larvicided.

Pyrethrum Larvicides

The New Jersey pyrethrum larvicide has been used for many years on garden pools containing valuable aquatic plants and fish which might be harmed by other larvicides. It is also widely used to control pest mosquitoes where other larvicides are unsightly or undesirable, such as farm ponds, or in areas with gross pollution. The active ingredients are pyrethrins I and II obtained as a kerosene extract from the seeds of the *Chrysanthemum* plant. Usually the commercial stock emulsion is diluted with 10 parts of water by volume for the final spray which is applied with hand or power equipment at a rate of 50 to 70 gallons per acre, or 1 quart per 200 square feet of garden pool.

Paris Green

This is a copper acetoarsenite compound which has been used since the early 1920's as a mosquito larvicide following the research of Barber, Bradley, and King, and other malariologists. In controlling anopheline larvae, the paris green was mixed with hydrated lime, road dust, talc, or other inert carriers and the powder was blown over the water to kill the surface-feeding anopheline larvae as a stomach poison. When DDT and other organic insecticides came into wide use in the 1940's the use of paris green was largely discontinued. However, as mosquito larvae (particularly culicines) became resistant to the organic insecticides, the search for alternate materials was accelerated.

In Florida Rogers and Rathburn (1960) have shown that a paris green-vermiculite granular formulation is effective against both culicine and anopheline larvae. They no longer recommend malathion, for example, as a larvicide because the more selective pressure that is applied to the larval stage by an organic insecticide the more rapid will be the build-up of resistance to this chemical. Malathion is an extremely valuable adulticide for mosquitoes resistant to the organic hydrocarbons and it is desirable to ensure its continued use for that purpose. Paris green is not chemically related to the other adulticides used and no resistance problem has appeared over a long span of years.

For airplane application of paris green granular larvicide A. J. Rogers of the Florida State Board of Health (mimeographed operation release) recommends: vermiculite, 35 pounds; emulsifiable oil, 40 pounds; and paris green dust, 25 pounds. Paris green content is adjusted by diluting 90 percent commercial grade paris green as follows:

	Amount of each ingredient for 100 pounds of blend	
Paris green desired in finished formulation (percent by weight)	*90 percent paris green (pounds)*	*Marble dust (pounds)*
2.5	12	88
5.0	23	77
7.5	34	66
10.0	45	55

Note.—25 lbs. of blend is used per 100 lbs. of paris green-vermiculite formulation. This material is applied at the rate of 15 pounds of formulation per acre.

The vermiculite and emulsifier are first mixed together in a concrete mixer so that the outer surface of the vermiculite is well coated with the water-miscible sticker. The paris green blend is added in small quantities and the mixture agitated until the formulation is uniformly green. The pellets may be applied with ground or aerial equipment at a rate of 15 pounds of formulation per acre to give effective control of salt-marsh mosquito larvae. Commercially prepared granules are available at 5 and 10 percent strength. The granules float on water for several hours during which time the paris green is released through the action of the wetting agent in the sticker and is available to surface-feeding *Anopheles* larvae. The powder settles slowly through the water where the poison may be ingested by culicines. Thus, the granular formulation seems to meet the requirements of an all-purpose mosquito larvicide. The use of an arsenical is not advisable in some irrigated soils where calcium arsenate has been utilized for many years for boll weevil control.

Chlorinated Hydrocarbon Insecticides

The chlorinated hydrocarbon insecticides came into general usage as mosquito larvicides in the 1940's. Of these compounds, DDT, benzene hexachloride (BHC), lindane, chlordane, heptachlor, and dieldrin are the most widely used. Resistance to the chlorinated hydrocarbons has appeared in a number of important species of *Aedes, Culex,* and *Anopheles* (see page 53). All of these compounds may leave residues on vegetation eaten by cattle which may later appear in milk or meat above the tolerances allowed by the Food and Drug Administration. (U.S. Dept. of Agriculture, 1962). Many of these chemicals are also known to kill fish especially if used above the recommended rates of application. However, in many areas the chlorinated hydrocarbons continue to be used as the cheapest, most effective, long-lasting chemicals for the control of mosquito larvae, particularly in the northern half of the United States.

Susceptible populations of culicine or anopheline larvae can be controlled by DDT (0.05 to 0.2 pounds per acre) or by benzene hexachloride, lindane, chlordane, heptachlor or dieldrin (0.1 pound per acre). If these dosages are ineffective in situations where fish and other wildlife are not involved, such as sewage, lagoons, borrow pits, or land-locked marshes, the application rates can be doubled or quadrupled. These insecticides may be applied as emulsions, solutions, dusts, or granular or pelletized formulations. Some simple methods which are widely used for mixing these insecticides and the rates of application are given below:

DDT

1. Mix 1 part of a 25 percent emulsifiable concentrate of DDT with 24 parts of water. Use at a rate of about 2.5 gallons per acre to obtain approximately 0.2 lb. of DDT per acre.
2. Dissolve 0.1 pound of technical grade DDT in 1 gallon of diesel oil. Apply 2 gallons per acre to obtain 0.2 lb. DDT per acre.
3. In airplane application apply (a) 1 pint of 20 percent DDT emulsion or solution, or (b) 2 quarts of 5 percent DDT emulsion or solution per acre to obtain about 0.2 lb. DDT per acre.
4. Apply 4 pounds of 5 percent DDT dust or pellets per acre (about 0.2 lb. DDT per acre).

Benzene Hexachloride—12 Percent Gamma Isomer

1. Mix 1 part of 20 percent emulsifiable concentrate with 19 parts of water or fuel oil. Use at a rate of 2.5 gallons per acre to obtain about 0.2 lb. per acre.
2. Three percent agricultural dust. Apply at a rate of about 3 to 7 pounds per acre to obtain approximately 0.1 to 0.2 lb. BHC per acre.

Chlordane

1. Mix 1 part of 25 percent emulsifiable concentrate with 24 parts of water. Use 1¼ gallons per acre to obtain about 0.1 lb. chlordane per acre.
2. Mix 1 part of 46 percent emulsifiable concentrate with 45 parts of water. Use 1¼ gallons per acre to obtain 0.1 lb. chlordane per acre.

Heptachlor and Dieldrin

1. Mix 1 part of 20 percent emulsifiable concentrate with 39 parts of water or fuel oil. Use at a rate of about 2.5 gallons per acre to obtain about 0.1 pound dieldrin or heptachlor per acre.
2. Apply 2 pounds of 5 percent pellets to obtain 0.1 pound heptachlor or dieldrin per acre.

Organic Phosphorus Insecticides

The organic phosphorus insecticide came into general usage after World War II, chiefly because of the resistance of mosquitoes to the chlorinated hydrocarbons and the problem of residues of these last chemicals on forage crops. Chlorthion, EPN, and other organic phosphorus compounds have given good control in experimental tests but are not generally available. At the present time, malathion, parathion, and methyl parathion (especially in California) are the organic phosphorus compounds most widely used in mosquito control. Malathion at dosages of 0.25 to 0.5 pound per acre, or parathion at 0.1 pound per acre, is effective against most mosquito larvae (Communicable Disease Center, 1963). In California and Florida, especially, these chemicals have given good control of populations of *Culex tarsalis*, *Aedes sollicitans*, and *Aedes taeniorhynchus* which were resistant to the chlorinated hydrocarbons.

Parathion applications are usually applied by airplane at a rate approximately 0.1 pounds to the acre. Parathion is an extremely toxic material known to have caused the death of several people (Hayes, 1960). Pilots and workmen loading the planes must wear masks and take great precautions not to spill the concentrates. In 1956, when freak weather conditions resulted in tremendous mosquito production in the Tampa Bay area in Florida, 121,800 pounds of parathion pellets were applied by airplane on salt-marsh mosquito larvae. The excellent results obtained demonstrated the great usefulness of these pellets in disaster or epidemic situations.

Other organic phosphorus insecticides such as Baytex, and Naled, have been widely used in mosquito control. Details concerning the use of these relatively new compounds have been published by the Communicable Disease Center (1963).

Note: It is recommended that the larvicide used be a different chemical from that used for adult control. For example, it may be desirable to use fuel oil as a larvicide and a malathion-lethane fog to kill adult mosquitoes.

RESIDUAL LARVICIDES

In northern United States and Canada, the application of DDT to snow or frozen ground before the spring brood of mosquitoes has hatched has given good control of single-generation northern species of *Aedes* whose eggs are laid on the ground. In this type of control, known as Prehatch or Preemergence Treatment, the application rates approximate 1 pound of technical grade DDT per acre, such as 2 pounds of 50 percent water-wettable powder, 20 pounds of 5 percent granules, or 2.5 gallons of 5 percent liquid sprays per acre (see table 6.3). When conditions are favorable, this prehatch treatment may continue to give control for the first 6 to 8 weeks (or more) of the mosquito breeding season, particularly of *Culex* or *Anopheles* which lay their eggs on the water surface and *Aedes vexans* which lays its eggs on damp earth.

Studies at Savananh, Georgia with 5 applications per year of BHC gamma isomer at rates of 1 pound per acre, revealed no fish kill over a 3-year period. *However, residual larviciding with DDT, or dieldrin, at rates of 1 pound or more per acre is totally destructive to fish and should not be used where such wildlife is present.*

Additional studies reported by the Communicable Disease Center (1963) on residual larvicides are summarized in the table below:

TABLE 6.3.—*Mosquito control with residual larvicides in various parts of U.S.*

Insecticide	Application rate technical grade insecticide equivalent in pounds per acre	Weeks of satisfactory control	Species of mosquito, location of control study
BHC emulsion	1 (gamma isomer).	5–8	Anopheline and culicine larvae in land-locked ponds, Savannah, Ga.
*DDT emulsion	3	12–24	
*Dieldrin emulsion	1	Season	
*Dieldrin emulsion	3	14	*Culex tarsalis, Culex peus.*
Heptachlor emulsion	3	8	*Culex pipiens, Culiseta incidens* in log ponds in Oregon.
*DDT emulsion or granules	10	8 and 7	
Malathion emulsion	3	5	
Heptachlor emulsion	5	10	
Heptachlor granules	5	13	
*Dieldrin emulsion or granules	1	Season	*Aedes vexans, Aedes dorsalis, Culex tarsalis* in alfalfa fields and pastures in Montana.
*Dieldrin emulsion	1	Season	*Psorophora confinnis* in rice fields in Mississippi.
Dieldrin emulsion	0.25	Season	Various species in ditches, alfalfa fields and pastures in Montana.
DDT granules	1.5	Season	
Heptachlor granules	0.75	12	

*Totally destructive to fish and wildlife.

THE CONTROL OF ADULT MOSQUITOES

Screening, bed nets, protective clothing, repellents, aerosols and space and residual sprays are all used for protection against mosquito annoyance.

PROTECTION FROM MOSQUITO ATTACKS

SCREENING

Screens are made of galvanized iron, copper, bronze, aluminum, or plastic. Near the ocean iron and copper screens are not recommended because of the corrosive action of salt sprays. Plastic screens have given years of good service in these areas. Screens must be of the proper mesh, must fit tightly and be kept in good repair. The ordinary window screen with 16 x 16 or 14 x 18 meshes to the inch will keep out most mosquitoes, but screens with 16 x 20 or 23 mesh may be necessary in areas with small mosquitoes such as *Aedes aegypti* and *Ae. taeniorhynchus* according the Bidlingmayer (1959) and other authorities. Frequently mosquitoes follow people into buildings or enter on the human host. For this reason, screen doors should open outward and have automatic closing devices. Residual insecticide applications on and around screen doors give added protection. Xylene emulsions of insecticides often affect the galvanizing on ordinary iron screens, with subsequent rust problems, and may affect some plastic screens. Therefore, kerosene solutions are preferable for such residual sprays.

BED NETS

The bed net, or mosquito bar, is a useful item in temporary camps and in the tropics. Mosquito netting is a cotton or nylon cloth with 23 to 26 meshes per inch. White netting is best, as mosquitoes accidentally admitted into the net are easily seen and killed. Most bed nets are rectangular in shape and large enough to permit a person to sit up in bed. The net is suspended over the bed and tucked in under the mattress. An aerosol bomb may be used to kill mosquitoes in the net before retiring or they may be killed by hand.

MOSQUITO-PROOF CLOTHING

Head nets, gloves, and knee-length boots protect parts of the body not covered by other clothing. A dark-colored head net with 4 to 6 meshes to the inch is recommended for good visibility and comfort. Treatment with a repellent will discourage mosquito entry. Clothing of tightly woven material offers considerable protection against mosquito bites. Sleeves and collars should be kept buttoned and trousers tucked in socks when mosquitoes are biting. This type of protection may be necessary for people who must work outdoors in areas where salt-marsh, irrigation-field, or northern *Aedes* mosquitoes are particularly abundant.

REPELLENTS

Relief from mosquito attack may be obtained by applying certain chemicals to the skin and clothing to repel these vicious biting insects. Thousands of materials have been tested, many of them at the U.S. Department of Agriculture Laboratory in Orlando, Fla. Five of these materials have given outstanding protection against mosquitoes and certain other arthropods and are far superior to the older compounds such as oil of citronella:

Rutgers 612

Rutgers 612 is 2-ethyl hexanediol-1,3. It was very beneficial during World War II in protecting troops from the malaria mosquitoes (*Anopheles*), although it is less effective against pest mosquitoes.

Dimethyl Phthalate

Dimethyl phthalate is a very effective repellent, particularly against the malaria mosquito *Anopheles quadrimaculatus*.

Indalone

Indalone gives protection as a skin and clothing repellent.

6–2–2

6–2–2 containing six parts of dimethyl phthalate, and two parts each of Rutgers 612 and Indalone. This mixture is superior to these same materials alone, particularly in giving protection against a wide variety of species.

Deet or Diethyl Toluamide

Deet or diethyl toluamide (sold commercially as OFF or DET) was synthesized in Beltsville, Md., and tested by Gilbert and his coworkers of the U.S. Department of Agriculture, Orlando, Fla., Laboratory (1957). It gives better protection against most mosquitoes than the four listed above, for a longer time, and resists wiping and perspiration better. Diethyl toluamide is available as a liquid in bottles, or as a spray in a pressurized can, both containing about 1½ ounces of repellent.

When applied to the neck, face, hands, and arms, about 12 drops of these liquid repellents will prevent mosquito bites for 2 hours to half a day, depending on the person, species of mosquito attacking, and abundance of mosquitoes. These repellents can also be sprayed on clothes to make them repellent. Many repellents are solvents of paints and varnishes, and plastics such as watch crystals, rayon fabrics, and fountain pens. Diethyl toluamide will not affect nylon. Care should be taken not to apply repellents to the eyes or lips or other mucous membranes.

SPACE SPRAYING FOR MOSQUITO CONTROL

AEROSOLS

In 1959, it was estimated that the American public spent about 100 million dollars a year on insecticides, much of this amount for aerosol bombs or household sprays to kill flies and mosquitoes (editorial, p. 5 of the March 1960, issue of Pest Control). Aerosol bombs are used to kill mosquitoes in homes and hotels, or on camping trips. Most of them contain pyrethrum or allethrin because these insecticides give quick knock-down of insects, a synergist such as piperonyl butoxide, and a low-toxicity insecticide such as methoxychlor or DDT to produce the final kill. The propellent is often Freon-12, a liquid used in many refrigerators. A few seconds' release of the aerosol will kill all species of mosquitoes (and flies, midges, and gnats) in an ordinary-sized room, tent, or trailer. It is not hazardous to humans if used as directed on the container.

FOGGING AND MISTING

Space spraying is the chief activity of many organized mosquito abatement districts and is (wrongly) the only method used by an even larger number of communities which attempt to reduce mosquito annoyance without the aid of an entomologist, engineer, or trained mosquito control specialist.

Fogging and misting operations are conducted during the late afternoon and early evening, at night, or in the early morning when the air is calm, or winds vary from 1 to 6 miles an hour. If winds are exceptionally strong, fogs and mists are dispersed so swiftly that effectiveness is reduced. Similarly, fogs generated during the middle of a hot day, may drift across hot pavements or roads and be dispersed by rising currents of warm air known as *thermals*. By contrast, at night, there may be an *inversion* of air temperature so that fogs are held close to the ground as thick, long-lasting blankets, producing excellent control of mosquitoes. Under normal operating conditions, *the space-spraying machines travel at 3 to 7, averaging 5 miles per hour*. Some of the larger thermal fog generators have a rated maximum output of about 40 gallons per hour, but normally disperse 15 to 25 gallons per hour. Many of the larger mist machines have a greater output.

Outdoor space treatments with mist or fog machines have been carried out effectively against species of *Aedes*, *Culex*, and *Psorophora* mosquitoes. Susceptible populations of these mosquitoes can be reduced effectively by the use of fuel oil solutions of 5 percent DDT, 2.5 percent chlordane or 6 percent malathion. Control of adult mosquitoes by space spraying effects only temporary control. If mosquito populations are high, and the species are strong fliers, such as pest mosquitoes in the genera *Aedes*, *Psorophora*, and *Mansonia*, migration back into the area may occur following treatment making daily applications necessary.

DDT is the most generally used space spray in the northern half of the United States and in Canada. In the southern part of the United States, from Florida to California, widespread resistance of mosquitoes to DDT and other chlorinated hydrocarbons has led to the use of the organic phosphate insecticides. In Florida extensive tests have shown that malathion (6 percent in fuel oil, with lethane) fog dispersed at a rate of 8 gallons per linear mile gave good kills of caged salt-marsh mosquitoes at 330 and 660 feet in open terrain. The Communicable Disease Center (1963) reported that mist sprays of 6 percent malathion emulsion, dispersed at a rate of 25 gallons per mile, produced satisfactory kill of caged salt-marsh mosquitoes at 330 feet in partially wooded terrain. Typical examples of ingredient combinations are listed below:

Material	*Combination*	*Malathion alone*
Malathion (90% concentrate)	3 gallons	3 gallons
Lethane 384*	3 gallons	....
No. 2 fuel oil	94 gallons	97 gallons
	100 gallons	100 gallons

*Trademark of Rohm and Haas Chemical Company.

When 40 gallons or more of malathion fog solution is applied per hour over a swath width of one city block (about 400 feet) at a vehicle spread of 5 miles per hour downwind, good control of adult mosquitoes should ensue. This application results in a dosage of 0.15 pounds of malathion per acre, the minimum for effective control. Fog and mist applications are effective only for immediate kill of mosquito application, being much too light to act as residual poisons. Wind velocities of 3 to 5 miles per hour produce a satisfactory swath width.

Mist applicators can be calibrated to give applications of as much as 0.5 pounds per acre in wind velocities as high as 10 miles per hour. Mists settle much more rapidly than fogs and the problem lies in obtaining a sufficiently small particle size to obtain an adequate swath width.

DUSTING

In recent years there has been an increasing interest in the use of dusts for the control of adult mosquitoes. Three percent gamma isomer BHC agricultural dust has been used for emergency mosquito control in Oklahoma, Texas, and New Mexico. In Montana, the application of 3 percent gamma isomer BHC dust at 30 to 35 pounds per linear mile has given effective reduction of nighttime populations of *Aedes vexans*, *Ae. dorsalis*, and *Ae. nigromaculis* on the evening of treatment. Comparative tests of malathion fogs, mists and dusts carried out at Savannah, Georgia against caged saltmarsh mosquitoes using commercial space treatment machines indicate that dust applications gave less satisfactory kills than either the fog or mist applications. The overall impression from many experiments conducted with a wide variety of insecticides is that fog and dust treatments are approximately the same in effectiveness, but that fog applications generally provide slightly higher kills. Mist applications are highly effective but usually for limited distances, since there is a rather quick fallout of the larger-sized particles. For these reasons, together with the ready public acceptance, fogging seems to be the technique of choice for controlling adult mosquitoes (Communicable Disease Center, 1963).

Malathion as a Fog, Dust, and Mist Application Against Caged Aedes taeniorhynchus—Savannah, Georgia

Treatment*	Dosage lbs/acre**	Percent mortality at distance in feet			
		135	270	540	810
Fog	0.1	98	53	39	0
Mist	0.2	95	55	32	27
Dust	0.3	63	81	3	2

*Three replicates each on same night.
**Based on 300-foot swaths.

AIRPLANE APPLICATION OF INSECTICIDES

Aerial applications have been carried out for many years using dusts, sprays, and thermal aerosols. Good discussions and photographs are included in Circular 977 of the U.S. Department of Agriculture (1955). In experiments in the early 1940's with cargo type planes, the insecticide was dispersed through a simple straight pipe and broken up into droplets by the stream of air beneath the plane. Exhaust generators with venturi were also tested. These produced a dense smoke-fog which helped the pilot in covering the area but only about 10 percent of the insecticide reached the water, the rest being so fine that it drifted away from the target area. Today, the pressurized spray-boom type of equipment suspended from the wings is generally considered far superior from the viewpoint of atomization and effective swath width.

Aerial application of fuel oil solutions of DDT (with or without lethane, thanite, or pyrethrum to produce quick knockdown) have given effective kill of susceptible mosquito adults when dispersed at a dosage rate of about 2 quarts (0.2 pound technical DDT) per acre. Twenty percent DDT in special petroleum distillates has also been used at a rate of about 1 pint (0.2 pound technical DDT) per acre. The relative merits of using a large volume of a low concentration spray versus a small amount of a stronger concentrate were discussed at the Toledo Seminar of the American Mosquito Control Association (1954, p. 24). Some authorities felt that the larger volume of a low concentration spray gave better coverage and kill when fogging to kill adults. Others believed that a larger acreage per plane load should be covered with the more concentrated insecticide, thus effecting important operational economies. This is more applicable to larviciding.

In areas where mosquito adults are resistant to DDT and related compounds, experimental work in Georgia and Florida indicate good control with aerial sprays of malathion using 3 quarts of formulation per acre (at about 0.1 pound of toxicant per acre). In Florida, aerial application of thermal aerosols produced from fuel oil formulations containing 5, 10, and 15 percent malathion produced satisfactory kills of saltmarsh mosquitoes.

RESIDUAL SPRAYING AND FUMIGATING FOR MOSQUITO CONTROL

RESIDUAL SPRAYING

Residual spraying is the application of an insecticide to a surface in order to leave a film, or a deposit of crystals, which will kill insects for weeks or months thereafter. This method is particularly adapted to the control of *Anopheles* mosquitoes because of their habit of entering buildings and resting on surfaces. This method can also be used against other house-frequenting mosquitoes including important vectors of encephalitis such as *Culex tarsalis*, and *C. quinquefasciatus*, or carriers of yellow fever and dengue such as *Aedes aegypti*.

The insecticides are usually chlorinated hydrocarbons, such as DDT, or organic phosphorus compounds, such as malathion, applied as solutions, emulsions, or suspensions. In the United States oil solutions or water emulsions have been widely used because these formulations do not leave unsightly deposits in houses with painted walls, wallpaper, or good furniture. In most tropical areas, water suspensions have been used because of economy in transporting and handling water-wettable powders. The powdery deposit of these suspensions is not particularly noticeable or objectionable on mud, adobe, or thatched walls or roofs, and the insecticide is readily available to kill mosquitoes, rather than being absorbed into the sprayed surfaces as is the case with solutions or emulsions.

In the United States the insecticide of choice for residual applications to houses is DDT applied at a rate of 200 mg. per square foot (approximately 1 gallon of 5 percent spray per 1,000 square feet). In areas where mosquitoes are resistant to DDT, sprays containing 1.25 percent dieldrin or gamma BHC, or 2.5 percent malathion have been used. According to studies reported by the Communicable Disease Center, residual sprays containing 5 percent DDT or 1.25 percent to 1.5 percent dieldrin gave effective control of *Anopheles quadrimaculatus* for 32 to 36 weeks. In Mississippi, residual sprays containing 2.5 percent malathion gave 100 percent kills of dieldrin-resistant *A. quadrimaculatus* for the entire 4-month observation period. In El Salvador, 2.5 percent to 5 percent malathion suspensions gave satisfactory control of dieldrin-DDT-resistant *Anopheles albimanus* for 10 to 12 weeks.

The compressed air sprayer of 1- to 4-gallon capacity is usually employed for residual applications. The tank is filled ¾ full of the spray liquid and the air above compressed by a cylindrical air pump or other source of compressed air to *50 psi* (pounds per square inch), after which spraying may continue until pressure drops to approximately *30 psi.* Then, the pressure is again pumped to *50 psi.* In this way, an average, but not constant, pressure of *40 psi* is maintained. The spray pattern is determined by this air pressure inside the compressed air sprayer but, even more, by the type of nozzle used. One type of standard spray nozzle is the Teejet, manufactured by the Spraying Systems, Inc., Bellwood, Ill.

On programs of the Public Health Service, Agency for International Development, and World Health Organization, four Teejet nozzles have been employed: 8002, 8004, 5002, and 5004. These nozzles produce a flat fan-shaped spray, either 80° or 50°. At an average pressure of *40 psi,* they deliver either 0.2 or 0.4 gallons per minute. The 8002 and 5002 nozzles with the smaller openings are used in spraying solutions and emulsions, while the 8004 and 5004 nozzles with the large openings are designed for suspensions. The small openings in the 8002 and 5002 nozzles often become clogged with the chalk-like particles in suspensions necessitating frequent time-consuming cleaning.

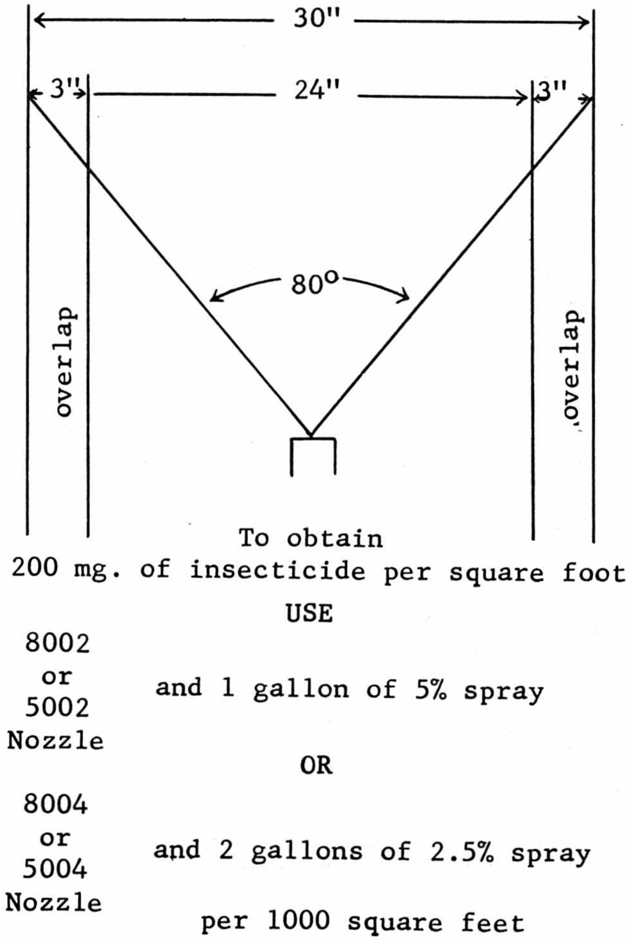


Figure 6.41 Residual Spray Pattern

The sprayman faces the wall and moves the spray nozzle up and down to cover the wall in successive strips. To produce a 30-inch swath, the 8002 and 8004 nozzles are held about 18 inches from the wall, and the 5002 and 5004, at 32 inches distance. In order to obtain complete coverage, an overlap of about 3 inches is allowed on each 30-inch spray swath. To obtain 200 mg. of DDT per square foot (2 grams per square meter), 5 percent DDT is sprayed with an 8002 or 5002 nozzle at a rate of about 190 square feet per minute (approximately 1 gallon of 5 percent spray for each 1,000 square feet in 5 minutes). If the 8004 or 5004 nozzle is used, the concentration of DDT in the spray is reduced by one-half to compensate for the nozzle delivery rate which is twice that of the 8002 or 5002 nozzle.

If a deposit of 100 mg. of insecticides such as malathion is desired, this application may be obtained using 8002 or 5002 nozzles (fig. 41) to apply 2.5 percent sprays, or 8004 or 5004 nozzles to apply 1.25 percent suspensions.

Residual spraying has also been used outdoors as *barrier strip treatments* to give daytime relief from certain culicine mosquitoes. The Communicable Disease Center (1963) reported that in the Savannah, Ga. area, DDT applied as a 1.25 percent emulsion at rates of 5 to 10 pounds of toxicant per acre to the outside of houses and to shrubbery, grass, and other vegetation caused significant reduction in daytime annoyance from salt-marsh mosquitoes for periods of 1 to 9 weeks. . . . Other pesticides—BHC (1.3 pounds gamma isomer per acre), lindane (0.5 pound per acre), and diazion or malathion (2 pounds per acre) were ineffective. In Montana similar application of 5 percent DDT emulsion on farm premises resulted in 75 to 98 percent reduction of daytime biting rates of *Aedes vexans, Ae. nigromaculis,* and *Ae. dorsalis.* Because new populations of mosquitoes invade an area at dusk, these barrier strip treatments have little effect on nighttime biting rates.

Residual spraying is a primary method of controlling mosquitoes which breed in *Catch Basins.* In many large cities with thousands of catch basins, surveys indicate that one catch basin in every ten holds enough water to produce broods of house mosquitoes (*Culex pipiens* or *C. quinquefasciatus*). The application of petroleum oils, or granular insecticides, to the breeding places is not the complete answer to this type of mosquito control as a single shower produces enough run off to flush the larvicide into the storm sewers. Therefore, a nozzle has been developed with a radial spray pattern which deposits a coating of DDT emulsion on the walls of the catch basin. Since DDT is almost insoluble in water, the residual application remains on the walls for weeks or months killing adult mosquitoes after they emerge from their pupal cases and rest on the walls while the wings and body harden sufficiently for flight. Twelve to 25 percent DDT emulsifiable concentrates have been used, approximately one pint per catch basin.

RESIDUAL FUMIGANTS

The discovery by Mathis and co-workers (1959) that some of the new organophosphorus insecticides have the ability to kill adult mosquitoes by fumigant action may revolutionize the insecticidal approach to global malaria eradication, and perhaps that of other mosquito-borne diseases, such as filariasis. A solid type cylindrical formulation of DDVP (1.5″ x 5″) developed in Georgia produces effective kill of caged *Anopheles quadrimaculatus* in closed or partially ventilated plywood huts (1,000 cu. ft. each) for 8 to 12 weeks (Communicable Disease Center, 1963). The formulation contains 25 percent DDVP, 25 percent dibutyl phthalate, and 75 percent montan wax by weight and releases DDVP vapor over a long period of time. This new method may revolutionize manpower requirements drastically and result in important savings in equipment, insecticides, and operational costs.

Field tests in 1961 and 1962 indicate that DDVP can also be used to control mosquitoes breeding in catch basins over a period of 6 to 8 weeks or longer.

EQUIPMENT FOR APPLYING INSECTICIDES

The equipment selected for insecticidal control depends on many criteria such as:

1. Extent of area to be treated,
2. Application indoors or outdoors,
3. Application as larvicidal, residual or space spray,
4. Type of equipment available,
5. Time and money available, and
6. Whim of the individual control organization.

HAND SPRAYERS

Hand sprayers of the plunger type (fig. 6.42) are useful for destroying adult mosquitoes with kerosene-pyrethrum mixtures in homes, or mosquito larvae in small puddles or containers in the yard. The types which build up pressure in the spray tank and give a continuous spray are more expensive but give better results.

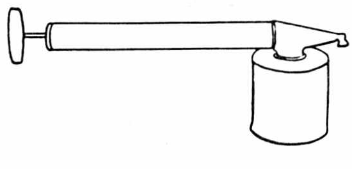


Figure 6.42 **Hand Sprayer**

Hand-operated sprayers usually 1- to 3-gallon capacity, are often used around the home, or on small community operations, to apply mosquito larvicides or residual sprays. These may be of the knapsack, trombone, or bucket-pump types with various types of nozzles.

AEROSOL BOMBS

The aerosol bomb (fig. 6.43) containing pyrethrum or allethrin is best for applying space sprays within enclosures. It is also used on picnics or on camping trips.

Figure 6.43 **Aerosol Bomb**

COMPRESSED AIR SPRAYERS

Compressed air sprayers (fig. 6.44) or 3- or 4-gallon capacity are used in treating aquatic areas of an acre or more and for residual application of insecticidal in the home or business establishment.

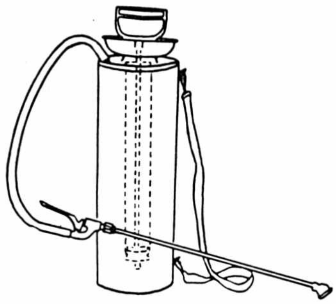


Figure 6.44 **Compressed Air Sprayer**

POWER EQUIPMENT

Power equipment of many types (figs. 6.45 and 6.46) is available for large-scale mosquito control operations. Large areas can be treated rapidly with orchard type sprayers, special dusting machines, mist blowers, heat-generated fog or aerosol machines.

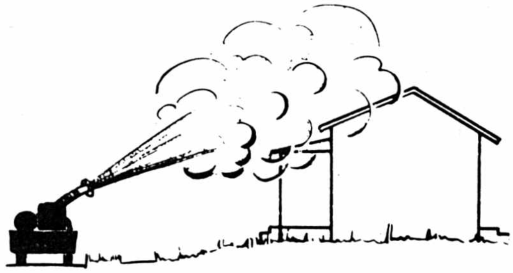


Figure 6.45 **Mist Machine**

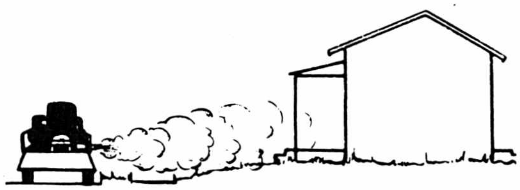


Figure 6.46 **Fog Machine**

AIRCRAFT APPLICATION

Airplane application is useful if areas to be controlled are too large or are inaccessible for economical treatment with ground power equipment or under emergency conditions.

The equipment for mosquito control is discussed in detail in Part III of this Insect Control Series and in special publications of the American Mosquito Control Association (1948, 1952, 1954), the U.S. Department of Agriculture (1955), and other articles listed in the Selected References at the end of this publication.

RESISTANCE OF MOSQUITOES TO INSECTICIDES

In general *resistance of mosquitoes to insecticides is defined as the ability to withstand a poison which was generally lethal to earlier populations.* Two main types of resistance occur in mosquitoes:

Physiological resistance: The ability through physiological processes to withstand a toxicant after it has entered the body.

Behaviouristic resistance: The ability through protective habits or behavior to avoid lethal contact with a toxicant.

Physiological resistance is the important type in the United States. It has not appeared in those mosquitoes with a single generation a year, such as the northern snow-water species of *Aedes*, but rather in those which have a number of generations a year and have been exposed to the selective action of insecticides for years.

Schoof (1959) listed 46 species of insects of public health importance in which physiological resistance had been reported, 20 of them mosquitoes. He reported that the following species which occur in the United States are resistant to insecticides:

TABLE 6.4—*Species of U.S. mosquitoes resistant to insecticides*

Species	Area	Insecticide
Aedes aegypti	Trinidad, Florida	DDT, dieldrin.
dorsalis	California	DDT.
nigromaculis	do	DDT, toxaphene, lindane, aldrin, heptachlor, malathion, parathion.
sollicitans	Florida	DDT, dieldrin.
taeniorhynchus	Florida, Georgia	Do.
Culex pipiens	Massachusetts	DDT.
quinquefasciatus	Puerto Rico	DDT, malathion, dieldrin.
tarsalis	California, Oregon	DDT, malathion.
Psorophora confinnis	Mississippi	Dieldrin.
discolor	do	Do.
Anopheles quadrimaculatus	Georgia, Mississippi	DDT, dieldrin.

This list includes not only many of the most annoying pest mosquitoes but also the most important vectors of human disease in the United States.

This resistance is probably a genetic phenomenon not created by the insecticide, but merely revealed by it. Many authorities feel that this phenomenon is simply Darwinian selection, or survival of the fittest, which may be explained in large part as follows:

1. There is tremendous overproduction of mosquitoes;
2. Mosquitoes exhibit great variability;
3. There is a struggle for existence, with natural selection; and
4. There is survival of the fittest.

Kits (fig. 6.47) to determine the resistance of adult mosquitoes to insecticides have been developed in England by Busvine and Nash and in the United States by Mathis, Schoof, and Fay (1959). A modified kit made of plastic based on these two studies is now sold for about $50.00 by the World Health Organization. Groups of mosquitoes are collected and blown into exposure tubes. Here they are exposed for a standard time interval, usually one hour, to a graded series of known insecticide deposits on treated papers and to an untreated check paper. After the test, the mosquitoes are blown back into the collection tubes and held for 24 to 48 hours. The percent of mosquitoes killed by the insecticide on each treated paper (such as 0.1, 0.2, 0.4, 0.8, 1.6, 3.2 and 4 percent dieldrin) can be plotted to determine if resistance is present.

Kits to determine the resistance of mosquito larvae to insecticides have also been developed. The World Health Organization test kit for mosquito larvae has been described by Brown (1958). It may be purchased for about $10.00.

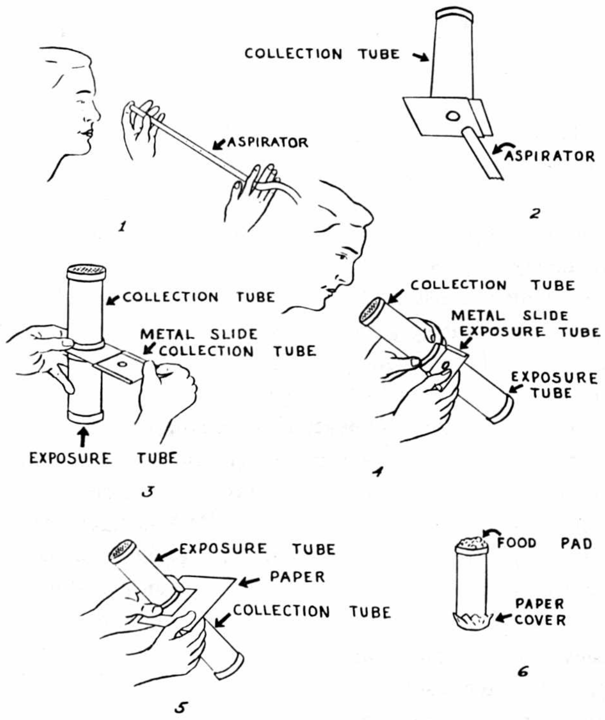


Figure 6.47 **Steps in Resistance Test. From Mathis, Schoof and Fay (1959)**

LEGAL ASPECTS OF MOSQUITO CONTROL

Enforcement of mosquito control within the United States is dependent upon the written authority contained in the State law which authorized the State or a lesser geographical area to conduct mosquito abatement operations and to expend money for the purpose. "Organization for Mosquito Control" Bulletin No. 4 (AMCA 1961) tabulates 39 States, applicable laws and other information, and furnishes data on the organizations of a mosquito control program. Effective mosquito control on an organized basis requires legal backing, variously termed a Mosquito Control Ordinance, or a Mosquito Abatement Act.

Two analyses of mosquito control legislation have been published by Keefe and Beadle (1956) and Beadle (1957). These laws usually include some of the following features; the legally constituted, tax-supported mosquito control organization has the authority

1. To take necessary steps to exterminate mosquitoes in or within migrating distance of the district;
2. To abate as public nuisances artificially created mosquito breeding places; and
3. To notify a property owner of the existence of a nuisance. In California the mosquito abatement board may also hold hearings on the notice, determine whether abatement must be made, direct him to comply, or abate the nuisance when he fails, and initiate lien action against the property involved to enforce payment. Most States do not have these last provisions in their mosquito control legislation.

Experience in many States indicates general agreement of these legal aspects of mosquito control as discussed by Beadle (1957):

1. Legal responsibility for mosquito control is associated with land ownership or operating rights;
2. Legal responsibility pertains to man-made situations rather than to "Acts of God";
3. The desirable approach for the control of the problem is by means of education rather than by litigation;
4. The legal approach should be used as a last resort for the few who will not cooperate; and
5. Legal action should not be taken unless public opinion is in sympathy with such action.

PUBLIC RELATIONS

To be of maximum effectiveness mosquito control must be understood and supported by the people for whom protection is provided. People who are informed about mosquito biology and control are more likely to mosquitoproof their homes, to use insecticides and repellents against adult mosquitoes, and to control mosquito breeding places on their own property. For people to be informed about mosquito control, they must have specific facts and instruction which should result in the development of sound habits, practices, and attitudes. In reaching the public it is important to work through officials of established organizations and agencies, such as the schools, PTA's, Agricultural Extension Service, the Grange, and civic groups. If newspapers, and local radio and television stations, are approached and the program is explained to them, they usually are willing to devote a portion of their activities to a discussion of mosquito control, frequently as a free public service. Utilization of established agencies and organizations to secure good public relations offers several advantages. The public relations worker does not need to spend valuable time organizing numerous community meetings but can reach groups of people through established meetings. The majority of the population in any one area, large or small, can be reached. When local leaders are co-

Figure 6.48 **Radio Programs Help Mosquito Control**

operating, the services of newspapers, radio, motion picture projectors, mimeograph machines, and other equipment can be readily secured.

The methods of reaching people with information should be varied according to the ages and interests of each group. Different presentations should be made, for example with school children, women's clubs, or the local medical association. Good public relations do not result merely because someone tells people that mosquito control is good for them. They need to understand the many facets of mosquito control and how they can benefit from this program. To supplement the spoken and written word, charts, maps, diagrams, photographs, slides, filmstrips, and motion pictures may be used. Some of the motion pictures and filmstrips listed on pages 55 and 56 of this guide are valuable in this part of a total program. However, good public relation workers know that in slide or motion picture presentations, the more local, readily recognized scenes are used, the greater is the impact. In some areas school children in civics or science classes have brought home "check lists" to "check off" on their own property such typical mosquito-breeding places as tin cans or bottles, old automobile tires, stopped-up gutters, low ditches, or a farm pond. Exhibits at local, county, or State fairs are used by some mosquito abatement districts and attract particular attention if they include live mosquito eggs, larvae, pupae, and adults—one way to teach large groups about the life history of these insects. Some mosquito control organizations buy a page of a local newspaper once a year and print their annual report, with well-selected photographs to illustrate typical activities, in a mass medium read by thousands rather than the more expensive annual report sent to a select few who may file it away with or without reading it.

Finally, mosquito control organizations should have a courteous, well-informed staff who can answer telephone or person-to-person inquiries, personnel who can speak at a variety of meetings, and supervisors who are always ready to answer complaints promptly and give advice on a wide variety of problems.

SUGGESTED AUDIOVISUAL AIDS

The following films and filmstrips are available on free, short-term loan within the United States. Please indicate exact dates that films are to be used (and alternate dates if possible) and allow ample time for shipment. Requests should be addressed to:

The Communicable Disease Center
Atlanta, Georgia 30333
Attention: Public Health Service Audiovisual Facility

AEDES, AEGYPTI SURVEY TECHNIQUES (F–290), filmstrip, 35 mm. color, silent, 82 frames, 1957.

AIRCRAFT QUARANTINE (4–045), motion picture, color, sound, 15 minutes, 1947.

ARTHROPOD-BORNE ENCEPHALITIS—ITS EPIDEMIOLOGY AND CONTROL (M–542), motion picture, 16 mm., color, sound, 17½ minutes, 1963.

BIOLOGY AND CONTROL OF DOMESTIC MOSQUITOES (M–357), motion picture, 16 mm., color, sound, 782 ft., 21 min., 1960—TV cleared.

CONCRETE DITCHING FOR MALARIA CONTROL (4–046), motion picture, 16 mm., color, sound, 7 minutes, 1949.

CONSTRUCTING A FARM POND (5–136), filmstrip, 35 mm., black and white, sound, 10 minutes, 78 frames, 1949.

DOMESTIC VECTOR CONTROL BY BASIC SANITATION (SPF–296), filmstrip, 35 mm., color, sound, 49 frames, 6½ minutes, 1958.

FILARIASIS (5–036), filmstrip, color, sound, 21 minutes, 1947.

HEALTH HAZARDS OF PESTICIDES (M–204), motion picture, 16 mm., color, sound, 527 ft., 14½ minutes, 1958—TV cleared.

IDENTIFICATION OF FEMALE ANOPHELINES OF THE U.S. (5–019), filmstrip, 35 mm., color, sound, 73 frames, 21 minutes, 1946.

IDENTIFICATION OF SOME MOSQUITOES OF PUBLIC HEALTH IMPORTANCE (F–95), filmstrip, 14 minutes, 35 mm., color, sound, 56 frames, 1952.

IDENTIFICATION OF U.S. GENERA OF ADULT FEMALE MOSQUITOES (5–015), filmstrip, color, 15 minutes, 35 mm., 92 frames, 1948.

IDENTIFICATION OF U.S. GENERA OF MOSQUITO LARVAE (5–042), filmstrip, color, 35 mm., sound, 18 minutes, 1947.

IDENTIFICATION OF U.S. SPECIES OF ANOPHELES LARVAE (5–061), filmstrip, black and white, 35 mm., sound, 16 minutes, 78 frames, 1950.

INFECTIVE LARVAE OF WUCHERERIA BANCROFTI (4–059), motion picture, color, silent, 4 minutes, 1947.

INTRODUCTION TO ARTHROPOD-BORNE ENCEPHALITIS (M–237), motion picture, color, 16 mm., 17½ minutes, 1957.

MALARIA CONTROL ON IMPOUNDED WATERS (4–069.1), motion picture, 16 mm., color, sound, 19 minutes, 1948.

MOSQUITO LARVAL HABITATS (F–190), filmstrip, 35 mm., color, silent, 74 frames, 1958.

MOSQUITO PREVENTION IN IRRIGATED AREAS (M–73), motion picture, black and white, sound, 7 minutes, 1955.

MOSQUITO SURVEY TECHNIQUES (M–127), motion picture, 16 mm., color, sound, 15 minutes, 1958—TV cleared.

ORGANIZED MOSQUITO CONTROL (M–191), motion picture, 16 mm., color, sound, 16 minutes, 1955—TV cleared.

PERMANENT DITCH LININGS (5–034), filmstrip, 35 mm., color, sound, 15 minutes, 107 frames, 1945.

SPACE SPRAYING OF INSECTICIDES (M–442), motion picture, 16 mm., color, sound, 11 minutes, 391 ft., 1961.

SPRAYING EQUIPMENT AND PROCEDURES. PART I: RESIDUAL SPRAYING (4–091), motion picture, 16 mm., color, sound, 9 minutes, 1951—TV cleared.

THE USE OF AIRCRAFT FOR INSECT CONTROL, PART I: MOSQUITO CONTROL (4–077), motion picture, 16 mm., black and white, sound, 13 minutes, 1949.

These and many other films produced by the Communicable Disease Center are included in the Public Health Service Film Catalog, 1962, Public Health Service Publication No. 776, 78 pp.

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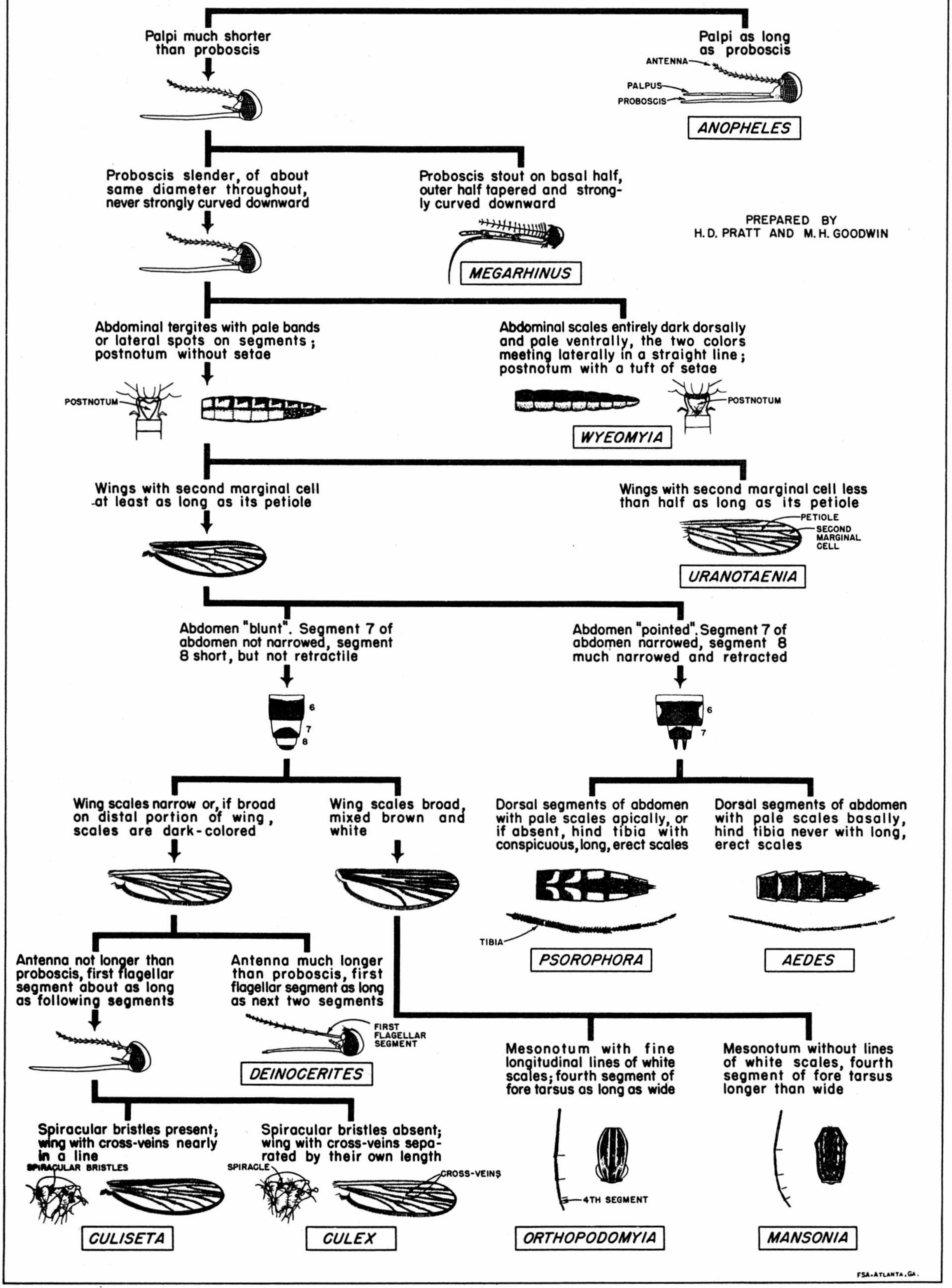
MOSQUITO IDENTIFICATION

There are approximately 150 species of mosquitoes in the United States. Excellent keys listed in the "Selected References" are available for the entire United States and for many individual states. Identification of adult or larval mosquitoes to genus may be accomplished by using the "Pictorial Key to U.S. Genera of Female Mosquitoes" or "Pictorial Key to U.S. Genera of Mosquito Larvae," pp VI– and VI– In most areas of the United States only five or six species of mosquitoes are of primary importance as pests or potential vectors of disease. Female specimens of most of these common and important species may be identified by using the "Pictorial Key to Some Common Female Mosquitoes of the United States".

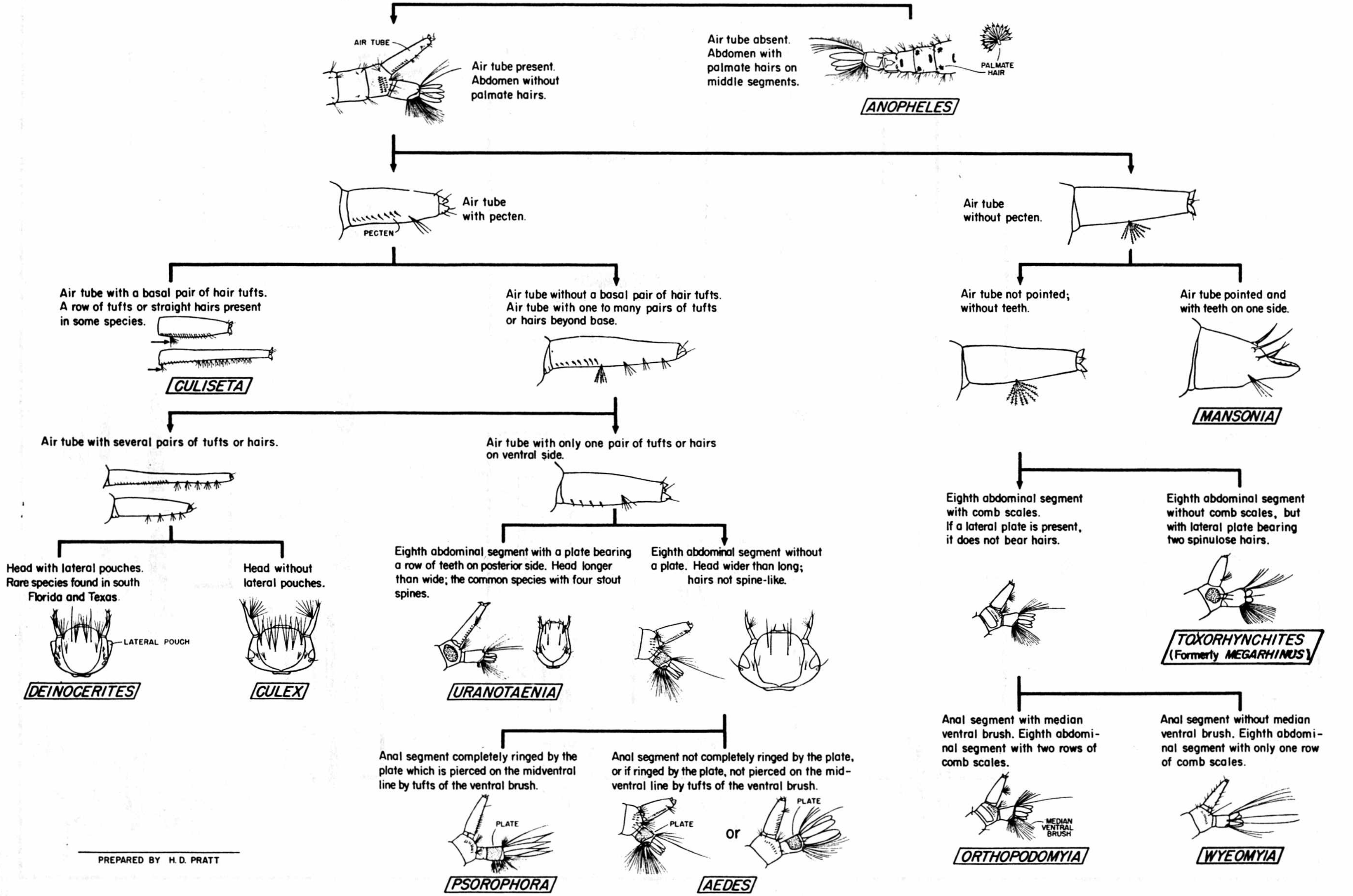
In each pictorial key the significant structures are illustrated and described. In the two keys to female mosquitoes, for example, a person must first decide whether the specimen has the palp as long as, or much shorter than, the proboscis. To determine the specimen, a choice must be made depending on this one character. Other characters are used in a similar manner to work down on the key to the correct scientific name of the mosquito.

In using the pictorial key for mosquito larvae, the user must first decide whether the mosquito has an air tube or whether this structure is absent. In working down on the key, other characters such as pecten, comb scales, and shape of air tube are used to determine the correct generic name of the mosquito larva.

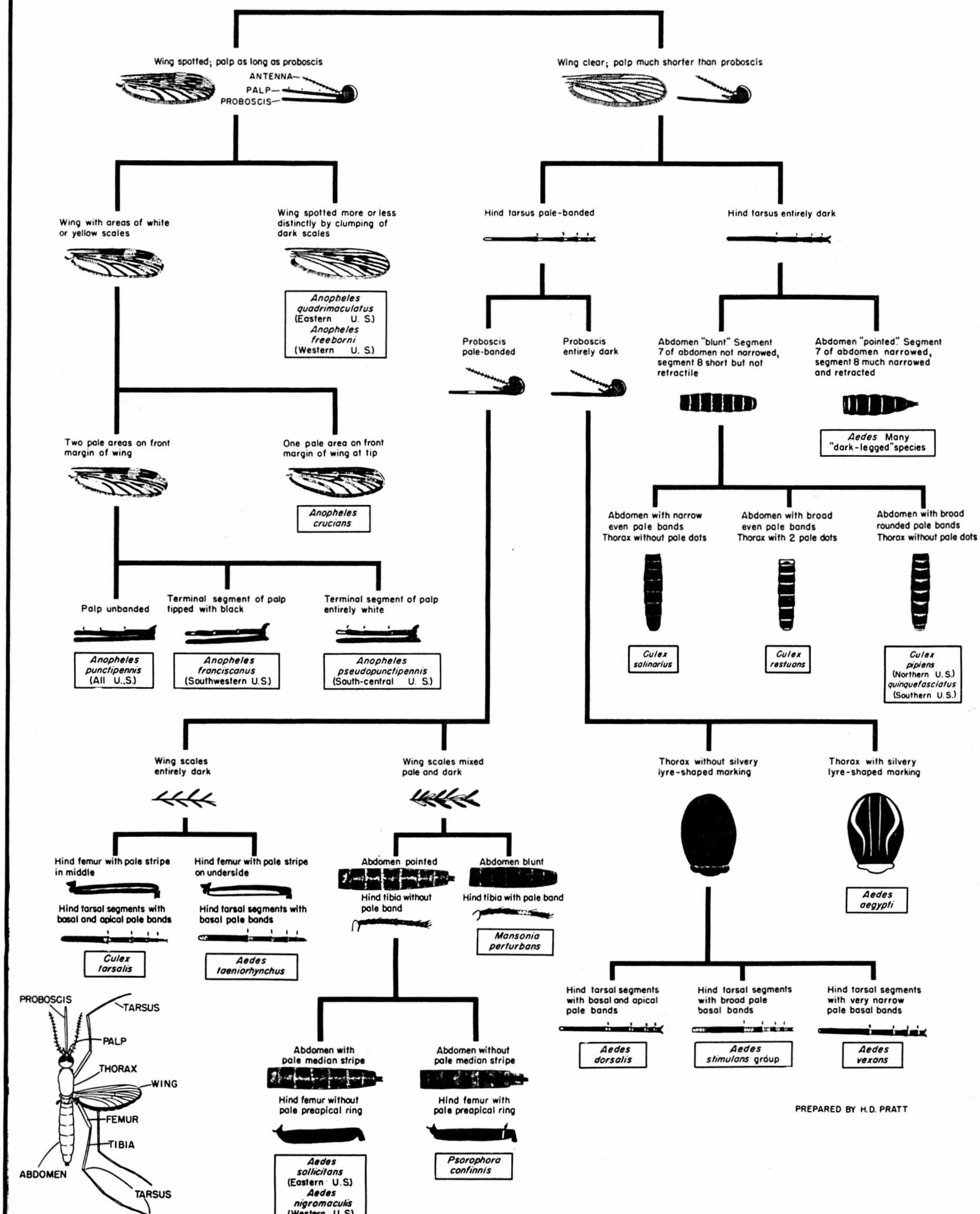
PICTORIAL KEY TO U. S. GENERA OF FEMALE MOSQUITOES



PICTORIAL KEY TO U S GENERA OF MOSQUITO LARVAE



PICTORIAL KEY TO SOME COMMON FEMALE MOSQUITOES OF THE UNITED STATES



Standard Recommendations for Controlling Mosquito Larvae*

Problem	Suitable equipment	Formulation	Dosage
Catch basins	Hand compressed-air, motorcycle, or jeep sprayers.	5 percent DDT emulsion or oil; 12–25 percent DDT emulsion.	About 1 pint, applied primarily to wall surfaces.
	Bellows duster	5 percent paris green pellets	Dust lightly.
Ornamental fish or lily ponds.	Hand compressed-air or knapsack sprayers.	New Jersey pyrethrum larvicide.	1 part New Jersey larvicide to 9 parts water, applied at a rate of 1 quart per 200 feet.
Small artificial breeding places.	Hand plunger-type, or hand compressed-air sprayers.	0.5 to 1 percent DDT in oil; 0.5 to 1 percent DDT emulsion.	Cover water surface lightly if breeding place cannot be eliminated.
	Bellows duster	5 percent paris green pellets	Dust water surface lightly.
Ditches, ponds, small swamps, temporary pools inaccessible to motor equipment.	Hand compressed-air, knapsack, or other hand sprayers.	0.5 to 1 percent DDT in oil; 0.5 to 1 percent DDT emulsion; 0.5 to 2 percent malathion emulsion.	5 quarts to 5 gallons per acre (0.05 to 0.4 lb. of DDT per acre; up to 0.5 lb. malathion per acre).
Large marshes inaccessible to standard motor vehicles or requiring special transportation.	"Weasels" and special automotive vehicles equipped with power sprayers or mist blowers; airplanes, or helicopters.	0.5 to 1 percent DDT in oil; 0.5 to 1 percent DDT emulsion; 5 to 10 percent DDT granules; 0.5 to 2 percent malathion emulsion.	5 quarts to 5 gallons of DDT spray; 1 to 5 lbs. of DDT granules (0.05–0.4 lb. actual DDT per acre; up to 0.5 lb. malathion per acre).
	Airplanes	5 percent paris green pellets	15 lb. per acre.
Salt-water marshes	Hand compressed-air, knapsack, or power sprayers; mist blowers; airplanes.	0.5 to 2 percent DDT in oil; 0.5 to 1 percent DDT emulsion; 5 to 10 percent DDT granules; 0.5 to 2 percent malathion emulsion.	5 quarts to 5 gallons of DDT spray; 1 to 5 lbs. or more of granules (0.05 to 0.4 lb. actual DDT per acre; up to 0.5 lb. malathion per acre).
	Airplanes	5 percent paris green pellets	15 lb. per acre.

*Adapted from American Mosquito Control Association Bulletin No. 2, 1952. DDT is currently the most widely used mosquito insecticide, particularly in the northern part of the United States. If mosquitoes are resistant to DDT and related chlorinated hydrocarbons, then alternate insecticides such as paris green, malathion or parathion may be used as discussed on pages of this training guide.

Standard Recommendations for Controlling Mosquito Adults*

Problem	Suitable equipment	Formulation	Dosage
Residual spray inside homes and other buildings.	Hand compressed-air or knapsack sprayers; bucket pumps; wheelbarrows; small power sprayers.	5 percent DDT emulsion or oil solution; 2.5 percent DDT wettable powder.	200 mg. of DDT per square foot. Apply to point of runoff. (1 to 2 gallons per 1,000 square feet.)
Residual spray outside (vegetation not involved).	Hand compressed-air or knapsack sprayers; bucket pumps; wheelbarrows; small power sprayers.	5 persent DDT emulsion or oil solution; 2.5 percent DDT wettable powder.	200 mg. of DDT per square foot. Apply to point of runoff. (1 to 2 gallons per 1,000 square feet.)
Residual sprays outdoors on vegetation.	Hand compressed-air, knapsack, or wheelbarrow sprayers; small portable power sprayer or mist blower; large power units if accessible to vehicles.	0.5 percent DDT wettable powder or emulsion (with or without rosin "sticker").	10 to 25 gallons per acre (1 to 2 pounds of DDT).
Space spraying of homes, cabins, or tents.	Aerosol bomb; hand-siphon atomizers.	Pyrethrins or allethrins plus DDT.	12 mg. of pyrethrins per 1,000 cubic feet; 18 mg. of allethrins per 1,000 cubic feet; 90 mg. of DDT per 1,000 cubic feet.
Space treatment of large enclosures.	Mechanical aerosol and fog machines and electric sprayers.	5 percent DDT in oil; Pyrethrum or allethrin sparys.	To agree with underwriters requirements.
Small-area space treatment—ball parks, picnic areas, home lawns, and other outdoor gathering areas.	Aerosol bombs, hand-siphon or pressure-tank atomizers, small fog machines, mechanical aerosol machines.	5 to 12 percent DDT solutions in fog machines; 1 to 3 percent DDT in mist blowers; 3 to 6 percent malathion in foggers.	0.1 to 0.3 pound of actual DDT per acre. Up to 0.5 pound of actual malathion per acre.
Large-area space treatment out-doors—campsites, resort areas.	Large fog or mist-producing machine; airplanes or helicopters.	5 to 12 percent DDT solutions in fog machines; 1 to 3 percent DDT in mist blowers; 3 to 6 percent malathion in foggers.	0.1 to 0.3 pound of actual DDT per acre. Up to 0.5 pound of actual malathion per acre.

*Adapted from American Mosquito Control Association Bulletin No. 2, 1952. DDT is currently the most widely used mosquito insecticide, particularly in the northern part of the United States. If mosquitoes are resistant to DDT and related chlorinated hydrocarbons, then alternate insecticides such as paris green, malathion or parathion may be used as discussed on pages of this training guide.