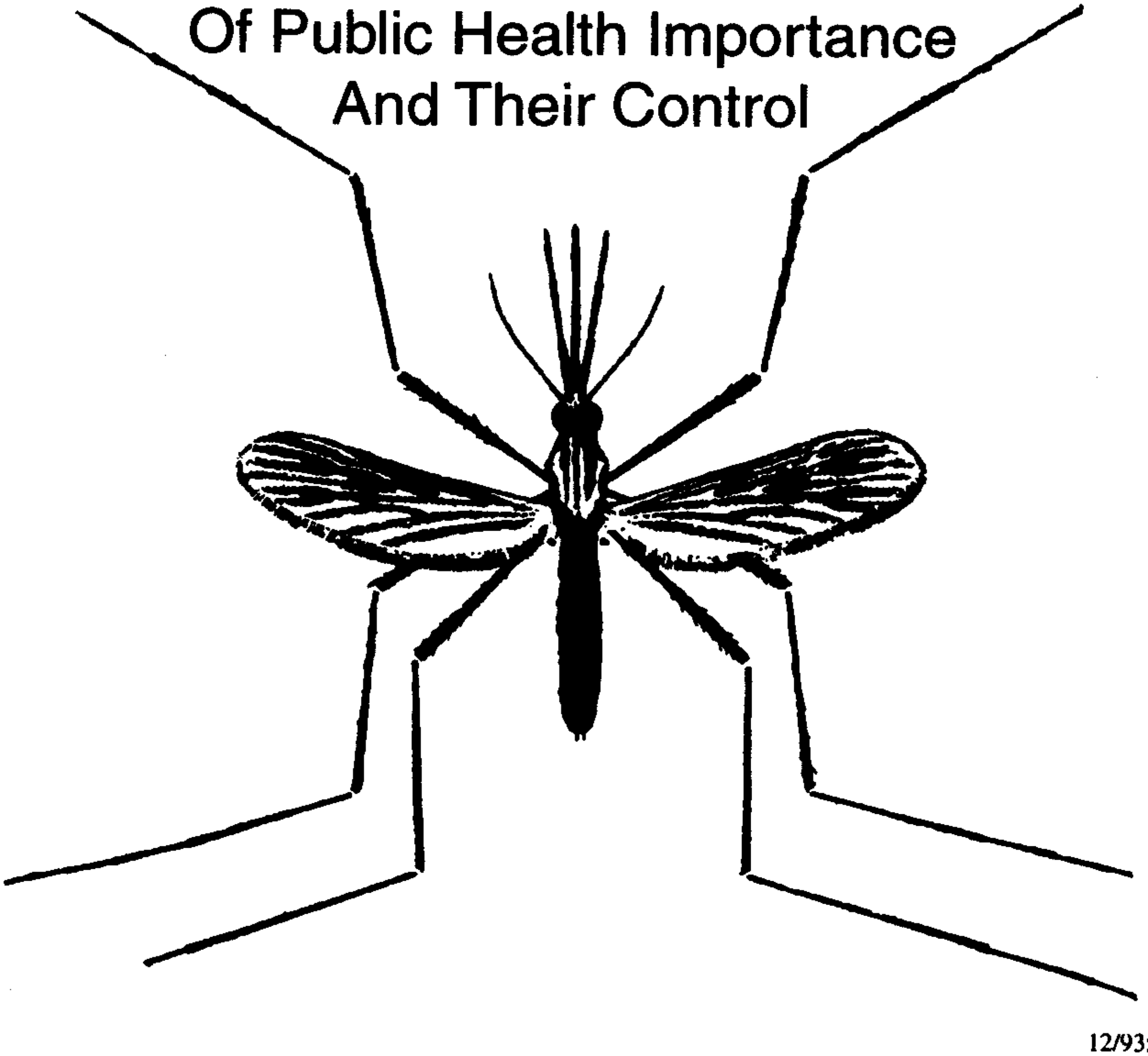
SELF-STUDY

SELF-STUDY COURSE 3013-G

Vector-Borne Disease Control

MOSQUITOES

Of Public Health Importance And Their Control



12/93:6R

U.S. DEPARTMENT OF HEALTH & HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
Public Health Practice Program Office
Atlanta, Georgia 30333

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

MOSQUITOES
Of Public Health Importance And Their Control

Harry D. Pratt
and
Chester G. Moore

Prepared and Printed 1960
Revised 1969
Revised 1976
Revised 1977
Reprinted 1988
Revised 1992
Revised 1993

U.S. DEPARTMENT OF HEALTH & HUMAN SERVICES
Public Health Service
CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

CONTENTS

INTRODUCTION

Throughout history mosquitoes have occupied a position of importance as a pest of mankind, but not until the late 19th century were these arthropods identified as the agents responsible for transmission to man of some of his more devastating diseases. During subsequent years, knowledge of the relationship of mosquitoes to disease has expanded; and knowledge of methods for controlling these disease vectors has often provided us with means toward reducing or eliminating the diseases in many areas. In this manual the importance of mosquitoes to human health in the United States is considered, along with basic information on mosquito, identification, biology, and control.

MOSQUITOES AS DISEASE VECTORS

World-wide, mosquitoes are responsible for the transmission of disease to millions of people each year. These diseases include encephalitis, dengue, yellow fever, malaria, and filariasis. In the past, most of these diseases have been highly important as endemic or epidemic diseases in the United States, but presently only the arthropod-borne encephalitides continue to occur with some frequency in this country.

ENCEPHALITIS

A high proportion of the arthropod-borne viruses known to affect humans are transmitted to humans by mosquitoes. Several of these viruses are responsible for encephalitis, a disease affecting the central nervous system. The five major types of arboviral encephalitis in the United States are: Eastern equine encephalitis (EEE), Western equine encephalitis (WEE), St. Louis encephalitis (SLE), LaCrosse encephalitis (LAC) and Venezuelan equine encephalitis (VEE); each is caused by a distinctly different virus or virus complex. These viruses are normally infections of birds or small mammals. During the course of such infections the level of virus may increase (amplification), facilitating further extension of transmission. The occasional infection of human or equine hosts may result in severe illness or death. In most cases, the human or equine host is a "dead end" for the virus, with little or no possibility of subsequent transmission of the disease from these hosts because of their inability to infect mosquitoes.

The viruses that cause Eastern equine, Western equine, or St. Louis encephalitis are normally transmitted from bird to mosquito to bird, and less commonly from bird to mosquito to human or horse. The viruses that cause LaCrosse encephalitis and Venezuelan equine encephalitis are normally transmitted by mosquitoes among small mammals, but occasionally are transmitted to humans or, in the case of VEE, to horses. Because of the higher VEE viremias common in infected horses, these hosts may provide a source for the mosquito transmission of the virus to new hosts.

Human cases of arbovirus infections range from inapparent or mild to very severe illnesses which may permanently damage the central nervous system and, in some instances, are fatal. Similarly, horses may have mild to severe or fatal infections with EEE, WEE, or VEE viruses. SLE virus causes only asymptomatic infections in horses (they develop antibodies but not clinical illness). Birds may die of infection caused by some

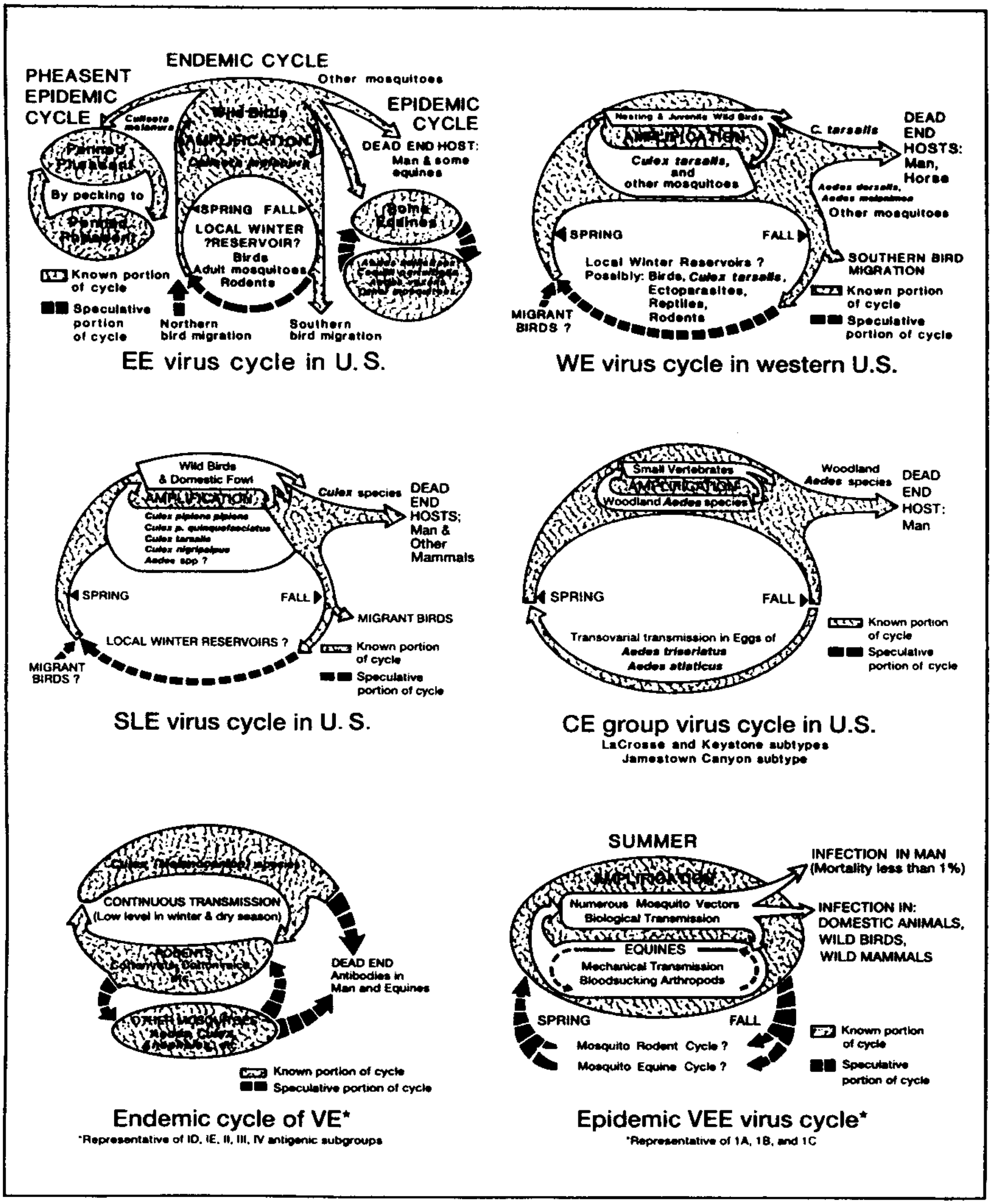


Figure 1. North American Mosquitoborne Arboviral Encephalitis Cycles

encephalitis viruses but not by others. For example, deaths due to EEE virus have been reported in red-winged blackbirds, house sparrows, whooping cranes, and pheasants. SLE virus produces no outward signs in birds.

Schematic illustrations of the basic transmission cycles of the five major types of encephalitis viruses of North America are presented in Figure 1. Portions of some of these cycles are still speculative and await further confirmation. The geographic distribution of four of these viruses is shown in Figure 2. The human cases of four major mosquito-borne viral encephalitides of North America reported by the states to the Centers for Disease Control and Prevention since 1970 are summarized in Table 1.

TABLE 1. REPORTED CASES OF ARBOVIRAL ENCEPHALITIS IN THE U. S.

	TYPE OF ENCEPHALITIS				
YEAR	EEE	SLE	WEE	LAC/CE	TOTAL
1970	2	15	4	89	110
1971	4	57	11	58	130
1972	0	13	8	46	67
1973	7	5	4	75	91
1974	4	74	2	30	110
1975	3	1815	133	160	2111
1976	0	379	1	47	427
1977	1	132	41	65	239
1978	5	26	3	109	143
1979	3	32	3	139	177
1980	8	125	0	49	182
1981	0	15	19	91	125
1982	12	34	9	130	185
1983	14	19	7	64	104
1984	5	33	2	89	129
1985	0	21	1	68	90
1986	1	43	7	64	115
1987	3	17	41	87	148
1988	1	0	0	41	1
1989	9	34	0	65	108
1990	5	240	0	62	245
1991	12	70	1	6	89
TOTALS	99	3199	297	1531	5126

Eastern Equine Encephalitis

Eastern equine encephalitis (EEE) is found along the Atlantic and Gulf Coasts and inland in limited areas in New York and the Midwest. As will be noted in Table 1, cases usually occur in small numbers in any one year. Cases generally occur in the late summer and are concentrated in the young age groups. There were localized epidemics in Massachusetts in 1956 (12 cases), and in New Jersey in 1959 (32 cases); 1968 (12 cases); 1982 (12 cases) and 1983 (14 cases). Eastern equine encephalitis is the most deadly of the North American mosquito-borne viral diseases, with 50 to 75% of the human cases ending fatally and leaving a high proportion of the survivors with severe central nervous system sequelae. The disease often occurs in horses and in game farm pheasants and may be fatal in up to 90% of these animals. The bird-to-bird cycle of the virus is typically maintained by *Culiseta melanura,* a mosquito whose larvae are found in freshwater swamps. Because this mosquito rarely bites humans or horses, other mosquitoes, such as the eastern salt marsh mosquito *Aedes sollicitans, Coquillettidia pertubans,* and *Aedes vexans,* are probably the vectors responsible for transmission of the disease to these dead end hosts.

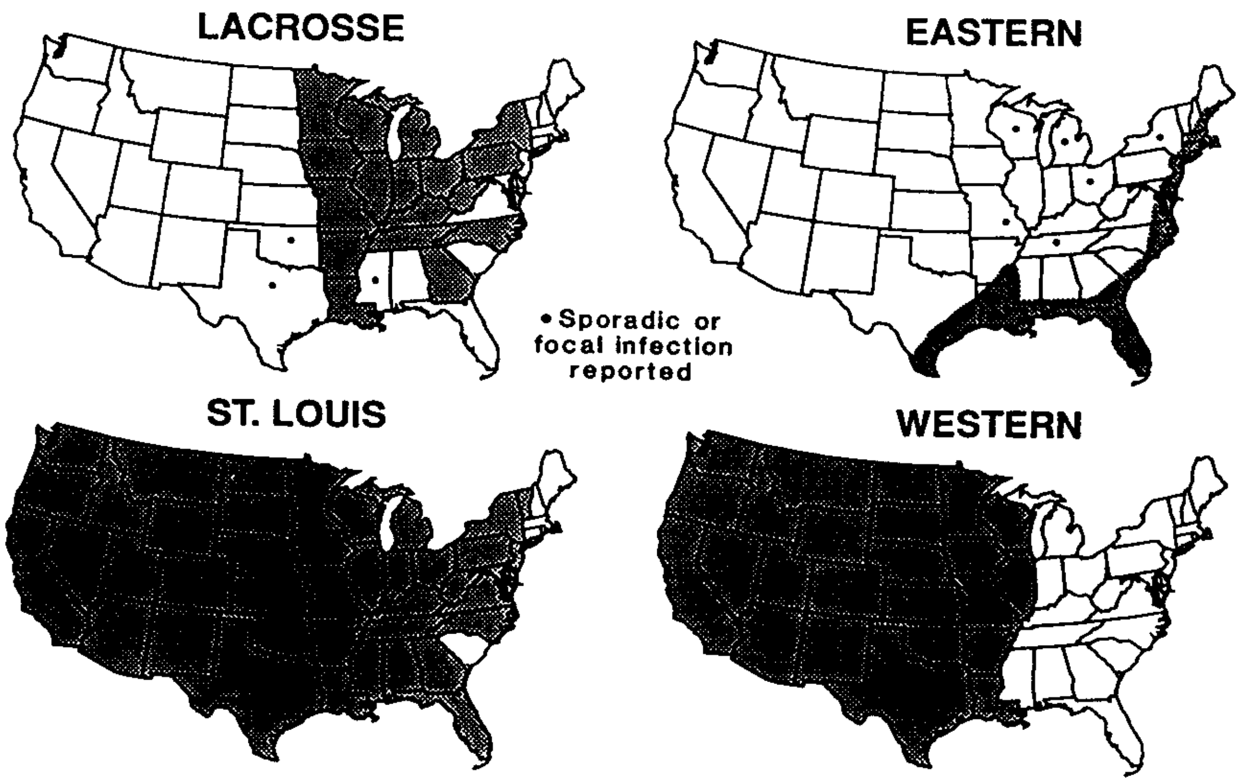


Figure 2. Distribution of 4 Types of Mosquitoborne Arboviral Encephalitis

Western Equine Encephalitis

Western equine encephalitis (WEE) is found in the states west of the Mississippi River, Wisconsin, and Illinois, as shown in Figure 2. As in Eastern equine encephalitis, cases are concentrated in the young. There were many major outbreaks in horses in the 1930's, with thousands of cases and many deaths. The largest human epidemic, probably over 3,000 cases, occurred in the western United States in 1941. Another large epidemic occurred in 1952, primarily in the Central Valley of California (Reeves 1990). There were 141 cases in 1958 and 172 cases in 1965. In 1975 133 cases were reported, primarily in the Red River Valley of Minnesota and South and North Dakota. While deaths have been reported in human cases of WEE, it is generally a much milder disease than EEE. Mortality has been reported as ranging from 1 to 5% of the cases. The death rate in horses is considerably higher.

Culex tarsalis and *Aedes melanimon* are the important mosquito vectors of Western equine encephalitis. Isolations of WEE virus have been made from many species of mosquitoes and birds. (Reisen and Monath, 1988).

St. Louis Encephalitis

St. Louis encephalitis (SLE) was first recognized during an epidemic in the St. Louis, Mo., area in 1933, although retrospectively the first known outbreak of the disease was found to have occurred in 1932 in Paris, Illinois. Since that time, human cases of SLE have been reported from all of the contiguous states, with the exception of the New England area and South Carolina (Fig. 2). (Monath, 1980; Chamberlain, 1987; Tsai and Mitchell, 1988).

The largest number of cases of SLE on record for a single year occurred in 1975 when 1815 cases were reported from 30 states, the majority of them in the Ohio and Mississippi valleys. Human cases of SLE typically occur in late summer and fall. During the Florida epidemic of 1990, in order to prevent infection from night-biting mosquitoes, people were advised to stay indoors after dark and many football games were rescheduled for afternoon playing.

The following major outbreaks have occurred:

Location	Date	Cases	Deaths
St. Louis, MO	1933	1,097	221
St. Louis, MO	1937	431	107
Hidalgo Co., TX	1954	373	10
Louisville, KY	1956	110	12
Cameron Co., TX	1957	114	3
Tampa Bay area, FL	1962	222	43
Houston, TX	1964	243	27
Dallas, TX	1966	172	22
Florida	1990	226	10

St. Louis encephalitis is considered to be a more serious disease than Western equine encephalitis but less so than Eastern equine encephalitis. The disease is more commonly seen and is more severe in older people. Case fatality rates for most outbreaks of SLE have varied from 2 to 20%, and neurologic sequelae have been reported in a small percentage of cases. However, most infections of SLE virus in humans do not result in illness, and many mild cases show aseptic meningitis or fever only.

St. Louis encephalitis virus exists primarily as an infection of birds transmitted by mosquitoes. It may be enzootic in some areas but occasionally epizootics may occur in which a large percentage of birds in the area become infected. Birds develop the levels of viremia needed to infect mosquitoes but do not suffer ill effects from the disease. Humans and horses acquire SLE infections from mosquitoes which have previously fed on infected birds, but apparently do not develop a sufficient amount of virus to infect mosquitoes that feed on them.

Members of the *Culex pipiens* complex, *Culex pipiens pipiens* (the northern house mosquito) and *Culex pipiens quinquefasciatus* (the southern house mosquito) are the main urban vectors of St. Louis encephalitis. *Culex tarsalis* is the chief vector in rural areas in western states. *Culex nigripalpus* is the main vector in Florida.

Culex salinarius and *Culex restuans* are potential vectors in some localities, but this observation requires confirmation.

LaCrosse Encephalitis/California Encephalitis

Transmission of LaCrosse (LAC) and other California serogroup viruses including California encephalitis (CE) and Jamestown Canyon (JC) to humans is rather constant. As shown in Table 1, there are about 75 reported cases nationally (range 30 to 160) each year. Routine testing for and reporting of California serogroup encephalitis was initiated widely in the United States beginning in 1963. "Between 1963 and 1984, 1611 cases of CNS (central nervous system) illness, serologically confirmed as CE, were reported to CDC...., the vast majority of these cases undoubtedly resulted from infection with LAC virus." (Grimstad, 1988). The greatest number of cases of LaCrosse encephalitis have been reported in the midwestern states of Ohio, Indiana, and Wisconsin, in August and September, usually in children under 16 years of age, and more often in males than in females. As shown in Table 1, each year from 1970 to 1991 more cases of LAC/CE were reported than cases of EEE or WEE, and often than cases of SLE. Fortunately infections with LAC virus cause a less severe illness than is commonly found with other mosquito-borne encephalitides. The mortality rate is probably in the order of 4 per 1,000.

Human cases of California encephalitis (CE) have been reported from California where the CE virus has been isolated from *Aedes melanimon* mosquitoes. Human cases of Jamestown Canyon (JC) encephalitis have been reported from Michigan, New York, and Ontario. *Aedes stimulans* may be the principal vector of JC virus. Other viruses in the California encephalitis serogroup include Keystone and Trivittatus--usually with *Aedes* mosquito vectors.

LaCrosse encephalitis differs from Eastern equine, Western equine, and St. Louis encephalitis in that it has mammalian, rather than an avian, vertebrate host system. The major mammalian hosts are the eastern chipmunk, tree squirrels, and foxes. The principal vector is the eastern treehole mosquito, *Aedes triseriatus*. The virus has been shown to overwinter in the eggs of the treehole mosquito and has been passed through the eggs to larvae, pupae, females and males (Watts *et al.* 1973). The virus is maintained in woodland habitats and even within small, isolated woodlots, which are quite numerous in some north central states. There is a strong association between the occurrence of human LAC encephalitis cases and the presence of *Ae. triseritus* in artificial containers, such as tires, on patients' premises. Detailed accounts of the California encephalitis group, including data on human cases and isolations of the various subtypes from many species of mosquito and vertebrate hosts, has been published (Sudia *et al.* 1971 and Calisher and Thompson 1983).

Venezuelan Equine Encephalitis

Venezuelan equine encephalitis (VEE) is caused by a number of subtypes of virus. The endemic Everglades virus (EV) in Florida is of low virulence and is transmitted by *Culex (Melanoconion)* mosquitoes from wild rodents. Three clinical human cases have been reported in southern Florida (Ventura *et al.* 1974). In addition, antibodies to Everglades virus have been found in Seminole Indians, hunters, fishermen, and campers in localized areas in southern Florida. The virulent epidemic type 1A and 1B viruses have been involved in extensive epizootics in horses and epidemics in humans in tropical America since 1935.

In 1971 an outbreak of the 1B type of VEE occurred in Texas, in association with a similar outbreak in Mexico, and more than 1500 equines were fatally infected. Although only 19 human cases of VEE were reported to the Center for Disease Control during 1971, one authority places the number of cases in Texas at 110, with no deaths (Bowen *et al.* 1976). *Psorophora columbiae, Ps. discolor, Aedes sollicitans,* and *Ae. thelcter* were the primary vectors in South Texas during the 1971 epidemic. Other species of *Culex, Anopheles, Mansonia* and *Deinocerites* were also found infected in Texas in 1971, and may be important in other countries. The Texas epidemic was controlled by a three-fold program involving (a) vaccination of equines with live, attenuated vaccine to protect horses and to preclude them as a source of virus for mosquito vectors; (b) quarantine of equines in Texas and adjoining states; and (c) ultra-low volume aerial application of technical malathion to some 13.5 million acres of mosquito-producing area along the Mexico-Texas border and the Gulf Coast of Texas and Louisiana (Sudia and Newhouse 1975). No further Venezuelan equine encephalitis activity has been reported in equines or humans in the United States during the period of 1972 to 1975.

DENGUE

Dengue is a viral disease transmitted from person to person by mosquitoes. It may occur in epidemic form in almost any part of the tropics or subtropics. It is usually an acute, nonfatal disease, characterized by sudden onset of fever, headache, backache, joint pains, nausea, and vomiting. There are four virus serotypes (DEN 1-4). Three of the four serotypes (DEN-1, DEN-2, and DEN-4) have been circulating in the Americas since 1981. Although endemic transmission of DEN-3 has not occurred in the region since 1977, it could be reintroduced. While most infections result in relatively mild illness, some may cause the severe forms of the disease, dengue hemorrhagic fever (DHF) characterized by severe rash, purpura, mild gum bleeding, nosebleeds, gastrointestinal bleeding and circulatory failure resulting in dengue shock syndrome (DSS) and even death.

In the Western Hemisphere the principal and perhaps the only mosquito responsible for transmission of dengue in human populations has been *Aedes aegypti*. *Aedes albopictus* has been a vector in Hawaii, the Philippines, and Southeast Asia and may become one in the New World. The mosquitoes obtain the virus from the blood of infected persons during the period from the day before the initial fever through the third or fourth day of illness. The virus multiplies in the mosquito, which becomes infective to man 8 to 14 days after the infective blood meal. The mosquitoes may remain infective for the rest of their lives with the ability to transmit the disease-causing virus during subsequent blood feedings on humans. (Gubler, 1988).

Dr. Benjamin Rush reported one of the earliest outbreaks of dengue in the United States from Philadelphia in 1780. In 1922 there was a large epidemic from Florida to Texas with an estimated 2 million cases, and with perhaps a million cases in Texas alone. Cases of dengue were reported in Louisiana in 1945. Dengue epidemics spread from Jamaica in 1977, to Honduras in 1978, to Mexico in 1979, and to Texas in 1980 where 27 cases were reported in people who apparently had not been out of the country. Cases of dengue contracted overseas but occurring in the

United States have been reported for many years, as 102 cases in 1990 (CDC, 1991).

Epidemics of dengue, some with cases of dengue hemorrhagic fever (DHF) and dengue shock syndrome (DSS) have occurred in the Americas. The estimated cost of the DEN-2 and DEN-3 epidemic in Puerto Rico in 1977 was between $6 and $16 million (U.S.) in medical costs, lost work, and control measures. The 1981 DHF epidemic in Cuba had an even greater economic impact with an estimated cost of over $100 million (U.S.) in control measures and medical costs during a 4-month period from July through October. Gubler (1988) reported 502,026 cases in 1977 in the Americas and 362,398 in 1981 with 116,143 persons hospitalized and 158 deaths, with most of the 1981 cases from Cuba. Some authorities have theorized that the severe hemorrhagic forms of the disease (DHF and DSS) occur only in persons experiencing a second infection with a different (heterologous) dengue serotype. For example, the 1981 Cuban epidemic of DHF caused by DEN-2 virus was preceded by a large DEN-1 epidemic in 1977.

Dengue is endemic in Puerto Rico with 11 outbreaks since 1963. Starting in 1986, from 6,000 to 11,000 cases of dengue-like illness have been reported each year in Puerto Rico.

The most recent major epidemic of dengue in the Americas occurred in Peru in 1990, with 76,000 cases reported. The most recent outbreak of dengue hemorrhagic fever (DHF) occurred in Venezuela in 1989-90 involving 3,108 cases of severe dengue and 73 deaths (CDC, 1991).

YELLOW FEVER

Yellow fever is a viral disease which is transmitted to humans by mosquitoes. Illness from this infection may be acute and fatal or so mild as to be inapparent. There are two distinct epidemiologic types of the disease in the Americas: Urban yellow fever and jungle yellow fever. In both the virus is the same, and humans are protected from each by the same vaccine; however, the mosquito vectors and normal vertebrate hosts differ.

Urban Yellow Fever

In the classical urban type of yellow fever, epidemics are the result of human-to-human transmission of the virus by *Aedes aegypti*, commonly called the yellow fever mosquito. Although no epidemics have occurred in the United States since the outbreak of 1905 in New Orleans, epidemics were reported with some frequency during the 18th and 19th centuries from most of the larger seaports in the eastern United States, even as far north as Philadelphia, New York, and Boston. These epidemics probably originated from the importation of cases from infected areas of Central and South America. Although *Aedes aegypti* is commonly found in many areas of the United States, importation of cases leading to the establishment of epidemics in this country is a theoretical but highly remote possibility because of vaccine usage and the absence of urban yellow fever elsewhere in the Americas.

Jungle Yellow Fever

Jungle yellow fever, also called sylvan or sylvatic yellow fever, is normally a disease of monkeys and perhaps other wild animals, transmitted most frequently by sylvan, treetop-frequenting mosquitoes in the genera *Haemagogus, Sabethes* and *Aedes*. Enzootic and epizootic yellow fever is maintained in the jungle primates by these vectors. Humans usually become involved when they invade jungle habitats for occupational or other purposes and are bitten by the sylvan vectors. Epizootics continue to occur in jungle areas. The most recent extension of activity toward the United States occurred in 1956 (Trapido and Galindo 1956) reaching as far north as Mexico. The yellow fever virus may be highly fatal to some of the species of monkeys involved in the jungle cycle, while others develop viremias with little or no apparent illness. The potential for initiation of urban transmission of the disease depends on the return of a human who has become infected in the forested area to an area where *Aedes aegypti* is present to initiate and maintain human-to-human transmission. This has occurred only rarely in the Americas and has in no case resulted in an epidemic. Establishment of the urban cycle may occur with some frequency in Sudan, Ethiopia and other African areas (Monath 1988).

MALARIA

Although malaria had disappeared as a significant problem within the United States by the early 1950's, it is still one of the most important communicable diseases on a worldwide basis. Malaria in humans is an acute or chronic disease caused by any one of four species of microscopic protozoan parasites in the genus *Plasmodium (P. vivax, P. falciparum, P. malariae* and *P. ovale)*. The parasite is transmitted from person to person by the bite of *Anopheles* mosquitoes. Although there are 17 species of *Anopheles* in the United States, only three served as significant vectors of the disease: *An. quadrimaculatus* east of the Rocky Mountains, *An. freeborni* and *An. hermsi* in the West.

Malaria was the number one insect-borne disease in the United States from colonial days until the late 1940's. As shown in Figure 3 malaria control has been a continuing battle from 1930 to the present time. During the Great Depression of the 1930's over 100,000 cases were reported each year, but the number was probably grossly underreported. In the late 1930's the TVA, WPA, and other governmental agencies began area-wide malaria control programs and reduced the number of cases to about 60,000 a year at the beginning of World War II. During World War II, a cooperative program of PHS and state and local health departments, the Malaria Control In War Areas Program (MCWA), helped control this disease, but the number rose at the end of the war due to cases contracted overseas in the China-Burma-India and Mediterranean theaters of war. As the result of a Malaria Eradication Program from 1945-1952, the number of cases dropped dramatically, from over 60,000 cases in 1945 to 2,184 in 1950 (Fig. 3).

As Veterans returned from the Korean conflict, many came down with malaria. The number of cases rose to 5,600 in 1951 and peaked at 7,023 in 1952, of which approximately 50 were transmitted in the United States. As the number of veterans returning from malarious areas decreased, the number of cases of malaria decreased, reaching a low of 132 in 1957. Beginning in 1965 soldiers returning from Vietnam came down with malaria in this country and the number of cases of malaria rose to a peak of over 4,000 cases in 1970. Following President Carter's decision to admit up to 14,000 Asian refugees a month, the number of cases rose to 1,864 in 1980, due in part to infected Indochinese refugees. Since 1980 about a thousand cases of malaria have been reported each year, almost all of them contracted overseas. However, migrant agricultural workers from Mexico (some suffering from malaria) came across the border and slept outdoors in California where they were bitten by malaria mosquitoes which later transmitted malaria to other migrants and residents who had never been out of the country. In San Diego county, California 27 malaria cases were reported in 1986 and 30 cases in 1988.

The malaria parasite inhabits the human red

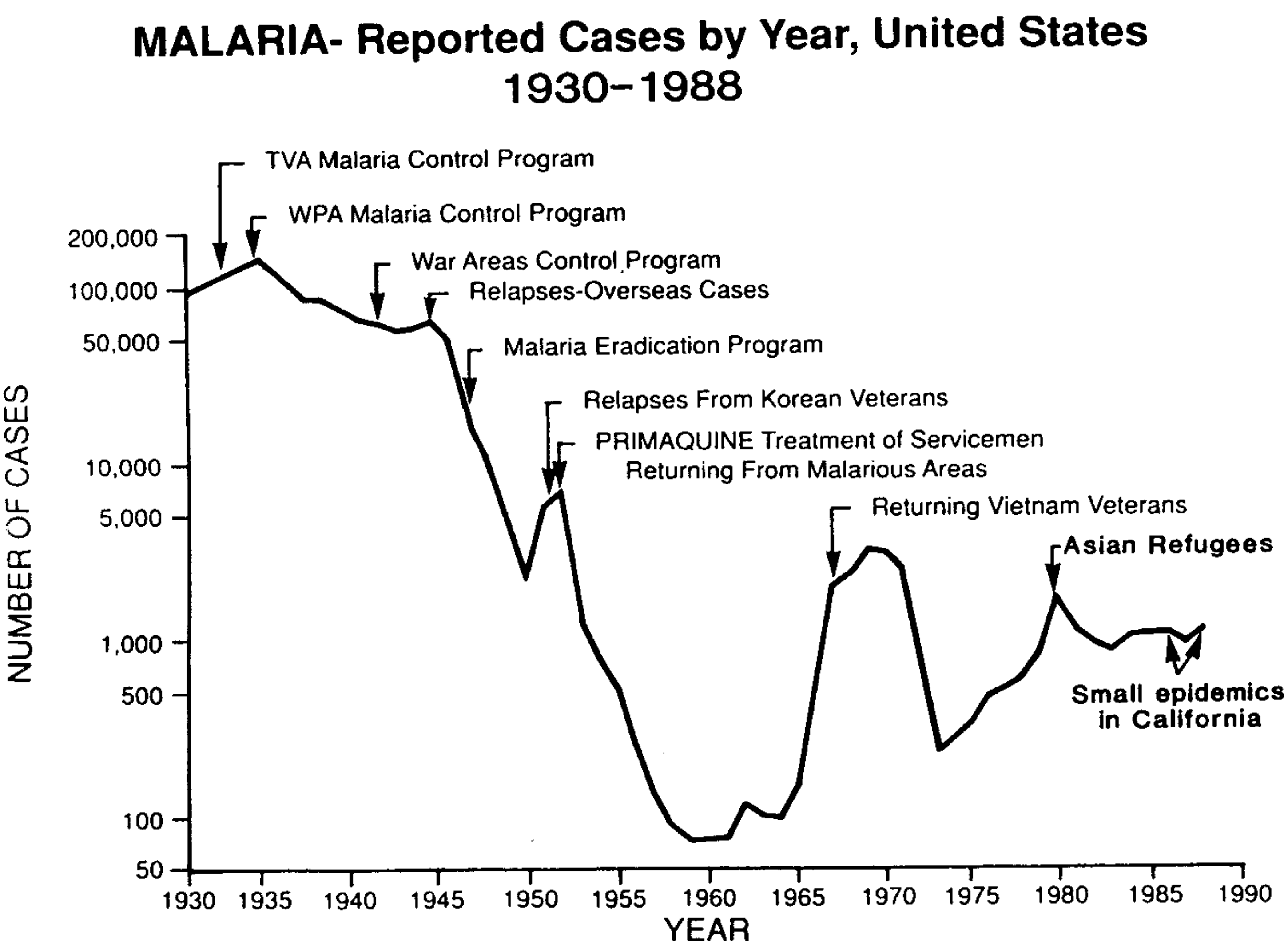


Figure 3. Malaria -- Reported Cases by Year, United States. 1930-1988

blood cells, where it multiplies asexually over a period of about 48 or 72 hours, depending on the species. After reaching maturity it bursts from the red cell, releasing a large number (usually 8 to 20) new parasites which enter new red cells and reinitiate the cycle. Typical malaria symptoms, chills and fever, are associated with the rupturing of infected red cells and release of the parasites. This process is often synchronous, which accounts for the intermittent nature of the symptoms, often occurring at about 48- or 72-hour intervals (the so-called "tertian" or "quartan" cycles). In addition to this asexual cycle in humans, some of the parasites develop into sexual forms, the male and female gametocytes. Infection of the mosquito takes place when a receptive anopheline feeds on an infected person who is carrying the gametocyte stages. The parasite then undergoes an asexual cycle in the mosquito which requires 7 to 20 days and culminates with the invasion of the mosquito salivary gland with numerous microscopic, spindle-shaped forms known as sporozoites. The human infection is initiated when these forms are injected during the bite of the infected mosquito. Before the asexual cycle in the red cells is established, the parasite must complete a 5- to 10-day period of multiplication in cells of the liver.

Clinically, the malaria infection varies from a moderately severe to a highly fatal illness, depending on the species of parasite and the host's condition. In the absence of prompt treatment, the so-called "malignant tertian" malaria, caused by *P. falciparum*, is particularly severe and often fatal in infants and young children and in those adults who possess no partial immunity due to previous malaria experience. The benign tertian parasite, *P. vivax*, generally causes a less severe illness and a lesser rate of mortality. There appears to be no true "immunity" conferred by a malaria attack; persons in a highly endemic area may be infected over and over again, usually developing a tolerance for the parasite which prevents severe clinical consequences, but which does not prevent the continuation of a chronic, often debilitating infection.

If insufficiently treated, a malaria infection may persist in humans for many months or years and have a continuing or periodically renewed ability to infect mosquitoes, often in the absence of symptoms or with a less severe clinical attack. For two of the species, *P. vivax*, and *P. ovale*, the continuation of parasites in the liver cells for prolonged periods may give rise to relapses by reinvasion of the red blood cells from this source at intervals for several years after the initial infection. There is probably no such true relapse mechanism for *P. falciparum* or *P. malariae*. However, in the case of *P. malariae* low-grade parasitemias may continue to be present in persons who have developed a tolerance for the infection. These parasitemias are characteristically asymptomatic or with infrequent mild symptoms and are less likely to be treated with a specific drug for malaria than would be the primary symptomatic attack and, therefore, from time to time may provide an unsuspected source of infection to mosquitoes. The remaining hazard of malaria transmission within the United States stems from the possible importation of such cases, or of cases recently acquired in endemic areas but not yet clinically apparent, into receptive areas of the country.

Despite the widespread presence of anopheline mosquitoes throughout the United States, a highly susceptible human population, and the importation of thousands of cases of malaria acquired overseas during World War II and the conflicts in Korea and Vietnam, there have been reported between 1964 and 1990 a total of 79 cases in 16 episodes of introduced malaria, i.e., malaria due to local transmission from an infected individual who came into the United States. All cases of malaria in the United States which are suspected as introduced cases are carefully investigated by state and/or federal health authorities to determine the exact origin. In the event of introduced malaria, immediate steps are necessary to prevent further spread, and these include detection and treatment of cases as well as mosquito surveillance and, if warranted, localized mosquito control measures.

FILARIASIS

The World Health Organization estimates that at least 250 million people are infected with the filarial nematode parasites *Wuchereria bancrofti* and *Brugia malayi,* transmitted by mosquitoes (WHO 1974). The adult worms live in various parts of the human lymphatic system, causing the diseases known as Bancroftian and Brugian filariasis. Persons may harbor the parasites with no apparent symptoms, or the filarial worms may cause inflammation and other complications. In some persons 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 rough skin.

The young filarial worms are transmitted from person to person by various species of mosquitoes. These nematodes undergo developmental changes in the mosquito which is an essential link in the cycle of transmission. The immature worms, called microfilariae, occur in the human bloodstream. 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 thorax before infective forms migrate to the mosquito proboscis, from which point they reach the new host at the next feeding. The infective filariae 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. Important vectors of *Wuchereria bancrofti* include species of the genera *Culex, Aedes,* and *Anopheles*. The generally accepted vectors of *Brugia malayi* are mosquitoes in the genus *Mansonia*.

Filariasis is widespread in many tropical and subtropical regions throughout the world. The Bancroftian type of filariasis is apparently an increasing public health problem in many of the larger cities in southeastern Asia. In the Western Hemisphere it occurs in the West Indies, Venezuela, Panama, and the coastal portions of the Guianas and Brazil. Filariasis control programs are based on control of the mosquito vectors and treatment of the human cases with diethylcarbamazine (Hetrazan).

A small endemic center existed for many years near Charleston, SC, but this has now disappeared. In many parts of the United States, people who have recently left the tropics may have the immature worms circulating in their blood. However the disease is not known to be naturally acquired in the United States at the present time.

DOG HEARTWORM

The dog heartworm *(Dirofilaria immitis)* is a common mosquito-transmitted filarial parasite of dogs which causes serious disease in these animals along the Atlantic and Gulf Coasts from Massachusetts to Texas and inland at least to Illinois and Minnesota. This nematode is also an occasional parasite of man; during the past 15 years at least 35 human cases have been reported in the United States (Gershwin *et al.* 1974). The parasite in man is usually located in the lung and less often in the heart. Other than as a lesion which may simulate other diseases in medical diagnosis, its clinical significance in man has not been fully determined.

The mosquito vectors of dog heartworm are not definitely known, but a list of infected mosquitoes has been published (Ludlam *et al.* 1970), and includes *Culex salinarius, Aedes aegypti* and *Ae. taeniorhynchus. Aedes canadensis* may be an important vector in the northeastern United States. *Aedes sierrensis* is a vector in California and Utah. *Aedes albopictus* is a competent vector of *D. immitis.*

GENERAL CHARACTERISTICS AND LIFE CYCLE OF MOSQUITOES

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 three characters in combination: long, many-segmented antennae; an elongate proboscis; and scales on the wing veins and wing margin. This is a very large group containing over 3000 species. There are approximately 165 species and subspecies in North America north of Mexico belonging to 13 genera distributed among 3 subfamilies according to Darsie and Ward (1981). Their general classification of the mosquitoes occurring in this area is outlined below:

Order Diptera (flies and mosquitoes)
- **Family Culicidae (mosquitoes)**
  - **Subfamily Anophelinae (anophelines)**
    - Genus *Anopheles*-17 species
  - **Subfamily Culicinae (culicines)**
    - Genus *Aedes*-79 species and subspecies
    - Genus *Coquillettidia* (formerly *Mansonia*) 1 species
    - Genus *Culex*-29 species and subspecies
    - Genus *Culiseta*-8 species
    - Genus *Deinocerites*-3 species
    - Genus *Haemagogus*-1 species
    - Genus *Mansonia*-2 species
    - Genus *Orthopodomyia*-3 species
    - Genus *Psorophora*-15 species
    - Genus *Uranotaenia*-3 species and subspecies
    - Genus *Wyeomyia*-4 species
  - **Subfamily Toxorhynchitinae**
    - Genus *Toxorhynchites* (formerly *Megarhinus*)-2 subspecies

LIFE HISTORY

Mosquitoes have four distinct stages in their life history, the egg, larva, pupa, and adult (Fig. 4). The first three stages occur in water, but the adult is an active flying insect that feeds upon 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: (a) those laid singly on the water surface: (b) those laid together to form rafts which float on the water surface; and (c) those laid singly on damp soil or vegetation. These differences are reflected in the structure of the egg.

Anopheline eggs are laid singly on the water surface. They are elongate oval, usually pointed at one end and provided with a pair of lateral floats (Fig. 4). They average about one-half millimeter in length. Hatching usually 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 *Culex, Culiseta, Coquillettidia, Mansonia* and *Uranotaenia* are laid side by side to form a raft often containing 100 or more eggs. They remain afloat on the surface of the water until

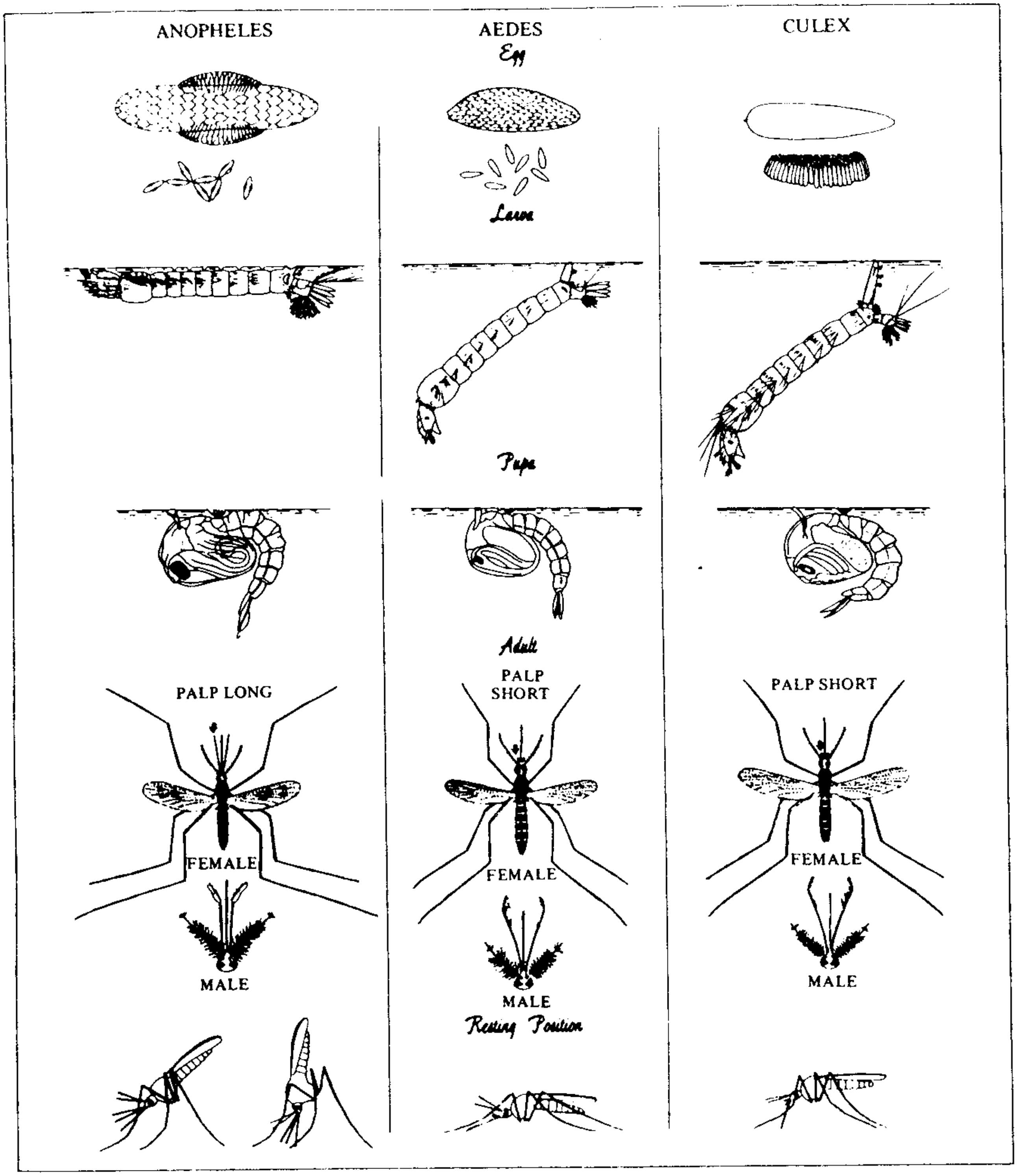


Figure 4. Characteristics of Anophelines and Culicines
(Kent S. Littig and Chester J. Stojanovich)

hatching occurs, usually after only a few days.

Eggs that are not laid on water must be placed so that the larvae can readily reach water or they must be able to survive long periods of drying until they are flooded. The eggs of *Aedes aegypti, Ae. triseriatus*, and *Orthopodomyia* are laid on the sides of containers or tree holes just above the water level. 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 flooded. The eggs of some species can survive for 3 to 5 years if flooding does not occur. In some cases eggs hatch as soon as they are flooded; thus, there can be several generations a year. This is typical of the *Psorophora* group and of *Ae. vexans* and *Ae. sollicitans*. Eggs of some other species must be subjected to freezing before they will hatch; thus, there can be only a single generation per year. Many species of *Aedes* belong in this group; examples are *Ae. stimulans* and *Ae. abserratus*.

Larvae

The larvae of all mosquitoes live in water, permanent ponds and marshes, temporary flood waters or woodland pools, water contained in tree holes, leaves of plants, or 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*, or *Coquillettidia*, obtain air from the underwater portions of plants.

The larval period includes four developmental instars, or stages, which collectively require at least 4 days for completion, often one to two weeks, the time of development being controlled by such factors as water temperature and food supply. At the end of each instar the larva molts--sheds its skin. The fourth instar is the last larval stage, and the fourth molt produces the pupa.

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 the palmate hairs in the anophelines, suspend the larvae from the water surface film.

Mosquito larvae are affected by light and by water conditions including temperature and movement, as well as by the dissolved gases and salts, and other living organisms present in their water habitat. 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 (Fig. 5).

The **head** bears the antennae, eyes, and mouthparts. 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 underside 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 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.

The **thorax** is broader than head or abdomen and somewhat flattened. It has several groups of hairs which are useful in identification of species.

The **abdomen** is long and subcylindrical, consisting of ten segments. The first seven segments are similar, but the eighth, ninth, and tenth are considerably modified. Anopheline larvae have float hairs, called palmate hairs, on some of the abdominal segments; culicine larvae do not have palmate hairs. The eighth segment bears the respiratory apparatus. In anophelines this consists of a spiracular plate with two spiracular openings. In culicines these openings are at the tip of a siphon, or air tube. The tenth segment is out of line with the other segments and bears two or four membranous, tapering appendages known as anal gills. These anal gills serve more for the regulation of osmotic pressure than for respiration (Fig. 5).

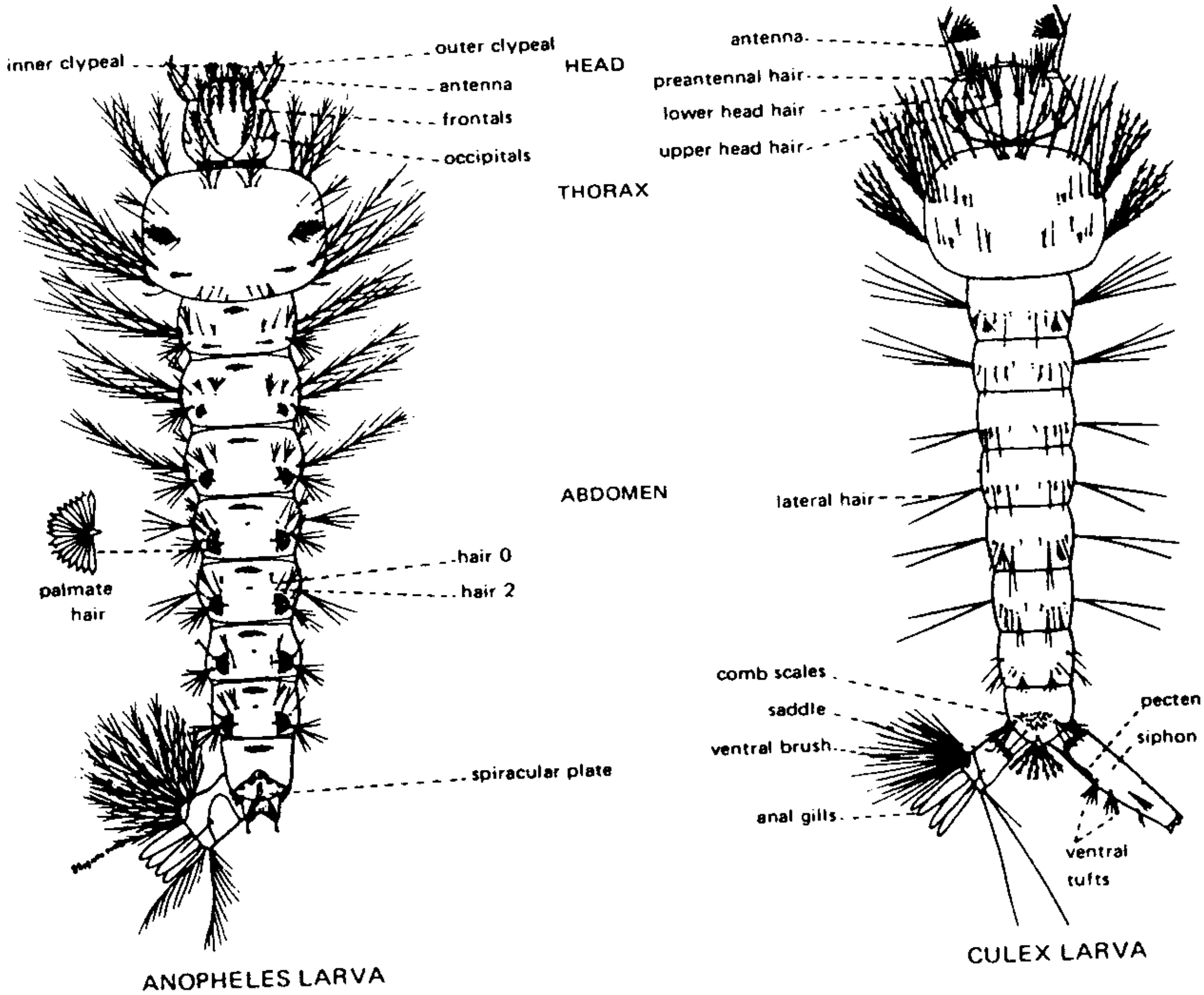


Figure 5. Fourth Stage *Anopheles* and *Culex* Larvae

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* or *Coquillettdia spp.* The pupa differs greatly from the larva in shape and appearance.

The head and thorax are 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 probably 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.

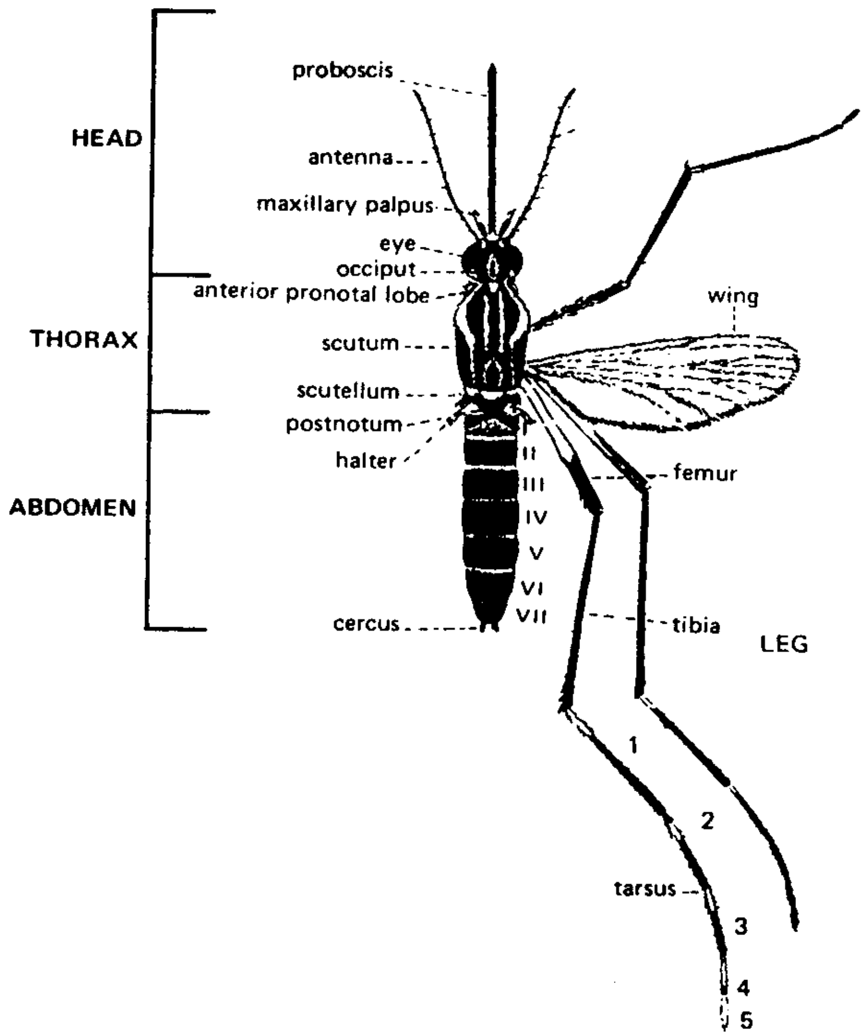


Figure 6. Diagram of Female Mosquito

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 opens 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) 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 1/16 inch to about 1/2 inch (2-15 mm). The three body regions, head, thorax, and abdomen are well-defined.

The head of a mosquito (Fig. 6) 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 a 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 13 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 anophelines the palpi of the female are about as long as the proboscis, while those of the male are enlarged at the tip (Fig. 4). In culicines the palpi of the females are short, while those of the male are usually long, densely haired, and pointed. 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 pierce the skin when the mosquito is biting. The stylets penetrate the skin of the host animal and form a small duct through which saliva is injected into the wound and a canal through which liquid food is ingested. The mouth-parts of the male are incapable of piercing the skin of humans or animals.

The **thorax,** or middle region of the body, bears the wings and legs. The upper surface of the thorax or scutum 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 clothed with scale patches and bear several groups of hairs or bristles, which are useful for identification. 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 stout femur, a long slender tibia, and a 5-segmented tarsus. The first segment of the tarsus is the longest and is often equal in length to the tibia. The fifth tarsal segment bears a pair of small claws. The legs are covered with dark or colored scales that form 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, sometimes useful in identification. The hind margin of the wing also bears a close-set row of long, slender, fringe scales. Two small knobbed structures known as halteres are located behind and slightly below the wings. The halteres vibrate rapidly when the mosquito is in flight and serve as organs of equilibrium.

The elongate, nearly cylindrical **abdomen** consists of ten segments, only eight of which are readily visible. The ninth and tenth segments are greatly modified for sexual functions. North American species of *Anopheles* usually have no scales on the upper surface of the abdomen. 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 (Fig. 7). 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 mating and are of value in identification of the species.

HABITS OF THE ADULT MOSQUITOES

About equal numbers of male and female mosquitoes are produced. The males ordinarily emerge first, remaining near the larval habitats and 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 domesticated of all mosquitoes, breeds primarily in and around human habitations and flies short distances, usually a "block" or about 200 yards. Most anophelines have a maximum flight range of about 1 mile. However, other species such as *Ae. vexans* and *Ae. sollicitans* can fly 10 to 20 miles or more.

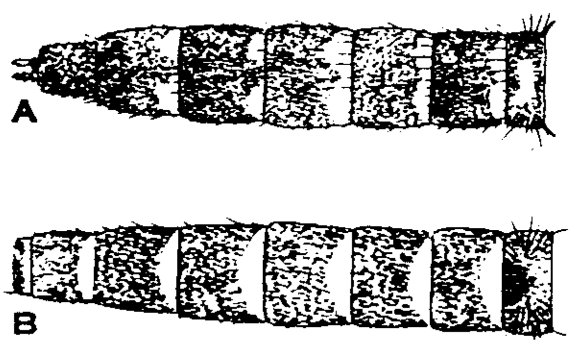


Figure 7. A. Pointed Abdomen of *Aedes*. B. Blunt Abdomen of *Culex*.

Mosquitoes also show considerable variation as to their preferred sources of blood meals. Some species by preference feed on birds or domestic animals such as cattle or horses, while others seem to prefer man. Because these preferences are not exclusive, a species will accept an alternate available host, which accounts for the transmission of encephalitis viruses from birds to humans or horses and of the yellow fever virus from monkeys to humans. A few species, which are not involved in human disease transmission, feed only on cold-blooded animals or subsist entirely on nectar or plant juices. Some mosquitoes feed entirely during the daytime while others may be active only during the evening or at night. The female mosquito requires two or more days to digest a blood meal, lay a batch of eggs, and then seek another blood meal. This cycle of feeding, laying eggs, and feeding again can be repeated many times in the life of a single female. Only one mating by the female is generally required to fertilize her lifetime egg production. The life span of adult mosquitoes is not well known. Some species apparently live one or two months during the summer. Adults that hibernate can live for six months or more.

A knowledge of the mosquito life cycle helps in understanding the epidemiology of mosquito-borne diseases. The transmission, for example, of arboviruses or the malaria parasite depends not only on an initial blood meal from an infected host and a subsequent feeding on the victim, but also requires a period of maturation of the infection in the mosquito, perhaps a week or more for the viruses and about 10 to 20 days for malaria. Once the mosquito becomes infective, she may often remain so for her lifetime, with the potential for transmitting the infection each time she feeds on a susceptible host. Thus, a knowledge of the frequency of feeding, the selection of hosts, life span, flight range, seasonal occurrence, and many other factors are important in disease epidemiology.

ECOLOGIC AND BIONOMIC TYPES OF MOSQUITO LIFE HISTORIES

For practical purposes, the numerous species of mosquitoes can be grouped on the basis of similarities in their larval habitat preferences which generally reflect other important aspects of their bionomics and ecology, e.g., oviposition habits, developmental patterns, brood patterns, seasonal density and dispersal. A convenient grouping of species includes: (1) The permanent pool group, (2) the transient water group, (3) the floodwater group, and (4) the artificial container and tree-hole group.

The Permanent Pool Group

Mosquito species belonging to this group are generally found in fresh bodies of quiet water exposed to sunlight and containing an abundance of surface vegetation and flotage at the air-water-plant interface. Typical habitats are shallow margins of ponds, lakes and smaller impoundments, the main characteristic being a degree of permanency. Such habitats are particularly suitable for *Anopheles spp.*, *Culex (Melanoconion) spp.*, *Cx. salinarius*, *Cx. territans*, *Coquillettidia spp.*, and *Mansonia spp*.

The mosquito species inhabiting permanent waters deposit their eggs on the water surface, singly in the case of *Anopheles*, and in rafts in the case of *Culex*, *Coquillettidia*, and *Mansonia*, with some variation in place of oviposition in the latter genus. Such sites are sheltered from wave action and are always in the presence of vegetation suitable for larval attachment or protection. Larval production is generally continuous in these species with several generations per year. Most *Anopheles* and *Culex* overwinter as adult females, but some, e.g., *Ae. walkeri*, may overwinter in the egg stage, while *Mansonia* and *Coquillettidia* overwinter as larvae attached to roots of plants. Except for *Coquillettidia* and *Mansonia*, the effective flight ranges of permanent pool species are relatively short, usually within a mile or so of the breeding area.

The Transient Water Group

The members of this group are mostly *Culiseta spp.*, some *Culex* and occasionally *Anopheles*. Their habits are similar to those in the permanent pool group, but they seem to be more often associated with pools of a temporary nature as opposed to species with an affinity for ponds and lakes. Typical sites are roadside ditches, borrow pits, canals, ground pools, clogged streams, irrigated lands, etc. Some species associated with such habitats include *Culex pipiens quinquefasciatus*, *Cx. tarsalis*, *Cx. restuans*, *Culiseta inornata* and *Culiseta melanura*. If water remains sufficiently long, anophelines frequently become established in late season, particularly such species as *An. albimanus*, *An. punctipennis* and *An. pseudopunctipennis*.

The Floodwater Group

The floodwater species of mosquitoes of the genera *Aedes* and *Psorophora* generally deposit their eggs singly on damp soil in grassy or woodland depressions or along vegetated shorelines that are intermittently flooded. Salt-marsh mosquitoes are also included in this group. When flooded after a period of desiccation, the eggs hatch if conditions (temperature, pH, oxygen concentration, etc.) are favorable; otherwise, the eggs may remain dormant and viable on the soil until a more favorable inundation. Typically, large numbers (broods) are produced at a hatching; larval development is uniform; and adults may appear as early as six days after flooding. Some species produce a single brood, particularly *Aedes* in northern areas, while many species of *Aedes* and *Psorophora* produce multiple broods in a given year. They overwinter in the egg stage. These species are particularly troublesome as pests and some characteristically fly long distances from larval habitats, e.g., 5-20 miles in the case of *Aedes sollicitans, Ae. dorsalis,* and *Ps. columbiae;* the woodland species such as *Ae. atlanticus/tormentor* and *Ps. ferox* tend to remain near the larval habitat. Some important vectors and pest species in this ecologic group are *Aedes sollicitans, Ae. taeniorhynchus, Ae. atlanticus/tormentor, Ae. thelcter, Ae. dorsalis, Ae. nigromaculis, Ae. vexans, Psorophora ferox* and *Ps. columbiae.*

The Artificial Container and Tree-Hole Group

Characteristic of this group are members of the genus *Aedes,* with specialized habits, the more important being *Ae. aegypti, Ae. triseriatus,* and *Ae. sierrensis.* Eggs are laid singly on the inside wall of the container, at or above the waterline, and hatch when inundated after a period of desiccation. Overwintering is in the egg stage and there are multiple broods.

Aedes aegypti and *Ae. albopictus* normally lay their eggs in artificial containers, whereas *Ae. triseriatus* and *Ae. sierrensis* females usually oviposit in natural cavities containing water, such as tree holes, but their larvae are frequently found in artificial containers with heavy sediment or decaying leaves.

This group includes not only the important *Aedes* species mentioned, but species of *Toxorhynchites* and *Orthopodomyia* as well, none of which are troublesome to man.

Although not included in this group on the basis of ecology and bionomics, females of the *Culex pipiens* complex often oviposit in artificial containers of all types, particularly those rich in organic matter.

Because of the association of artificial containers with human habitations and disease implications, *Aedes albopictus, Ae. aegypti,* and *Culex pipiens quinquefasciatus* all may become locally abundant and annoying, and are important targets of urban mosquito control campaigns.

This manual will concentrate on characterization of species which have known potential importance as disease vectors, as well as some of the more commonly found non-vector species which may occupy the same habitats and are important because of their abundance or noxious habits. However, it is not feasible to describe all mosquito species which will be encountered in vector surveillance. Identification of mosquitoes to species requires considerable knowledge of morphologic characteristics which are needed for separation of genera and species. Simple keys are appended at the end of the Manual which will assist in separating the genera found in the United States and in identifying some of the more common species. For mosquito survey and surveillance activities in any given region or locality, state or regional keys should be used, and simple keys can be devised to facilitate identification of both commonly found and target vector species. Virus associations of the mosquito species discussed have been taken from numerous sources particularly the 5 volumes, "The Arboviruses: epidemiology and ecology" edited by T. Monath (1988), Reeves (1990), Sudia *et al.* (1971), Calisher and Thompson (1983), and Tsai (1991).

NOTES ON IMPORTANT SPECIES OF MOSQUITOES

THE GENUS *AEDES*

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 the major pest species as well as important disease vectors. There are some 70 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 the northern United States, as well as in Canada and Alaska, many species of *Aedes* occur and are often present in astronomical numbers.

Species of *Aedes* characteristically lay their eggs either singly on the ground, on the waterline, or slightly above the waterline in tree holes or containers. These eggs hatch after flooding and in some species they are able to survive long periods of drying. Many of the northern species have only one brood a year. Their eggs do not hatch until they have been subjected to periods of drying or cold. Other species are intermittent breeders and have several generations per year depending on rainfall or irrigation practices. *Aedes* species occurring in regions with cold winters pass the winter in the egg stage.

Larval habitats of *Aedes* are extremely variable. In general, they are found in temporary pools formed by rains, melting snow, or overflows. Some species occur in coastal salt marshes that are flooded at intervals by unusually high tides. Others have become adapted to irrigation practices. A few species occur in tree holes, rock pools, and artificial containers.

Practically all species of *Aedes* are blood sucking. Many species are vicious biters of great economic importance. Their biting habits vary but they most frequently attack during evening hours. Some species, however, bite only during the day, and others bite either by day or by night. Flight ranges are extremely variable, being rather short for domestic and woodland species, and extremely long for many floodwater and salt-marsh species.

Aedes aegypti (Yellow fever mosquito)

The yellow fever mosquito is a small dark species that can be recognized by the lyre-shaped silver-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 (Fig. 8).

Ae. aegypti was originally a tropical species, thought to have been introduced into the Western World from Africa. Its current distribution in the United States includes the southeastern and southern states extending

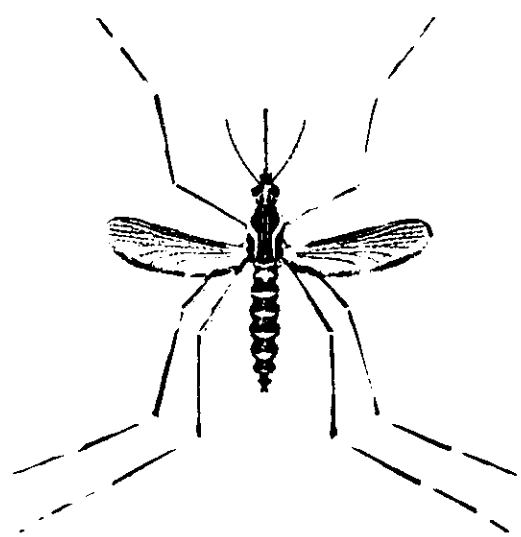


Figure 8. *Aedes aegypti*

northward to North Carolina, Tennessee and Arkansas. It was formerly an abundant species in most southern cities and extended northward along the Atlantic Coast probably into New England and in the Mississippi basin only as far north as Illinois.

Aedes aegypti is semi-domesticated. Its larval habitats are almost exclusively in artificial containers in and around human habitations. The eggs are laid singly on the inside of containers at or above the waterline, or less often on the water surface. They are able to withstand drying for several months and hatch quickly when containers are again filled with water. Hatching can take place in two or three days if temperatures are high. Typical artificial containers are flower vases, tin cans, jars, discarded automobile tires, unused water closets, cisterns, rain barrels, sagging roof gutters and tree holes.

The larvae can complete their development in 6 to 10 days under favorable conditions. In cool weather development is longer. The pupal period is about 2 days. The life cycle can be completed in 10 days, or it may vary as long as three weeks or more. This mosquito breeds throughout the year in the tropics, where generations succeed each other rapidly. In the southern United States, the reproduction rate is slower during the winter. The eggs sometimes remain dormant for several weeks or months. This species is very susceptible to cold and usually does not survive the winter in the northern United States.

The adults apparently prefer the blood of man to that of other animals. *Aedes aegypti* enter houses readily, even those that are well screened. This mosquito bites principally during the morning and late afternoon. It attacks quietly and prefers to bite about the ankles, under coat sleeves, or at the back of the neck. It often becomes a troublesome pest. The adults live four months or more in the laboratory. Their usual flight range is from 100 feet to 100 yards, but longer distances have been recorded.

Aedes albopictus (Asian tiger mosquito)

The Asian tiger mosquito was introduced many times into the United States, usually as eggs or larvae in used tires from Asia. It became established and was detected in Houston, Texas in 1985 and has since spread to 21 states and 257 counties. Known infestations have been reported as far east as Florida and Georgia, north to Maryland and Delaware in the east and Chicago, Minnesota and Nebraska in the west. *Aedes albopictus* has been reported as a vector of dengue in Hawaii, the Philippines, and Southeast Asia. It is a competent vector of *Dirofilaria immitis*, the heartworm of dog. It has been found infected with the virus of eastern equine encephalitis in Florida (Mitchell, *et al.*, 1992). *Ae. albopictus* strains established in the United States are efficient vectors the viruses of dengue and LaCrosse encephalitis in the laboratory (Francy *et al.*, 1990; Mitchell, 1991).

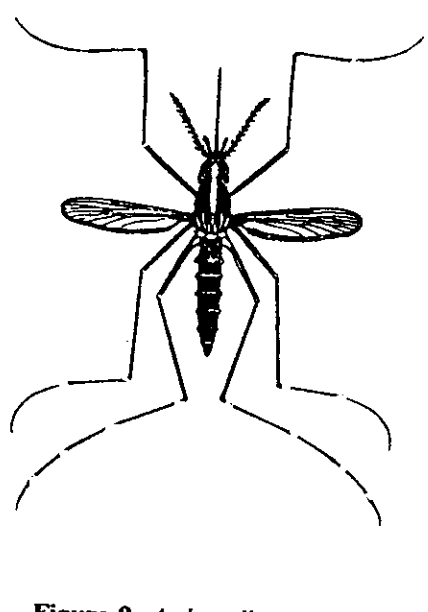


Figure 9. *Aedes albopictus*

The Asian tiger mosquito resembles the yellow fever mosquito (*Ae. aegypti*) in having bright silvery thoracic and abdominal markings and white-banded legs. *Ae. aegypti* has a characteristic silvery lyre-shaped marking on the scutum whereas *Ae. albopictus* has a single longitudinal silvery stripe in the middle of the scutum hence its name (Fig. 9). The larvae of both species, and the treehole mosquito (*Ae. triseriatus*) are found in water-holding containers, particularly used tires, but differ in the shape of the comb scales and other characters as discussed by Darsie (1986). The biology of *Ae. albopictus* is described in detail by Hawley (1988). The mean development time from egg hatch to pupation takes 5 to 10 days at temperatures near 25° C (77 °F) but may take longer at lower temperatures or with suboptimal larval food. Adult females live longer than males. Females live from 4 to 8 weeks in the laboratory but may survive up to 3-6 months, particularly if water, sugar from flowers, or blood is available. In some parts of southeastern United States *Aedes albopictus* is replacing *Aedes aegypti* and is becoming more abundant than *Ae. aegypti*.

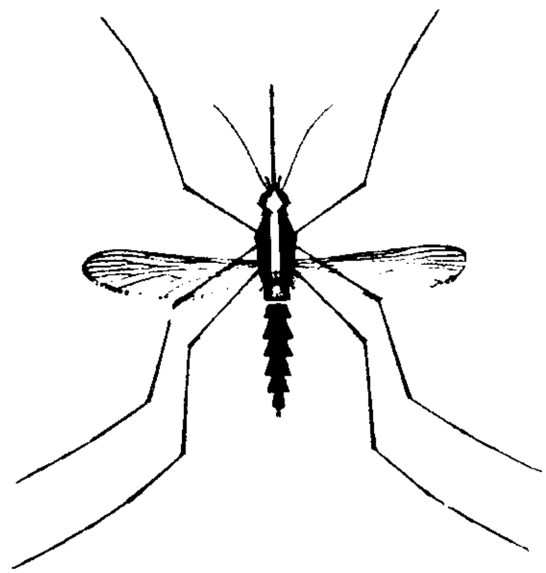


Figure 10. *Aedes atlanticus*

Aedes atlanticus

These brownish mosquitoes with a white stripe on the scutum (Fig. 10) can be separated from *Ae. tormentor* only in the larval stage or by the male genitalia. They are distributed throughout the southeastern states. The species is typically a "woodland" floodwater species whose larvae are found in flooded woodland bottoms or temporary grass pools in or near woods.

Aedes canadensis (Woodland pool mosquito)

This dark mosquito has the tarsi with white at both ends of the segments. It is widely distributed in the United States and is particularly common in the northern states. It is often a serious pest in woodland situations but rarely migrates far from its larval habitats. The viruses of LaCrosse and Eastern Equine encephalitis have been isolated from this species. It has been incriminated in the transmission of dog heartworm (Crans and Feldlaufer 1974).

Aedes canadensis is one of the first mosquitoes to appear in early spring. The larvae live in woodland pools filled by melting snow or by spring rains. This mosquito prefers pools with a bottom of dead and decaying leaves, although larvae are also found in roadside puddles, sink holes, wooded swamps, and isolated oxbows of small woodland streams. There can be more than one generation per year. The adults live for several months. They usually occur from March until October, although they become less abundant in late summer and early fall.

Aedes cantator (Brown saltmarsh mosquito)

The brown salt-marsh mosquito is a rather large, brown species with indistinct white bands on the abdomen and tarsi. It is important along the North Atlantic Coast from Maine to Virginia. *Aedes 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 and is primarily an evening mosquito. Broods frequently migrate considerable distances, invading shore towns and summer resorts. It is often the dominant species of the salt marshes early in the season but yields this position to *Ae. sollicitans* later in the summer.

Aedes cinereus

This small brown species occurs sparsely throughout most the United States. It is occasionally important 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 larval habitats. It is usually single brooded. The larvae occur in shallow woodland pools and along margins of large ponds.

Aedes dorsalis

This is a medium-sized mosquito that varies in color from dark brown to a whitish straw color. The upper surface of its abdomen is marked with a longitudinal stripe of pale scales. The hind tarsi have both ends of each segment banded with pale scales (Fig. 11). *Aedes dorsalis* is a severe pest of humans and cattle throughout the arid and semi-arid regions of the western United States and has been shown to be a vector of Western equine encephalitis. It occurs over most of the country, but is rare and unimportant in the eastern and southern states. Another western species, *Ae. melanimon* is very similar to *Aedes dorsalis.*

A typical floodwater species, the larvae develop in the salt marshes of the Pacific Coast and in irrigation and floodwaters of the interior. They are particularly abundant in irrigated pastures and in waste-water pools. Several broods are produced each year in irrigated areas, each flooding being followed by a brood.

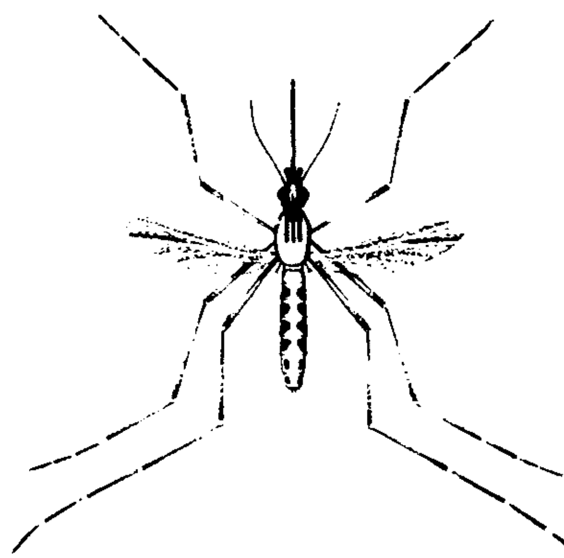


Figure 11. *Aedes dorsalis*

The females of *Ae. dorsalis* are vicious biters that attack by day or night. They are particularly active in the evening or on calm, cloudy days. They are strong fliers and occasionally migrate in large groups. They are often found miles from their larval habitats. The females, and at times the males, are taken in great numbers in light traps. Overwintering takes place in the egg stage. Some eggs can remain viable for several years.

Aedes nigromaculis

This medium-sized mosquito has a longitudinal line of yellowish-white scales on the upper surface of its abdomen. It has a broad band of white scales at the base of each tarsal segment (Fig. 12). This floodwater species is an important pest mosquito throughout the western plains from Minnesota west to Washington and south to Texas and Mexico. Since World War II it has become prominent 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 to be in 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 irrigation waste water and other intermittent water.

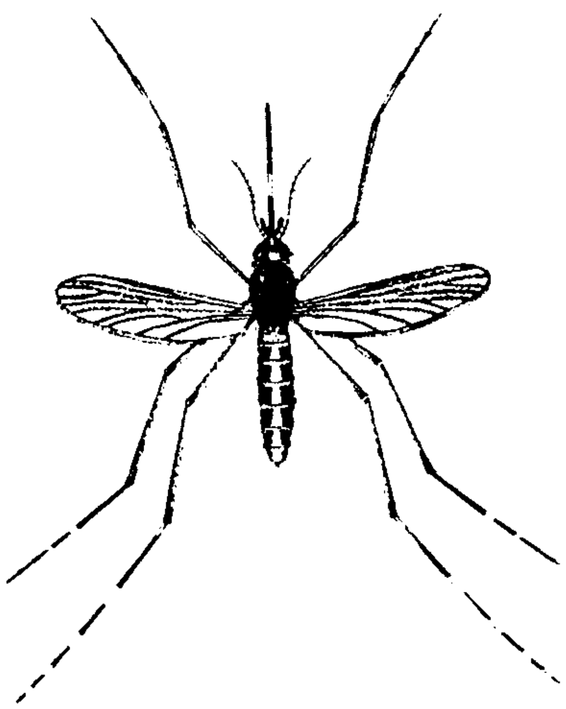


Figure 12. *Aedes nigromaculis*

This species is extremely well adapted to pasture irrigation. The eggs will hatch within 2 to 6 days after flooding. It is able to produce a brood following each irrigation (usually at intervals of 8 to 12 days) in the Central Valley of California. Under favorable conditions, a brood can be produced in 5 days, and as many as 20 broods can occur in one year. The adult is a very annoying pest of man and animals; it attacks readily and inflicts a painful bite. The viruses of WEE, CE and SLE are associated with this species.

Aedes punctor (and related species)

This group of dark-legged *Aedes* includes such species as *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 difficult to identify. The group is well represented throughout the northern United States, Canada, and Alaska.

All species of this group have a single generation per year. The larvae develop in temporary pools formed by melting snow and along the grassy margins of lakes, ponds, and streams. The flight range of adults is probably less than a mile. Females often cause great annoyance in recreational areas near their larval habitats.

Aedes sollicitans (Saltmarsh mosquito)

Aedes sollicitans, the most important of the saltmarsh species (Fig. 13), can be recognized by the golden color of the upper side of the thorax and longitudinal stripe of white or yellowish-white scales on the abdomen. The proboscis and tarsi also have wide pale bands.

The eggs of this species are laid on the mud or on plants in marshes where they remain until flooded by high tides or rains. Larval production 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 large numbers of larvae are found over rather extensive level areas.

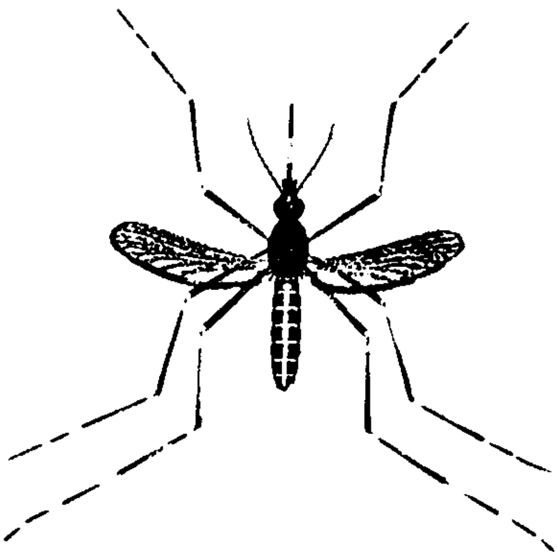


Figure 13. *Aedes sollicitans*

After the eggs have been dry for a week or two, they hatch within a few minutes if covered with water. The development of the larvae and pupae to the adult stage requires 7 to 10 days during warm weather. Several generations are produced each year in the northern states. In South Florida breeding is continuous throughout the year.

The adults of *Ae. sollicitans* are strong fliers that often migrate in large swarms from the marshes to cities and towns many miles away. They often fly 5 to 10 miles and can travel 40 miles or more. The migratory flights begin just before dark and frequently consist of tremendous numbers of mosquitoes. In the daytime they rest on vegetation, and will readily attack anyone who disturbs them, even in full sunlight. They are fierce biters and have been a very severe deterrent to the development of some of the coastal resort areas. Large numbers of females and males are often collected in light traps, but the adults do not often invade houses.

This mosquito species is considered to be an important accessory vector responsible for the transmission of Eastern equine encephalitis from birds to humans and horses.

Aedes spencerii

This species, along with its close relative *Ae. idahoensis,* is an important pest mosquito of the prairie regions of Minnesota, North Dakota, and Montana, extending northward into Canada and southward to Illinois, Iowa, Nebraska, and Utah. The females are fierce biters, attacking during the day, even in bright sunlight. They are serious pests of humans and livestock. They often migrate into cities and towns, but 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 (Floodwater mosquito)

Aedes sticticus is a medium-sized species. The scutum is striped with dark-brown scales and the legs are speckled with white scales but are not banded. It is a floodwater species that occurs throughout most of the United States. It is an important pest mosquito in such widely separated areas as central New York and the Columbia River Valley of Washington and Oregon.

Aedes 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 eggs will survive 2 or 3 years. Larval development requires 10 days to 3 weeks depending upon temperature.

Adults are often very abundant following spring floods. The females are ferocious biters during the evening, and also during the day in 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 the 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.

Aedes taeniorhynchus (Black saltmarsh mosquito)

This species, known as the black saltmarsh mosquito, has cross bands of white scales on the upper side of the abdomen, a white band on the proboscis, and white bands on the tarsi (Fig. 14). It occurs on the coastal plain 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. It is the most abundant and troublesome salt-marsh species along the south Florida coasts and can be a severe pest as far north as New Jersey. It has been incriminated as a vector of dog heartworm.

Larval habitats are similar to those of *Ae. sollicitans,* but larvae are also found 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 Elmore and Schoof (1963), 75 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 miles.

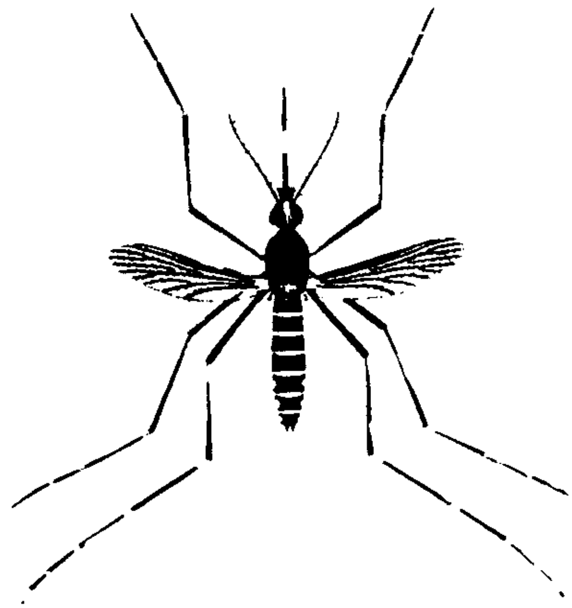


Figure 14. *Aedes taeniorhynchus*

Aedes triseriatus (Eastern treehole mosquito)

This tree-hole mosquito is blue-black and has silvery-white scales on the sides of its scutum (Fig. 15). It occurs throughout the eastern United States, the larvae developing principally in tree holes, old tires, tin cans, barrels, and other artificial containers. Larval development appears to be rather slow; nearly a month is required to reach maturity. Adults are fierce daytime biters in or near infested woods, and are also annoying around

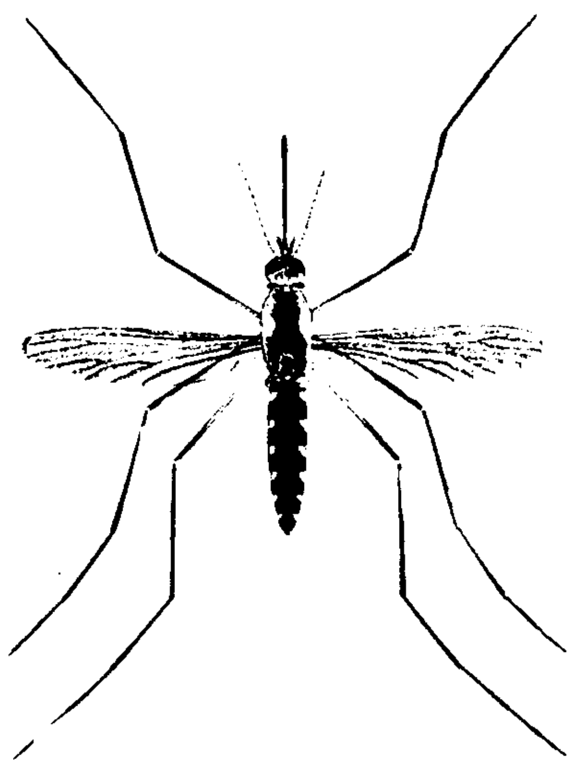


Figure 15. *Aedes triseriatus*

dwellings where larval development occurs in containers or tree holes. The flight range is characteristically short. This species is an important vector of LaCrosse encephalitis virus and dog heartworm.

Aedes trivittatus

Aedes trivittatus is widely distributed in the northern United States from Maine west to Idaho. It has been collected 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 floodwater 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 on grasses and other vegetation during the daytime. They will bite when disturbed and are especially active in the evening. They do not appear to migrate far.

Aedes "varipalpus" Group (Western treehole mosquito)

Collectively, these western tree-hole mosquitoes are a group of small, dark species with brilliant white bands at both ends of each tarsal segment (Fig. 16). They occur in western North America from Arizona to British Columbia, and are important as pest species in some parts of California. At present, *Aedes sierrensis* is considered the correct name for the species on the Pacific Coast. *Aedes varipalpus, Ae. deserticola, and Ae. monticola* occur in other parts of the West. 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. *Aedes sierrensis* has been shown to be an experimental vector of WEE and vector of dog heartworm.

Aedes vexans (Inland floodwater mosquito)

Aedes vexans (Fig. 17), the inland floodwater mosquito, is a medium-sized, 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

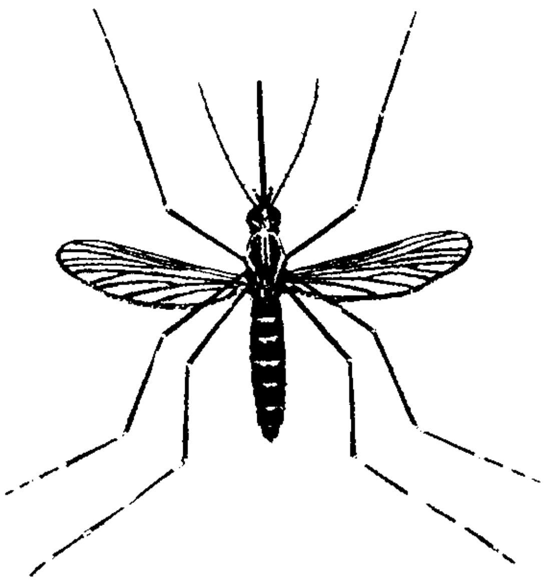


Figure 16. *Aedes sierrensis*

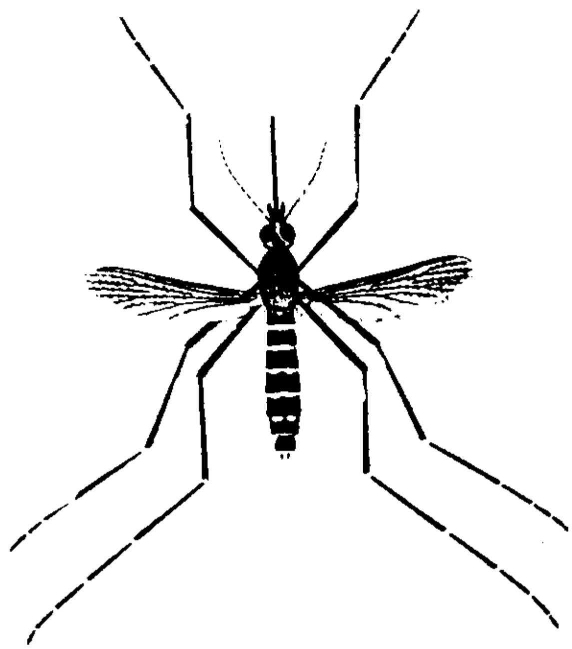


Figure 17. *Aedes vexans*

areas. It has been reported from every state, and is a major pest in most of the northern states from New England to the Pacific Coast. It is less abundant in the extreme South. This species has been found to be naturally or experimentally infected with several arboviruses including SLE, EEE, WEE and LAC.

Aedes vexans larvae are found in rain pools, floodwaters, roadside puddles, and practically all temporary bodies of fresh water. Eggs are laid on the ground, hatching when flooded. 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 generations per year.

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. Clarke and Wray (1969) published an important article indicating that *Ae. vexans* migrated several miles into cities in Illinois about 15 days after flooding by rain of an inch or more in a 24-hour period. Their studies on light trap collections, temperature, and rainfall as they relate to fogging for adult mosquito control contain important information for operational personnel.

GENUS *ANOPHELES*

Anopheline mosquitoes are distributed throughout the United States. One or more species is present in every state except Hawaii. Most anophelines have spotted wings while most culicines have no wing spots. Female anophelines have the palpi about as long as the proboscis, whereas female culicines have the palpi much shorter than the proboscis. Anophelines rest with the head, thorax, and abdomen all in a straight line, held at an angle of 40 to 90° to the surface on which they are sitting. Culicines usually rest with the thorax and abdomen somewhat parallel to the surface on which they are sitting (Fig. 4).

The eggs of anophelines are always laid singly on the water surface and are supported by lateral floats. The female lays her eggs in batches of 100 or more. Each female can lay several such batches in her lifetime--a total of 400 to 500 eggs or more. The eggs hatch in two to six days. Larval production is continuous during the warm seasons of the year.

Anopheline larvae are found in many different types of water, but mainly in permanent bodies of fresh water. Larvae of two species, *Anopheles atropos* and *An. bradleyi* are found in salt or brackish waters. Larvae of all other anophelines in this country develop in fresh water. The larval stages last from 6 to 7 days to several weeks, depending upon the species and environmental conditions, especially water temperature. The larvae feed just beneath the water surface where they ingest microscopic animal and plant life.

Most anophelines favor water that contains aquatic plants, and larvae are often abundant where aquatic plants provide protection from fish and other predators. Most adult anophelines are active at night. They spend the daytime hours resting in dark, damp shelters. They are most active just after dark and again just before daylight. The flight range varies from less than one mile to several miles. Most anophelines need a blood meal before they can produce fertile eggs. The species in the United States feed more frequently on the blood of domestic animals than on man. The winter is usually passed as hibernating, fertilized females. *Anopheles walkeri* overwinters in the egg stage. Anophelines were formerly highly important as malaria vectors in the United States. Currently, however, malaria transmission in this country is a rarity, although anopheline vector populations still exist in many areas. Anophelines have been found infected with encephalitis viruses and might have a role in their transmission.

Anopheles albimanus

This species is the major vector of malaria in the Caribbean Region and in Central America, but has been found only in southern Texas and the Florida Keys in the United States. It is the only anopheline in the continental United States with a broad white band on the hind tarsus.

Anopheles crucians

This anopheline has areas of pale and dark scales on the wings and three prominent dark spots on the last wing vein. The palpi are banded with white (Fig. 18). It has not been considered an important vector of malaria. However, it is susceptible to infection in the laboratory and may have been the vector of a case of malaria contracted in Georgia in 1968. It bites humans readily but is not ordinarily significant as a pest. It occurs throughout the southeastern United States and northward along the coastal plain to Massachusetts. It is most abundant on the Atlantic and Gulf Coastal Plains.

Anopheles crucians larvae are often found in the acid water typical of cypress swamps and ponds in coastal Florida and Georgia.

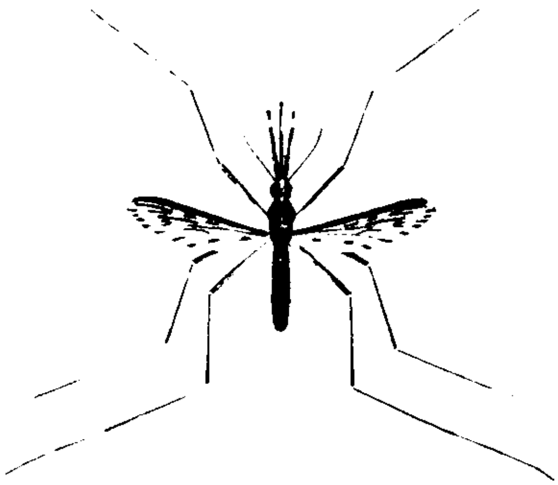


Figure 18. *Anopheles crucians*

Larvae are also found in many other habitats such as lake margins, wheel ruts, and sluggish streams. Adults are found in shelters of the same type frequented by *An. quadrimaculatus*. They are often taken in great numbers in light traps. Their flight range may be somewhat greater than one mile, especially in areas where they are abundant. Two other species in the *An. crucians* complex are *An. bradleyi,* typically a salt-marsh breeder, and *An. georgianus,* whose larvae are found in fresh water seepage.

Anopheles franciscanus

Anopheles franciscanus is similar to *An. 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 is not believed to have been an important malaria vector. *Anopheles franciscanus* is often found at the mouths of rivers entering the Pacific and their larvae occur in abundance in the shallow pools of sandy arroyos. Their larval habitats are similar to those of *An. pseudopunctipennis*.

Anopheles freeborni

This species is similar in appearance to *An. quadrimaculatus,* and was the most important vector of malaria in the western United States. It enters houses 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 from eastern Montana to western Texas and eastern New Mexico.

The aquatic stages of *An. freeborni* are found in permanent or semipermanent waters that are at least partially exposed to sunlight, and contain vegetation or flotage. Clear, clean, slightly alkaline water is preferred. Larvae are also found in slightly brackish water near the ocean or in desert pools. This species usually avoids water polluted with sewage or other organic materials. Habitats may be very similar to those in which *An. 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 or irrigation canals. Rice fields are a particularly favored site for this species. This mosquito is well adapted to the semi-arid region in which it occurs. The midseason flight range of *An. freeborni* females is usually restricted to a one-mile radius. In cases of very large populations in rice fields, longer flights up to 2 1/2 miles have been reported. Males, however, are seldom found more than one-quarter mile from their larval habitats.

In California, *An. freeborni* leave their hibernating places in February, take a blood meal, and lay eggs for the first generation. Because of the abundance of water areas 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 habitats. In late fall at the end of the dry season, females migrate long distances, sometimes 10 to 12 miles, finding shelter in outbuildings, homes and cellars. During the winter season they are in a state of semi-hibernation from which they emerge on warm days and nights for feeding. This winter feeding is seldom to repletion and usually does not result in the development of eggs.

Anopheles hermsi

Adults of *Anopheles hermsi* closely resemble those of *Anopheles freeborni* as described by Barr and Guptavanij (1988). Studies by Fritz, *et al.* (1991) indicate that at present there are no reliable anatomical characters that distinguish eggs, larvae, adults, or X-chromosome of *An. hermsi* from those of *An. freeborni*. These authors wrote "Crossing studies or examination of rDNA restriction enzyme profiles, are presently the only means of identifying *An. hermsi.*" *Anopheles hermsi* occurs in California south of the Tehachapi and west of the Coast Range as far north as San Mateo county. *An. freeborni* has a wide distribution in the western third of the United States. *Anopheles hermsi* wàs probably the vector of malaria from Mexican immigrant agricultural workers to other migrants and a few residents who had never been out of the country in San Diego county, California in 1986 (27 cases) and in 1988 (30 cases).

Anopheles pseudopunctipennis

This species is similar in appearance to *A. punctipennis* except that the palpi are banded with white (Fig. 19). It occurs in south central United States, extending into Mexico, Central and South America. *Anopheles pseudopunctipennis* is considered an important vector of malaria in foothill regions of Mexico and parts of South America.

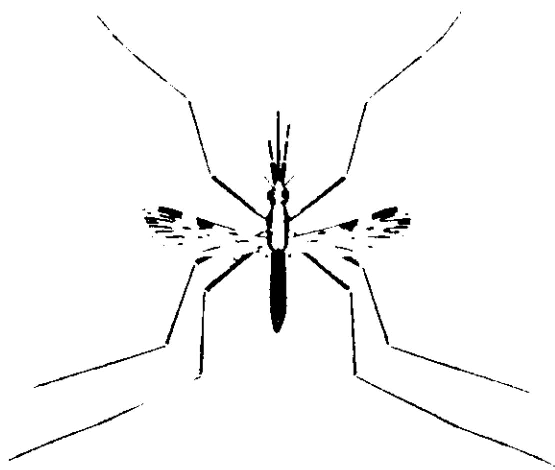


Figure 19. *Anopheles pseudopunctipennis*

Anopheles pseudopunctipennis larvae are found in pools in shallow or receding streams, especially those in full sunlight containing luxuriant growth of green algae. They also are found in other ground pools, 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 usually a mile or less.

Anopheles punctipennis

This mosquito has the wings conspicuously marked with spots of pale and dark scales (Fig. 20). The palpi are entirely dark. It probably occurs in all of the contiguous states. This species is not known 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 *An. quadrimaculatus* and *An. freeborni*.

Anopheles punctipennis larvae occur in a wide variety of habitats. Larvae are often found along with *An. quadrimaculatus* in

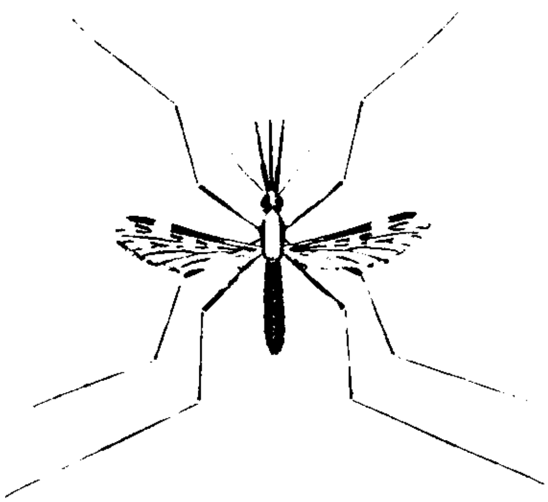


Figure 20. *Anopheles punctipennis*

permanent pool situations, or in rain barrels, hog wallows, grassy bogs, spring pools, swamps, and along margins of streams. They seem to prefer cool water and are the first anophelines to appear in the spring. They are the most abundant during the spring and fall in the southern states but are found in more uniform numbers throughout the summer in the northern states.

Anopheles quadrimaculatus (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 (Fig. 21). This species was the most important vector of malaria in the United States. It is the anopheline most frequently found in houses and is, with the possible exception of *An. freeborni*, more likely to attack humans than any other anopheline of the United States. *Anopheles quadrimaculatus* has probably been responsible for the transmission of almost all human malaria that has occurred east of the Rocky Mountains.

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 is most abundant 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.

Anopheles quadrimaculatus larvae are found 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. It 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. Production is greatest in waters with aquatic vegetation or flotage of twigs, bark and leaves.

The most favorable temperature for the development of *An. quadrimaculatus* is between 85 and 90° F at which temperature only about 8 to 14 days are required. The 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 males emerge first, remaining near the larval habitats. The females mate soon after emergence, often during their first day, either before or after the first blood

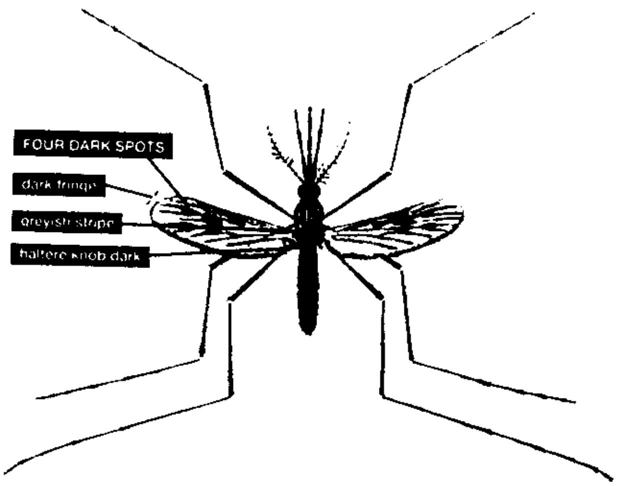


Figure 21. *Anopheles quadrimaculatus*

meal and egg laying begins from 2 to 3 days after the first blood meal. A single female may deposit a total of over 3,000 eggs in as many as 12 batches.

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 and readily 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 not more than one-half mile from their larval habitat and only a small percentage fly farther than one mile. *Anopheles quadrimaculatus* is not ordinarily taken in light traps in great numbers. In the most southern part of the country, *An. quadrimaculatus* production occurs continuously throughout 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 females 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 from 4 to 5 months.

Anopheles walkeri

This species resembles *An. 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, and as far west as Minnesota, Nebraska, Kansas, and Texas. *Anopheles walkeri* readily bites humans and is a good laboratory vector of malaria. Its past epidemiological importance in relation to malaria is undetermined.

Anopheles walkeri larvae are often found 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 passes the winter. The adults often rest during the day on the lower part of the stems of sedges and grasses and other emergent vegetation of their larval habitats. *Anopheles walkeri* is frequently collected by the hundreds or thousands in light traps.

THE GENUS *CULEX*

The genus *Culex* includes about 300 species, most of which occur in the tropical and subtropical regions of the world. Some 29 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 mosquito larvae are found 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 larval habitat. The eggs are deposited in rafts of 100 or more. They remain afloat on the water surface until hatching occurs some 2 or 3 days later. Larval development continues throughout the warm season with several generations a year in the southern states. The adult females are generally inactive during the day, biting at night.

Culex erraticus, (and the subgenus *Melanoconion)*

Culex erraticus, Cx. peccator, and *Cx. pilosus* are rather small and dark species found in the southeastern states. The females are difficult to determine. Larvae of *Culex erraticus,* the most common species of this group, occur in grassy permanent pools and ponds often in association with anophelines. They have been reported 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.

Culex nigripalpus

This is chiefly a tropical mosquito but occurs as far north as Tennessee and North Carolina. It is quite common in Florida where it is an important pest species in flooded fields. Larvae are also found in ditches and grassy pools. *Culex nigripalpus* was the vector of St. Louis encephalitis virus in the Tampa Bay, Florida, outbreak in 1962 (Chamberlain, 1987), and in Florida in 1990.

Culex stigmatosoma

This is a western species similar in appearance to *Cx. tarsalis.* Larvae are found in almost all types of ground pools and artificial containers. In California tremendous numbers of larvae have been reported in oxidation ponds. *Culex stigmatosoma* rivals *Cx. tarsalis* in abundance in the Pacific Coast states, but apparently seldom bites humans. It has been found infected with western equine encephalitis virus.

Culex pipiens Complex (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. *Culex pipiens pipiens,* the northern house mosquito, occurs throughout northern United States and is found as far south as Georgia and Oklahoma. *Culex pipiens quinquefasciatus*, the southern house mosquito, (Fig. 22) occurs in all southern states from coast to coast and is found northward to Nebraska, Iowa, Illinois, and Ohio. One or both of these mosquito species are found in every state. In many published articles from outside the United States, this mosquito is referred to as *Culex fatigans*.

In the United States, members of the *Culex pipiens* complex are important vectors in urban epidemics of St. Louis encephalitis.

Culex pipiens pipiens and *Cx. pipiens quinquefasciatus* develop 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. Heavy production is often found in water with high organic content.

House mosquitoes lay their eggs in clusters

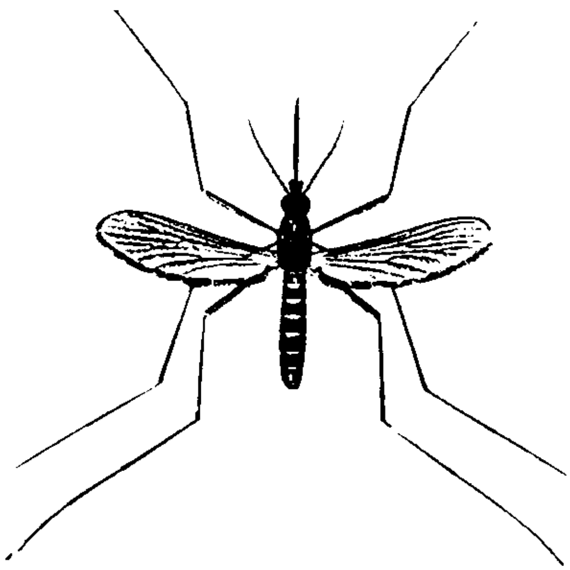


Figure 22. *Culex pipiens quinquefasciatus*

of 50 to 400. These clusters, known as egg rafts (Fig. 4), float on the surface of the water. The eggs hatch within a day or two in warm weather. 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, these aquatic stages may require weeks or more. Larval production continues throughout the warmer months of the year. Some strains can survive and produce fertile eggs without a blood meal (autogeny).

House mosquitoes migrate only short distances unless great numbers are produced. Ordinarily, when adults are present, larvae will be found nearby. These species 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 larval habitats. They are attracted to light traps, but the numbers collected may not represent an accurate index of their actual abundance.

Culex restuans (White dotted mosquito)

This species is widely distributed east of the Rocky Mountains from the Gulf of Mexico into Canada. Some observers report that it is often abundant and annoying in the eastern states, while others say that it rarely bites man. It is similar in appearance and habits to *Cx. pipiens* although it is not usually as important a pest and is more rural in its occurrence. It is distinguished from *Cx. pipiens* by the two silvery dots on the scutum (Fig. 23) and by the pattern of bands on the abdomen.

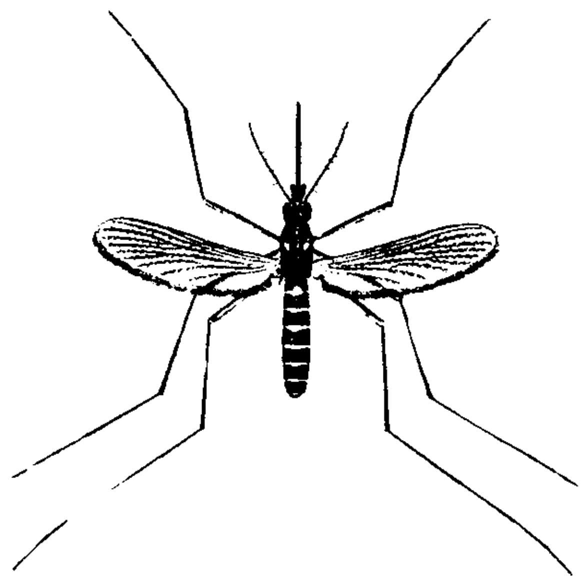


Figure 23. *Culex restuans*

Culex restuans larvae often are found in rather foul water such as that containing decaying grass or leaves. Favored larval habitats are woodland pools, ditches, pools in streams, rain barrels and tin cans. It appears early in the season and continues development throughout the summer.

Culex salinarius (Unbanded saltmarsh mosquito)

Culex salinarius occurs throughout most of eastern United States. It is 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, along lake margins, and in marshes, cattail bogs, ponds, and ditches.

Culex tarsalis

Culex tarsalis mosquito (Fig. 24) 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 an important pest species in some parts of its range. It is most active soon after dusk and may enter buildings in search of blood.

Culex tarsalis has been found naturally infected with the virus of both St. Louis and Western equine encephalitis and laboratory experiments have also demonstrated its ability to transmit both diseases. *Culex tarsalis* is considered to be the most important vector of encephalitis to man and horses in the western states (Reeves 1990).

Culex tarsalis is widely distributed and abundant west of the Mississippi River. It occurs less commonly east to Ohio, Rhode Island, Virginia, and Florida, and in southwestern Canada and northern Mexico.

Larvae of this species develop in a wide variety of aquatic situations. In the arid and semi-arid regions, they utilize almost all types of water and are most frequently found in temporary to semipermanent bodies of water associated with irrigation. These include canals, ditches, borrow pits, impoundments, ground pools, and hoof prints. Larvae develop in effluent from cesspools and other waters containing large quantities of organic material from human wastes, and in artificial containers of various types such as cans, jars, barrels, drinking troughs, ornamental ponds, and catch basins. Females deposit egg rafts that contain from 100 to 150 or more eggs each. The eggs usually hatch within 48 hours. The larval and pupal stages develop rapidly. Larval production continues from early spring until late fall.

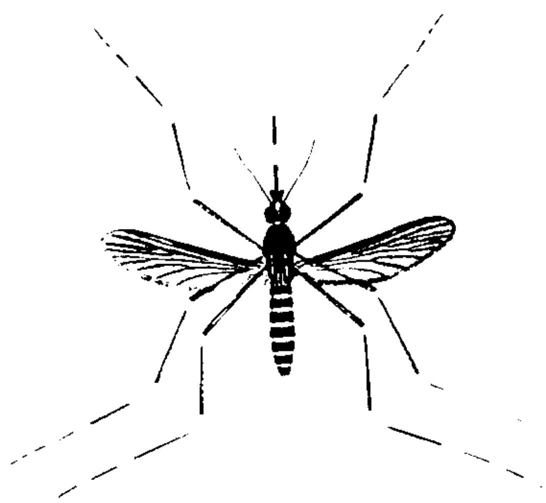


Figure 24. *Culex tarsalis*

Adult females hibernate in the northern areas of the United States. 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, in rodent burrows, or along cut banks of streams. It has a wide range of hosts, showing some preference for birds, but also feeding on cows, horses and humans. Dispersion studies have shown that *Cx. tarsalis* will fly at least 11 miles, although the majority 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 (Sudia and Chamberlain 1967).

Culex territans

Culex 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.

THE GENUS *CULISETA*

Members of this genus are somewhat similar in appearance and habits to *Culex*. There are 8 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 is the most common culicine mosquito with spotted wings in the United States. It is principally western in distribution and is reported from Texas, Oklahoma, Nebraska, and all states in 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. *Culiseta incidens* larvae are found 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.

Culiseta inornata

This is a large, grayish-brown mosquito with broad, pale-scaled wings (Fig. 25). 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; in the South it is more common during the winter. This mosquito does not usually attack man, but it does feed on domestic animals and is sometimes a considerable annoyance to livestock. *Culiseta inornata* has been found naturally infected with western equine encephalitis virus and Jamestown Canyon virus. In laboratory experiments it has been shown capable of transmitting WEE virus. However, since it seldom feeds on humans, it is unlikely to be an important vector of WEE to humans.

Larvae of *Cs. 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.

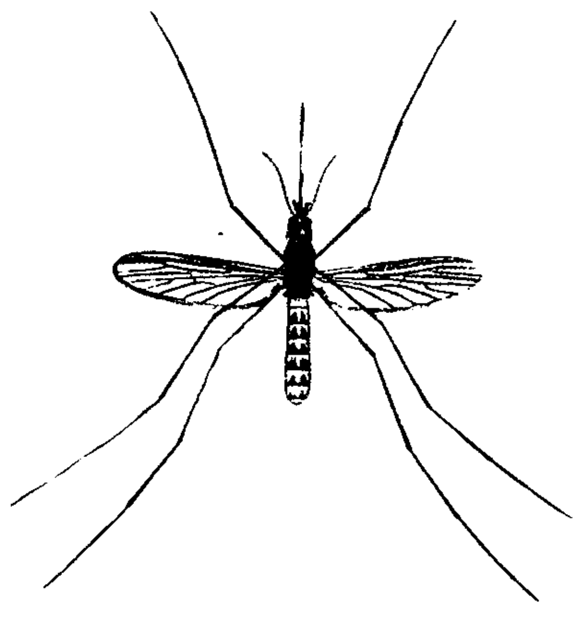


Figure 25. *Culiseta inornata*

Culiseta melanura (Blacktailed mosquito)

Culiseta melanura (Fig. 26) is a small dark species that resembles members of the *Culex* group more closely than do other species of *Culiseta*. It occurs throughout most of the eastern United States from the Gulf States to

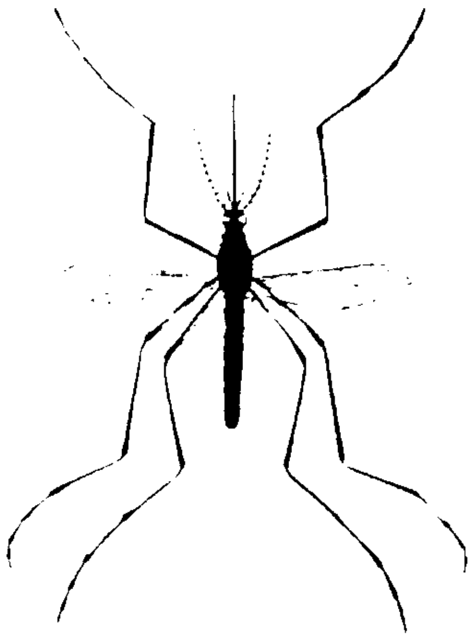


Figure 26. *Culiseta melanura*

Canada. The larvae develop in water beneath stumps and roots of trees in wooded swamps. Adults have been taken in considerable numbers in light traps and to a lesser extent in daytime resting stations. This mosquito has often been found naturally infected with the viruses of Eastern equine, Highlands J and California encephalitis. *Culiseta melanura* is considered the primary vector of EEE virus from bird to bird. Since it rarely bites man it is not the vector of EEE virus to humans (Chamberlain 1987).

THE GENERA *MANSONIA* AND *COQUILLETTIDIA*

These closely related genera include three species in the United States, one of which is widespread and common. They are vicious biters in many areas. They lay their eggs 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 and obtain air from the plants. Because of this unique habit, these larvae cannot be controlled by the use of ordinary surface larvicides.

Coquillettidia pertubans (formerly *Mansonia perturbans)* (Irritating mosquito)

This is a rather large, speckled, brown and pale mosquito (Fig. 27). It has characteristic pale bands at about the outer third of both the hind femur and the hind tibia. This species is found 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 Pacific Coast states. This species has been found naturally infected with the virus of eastern equine encephalitis in many states from Florida to New York. It may be a primary vector in many inland areas.

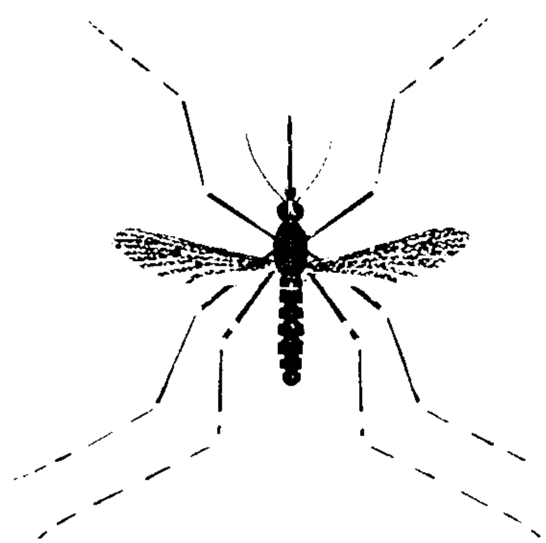


Figure 27. *Coquillettidia perturbans*

Coquillettidia perturbans larvae are found in marshes, ponds, and lakes that have a thick growth of aquatic vegetation. Larval development is unusually slow. The larvae that hatch in any one season do not ordinarily complete their development until the following spring. Although they may detach from their host plants and move about, the larvae remain below the water surface during the entire larval period. 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 state requires 5 to 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 smaller second brood may be produced in Florida. Larvae have been found attached to a number of different kinds of plants, particularly pickerel weed, cattail, water lettuce, arrowhead, aquatic sedges, and swamp loosestrife.

The females bite during the daytime in shady, humid places but are much more 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.

Mansonia titillans

This tropical species is fairly common in Florida and has also been reported from south Texas. It has been found in nature infected with Venezuelan equine encephalitis virus. The adults are severe biters and fairly important pests in Florida. The eggs of *Ma. 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 *Cq. perturbans*. The adults are frequently taken in light traps.

THE GENUS *PSOROPHORA*

Fifteen species of *Psorophora* are found in the United States, ten of which are widely distributed in the southern and eastern states. Two species, *Ps. columbiae* and *Ps. discolor*, probably were important vectors of Venezuelan equine encephalitis virus during the Texas outbreak in 1971 (Sudia and Newhouse 1975). Many species of *Psorophora* are fierce biters. The larval habitats of this group are similar to those of the typical *Aedes*, to which they are closely related. Females lay eggs on the ground. These eggs can withstand drying and lie dormant for months. They hatch quickly upon being flooded and the larvae develop rapidly.

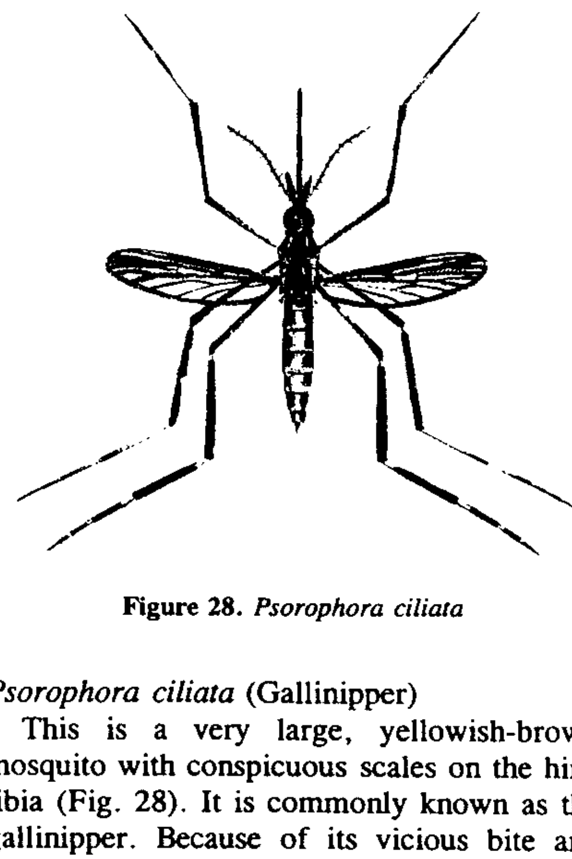


Figure 28. *Psorophora ciliata*

Psorophora ciliata (Gallinipper)

This is a very large, yellowish-brown mosquito with conspicuous scales on the hind tibia (Fig. 28). It is commonly known as the gallinipper. Because of its vicious bite and large size, this is one of the most formidable mosquitoes. *Psorophora ciliata* is widespread through the eastern United States from Mexico to Canada. It is locally abundant in the South and the Midwest. When present in numbers, it is a very annoying pest that attacks both by day and by night. *Psorophora ciliata* is one of the few species whose larvae feed on other aquatic insects, including mosquito larvae. These larvae are found in temporary pools, often in association with *Ps. columbiae* and *Aedes vexans,* upon which they feed. A fourth instar larva of *Ps. ciliata* can consume three or four other larvae in one day. *Psorophora ciliata* larvae are easily recognized in the field as they are two or more times as long as larvae of most other species. They hang almost straight down from the water surface. The larval and pupal stages are short as is characteristic of this genus of mosquitoes. The eggs are laid on the surface of drying soil. They hatch when flooded as do *Ps. columbiae.* Overwintering takes place in the egg stage.

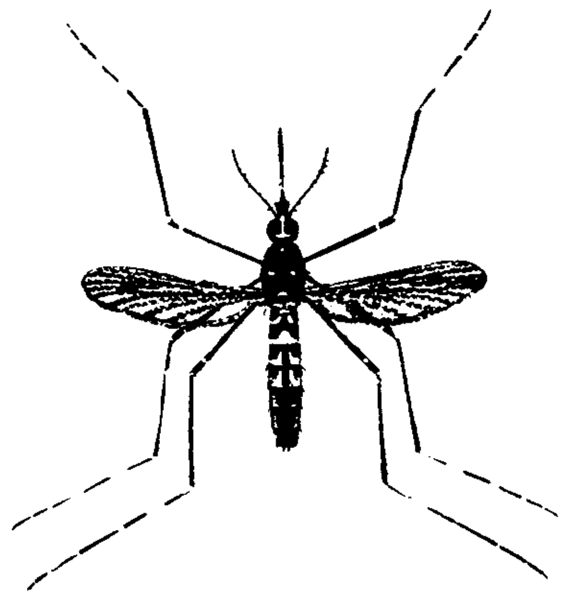


Figure 29. *Psorophora columbiae*

Psorophora columbiae (formerly *Psorophora confinnis)* (Dark rice field mosquito)

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 and has a narrow ring of white-scales near the tip of each femur (Fig. 29). *Psorophora columbiae* is the most widespread and important species of *Psorophora* in the United States. It occurs throughout the southern United States, extending westward to southern California and northward to Nebraska, lowa, New York, and Massachusetts. It reaches its greatest abundance in the Florida Everglades and in the rice fields of Texas, 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. This species was incriminated in the transmission of Venezuelan equine encephalitis virus during the epidemic in Texas in 1971 (Sudia and Newhouse 1975). Other viruses isolated from the species include WEE and CE.

Psorophora columbiae larvae develop 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 one of the preferred sites for egg laying. If eggs remain on the surface of the soil for 2 or 3 weeks or longer, and are then flooded, hatching can begin within a few minutes. This species overwinters in the egg stage. During the midsummer in Arkansas, the larval stages can be completed in as few as 4 days. The average time at a mean temperature of 79° F is slightly over 5 days. The pupal stage lasts 1 or 2 days. The number of generations per season is from one to many, depending on how often suitable hatching conditions occur. Areas which dry up and are then flooded a few days later can produce a brood with each flooding. Such conditions are provided with certain types of irrigation, particularly wet rice culture. Many adults live only a week or two:

some live as long as a month or two. The flight range is at least 10 miles.

Psorophora cyanescens
This metallic blue species has entirely dark tarsi. It has been reported from all the southern states north to Illinois and Indiana. It is abundant in Oklahoma and Arkansas, as well as in certain areas of Alabama, Mississippi, Louisiana, and Texas. It is a vicious biter and attacks during either the day or night. In Arkansas and Oklahoma, it has on occasion become extremely numerous and pestiferous after rains in July and August. It breeds in temporary rain pools and its life history is similar to that of *Ps. columbiae*. It was a most annoying pest in the Rio Grande Valley in Texas following the floods of 1967.

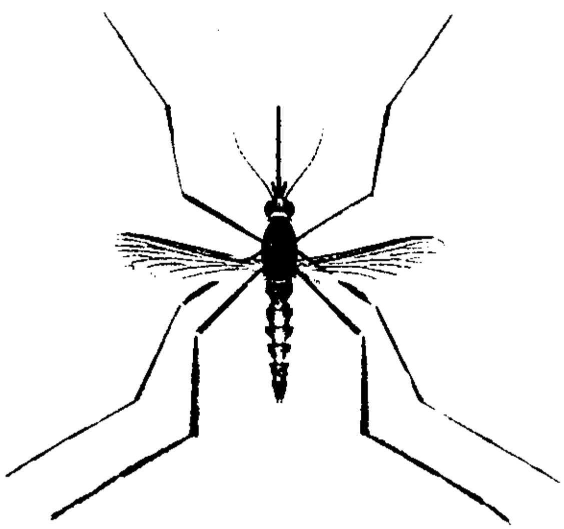


Figure 30. *Psorophora ferox*

Psorophora ferox (White-footed woods mosquito)
This brilliant blue-purple mosquito is known as the white-footed woods mosquito because the last two segments of the hind tarsi are entirely white (Fig. 30). It occurs in swampy woodlands in most of the states from Texas to Nebraska and eastward. It is a persistent and painful biter that attacks readily during the day. The larvae, which develop in temporary pools, are easily recognized by their antennae which are longer than the head.

Psorophora signipennis
This is a common species in the 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 severe a pest as the numbers taken in light traps might indicate. Both LAC and WEE viruses have been isolated from this species. *Psorophora signipennis* is well adapted to breeding in temporary ground pools in arid regions. Its development from egg to adult can be completed in 5 days under favorable conditions.

Other Species *of Psorophora*
A number of other species of *Psorophora* can be annoying at times, particularly in the southern states, and one or more may be important in disease transmission. These include *P. discolor, P. horrida, P. varipes,* and *P. howardii*. The latter is very similar to *P. ciliata* in both larval and adult habits. The other three species have breeding habits similar to *P. columbiae* but are rarely as abundant.

OTHER MOSQUITOES

Five other genera of mosquitoes occur in the United States. Four species of *Uranotaenia* larvae are found in ground pools, the grassy margins of lakes, and occasionally in tree holes and pot holes. *Uranotaenia sapphirina* is a tiny species with brilliant iridescent scales on some wing veins and the thorax. It is taken readily in light traps. Four species of *Wyeomyia* larvae develop in small collections of water in the leaves of pitcher plants and bromeliads, in other living or dead plants, and in tree holes. *Deinocerites cancer, De. mathesoni, and De. pseudes* comprise an interesting genus of mosquitoes whose larvae are found in salt water in crab holes in southern Florida and Texas. *Orthopodomyia signifera* and *Or. alba* are highly ornamented species that differ chiefly in their larval stages. Their larvae develop in water in tree holes and in water in leaf bases of bromeliads. *Orthopodomyia* sometimes are collected in large numbers in artificial containers, such as old refrigerators, when abundant organic matter is present. They often share the containers with *Culex restuans, Cx. pipiens quinquefasciatus,* and *Aedes triseriatus*. The two *Toxorhynchites* subspecies, *rutilus* and *septentrionalis,* are large, brilliantly colored, nonbloodsucking mosquitoes. The huge, clumsy larvae prey upon other mosquito larvae in tires, tree holes,bromeliads, and other water-holding containers.

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** determines the species of mosquitoes, and their sources, locations, densities, and flight ranges. It can also include information on life cycles, feeding preferences, larval habitats, adult resting places, transmission of human and animal diseases, susceptibility to insecticides, recommendations for a control program, and the setting up of immediate aims and long-term objectives
2. **The operational survey or surveillance** is a continuing evaluation, which is extremely valuable in the daily operation of a mosquito-control program. It furnishes 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 relative 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 schematic map is used for orientation and for locating and recording 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. 31) illustrates the type of information needed for a small project. When larger areas are to be protected, it is best to have a master schematic map and large-scale area maps showing details for planning drainage and other control operations in the field. Urban mosquito control programs require detailed maps in which each block is numbered. The master schematic map will show the areas to be protected, the possible flight range of mosquitoes from different larval habitats, and the degree of penetration into areas to be protected. All larva and adult stations are shown by symbols and numbers. Counts made at these stations at regular intervals permit evaluation of the mosquito problem at any time by indicating the abundance of mosquitoes, the species involved, the flight range, and the areas requiring high priority for treatment.

ADULT MOSQUITO SURVEYS

Purpose

The number and relative abundance of the various mosquito species in a community can be estimated by surveys of the adults. By consulting references on the habits of the different species, the vector control specialist can determine where to look for the larval habitats and decide the need for a control program. Adult mosquito information indicates the best times and places to use space spray equipment. It is also a source of reports to supervisors and the public concerning the extent of the problem and results of control operations. Interpreting mosquito survey reports correctly results in the most efficient use of manpower, materials, and equipment.

Equipment

The equipment required for a survey consists of a collecting tube (also known as an aspirator), a killing tube, pill boxes, cases for live mosquitoes, field record forms or notebook, flashlight, and map (Fig. 32). Various kinds of traps and other collecting devices can also be used.

The killing tube can be made from a glass or plastic tube of any convenient size. Test tubes about l-inch diameter by 7 inches long are preferred. Pour about an inch of plaster of paris mixed with water into the bottom of the tube and allow the plaster to dry. Add sufficient ethyl acetate to saturate the plaster of Paris. Then press two or three discs of blotting paper (cut slightly larger than the tube) down over the plaster. Close the tube with a cork or rubber stopper. The collecting tube will stay effective for several weeks and can be recharged when necessary by removing the discs and adding more ethyl acetate. Some workers wrap the base of the killing tube with adhesive tape to lessen the chance of breakage: some add a paper cone (base up) inside the mouth of the tube to trap specimens more easily. The addition of crinkled tissue paper to the tube helps keep specimens dry, and, by preventing their getting broken, makes identification easier.

A simple aspirator is prepared from a section of rigid 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 fine cloth netting or metal gauze and then inserted into a piece of rubber tubing 2 to 3 feet long (Fig. 32). A flashlight-battery-operated aspirator is described by Sudia and Chamberlain (1967).

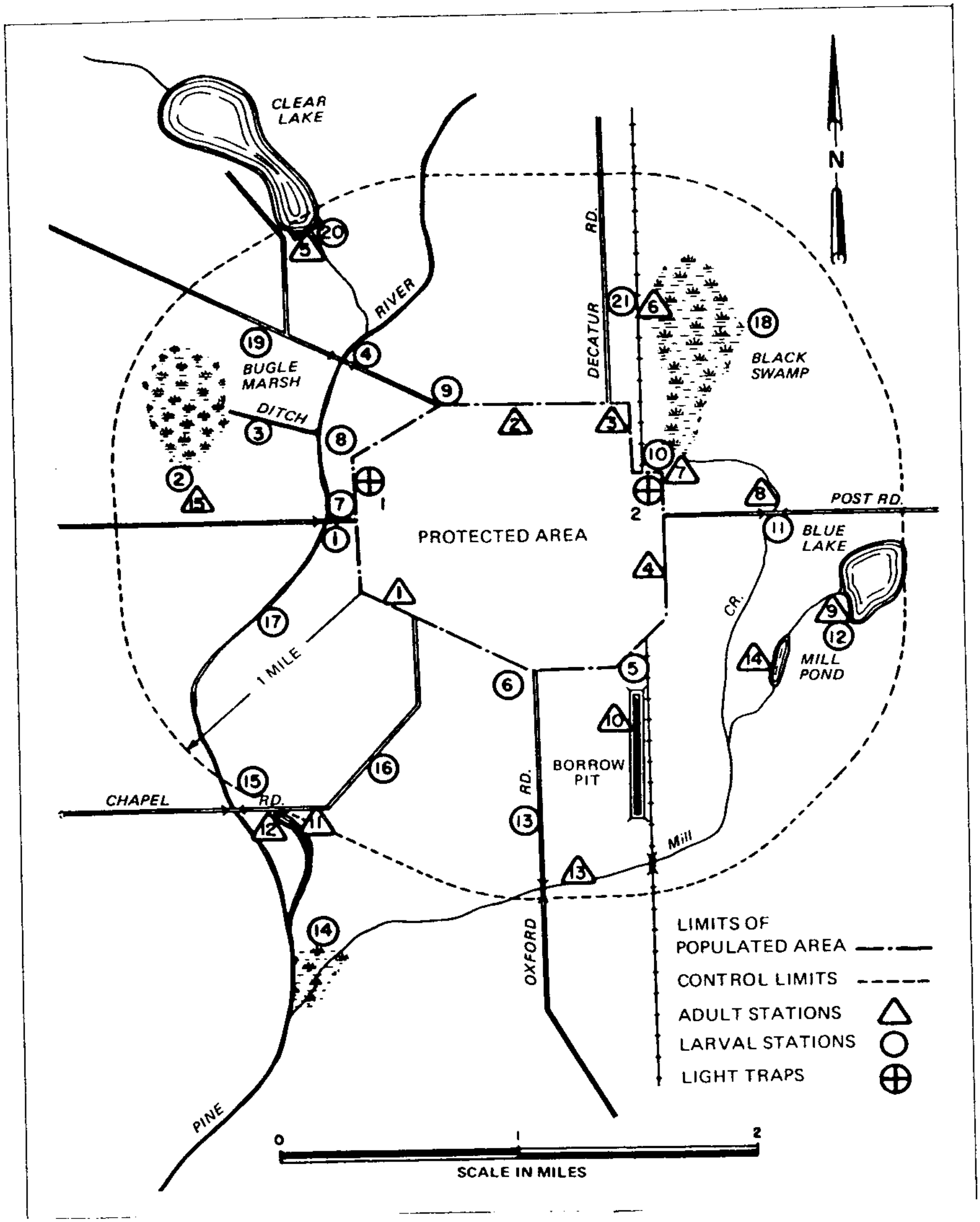


Figure 31. Schematic Map Showing Mosquito Sampling Stations

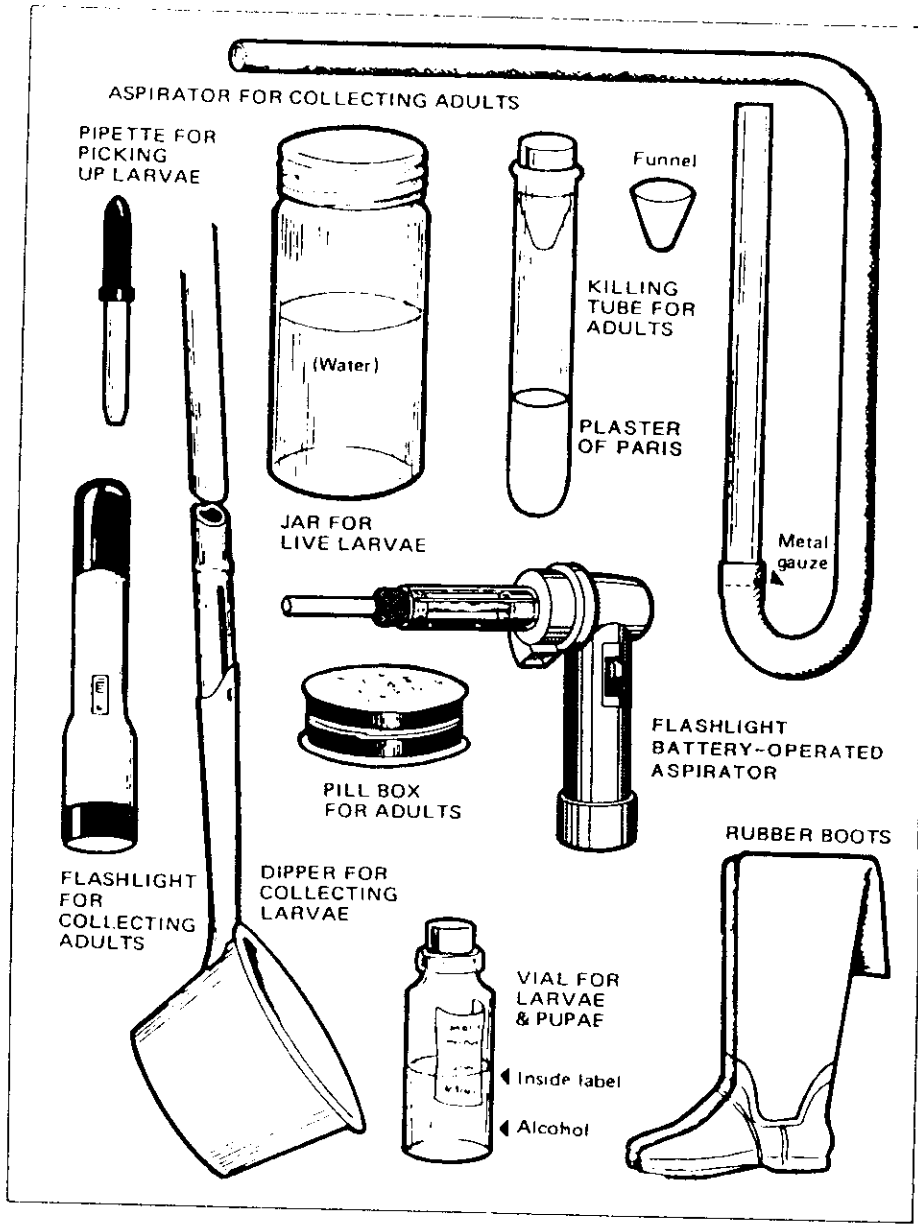


Figure 32. Equipment for Mosquito Surveys

Small pill boxes or salve boxes are convenient for holding dead mosquitoes until they can be identified. The mosquitoes should be placed between layers of facial tissue with enough additional tissue to prevent damage to the specimens as they are carried about or shipped to a laboratory for identification.

Excellent discussions and pictures of survey techniques and equipment are included in articles by Sudia and Chamberlain (1967); Bidlingmayer (1959); and Service (1976).

Biting Collections

Collecting mosquitoes as they bite or land to bite is a convenient method of sampling populations. In making biting collections or counts, part of a person's body is exposed by rolling up sleeves or trousers, or by removing the shirt. The person should sit quietly for a designated period of time, usually 10 or 15 minutes. Mosquitoes are collected with an aspirator 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 large cow or 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.

Biting collections should not be made from humans in areas where encephalitis activity is likely. 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 control efforts. The landing-rate method has been used especially with certain species of *Aedes* or *Psorophora* found in salt marshes, rice fields, and the arctic and subarctic tundras.

Bait Traps

Animal bait traps, or stable traps (Fig. 33), 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 numbers of other insects, and in areas where electric power is not available. 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 entrance slots 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 (Fig. 33), 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, mules, donkeys, calves, sheep, and hogs have been used as bait.

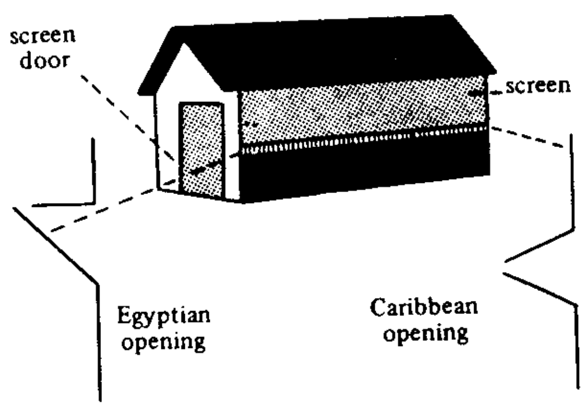


Figure 33. Animal Bait Trap

Window Traps

Window traps (Fig. 34) employing the same principle as the animal bait trap are sometimes used. The humans sleeping inside serve as bait. The entrance slots can be mounted in the windows of the buildings with the screen cages inside to catch mosquitoes as they enter. More frequently, in malaria control programs, the cages are placed outside, for mosquitoes which have rested on an insecticide-treated surface often have the urge to leave a treated house at daybreak.

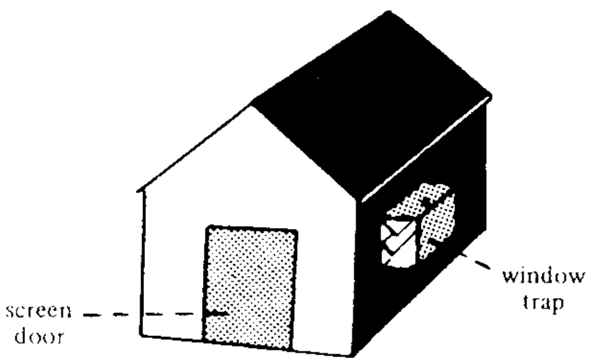


Figure 34. Window Trap

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. This trap (Fig 35), made from a 12-inch lard can with two inwardly directed screen tunnels, is baited with about 3 pounds of dry ice wrapped in newspaper. It is effective in capturing large numbers of *Culex tarsalis*.

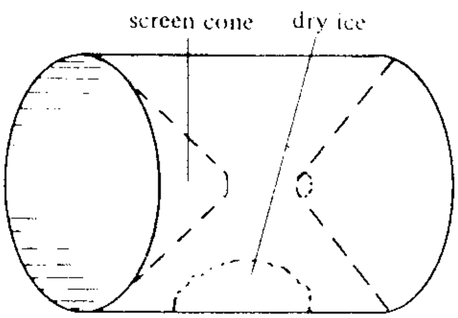


Figure 35. Carbon Dioxide Trap

Insect Nets

Insect nets are used to collect mosquitoes from grass and other vegetation. This type of collection is valuable in determining the abundance of those species, such as *Aedes vexans, Ae. sollicitans, Ae. taeniorhynchus, Ae. nigromaculi,* and *Ae. triseriatus,* which rest on vegetation.

Daytime Resting Places

Adults of many species are inactive during the day, resting quietly in dark, cool, humid places. Careful counts of mosquitoes in daytime shelters give an index to the population density of these mosquitoes. This method is especially useful for anopheline mosquitoes and is commonly used for *Anopheles quadrimaculatus* and *An. freeborni.* It is also of value in estimating populations of some culicines such as *Culex quinquefasciatus, C. tarsalis.* and *Culisela melanura.* The shelters are also a source of specimens for various tests. Mosquito resting stations are divided into two general types: natural and artificial.

Natural Resting Stations

These are the resting stations usually present in houses, barns, stables, chicken houses, privies, culverts, bridges, caves, hollow trees, and overhanging banks along streams. With experience one becomes capable of evaluating the suitability of shelters as adult mosquito resting stations. Dwellings, especially when unscreened, often prove to be satisfactory resting stations. They are especially important when mosquito-borne diseases are being investigated. Under such conditions they furnish an index to the number of mosquitoes which could bite man and transmit encephalitis, malaria, or other disease.

Artificial Resting Stations

Suitable resting stations may not be

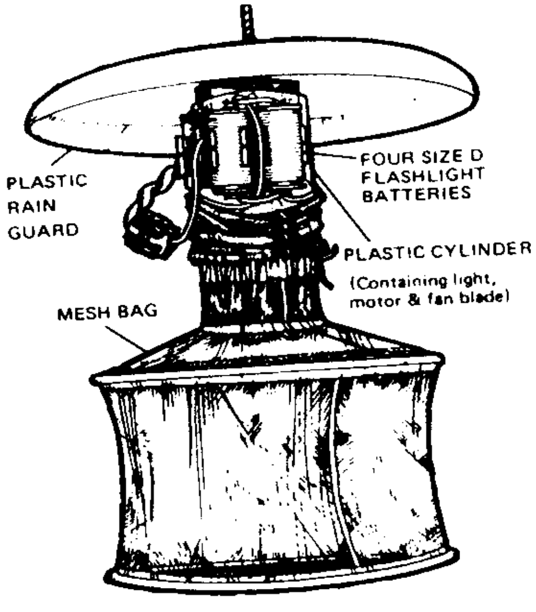
available in sufficient numbers to give a satisfactory evaluation of the mosquito population. It may be necessary to construct special shelters or to use boxes, barrels, kegs, etc., as artificial resting stations. Many different types of artificial shelters have been used. They should always be placed 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 as boxes, each side one foot long and painted red on the inside, or as artificial privies 4 feet square and 6 to 7 feet high, have been used successfully in the United States.

Light Traps

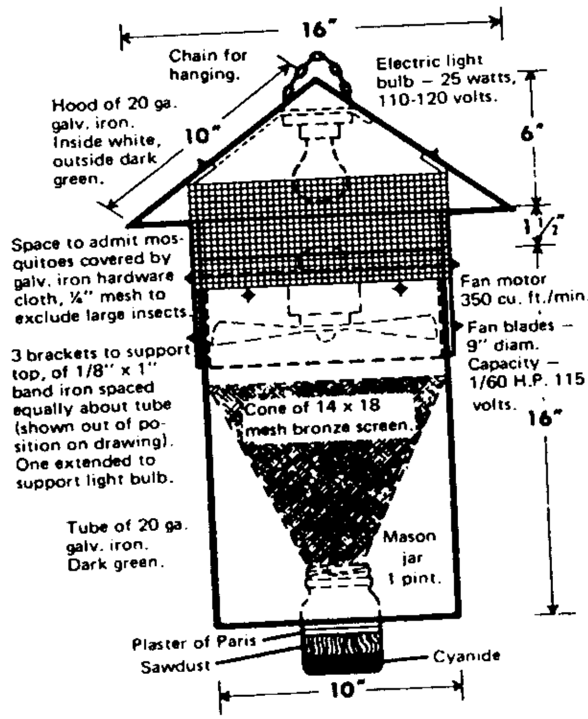
Many mosquito species are attracted to light. This reaction makes it possible to sample adult populations between dusk and dawn. The New Jersey mosquito light trap, developed in the 1930's, has been widely used in obtaining data on the density and species composition of mosquito populations.

The American mosquito light trap (Fig. 36) 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 capture of moths and other "trash insects" and to permit construction from easily available parts (Mulhern 1974).

Mosquito light traps attract adults from a considerable area when the traps are placed away from competing light sources. As the mosquitoes reach the light, they are blown downward through the screen funnel into a killing jar or mesh bag suspended below the trap. The light and fan are usually powered by alternating current, 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



A. CDC MINIATURE LIGHT TRAP



B. AMERICAN LIGHT TRAP

Figure 36. Mosquito Light Traps

or cotton and a layer of plaster of Paris or cardboard. For safety reasons, instead of cyanide, a layer of plaster of paris saturated with ethyl acetate can be used. Some workers use paradichlorobenzene or dichlorvos plastic strips in the killing jar. Frequently a perforated paper cup is placed in the mouth of the killing jar to hold the specimens, keep them dry, and make removal easier.

The mosquito light trap is mounted on a post, or hung from a tree, so that the light is about 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 that give off smoke or other fumes. 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 or photoelectric cell can start and stop the trap, or it can be turned on and off by hand. The collection should be removed each morning and placed in a properly labeled box, sorted and identified.

The CDC miniature light trap (Fig. 36) was developed for greater portability in making live mosquito catches in remote areas which could not otherwise be sampled (Johnston *et al.* 1973). This small plastic trap was field tested, resulting in catches of about one half as many mosquitoes as the New Jersey trap, or its modification, the American light trap used in California. 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 the American and CDC miniature light traps exclude many large insects.

The CDC miniature light trap weighs only 1 3/4 pounds. It can be disassembled readily for easy transport and has a collapsible catching bag. The large plastic aluminum canopy protects the operating mechanism, even in the heaviest rainstorms. It can be operated with one 6-volt battery or four 1 1/2-volt flashlight "D" cells, which provide sufficient power for one night. The Aristo-Rev No. I motor, which is available from hobby shops, has given between 15 and 25 nights of service before wearing out.

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*, *Ae. vexans*, *Ae. nigromaculis*, *Culex tarsalis*, and *Coquillettidia perturbans*. Some anophelines, especially *Anopheles albimanus*, *An. crucians*, *An. atropos*, and *An. walkeri*, are also readily taken in light traps. *Anopheles quadrimaculatus*, however, is seldom taken in significant numbers. *Aedes aegypti* is rarely collected in light traps. 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. The largest collections are made during the dark phase.

LARVAL MOSQUITO SURVEYS

Mosquito larvae are found in all types of aquatic habitats from warm, brackish, seaside marshes to the pure, cold, melted snow water. They are found in such diverse locations as rivers, lakes, ponds, crab holes, pitcher plants, eave troughs, funeral urns, bottles, cans, reservoirs, tree holes, old tires, and junk automobiles.

The inspector must assume that mosquitoes have adapted themselves to a wide variety of aquatic situations. 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 mosquito larvae occur and their relative abundance. For this reason they are of special value in control operations.

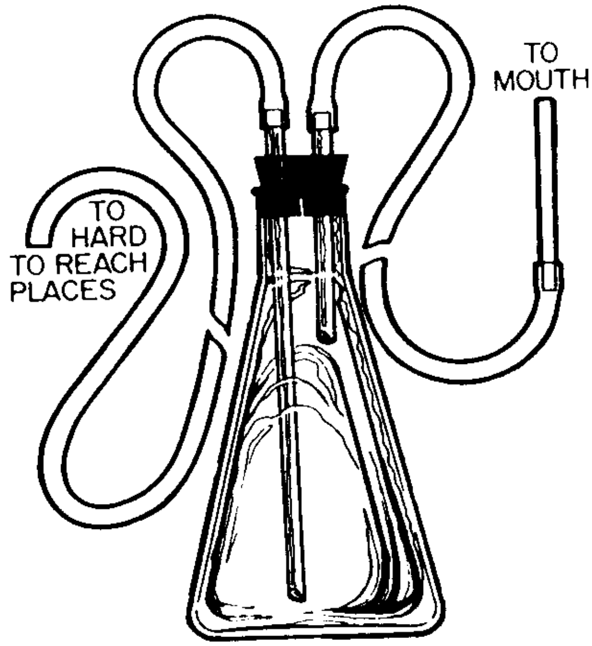


Figure 37. Suction Bottle

Equipment for Larval Mosquito Surveys

A white enamel dipper about 4 inches in diameter is most often used for collecting mosquito larvae (Fig. 32). 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.

Some inspectors prefer white enamel pans to dippers. A convenient size for a pan is about 14 inches by 9 inches by 2 inches deep. Such a pan is used to sweep an area of water until half full. It will then float in the water while the larvae are removed.

Inspection of small artificial containers or cisterns can call for a flashlight or mirror with which to reflect light into the shadowed area. Largebulb pipettes, siphons made of rubber tubing,' or suction bottles (Fig. 37) are sometimes used to remove water from small, inaccessible locations such as tree holes. The water can be put in a dipper or pan and the larvae counted and collected. Wide-mouth pipettes (eye droppers) are used for removing larvae from a dipper or pan. Small vials, preferably with screw caps, will hold the larvae until they can be identified or mounted on slides. Screenbottom spoons or tea strainers can be substituted for pipettes if the larvae are to be transferred to widemouth bottles or disposable polystyrene (e.g., Styrofoam (R) cups. Either 95% alcohol, or 100% cellosolve, is a satisfactory preservative, but 70% alcohol is in common use. An extensive account of equipment for collection of mosquito larvae is given by the World Health Organization (1975).

Inspection Procedures

In the larger ponds and lakes, mosquito larvae are usually found where surface vegetation or debris are present--ordinarily only in the marginal areas. It is necessary to proceed slowly and carefully in searching for mosquito larvae. If the water is disturbed, or a shadow is cast on them, the larvae often dive to the bottom. Anopheline larvae are collected by a skimming movement of a dipper with one edge pressed just below the water surface. The stroke is ended just before the dipper is full, because larvae will be lost if the dipper 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 with the surface-floating *Anopheles* larvae flows gently into the dipper. Culicine larvae such as *Aedes vexans, Ae. stimulans, Ae. sollicitans, Ae. taeniorhynchus,* or the species of *Psorophora,* require a quicker and deeper motion of the dipper, since these larvae hang down from the water surface and are more agile. Some species, e.g., *Ae. aegypti,* are more likely to dive below the water surface when disturbed.

Inspection for *Ae. aegypti* requires a careful search for, and examination of artificial containers in which these domestic mosquitoes breed. Such inspections are usually made premises-by-premises, checking bottles, tin cans, automobile tires, and all other water containers. The *Ae. aegypti* index is obtained by dividing the total number of premises inspected into those in which larvae are found. Collection of the *Ae. aegypti* larvae can be made with a dipper, but it is more frequently accomplished by means of a wide-mouth pipette.

Inspection for *Ae. triseriatus* and *Ae. sierrensis* involves searching for tree holes and artificial containers in which these larvae occur. Such breeding places are often too small to admit an ordinary dipper, but water can be removed by means of a suction bottle

An inspector should always record the number of dips and the number of larvae found, as in the record form on Figure 38. The larvae are transferred to small vials by a wide-mouth pipette and preserved for later identification. It is possible to get an approximate idea of the larval density by computing the number of larvae of each species per dip. The number of dips required will depend on 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 because areas which are entirely free of larvae at one time can have many larvae at other times. Laboratory identifications of specimens are tabulated on the record form as shown in Fig. 39.

Variations in the procedure described above are required when inspecting for certain species. For example, *Mansonia* and *Coquillettidia* 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 can 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 (1959).

MOSQUITO COLLECTION RECORD

Locality ______ Smithville ______ Date ______ July 20 ______

Collector ______ John Doe ______ Supervisor ______ J.B. Jones ______

LARVAL COLLECTIONS

Station Number	Date of Collection	No. of Dips	No. of Larvae Collected	Larvae per Dip	Larval Collections	Description Collection Site
1	July 19	10	15	1.5	Rain Barrel	Backyard 101 Main Street
2	July 19	30	75	2.5	Temporary Rain Puddles	South end of Bugle Marsh
12	July 19	60	30	0.5	Grassy Margin	South end of Blue Lake

(Front side)

ADULT COLLECTIONS

Station Number	Date of Collection	Type of Collection	Females per Trap Night	Landings per Minute	No. of Females (Resting Station)
1	July 20	Light Trap	6		
15	July 19	Biting Collection		45	
9	July 19	Daytime Resting Station			20

(Reverse side)

Figure 38. Mosquito Collection Record

MOSQUITO IDENTIFICATION RECORD

Locality________Smithville________ Date Received ____July 20________

Determined by______George Abbot______ Date ____July 24________

Station Number	Date of Collection	Type of Collection	Mosquito Species	No. of Larvae	No. of Males	No. of Females
1	July 19	Larval	*10 Aedes aegypti* *5 Ae. triseriatus*	15		
2	July 19	Larval	*50 Ae. vexans* *25 P. ferox*	75		
12	July 19	Larval	*12 A. quad.* *18 A. punct.*	30		
1	July 20	Light Trap	*5 Culex pipiens* *1 A. quad.*		*1 Culex pipiens*	*5 C. pipiens* *1 A. quad.*
15	July 19	Biting Collection	*40 Aedes vexans* *5 P. ferox*			*40 Ae. vexans* *5 P. ferox*
9	July 19	Daytime Resting Station	*20 A. quad.*			*20 A. quad*

Figure 39. Mosquito Identification Record

MOSQUITO EGG SURVEYS

Egg surveys are undertaken primarily to locate the larval habitats of salt-marsh, floodwater, 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 standing water, 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 and the larvae were 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 salt-meadow cord grass *(Spartina patens)*, than in the lower areas where water stands for longer periods of time characterized by growths of rushes *(Juncus spp.)* and marsh grass *(Spartina alterniflora)*. 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 solicitans* 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 of sod, leaves, and other ground material are taken by cutting around a board 6 inches square with a sharp trowel. They are then put into 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 (Ross and Horsfall 1965). This egg-separating technique has been used by many mosquito control districts to locate prolific breeding places of *Aedes* and *Psorophora* mosquitoes. These areas are then treated with insecticides, often by prehatch treatment.

Oviposition Traps

In a study of container-breeding mosquitoes, Fay and Perry (1965) showed that several species of mosquitoes were attracted to black jars containing water and would lay eggs on a hardboard paddle placed in these oviposition traps or "ovitraps" (Fig. 40). Technicians were trained to identify the eggs of *Ae. aegypti* from those of *Ae. triseriatus* and other container--bleeding mosquitoes. The eggs of *Aedes (Stegomyia) aegypti* and *Aedes (Stegomyia) albopictus* are very similar. In surveys they are listed as *Aedes (Stegomyia)*. The only way to separate them is to hatch the eggs and identify the larvae or reared adults. The ovitrap method of surveying or surveillance appears to be more sensitive and economical than larval or adult surveys of *Aedes aegypti*. It was used extensively in the United States, Puerto Rico, and the Virgin Islands in 1967 and 1968 during the *Aedes aegypti* Eradication Campaign, in Thailand in 1968 and 1969, and in dengue control on Guam in 1975.

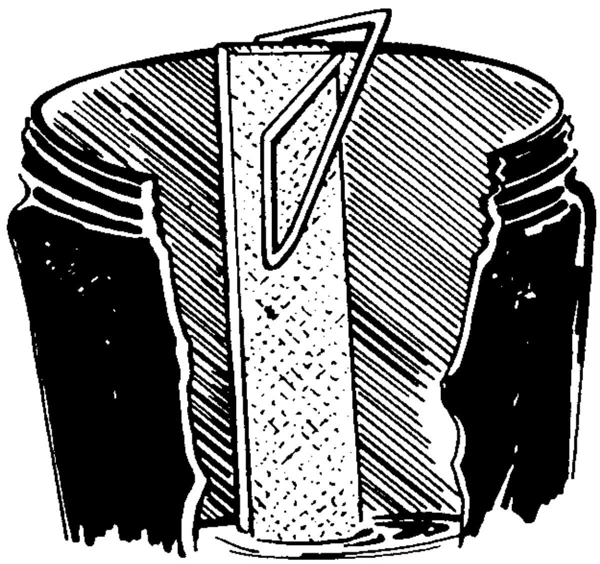


Figure 40. Oviposition Trap with Paddle

Reiter Gravid Trap

The Reiter gravid trap samples female *Culex* mosquitoes as they come to ovipost (Reiter, et al., 1986). It therefore is selective for females which have already taken at least one blood meal. If mosquitoes are being collected for virus isolation, there is a higher probability of collecting infected mosquitoes. Gravid trap counts might also have a higher correlation with disease transmission. The

Harris County Mosquito Control District in Houston, Texas has used these traps successfully in their SLE surveillance program.

UTILIZATION OF SURVEY DATA

Data from 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 vector control specialist can make an intelligent decision as to the need for a control program and the type of control operations that will be most effective and economical. The conclusions, together with a request for funds, can then be presented to the appropriate local officials.

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 effectiveness 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. On the other hand, if mosquito populations remain high, these facts should be known so that control work can be intensified. 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.

During World War II, malaria control officials felt that "satisfactory control"--i.e., the mosquito population level at which malaria would not be transmitted--would be reached when resting station collections of *A. quadrimaculatus* contained no more than 10 females per station in the control zone. Similarly, Reeves (1965) has indicated that little or no transmission of Western equine or St. Louis encephalitis occurred in California when light trap collections of *Culex tarsalis* contained no more than 10 females per trap per night.

Some authorities have worked out a 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. Standards for biting-or landing-rate collections, as well as for other sampling methods for adult mosquitoes, can also be established. It must be cautioned, however, that survey data are seldom absolute and interpretations must be made for each specific situation. Numbers of mosquito larvae found in surveys are more difficult to correlate with pest problems or disease hazards. However, larval surveys reveal the specific sources of mosquito production. This information is helpful 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 after due consideration has been given to the effect on the local environment in relation to the benefits realized from the mosquito control.

THE CONTROL OF MOSQUITOES

INTRODUCTION

Mosquito control activities are important to the public health, and responsibility for carrying out these programs rests with state and local governments. The federal government assists states in emergency situations and provides training and consultation in vector and vectorborne disease problems on an ongoing basis as requested by the states. The current interests in ecology and the environmental impact of control measures, and the increasing problems that have resulted from insecticide resistance emphasize the need for "integrated" control programs. An integrated approach to mosquito control involves accurate and complete assessment of the problem and the employment of control measures that are best suited to the situation. Mosquito control measures generally used in this approach include any one or a combination of techniques aimed at: (1) eliminating mosquito-producing habitats, (2) control of mosquito larvae by chemical means or by predatory fish, and (3) chemical control of adult mosquitoes. In addition, experimental efforts aimed at new alternative means of mosquito control are under way, including use of parasites and other pathogens, predators, and sterile male and other genetic techniques. These alternative methods, however have not been used extensively in public health mosquito control.

In many situations the application of insecticides is still necessary to achieve acceptable control. Persons with responsibility for the application of pesticides are regulated by the Federal Environmental Pesticide Control Act which became law in October 1972. This act is the amended Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947, and specifics that all pesticides must be classified for "general use" or "restricted use."

General-use chemicals are those which can be safely handled by home owners, farmers or others without special training. Restricted chemicals are those which can be handled only by trained and qualified people because they could be dangerous if carelessly applied.

The amended FIFRA requires persons who apply restricted-use pesticides to be certified as competent after passing an examination, or to work under a certified person's supervision. The certification examination is usually given by a state agency. In preparing for this examination, the U.S. Department of Agriculture and the U. S. Environmental Protection Agency have published a core manual on general standards entitled "Apply Pesticides Correctly."[1] All persons applying restricted-use pesticides will be expected to understand information in the core manual. In addition, mosquito control workers who apply pesticides must pass a competency examination covering insects of public health importance. Special manuals for mosquito control personnel have already been prepared in some states.

NATURALISTIC CONTROL

Naturalistic control, as used in this Manual, refers to all commonly employed methods of mosquito control other than chemical or biological. These "naturalistic" methods include mainly those which involve the physical or mechanical alteration of topography or the management of water. Elimination or reduction of mosquito larval habitats by these methods is often termed "source reduction." Although control of larvae by chemical or other means might also be considered "source reduction," such methods will be considered

1. Office of Pesticide Programs, U. S. Environmental Protection Agency, Washington, DC 20460.

separately in the section on biological and chemical control.

For ecological reasons, naturalistic control methods are generally considered to be more desirable than dependence on chemical control. Further, the emergence of widespread resistance of mosquitoes to the commonly used pesticides has, in some areas, necessitated virtually full reliance on the use of source reduction methods. It should be remembered that all source reduction methods require some manipulation of the environment, and all must be examined prior to use for possible undesirable effects on the aquatic or terrestrial environment. While naturalistic control techniques are effective, for environmental, economic or other reasons they may not always be feasible.

Source reduction today often requires an environmental impact statement, a permit from the U.S. Army Corps of Engineers, and compliance with the following laws: Clean Water Act of 1972, 1977, and 1987 (sections 404 and 401), U.S. Fish and Wildlife Coordination Act, Endangered Species Act, National Historic Preservation Act of 1966, National Environment Policy Act of 1969, and Coastal Zone Management Act of 1972.
Source reduction methods commonly used include filling, deepening, draining, ditching, management of water levels, shoreline maintenance, management of aquatic and inundated vegetation, and others. Impounded reservoirs, irrigation systems, navigational dredging, and natural wetlands present special problems in the production of mosquito breeding sites, as well as opportunities for mosquito control by environmental manipulation.

Filling, a method of mosquito habitat elimination, implies placing soil and similar compactable materials into depressions, pot holes, and low lying areas.

Deepening is a method used to modify impoundments or other depressions which are intended to hold water permanently. A backhoe, dragline, or other mechanical method may be used to deepen shallow and marginal areas and to increase the slope of the shoreline. The resulting steep, clean shoreline precludes or reduces growth of emergent vegetation. These modifications are frequently made on borrow pits to reduce mosquito breeding potential.

Draining of standing water is another method of larval control. This involves open ditching, use of subsurface drains, or pumping. Each technique has a specific application, and its use depends on the size of the area to be drained, the terrain, soil type, and economic feasibility.

Open drainage ditches are used throughout the United States and are a common means of salt-marsh mosquito control. For example, in New Jersey much of the tidal marsh was ditched for mosquito control about 1910-1920, although the ditching was often improperly installed. Subsequent to research on the "high" and "low" salt marshes, new ditching concepts have emerged which are more efficient. These will be discussed in more detail below.

Water and land management, i.e., the management of surface water and contiguous land areas, plays a very important role in the control of mosquito larvae, and poor management commonly leads to severe mosquito problems (USDA, 1967). This can apply to entire watersheds or to collections of waste water, precipitation runoff, irrigation water and other impounded water. As water becomes a more highly valued resource, water management practices are being revised to conserve and recycle water.

When considering control of mosquito larvae, it is difficult to separate water management from land management. In most

1. Office of Pesticide Programs, U. S. Environmental Protection Agency, Washington, DC 20460.

cases the two elements should be considered together because the bulk of the associated larval production occurs at or near their interface. This concept was clearly shown to be true by the Tennessee Valley Authority (TVA) for malaria control. The interaction of water level management on reservoirs, along with the proper preparation of reservoirs before impoundment, proved that anopheline vector production could be greatly reduced. The valuable lessons learned from TVA malaria control are still valid and should be considered by the major water resource developers in the planning, construction, operations, and maintenance of reservoirs. Mosquito problems on TVA projects have been minimized because mosquito biology and ecology are well understood, and naturalistic control measures are integrated into reservoir operation (USPHS and TVA 1947).

Water and land management practices for mosquito control can be more easily understood and appreciated if viewed in relation to specific types of water resource developments, such as reservoirs, irrigation systems, wildlife refuges, and navigable waterways.

Reservoirs are developed for multipurpose uses such as hydro-power generation, flood control, municipal and industrial water supply, outdoor recreation, and fish and wildlife interests. All types have caused mosquito problems. If a reservoir is not to cause mosquito problems, the following requirements must be satisfied: (1) proper preimpoundment preparation of the reservoir, (2) correct management of the pool level, and (3) proper maintenance of the shoreline.

Proper preimpoundment preparation of the reservoir is the most satisfactory means of eliminating potential mosquito producing habitats. Preparation involves shoreline conditioning, brush and vegetation removal, and providing for drainage. Preimpoundment preparations are the most desirable of available methods because any modifications attempted after filling are not easily made and are more costly.

Shoreline conditioning involves steepening the gradient in places which would otherwise be very shallow after the reservoir impoundment. Shallow vegetated areas produce mosquitoes prolifically and must be deepened wherever practicable. A shoreline gradient of 3:1 has been found to deter the establishment of emergent vegetation. Mosquito-producing habitats are commonly observed in the shallows of the upper reaches of a reservoir and in tributary embayments. Clearing of brush and vegetation within the zone of recession removes potential mosquito habitats. Much vegetation is not water tolerant and should always be cleared from the shoreline prior to impoundment and "rebrushed" during drawdown periods.

Another aspect of reservoir preparation which minimizes potential mosquito larval habitats is the installation of drains in natural depressions, borrow pits, and dikes. Water is frequently trapped in such sites within the summer fluctuation zone of a reservoir and when the pool level is drawn down, they can retain water and become serious mosquito-producing situations which must be controlled chemically.

Maintenance of the pool level and the contiguous land areas are important parts of mosquito control on reservoirs. The manipulation of the pool level through fluctuations was demonstrated by Hess and Kiker (1943) to be effective in minimizing anopheline mosquito production. The spring surcharge and subsequent drawdown serves to strand flotage such as plant parts and accumulated debris, which, if not removed from the reservoir pool, would create prolific mosquito habitats.

Another maintenance consideration is

seepage through the dam which is frequently observed. When such seepage occurs, it should be properly drained into the main outfall below the dam, or the resultant accumulation may become a mosquito habitat.

Irrigation systems are among the largest contributors to the mosquito problem in the western United States (USDA 1967). Mosquito production has been recorded from every aspect of the irrigation system, with sources off the irrigated field being the most important and difficult to control.

An irrigation system typically begins with an impounded reservoir which stores water and releases it as needed into the main distribution canal and through a series of smaller channels or laterals until it reaches the area requiring irrigation. Ideally, the unused water or runoff will be channeled into drain collection ditches, and finally returned through a main drain to the original source of the water or to a stream. Reservoirs that are drawn down sharply during the mosquito producing season generally do not cause mosquito problems.

Irrigation distribution canals in themselves are not major sources of mosquito production. Usually the water in the canals is in constant motion and does not provide the permanence or stability needed for ideal oviposition sites or larval development. Canals are usually 6-12 feet deep and steeply banked, factors which tend to preclude mosquito production.

The important sources of mosquitoes in the distribution system are seepages emanating from unlined canals. There are several solutions to the seepage problems, and all of them are expensive to install. For large canals, the installation of a lining is probably the only practical method. Concrete linings are the usual choice because of their durability but polyethylene sheeting and other impervious materials have been used successfully. The Bureau of Reclamation has installed laterals on certain projects in underground conduits where surface canals would be aesthetically objectionable. This is also a water conservation technique, since it has been estimated that as much as 75% of the water entering the distribution system is lost before it reaches the target because of seepage, evaporation and waste (USDA 1967).

In the past, **irrigated fields** were frequently observed to be abundant mosquito producers. Unlevelled fields with surface depressions and poor drainage at the low end of the field created mosquito habitats. Currently, the Bureau of Reclamation requires that fields be levelled, conditioned, and properly prepared for efficient irrigation before water is delivered to new systems.

Close-growing crops, such as alfalfa, and wildflooded pastures produce mosquitoes abundantly, whereas a row crop, such as cotton, does not. Fields of some crops (e.g. sugar beets and fruit orchards) usually do not produce mosquitoes because over-application of water will result in damage to these crops, and irrigation is carefully managed. Corn, on the other hand, is a row crop with a deep root system which tolerates much moisture, resulting in poor irrigation management and associated mosquito production. Over--application usually occurs with runoff accumulating at the low end of the field and in roadside ditches. *Aedes, Culex, Culiseta, and Psorophora* larvae are commonly found in agricultural waste water.

Efficient *drainage systems* are uncommon in irrigation agriculture. Once water reaches the field, there is likely to be little or no provision for removing the excess and abundant mosquito production may occur at the low end of the field and in adjacent roadside ditches. These ditches which often receive irrigation drainage, are not designed to dispose of such drainage efficiently. Throughout its range the larvae of *Culex tarsalis* may be abundant among the dominant species found in these poor drainage situations. This species was found in such situations in an area endemic for western equine encephalitis in west Texas (Harmston *et al.* 1956) and similar relationships have been seen in many other irrigated areas. Drainage is now being considered more carefully in the design of irrigation systems partly because it has become necessary to reclaim the waste water, and in the future more efficient design and maintenance of drainage systems in irrigation should serve to minimize mosquito production.

Other recent developments in irrigation include the development and refinement of sprinkler irrigation systems, which will probably reduce mosquito production in irrigated areas. Sprinklers apply water uniformly and more conservatively than other surface irrigation methods, but mosquito problems have been found where the land was improperly prepared, application was poorly managed, and water was allowed to accumulate: Center-pivot irrigation systems are being widely accepted by farmers in the United States, and are extending irrigation in the arid western United States (Splinter 1976).

Recent studies have shown that there is a strong correlation between good irrigation practices, high crop yield, and low mosquito production; and conversely, poor water and land management practices, low crop yield, and high mosquito production indices are also strongly associated. Because of the economic benefits that can be demonstrated, it is less difficult to encourage practices which will also diminish the production of vector mosquitoes.

The use of sewage effluent for irrigation is becoming an accepted practice, and the high nitrogen content of this waste makes it valuable in agricultural and horticultural pursuits. Where such effluent has been used for irrigation, pronounced changes may occur in the larval mosquito populations, including species composition, relative densities, and the introduction of new vector species. The association of *Culex* mosquitoes with waste water of high organic content is well known, a fact which has been demonstrated in these situations.

Because of **diked dredged spoils areas,** a serious mosquito control problem exists along some of the navigable waterways of the United States. The problem is due to production of *Aedes sollicitans,* a salt-marsh mosquito, in spoil material dredged from the waterways in the course of their maintenance. Among the states experiencing mosquito production with diked dredged spoils are Louisiana, Texas, California, and the Atlantic Coastal states on the inland waterway.

Spoil material from the dredge is a liquified substance consisting of silt, sand, and a large percentage of water for conveyance purposes. The normal practice has been to deposit some of this material in a designated site and allow it to dry. Once dry, the material may be bulldozed into a dike so that a large basin is created, into which more spoil material will be pumped. Spoil material does not spread uniformly but produces a "waffle" effect of high and low portions. The lower ones tend to hold precipitation, become vegetated quickly and provide excellent oviposition and development sites for *Aedes sollicitans.* As the spoil dries, it often becomes cracked due to shrinkage. The cracks collect precipitation, and may become productive *Aedes sollicitans* habitats. Spoils sites range in size from a few to more than 1,000 acres.

Various methods have been used to reduce mosquito production associated with these spoils areas, including plowing, harrowing, scraping, and other mechanical means of altering the topography. Research is needed to determine other naturalistic methods of control of mosquitoes in diked dredged spoils deposits.

Naturalistic control of mosquitoes on **wetlands**, along the Atlantic seaboard and in California, has been the subject of much work and research since the early 1900's. For many years, the wetlands were thought of as wastelands because their role in the ecosystem and their economic contributions were not well understood. Recent studies have shown that in addition to the production of salt grass hay, the salt marshes are valuable nursery areas for several species of fish and crustaceans. Intensive studies have been accomplished in California, Utah, New Jersey, Delaware, and Florida, for the control of saltmarsh *Aedes* and for the enhancement and protection of the environment. In all instances, consideration has been given to mosquito control, fish and wildlife interests, and agriculture. The original approach for mosquito control on salt marshes was drainage and miles of ditches were dug for this purpose. As knowledge of marsh-plant-mosquito production developed, it was seen that there was a high-marsh area which was subjected to intermittent tidal flooding, and this section of the marsh produced mosquitoes abundantly. The low-marsh portion received frequent flooding, making it unfavorable for oviposition for salt-marsh *Aedes*. Thus, the low-marsh was not the source of the problem, but had been indiscriminately ditched for mosquito control purposes (Provost 1974).

Two basic methods of marsh management for mosquito control are being used: water level management and management of the open tidal marsh. Both of the foregoing depend on the knowledge of the biology and ecology of *Aedes sollicitans* and *Ae. taeniorhynchus*. These saltmarsh mosquitoes lay their eggs on soil or plants, never on the water surface.

Water level management has been used successfully on salt marshes in Utah, New Jersey, and Florida. The areas under control were located near human population centers and were intermittently flooded, producing large numbers of mosquitoes. To correct this situation, the problem areas were diked appropriately to maintain the desired level of flooding. A pump may be required to fill the area or to add water when indicated. With a constant water level, optimum oviposition sites for salt-marsh mosquitoes are eliminated.

Other marsh areas indicate a need for open management techniques. Canal systems are developed to connect any section of isolated marsh with tidal waters. The important concept in this method is to bring circulation or tidewater into isolated marsh areas, which may hold floodwater or rainfall, within 1-2 days following the flooding. Minnows predaceous on mosquito larvae are provided access to all regions of the marsh as well (Provost 1974).

The Open Marsh Water Management (OMWM) concept (Ferrigino *et al.* 1975) is an important source reduction approach. OMWM is employed in marsh areas which are situated either slightly above the spring tide line, or slightly below it. Three basic modifications can be made, and they can be used separately or in conjunction. They are tidal ditches, ponds, and pond radials (short ditches). In some areas, a series of depressions are arranged in a linear distribution. Such depressions could be connected with a ditch to the nearest source of tidal flow in order to provide circulation. Some depressions could be linked to others by short lateral lines which would eventually connect to the main ditch. In other areas, several depressions might be arranged in a roughly circular fashion. In this case, a pond would be constructed by connecting all the depressions together and deepening them in the process. Smaller depressions, near the pond, could be tied into the pond by means of radials. All of these modifications serve to reduce the potential for salt-marsh mosquito breeding, with a minimum effect on the natural environment.

Land management practices which were discussed under "reservoirs" apply equally to **small ponds and impoundments.** Shorelines with a 3:1 gradient and without emergent vegetation are desirable. Farm ponds are usually constructed with one portion gently sloping and shallow so that livestock can have easy access to the water. Mosquito production has been observed on many farm ponds in the United States and the important breeding sites were commonly shallow, vegetated portions of the impoundment.

Sewage lagoons and stabilization ponds have produced abundant populations of *Culex tarsalis* and *Culex pipiens quinquefasciatus* mosquitoes. *Culex pipiens quinquefasciatus* prefers water with high organic content for oviposition, and *Cx. tarsalis* will tolerate this source as well. It has been found that mosquito production could be lessened by keeping lagoons free of aquatic vegetation, and by keeping the banks free of emergent vegetation. A minimum operating depth of three feet has been recommended to preclude mosquito production. Breeding has been observed in partially filled, vegetated lagoons; in such cases, rapid filling with sewage effluent would serve as a control measure.

BIOLOGICAL CONTROL

Biological control implies the destruction of larvae by predators or pathogens. Control of mosquito larvae by various biologic means has been the subject of considerable research and has shown much promise, but in practice, mosquito fish are used most often in control programs today. The pathologic agents under study have shown varying degrees of success in field trials, but as yet none are practical or have been licensed for mosquito control.

Larvivorous fish offer the greatest opportunity in biological control at this time, and a number of mosquito abatement districts propagate and distribute the mosquito fish *(Gambusia affinis)* and the guppy *(Poecilia reticulata)* for control of larvae in cisterns, garden pools, ponds, and livestock watering tanks.

In New Orleans, Marten (1990) reported elimination of *Aedes albopictus* larvae from tire piles by introducing the copepod *Macrocyclops albidus*. Some workers have reported varying degrees of success in controlling larvae of *Aedes aegypti*, *Ae. albopictus*, and *Ae. triseriatus* with the large predatory larvae of *Toxorhynchites*.

CHEMICAL CONTROL

Larval Control

If areas cannot be drained or filled at reasonable cost, and mosquito control by predator fish, impounding, or other naturalistic methods is not possible, larviciding may be required. Larvicidal control is of primary importance in areas where control of disease-carrying mosquitoes is necessary, particularly in situations with extensive flooding following natural disasters such as hurricanes or prolonged rainy seasons. Where chemicals are used for larviciding, it is recommended that the larvicide be with a different chemical from that used for adult control. For example, it may be desirable to use temephos (Abate) as a larvicide and malathion as an adulticide. The degree of control with larvicides differs with the various species of mosquitoes, degree of pH and pollution of the water, and type and amount of vegetation present. Table 2 lists insecticides and dosage rates currently being used to control mosquito larvae.

Types of Formulations

The synthetic organic insecticides can be applied as dusts, pellets, granular formulations, suspensions of wettable powders, solutions or emulsions. Dusts have been used as mosquito larvicides, but they are light in weight and subject to drifting in air currents causing spotty application, and they may not penetrate vegetation to reach the water. Pellets and granular formulations have larger particle size, so they slip through leaves or dense vegetation to reach the water surface to kill the mosquito larvae. Wettable powders are frequently used in prehatch treatment of areas for the control of mosquito larvae. Wettable powders can be applied to snow, ice, or earth in dried-up mosquito-breeding areas seeded with eggs of temporary pool mosquitoes. Oil solutions can be sprayed on water surfaces to kill both anopheline and culicine larvae and pupae, particularly in waters with high organic content. Water emulsions have been employed extensively to treat irrigated waters, as in rice fields, since oil solutions are toxic to cultivated plants. The water in the emulsion serves as a carrier for the insecticide.

Larvicidal Chemicals

Organic Phosphorus Insecticides (OP compounds): These chemicals came into general use after World War II, particularly after the emergence of the problems of resistance of mosquitoes to the chlorinated hydrocarbons and of environmental contamination. Soon after application, most organophosphates combine with water and break down into compounds which do not contaminate the environment.

At the present time, chlorpyrifos (Dursban(R)) and temephos (Abate(R)); are among the most widely used organophosphate larvicides. Malathion has also been used effectively. The degree of control varies widely with the species of mosquito, degree of pollution of the water, and type and amount of vegetation present (CDC 1973). Temephos is a safe and effective larvicide against most species of mosquito larvae. At recommended dosage rates, it usually does not kill predators (including fish) of mosquito larvae. It has been used to control mosquito larvae in rain barrels holding potable drinking water, in bird baths, and in animal watering devices. Chlorpyrifos (Dursban(R)) has given control of *Culex* larvae in polluted water, such as dairy drains and industrial waste water accumulations (Mulhern 1974).

TABLE 2-INSECTICIDES CURRENTLY USED IN MOSQUITO LARVICIDING

(These recommendations are guidelines only. There are many formulations available. The following are a few in current use. User must ensure that pesticides are applied in strict compliance with label and local, state, and federal regulations).

INSECTICIDE	RATE OF APPLICATION (Active Insecticide/Acre)	REMARKS
<u>Organophosphates</u> chlorpyrifos (Dursban)	0.4-1.6 oz/acre in water or oil	Dilute with water or oil for use in hand and power sprayers, mist applicators, and aerial spray equipment. Use 0.4 to 0.8 oz/acre for light (or no) to medium vegetation and 0.8 to 1.6 oz/acre for medium to heavy vegetation cover.

TABLE 2 (continued)

INSECTICIDE	RATE OF APPLICATION (Active Insecticide/Acre)	REMARKS
Malathion 57% EC	Up to 13 oz/acre	Mix 2.5 oz of malathion 57% with water to make 1 gallon. Apply up to 5 gal./acre depending on flotage and vegetation. (intermittently flooded areas, stagnant water, temporary rainpools).
Temephos (Abate)	0.05-0.1 lb/acre	Apply 5-10 lb. of 1% Abate sand and celatom granular per acre. Apply 2.5-5 lb. of 2% Abate sand and celatom granular per acre. Apply 1-2 lb. of 5% Abate sand and celatom granular per acre.
Temephos (Abate)	0.1-0.5 lb/acre	In some tidal water, marshes, and water with high organic or pollution content apply up to 25 lb. of 2% Abate sand and celatom granular, or up to 10 lb. of 5% Abate sand and celatom granular.
Temephos (Abate)	0.016-0.948 lb/acre	Mix 0.5--1.5 oz. of Abate 4E per gal of water. Apply at 1 gal./acre.
Proprietary Compounds Arosurf	0.2-1 gallon/acre	Apply as single layer monomolecular film to cover water surface.
Golden Bear Oil 1356	3-5 gallons/acre	Apply from air or ground to cover water surface.
Insect Growth Regulators Methoprene (Altosid SR 10 Altosid G Altosid Briquet Altosid Pellets)	3-4 oz. Altosid SR10 per acre 8-10 lbs. Altosid G per acre 1 Altosid briquet per 100 square feet	Mix 3-4 gallons of 10% Altosid in ½ to 5 gallons of water and apply to 1 acre. Use 8-10 lbs. of Altosid G per acre. Use Altosid Briquet 1/100 square feet. Kills 2nd, 3rd, and 4th stage larvae, not pupae or adults.
Diflubenzuron (Dimilin)	0.02-0.04 lb/acre	Interferes with formation of larval cuticle, inability to moult successfully.

TABLE 2 (continued)

INSECTICIDE	RATE OF APPLICATION (Active Insecticide/Acre)	REMARKS
Larvicidal Bacteria *Bacillus thuringiensis israeliensis* Many formulations of Bactimos, Teknar, et al.	Follow label directions.	Many formulations, follow label directions. After ingestion, toxins released by the bacteria cause paralysis of midgut and death within a day.
Pyrethrins and synergist Tossits	Follow label directions	For small watered areas one tossit per 100 square feet.

Proprietary Compounds: Special proprietary compounds such as AROSURF MSF and Golden Bear GB-1111 and GB-1356 are registered for mosquito control. These larvicides have given good control at application rates of 1-5 gallons per acre. They have low toxicity to plants and to non-target aquatic organisms. They act to suffocate larvae and pupae and thus eliminate the problem of resistance to organophosphate insecticides.

Insect Growth Regulators: Insect growth regulators have been studied intensively in recent years. Some of them have been called insect developmental inhibitors, or juvenile hormone-like materials. Some like methoprene (Altosid) cause mortality in the pupal stage, Others like diflubenzuron (Dimilin) prevent molting. Altosid is available as emulsion, granules, briquets, and pellets. These do not kill eggs, first stage larvae, pupae, or adults, but they do kill second, third, and fourth stage larvae and prevent development of pupae. Dimilin is available as a powder which prevents hardening of the cuticle and molting. None of the insect growth regulators produce the quick kill associated with many other larvicides.

Lavicidal Bacteria: Bacillus thuringiensis israeliensis is a bacterial compound used to control mosquito larvae. It is sold commercially under many trademarks as Bactimos, Teknar, and Vectobac in various formulations as liquids, granules, flowables, and briquets. After ingestion by the larvae, the bacteria liberate toxins that cause paralysis of the midgut to occur within a few hours and death in about a day. The microorganisms released into the environment do not self-perpetuate, so re-application is required. This larvicide does not harm the environment -- fish and other aquatic organisms, plants, wildlife, pets, and humans.

Pyrethrins: Larvicides containing pyrethrins are sometimes used to control mosquito larvae in lily ponds, and other situations with valuable vegetation. Tossits are gelatinous capsules containing 1% pyrethrins which can be tossed into small bodies of water such as stagnant pools, small ditches, catch basins, cisterns, and small marshy areas. The application rate is approximately one tossit per 100 square feet, per six inches of depth.

ADULT CONTROL

Control of adult mosquitoes by space spraying of any kind is only temporary since mosquitoes from nonsprayed areas can move rapidly into the sprayed area following spray applications. Also, aquatic stages are usually not affected by space spraying and new adults will continue to emerge.

Spraying operations are conducted during the late afternoon and early evening, at night or in the early morning when the air is cool and wind velocity does not exceed 6 miles an hour. If air movement is excessive, the small droplets used in space spraying are dispersed so swiftly that effectiveness is reduced or prevented. Similarly, during the middle of a hot day the droplets are dispersed by rising currents of warm air known as thermals. At night there may be an inversion of air temperatures so that small droplets are held close to the ground, usually producing excellent control of mosquitoes.

Outdoor space treatments with ground oraerial applications have been carried out effectively against many species. Susceptible populations of mosquitoes can be reduced effectively by space application of insecticides listed in Tables 3 and 4.

ULTRA-LOW VOLUME APPLICATION WITH GROUND EQUIPMENT

Ultra-low volume (ULV) application with ground equipment is becoming the most frequently used method of adult mosquito control in the United States and can be very effective in vector control. Ultra-low volume treatment is defined as the application of less than 2 quarts of insecticide per acre, usually 0.5 to 3.0 ounces per acre. Beginning in 1970, great advances were made in the development of ultra-low volume equipment and a number of ULV ground application models are now sold commercially. Ultra-low volume equipment utilizes insecticide concentrate without a diluent or carrier resulting in savings in fuel, loading time, and cost of the fuel oil required in thermal foggers. Other advantages of ULV aerosols are that they do not produce the dense fogs--as do thermal fogs -- which constitute a traffic hazard by reducing visibility. The ground ULV machine is relatively small. Its insecticide tank commonly holds 5 to 10 gallons and it is usually mounted on a small vehicle, such as a 1/2 ton pickup truck.

TABLE 3--INSECTICIDES CURRENTLY USED FOR CONTROL OF ADULT MOSQUITOES WITH ULTRA-LOW-VOLUME GROUND EQUIPMENT.

Modified from Rathburn and Boike (1975) and Evans (1992)

(These recommendations are guidelines only. User must ensure that insecticides are applied in strict compliance with label and local, state and federal regulations).

INSECTICIDES	FORMULATION/ LABEL	REMARKS/APPLICATION
chlorpyrifos (Dursban)	Dursban Dow Mosquito Fogging Concentrate	At vehicle speed of 10 mph, 2/3 to 1 1/3 fl. oz./min. Maximum flow rate 0.3 to 0.62 gal./hour.
malathion	Cythion ULV Concentrate	At vehicle speed of 5 mph, 1-2 fl. oz./min. Maximum flow rate of 1 gal./hour. At vehicle speed of 10 mph, 2-4 fl. oz./min. Maximum flow rate of 2 gal./hour.
naled* (Dibrom)	10% Dibrom 14 in HAN 1% Dibrom 14 in fuel oil with 1% Ortho additive	At vehicle speed of 10 mph, 6-12 fl. oz./min. Maximum flow rate of 6 gal./hour. At this rate persons may have serious irritation of eyes and respiratory tract. At vehicle speed of 10 mph, 40 fl. oz./min. Maximum flow rate of 20 gal./hour.
pyrethrum	5% pyretrhins -- 25% piperonyl butoxide	At vehicle speed of 5 mph, 2--2.25 fl. oz./min. Maximum flow rate of about 1 gal./hour. At vehicle speed of 10 mph, 4--4.5 fl. oz./min. Maximum flow rate of about 2 gal./hour.
resmethrin	(Scourge) 2-4% (3.3 lb/gal.)	At vehicle speed of 5 mph, 9 fl./oz./min. of 2% finished formulation.

Note mph - miles per hour fl. oz. - fluid ounce: HAN - Heavy Aromatic Naphtha.

*With naled, tank pressure should not be greater than 1.5 lbs. psi because of overatomization and poor mosquito control.

**Lower concentrations of this product should become available in the near future.

TABLE 4. INSECTICIDES CURRENTLY USED FOR ADULT MOSQUITO CONTROL WITH GROUND FOGGERS, MISTERS, AND DUSTERS.

(These are guidelines only. User must ensure that insecticides are applied in strict compliance with the label and local, State and Federal regulations).

INSECTICIDE	DOSAGE (Active Insecticide/Acre)	REMARKS
carbaryl (Sevin)	0.2-1.0 lb/acre	Dosage based on swath width of 300 feet. Apply as mist or fog between dusk and dawn. Mists are usually dispersed at rates of 7 to 25 gallons per mile at a vehicle speed of 5 mph. Fogs are applied at a rate of 40 gal./hr. dispersed from a vehicle moving at 5 mph; occasionally 80 gal./1 hr. and 10 mph. Finished formulations for thermal foggers contain from 0.5 to 8 oz. per gallon actual insecticide in oil. For nonthermal foggers or misters, water emulsions can be used. Dusts can also be applied with ground equipment.
chlorpyrifos (Dursban)	0.025-0.05 lb/acre	
fenthion (Baytex)	0.01-0.1 lb/acre	
malathion	0.075-0.2 lb/acre	
naled (Dibrom)	0.02-0.1 lb/acre	
propoxur (Baygon)	0.05-0.07 lb/acre	
pyrethrins (synergized)	0.002=0.0025 lb/acre	
remethrin (Scourge)	0.0035 lb/acre	

Performance requirements for ground ULV equipment have been published as follows (American Cyanamid Co. 1972):

(1) The ULV cold aerosol nozzle for dispersal of malathion to control adult mosquitoes must have the minimum capability of producing droplets in the 5 to 27 micron range. Large droplets may permanently damage automobile paint. The average diameter should not exceed 17 microns. Determination of droplet size should be made by depositing a sample of the aerosol on a silicone-coated glass slide and measuring the droplets under a microscope with an ocular micrometer.

(2) Tank pressure should not be less than 2 to 3.5 pounds nor greater than 6 pounds per square inch (psi).

(3) Flow rate must be regulated by an accurate flow meter. Flow meter data such as that in Table 3 should be recorded at the end of each day's operation.

(4) The nozzle should be in the rear of the truck and pointed upward at an angle of 45° or more.

(5) Vehicle speed should not be greater than 10 miles per hour. Some agencies have obtained special local need (24.C) authority to treat at 20 mph.

Five insecticides have EPA label approval for application as ULV aerosols by ground equipment; chlorpyrifos, malathion, naled, pyrethrum, and resmethrin. These insecticides are listed in Table 3 (Rathburn and Boike 1975).

ULTRA-LOW VOLUME AERIAL APPLICATIONS

Aircraft have been used for many years to apply insecticide dusts, pellets, sprays, and aerosols. Since 1964, aerial ULV has been used many times for controlling mosquitoes in disaster areas and for controlling epidemics of mosquito-borne disease. The ULV method was used in 1966 to kill infected *Culex pipiens quinquefaseiatus* during the Dallas, Texas, epidemic of St. Louis encephalitis; in 1967, to kill species of *Aedes, Psorophora, Culex, and Anopheles* in a 3-million acre flooded area in Texas; in 1969, in Ohio to kill *Aedes* vectors of LaCrosse encephalitis during an epidemic; in 1972 and 1974 in New England to kill species of *Aedes, Coquillettidia* and *Culiseta* during an outbreak of eastern equine encephalitis; in 1975, in North Dakota and Minnesota to kill infected *Culex tarsalis* during an outbreak of western equine encephalitis; and in 1975 in Guam and Puerto Rico to control the vectors of dengue.

The aerial ULV technique uses the application of 0.5 to 3.0 ounces of highly concentrated insecticide per acre for the control of adult mosquitoes. These insecticides are currently approved for adult mosquito control by the ULV method of application from airplanes: malathion at 3.0 fluid ounces per acre, naled at 0.5-1.0 fluid ounce per acre, and resmethrin at 3 fluid ounces per acre. On occasion, car paint spotting and bee kills have occurred as a result of ULV aerial applications.

Special aircraft equipment for the ULV involves special tanks, electrically-driven pumps, spray booms, and 8001 to 8008 Tee-Jet nozzles or other specialized delivery and nozzle systems. In general, airplane ULV applications should be made only under the following conditions (Kilpatrick 1967):

(1) when temperatures are below 80°F (usually early morning).
(2) with droplet size of not more than 50 to 60 microns MMD (Mass Median Diameter); no more than 10% of the droplets should exceed 100 microns. In some areas damage to car paint has occurred when larger droplets were dispersed or more than 10% of the droplets exceeded 100 microns. Effectiveness against adult mosquitoes requires 10 or more drops per square inch. Determination of droplet size should be made by depositing a sample of the aerosol on a silicone-/or Teflon-coated glass slide and measuring the droplets under a microscope with an ocular micrometer. Other droplet measuring systems are available.
(3) by multi-engine aircraft flying at a height of 100-150 feet, at speeds of about 150 miles per hour or more, with swath widths of 300-1000 feet with pump pressures and nozzle sizes and positions adjusted to provide the proper droplet size. Single-engine fixed wing and rotary wing aircraft are undesirable for this technique because of their slower air speed and resulting problems with droplet breakup. There are additional safety factors with single-engine aircraft and with their limited "pay load" which need to be considered when used in urban areas.

THERMAL FOG AND DUST APPLICATIONS

Thermal fog applications have been used successfully for adult mosquito control for many years. Thermal fogs require the addition of a fuel oil carrier and depend on a high temperature system to produce the fog droplets. Tests have shown ULV and thermal fogs to be similar in effectiveness. Disadvantages of thermal fogs include the hazard of the dense fog produced and the expense of carrying and using the fuel oil carrier.

In past years there has been much interest in the use of dusts for adult mosquito control, and they can be effective. Tests with ground-dispersed dusts (19% and 7.5%) of carbaryl have produced 99% reduction of adult salt-marsh mosquitoes at dosages of 0.2 and 0.3 pounds of carbaryl per acre.

OTHER METHODS OF ADULT MOSQUITO CONTROL

Residual treatment outdoors for mosquito control does not always produce good results. However, limited relief from biting mosquitoes can, at times, be obtained in small city parks, playgrounds, picnic areas, patios and yards. Water suspensions or emulsions with a low percent of insecticide (rather than oil solutions) are used in order not to "burn" vegetation. These applications can be made with power sprayers or with hand sprayers, using nozzles which provide a broad fan or cone and a coarse spray, such as the Tee-Jet 8004. The insecticides used for such outdoor applications include Punt (containing pyrethrin).

Residual spraying is a primary method of controlling mosquitoes that breed in catch basins. In many large cities with thousands of catch basins along the edges of the streets, surveys indicate that often one catch basin in every ten holds enough water to produce broods of mosquitoes of the *Culex pipiens* complex. The application of petroleum oils or granular insecticides to these catch basins is not the complete solution to this type of mosquito control because a single rain shower produces enough runoff to flush the larvicide into the storm sewer. Therefore, a special nozzle has been developed which produces a radial spray pattern and coats the walls of the catch basin with insecticide. Some of the insecticides used are not readily soluble in water and the residual insecticide may remain on the walls of the catch basin for weeks or months. It kills the adult mosquitoes as they rest on the walls after they emerge from their pupal cases, while their wings and body harden sufficiently for flight.

The organophosphate insecticide, dichlorvos, is formulated into resin strips which release an insecticide vapor. Usually one resin strip per 1000 cubic feet (10'x10'x10') provides good control of mosquitoes for 3 to 4 months. Results of tests with such strips for control of adult mosquitoes in catch basins, cisterns, etc. have been variable. Studies in Savannah, GA and elsewhere have shown good control as tested with caged *Culex pipiens quinquefasciatus* for 11-18 weeks when one resin strip was wired to the grating of a catch basin (CDC 1973).

ENVIRONMENTAL ASPECTS

Assistance should be sought from competent conservationists, fish and game specialists, and others in planning control measures in areas where delicate ecosystems could be disrupted by mosquito control practices. In mosquito control only those pesticides approved by the EPA for the planned use should be considered.

PERSONAL PROTECTION FROM MOSQUITOES

People can protect themselves from mosquitoes by using proper window screens, protective clothing and repellents. The ordinary window screen with 16x16 or 14x18 meshes to the inch will keep out most mosquito species. 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.

Long-sleeved clothing of tightly woven material offers considerable protection against mosquito bites. Sleeves and collars can be kept buttoned and trousers tucked in socks when mosquitoes are biting. This type of protection may be necessary for people who must work in areas where infected vector mosquitoes are particularly abundant. The use of mosquito netting to protect infants in their cribs may also be indicated in high risk circumstances.

Relief from mosquito attack may usually be obtained by applying insect repellents to the skin and clothing. A number of these have given adequate protection against mosquitoes. Effective protection may be obtained through the use of diethyl toluamide (Deet, Off). Use repellents with 25% to 30% (or lower) concentration of diethyl toluamide. Adverse affects have been reported in infants or sensitive adults treated with high concentrations of diethyl toluamide. Repellents are available as liquids in bottles, pressurized spray cans, and in stick form.

When applied to the neck, face, hands and arms, liquid repellents will prevent mosquito bites for 2 hours or more, depending on the person, species of mosquito attacking, and abundances of mosquitoes. These repellents can also be sprayed on clothes to make them repellent. Many repellents are solvents of paints and varnishes, 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, to the lips, or to mucous membranes. Clothing can be treated with aerosols of permethrin (Permanone) and allowed to dry for 2-4 hours before its worn to repel or kill mosquitoes.

Pressurized aerosol insecticide dispensers can be used in the home to kill adult mosquitoes. Most of these contain pyrethrum or allethrin because these insecticides have low human toxicity and cause a quick knockdown of mosquitoes. These aerosol dispensers may also contain a synergist such as piperonyl butoxide and another insecticide such as diazinon to kill the insects. Release of the aerosol for a few seconds usually kills most insects in an ordinary-sized room, tent, or trailer. These aerosols are not hazardous if used as directed on the container, except in rare cases where persons are allergic to pyrethrum or the synergist.

METHODS FOR ASSESSING CHEMICAL CONTROL OF MOSQUITOES

Evaluating the results of the treatments applied as larvicides and adulticides is important to any control effort. Resistance to the insecticide being used may become a problem, or improper application techniques may reduce the effectiveness of the method, or possibly increase the risk of killing nontarget species.

The basic approach used in evaluating larviciding or adulticiding applications is comparison of the number of specimens per collection made before and after the application. For this purpose collections should be made on each of several days before and after the application and as many sampling sites as possible should be included.

Another useful method is that of bioassay tests with caged specimens. A bioassay test for space sprays may be done by using the following technique:

Treatments may be applied by fog, dust, mist, or, ULV machine mounted on a vehicle and moving at 5 or 10 mph at the recommended label dosage. Field-collected, caged specimens (100-150/cage) are hung 6 ft above the ground at stations 150-300 ft from the point of discharge of the machine along each of three streets (270-300 ft apart). Ten to 15 minutes after exposure the cages are removed and the insects are transferred to holding cages, given food and held for a 24-hour female mortality count. Seventy percent or better kill is expected. If the kill at either 150- or 300-ft station is less than 70%, then the equipment and timing of application of insecticide should first be examined, and adjusted. If, after these adjustments have been made, the kills are still unsatisfactory, then a change of insecticide should be recommended.

Bioassay tests for larvicides are of less value than sampling of natural larval habitats for larvae before and after an application is made. A useful technique to improve reproducibility of larval sampling is that of placing numbered stakes at various sites and then taking a prescribed number of dips at the site each time it is sampled. A 70% or greater reduction in the number of larvae per dip is expected.

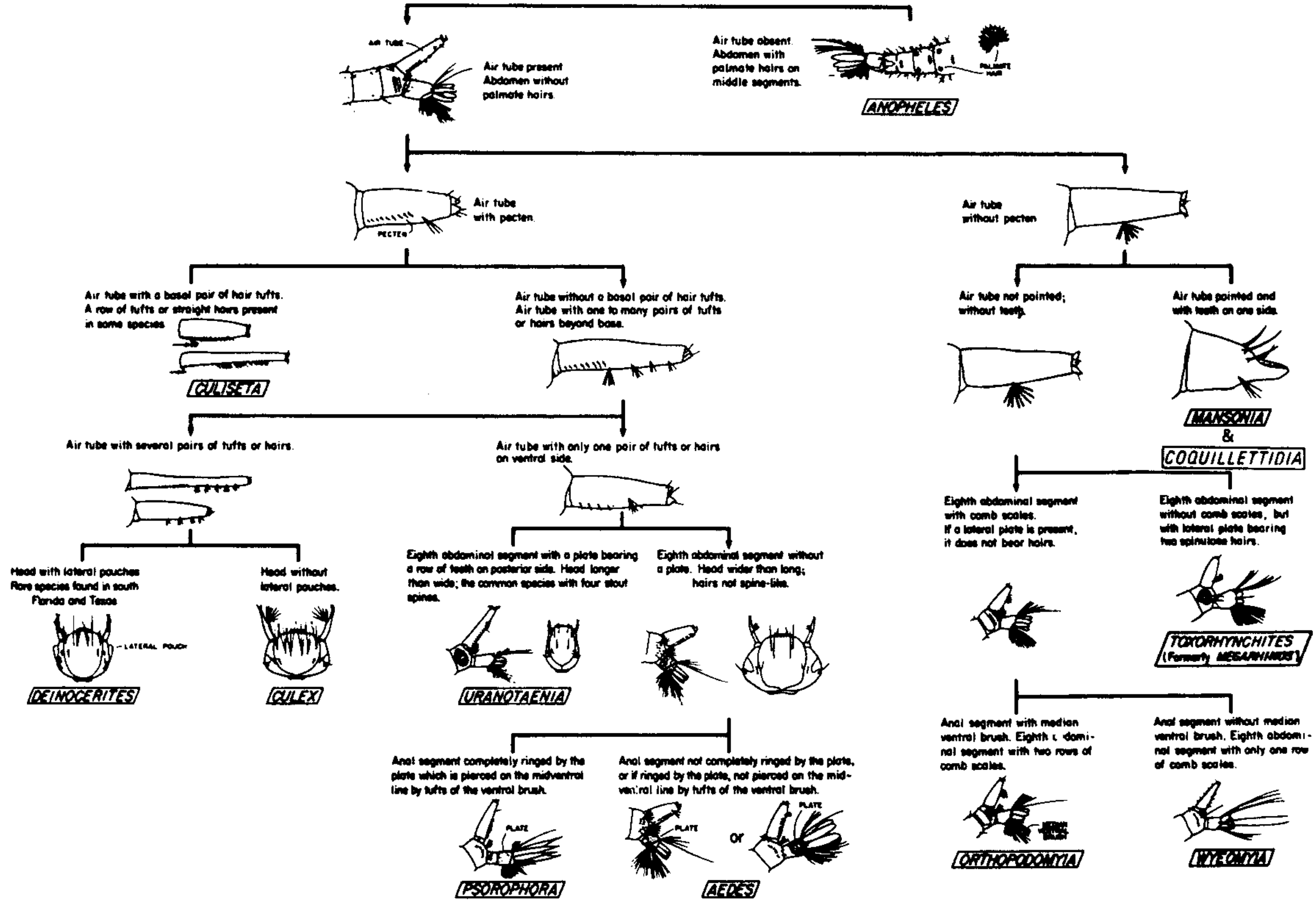
For years larval and adult mosquitoes have been tested for resistance to insecticides with kits purchased from the World Health Organization. These tests required large numbers of specimens, were usually conducted in the laboratory, and were subject to procedural variables such as temperature and humidity or age of the chemicals or test papers. Therefore, Brogdon and coworkers (1987, 1989) proposed the development of Nonspecific Esterase (NSE) Microplate Assay tests which permit: tests conducted in the field; analysis of single insects; up to thirty assays from a single insect; and fast and accurate methods which can be read in the field with the naked eye, at considerably lower costs than the WHO Bioassay kits.

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 mosquito-proof their homes, and to control mosquito breeding places on their own property. In reaching the public it is helpful 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 may be willing to devote a portion of their activities to a discussion of mosquito control, frequently as a free public service. In some areas school children have taken 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.

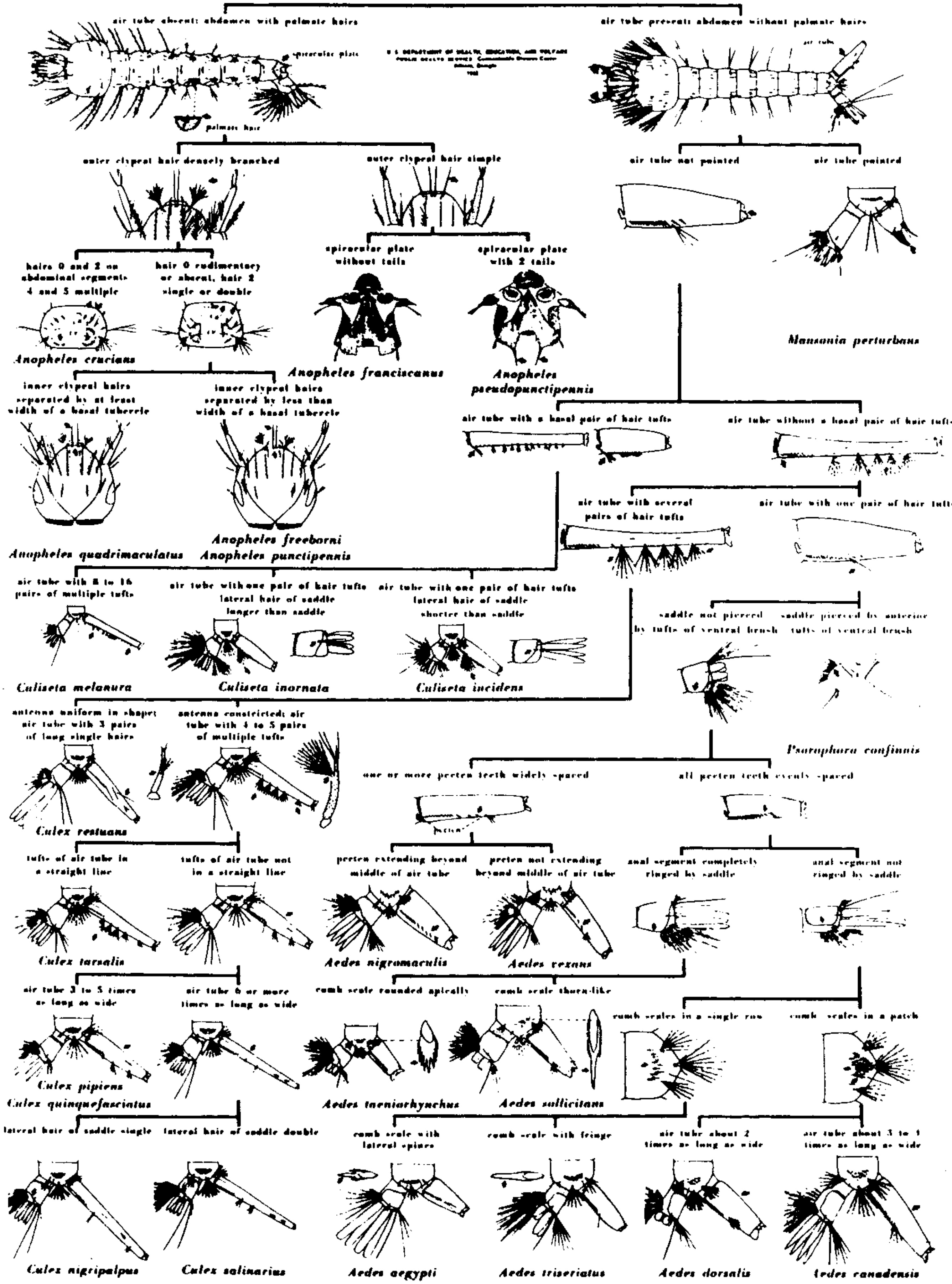
Finally, mosquito control organizations should have a courteous, well-informed staff who can answer telephone or person-to-person inquiries, personnel who can speak at a variety of meetings, and individuals who are prepared to answer complaints promptly and give adviceon a wide variety of problems.

PICTORIAL KEY TO U S GENERA OF MOSQUITO LARVAE



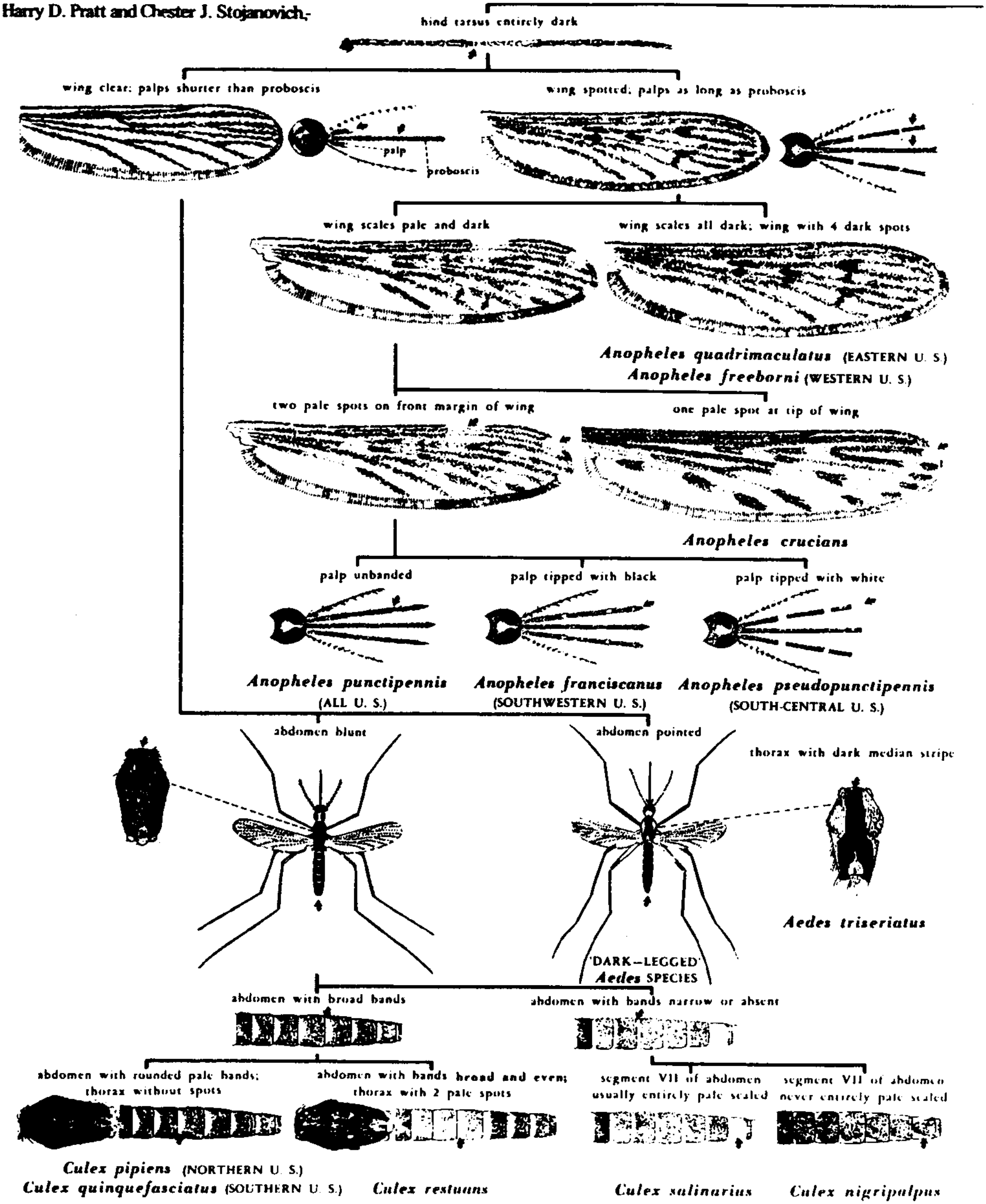
PICTORIAL KEY TO SOME COMMON MOSQUITO LARVAE OF THE UNITED STATES

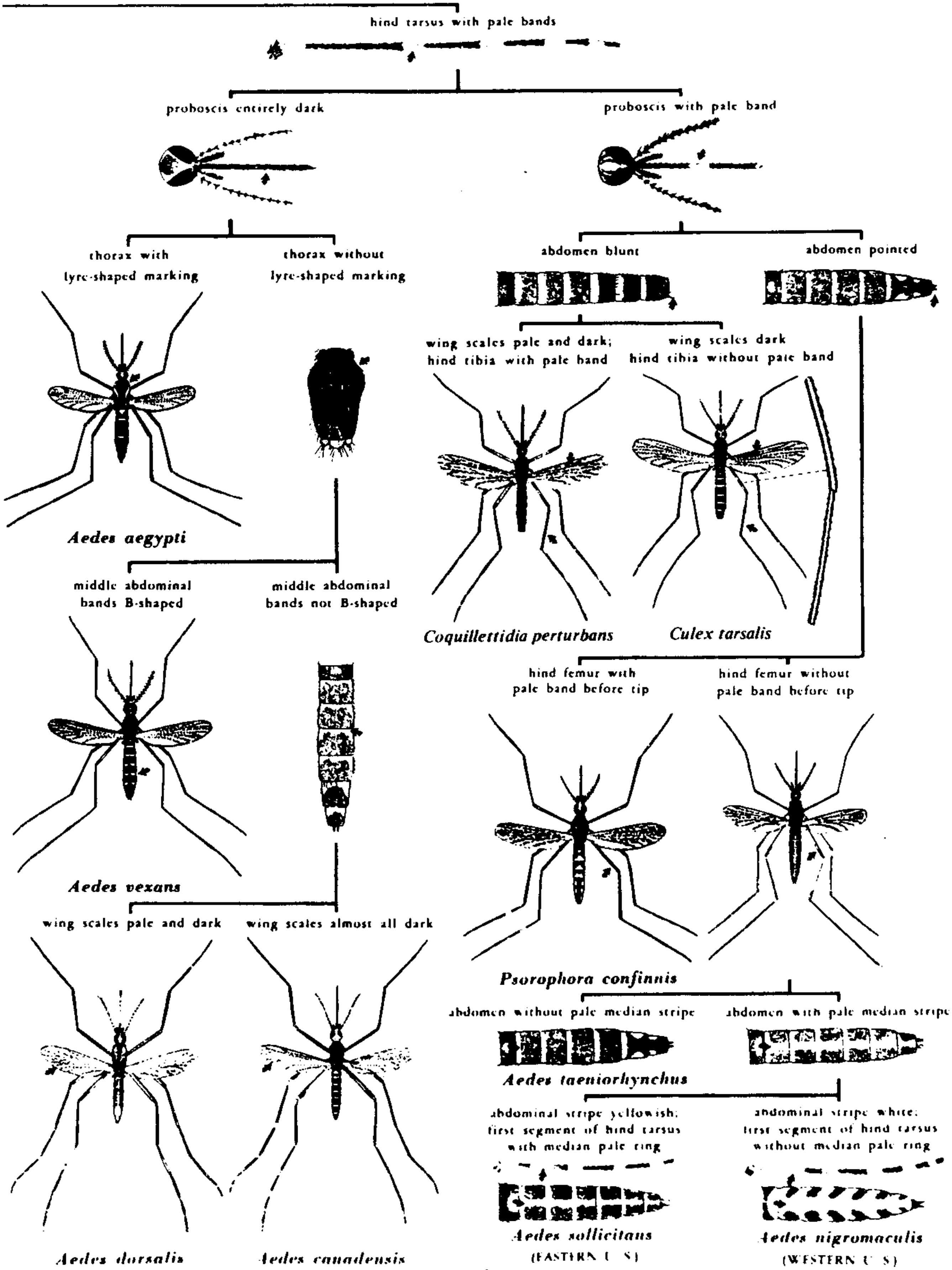
Chester J. Stojanovich and Harry D. Pratt



PICTORIAL KEY TO SOME COMMON FEMALE MOSQUITOES OF THE UNITED STATES

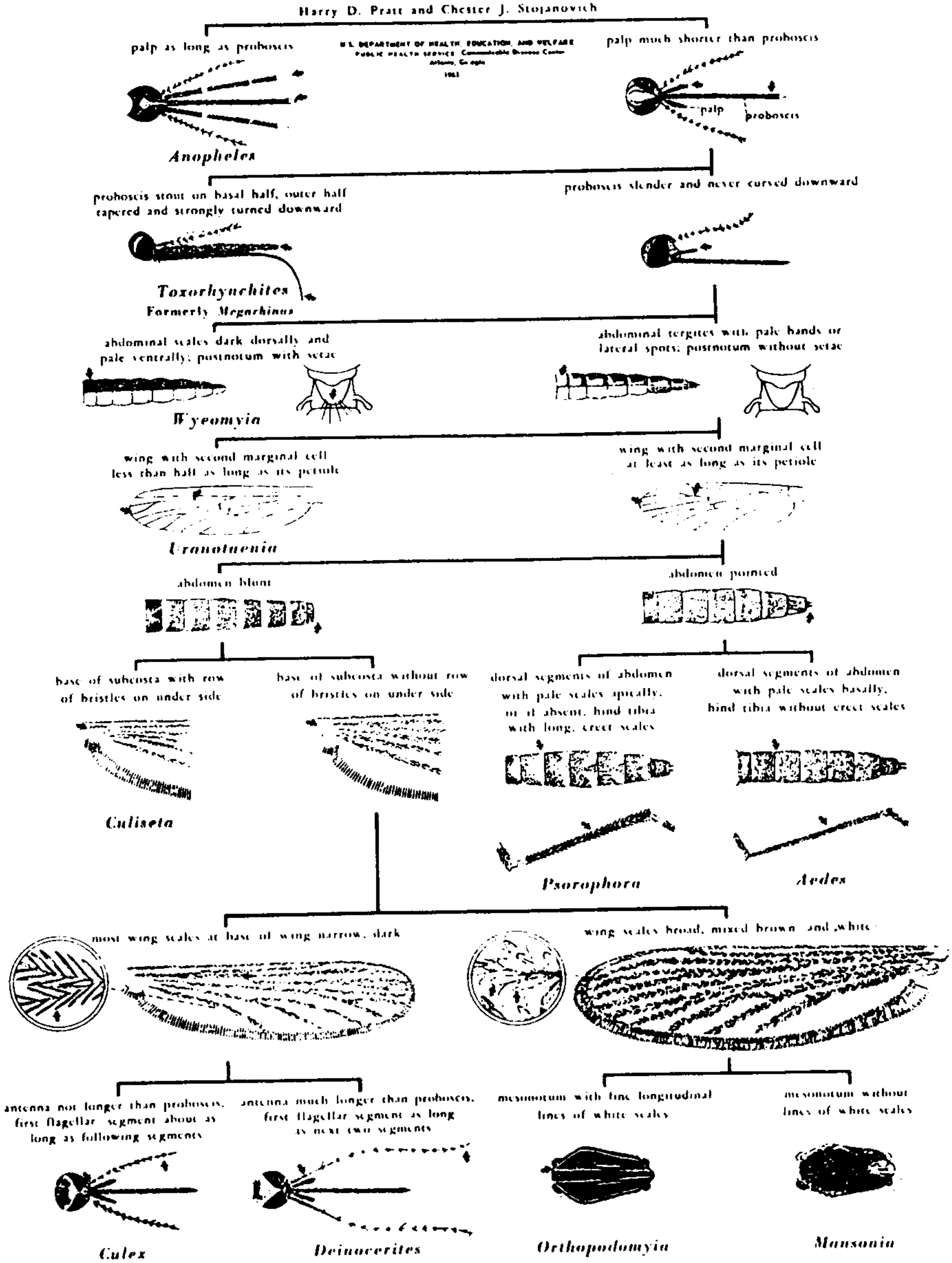
Harry D. Pratt and Chester J. Stojanovich,-




hind tarsus with pale bands
proboscis entirely dark
proboscis with pale band
thorax with lyre-shaped marking
thorax without lyre-shaped marking
abdomen blunt
abdomen pointed
wing scales pale and dark; hind tibia with pale band
wing scales dark hind tibia without pale band
Aedes aegypti
Coquillettidia perturbans
Culex tarsalis
middle abdominal bands B-shaped
middle abdominal bands not B-shaped
hind femur with pale band before tip
hind femur without pale band before tip
Aedes vexans
wing scales pale and dark
wing scales almost all dark
Psorophora confinnis
abdomen without pale median stripe
abdomen with pale median stripe
Aedes taeniorhynchus
abdominal stripe yellowish; first segment of hind tarsus with median pale ring
abdominal stripe white; first segment of hind tarsus without median pale ring
Aedes sollicitans
(EASTERN U. S.)
Aedes nigromaculis
(WESTERN U. S.)
Aedes dorsalis
Aedes canadensis

PICTORIAL KEY TO UNITED STATES GENERA OF FEMALE MOSQUITOES

Harry D. Pratt and Chester J. Stojanovich



★U.S. Government Printing Office: 1980—532-188

SELECTED REFERENCES

Anonymous. 1988. Modern Mosquito Control. 6th ed. Cyanamid Agricultural Division, VPC Ventures. Wayne, NJ. 35 pp.

Barr, A. R. and P. Guptavanij. 1988. "*Anopheles hermsi* n. sp., an unrecognized species of *Anopheles maculipennis* group (Diptera: Culicidae)." Mosquito Systematics 20:352-356.

Beadle, L. D. and F. C. Harmston. 1958. "Mosquitoes in sewage stabilization ponds in the Dakotas." Mosq. News 18:293-296.

Benenson, A. S. (ed.). 1990. Control of Communicable Diseases in Man. 15 ed., American Public Health Association, Washington, DC. 532 pp.

Bidlingmayer, W. L. 1959. "Mosquito penetration tests with louver screening." Fla. Entomol. 42:63-67.

Bowen, C. S., T. R. Fashinell, P. B. Dean, and M. B. Gregg. 1976. "Clinical aspects of human Venezuelan equine encephalitis in Texas." Bull. Pan. Am. Health Org. 10:46-57.

Bradley, G. H. and B. V. Travis. 1942. "Soil Sampling for Studying Distribution of Mosquito Eggs on Salt Marshes in Florida." Proc. 29th Ann. Meet. N. J. Mosq. Exterm. Assoc.:143-146.

Brogdon, W. G. 1989. "Biochemical resistance detection: an alternative to bioassay." Parasitology Today 5:56-60.

Brown, A. W. A. 1986. "Insecticide resistance in mosquitoes: a pragmatic view." J. Am. Mosq. Control Assoc. 2:123-140.

Calisher, C. H. and W. H. Thompson (eds.). 1983. California Serogroup Viruses. A. R. List, New York, NY. 399 PP.

Carlson, D. B., P. D. O'Bryan, and J. R. Ray. 1991. "A review of current salt marsh management issues in Florida." J. Am. Mosq. Control Assoc. 7:83-88.

Carpenter, S. J. and W. J. LaCasse. 1952. Mosquitoes of North America (North of Mexico). University of California Press, Berkeley, CA. 360 pp.

Centers for Disease Control. 1973. "Public health pesticides." Pest Control 41(4):17-50.

Centers for Disease Control. 1991. "Imported dengue -- United States, 1990." MMWR 40:519-520.

Chamberlain, R. W. 1987. "Historical perspective on the epidemiology and ecology of mosquito-borne virus encephalitides in the United States." Am. J. Trop. Med. Hyg. 37(3 Suppl.):85-175.

Chapman, H. C. 1985. Biological Control of Mosquitoes. AMCA Bull. 6, 218 pp.

Clark, G. G., A. V. Vorndam, I. Gomez, and E. Vergne. 1991. "Dengue activity in Puerto Rico in 1990 (Actividad de Dengue in Puerto Rico)." J. Am. Mosq. Control Assoc. 7:643.

Clarke, J. W., Jr and F. C. Wray. 1969. "Predicting influxes of *Aedes vexans* into urban areas." Mosq. News 27:156-163.

Crans, W. J. and M. F. Feldlaufer. 1974. "The likely mosquito vectors of dog heartworm in a coastal area of southern New Jersey." Proc. 42nd Ann. Conf., CA Mosq. Control Assoc.:168.

Darsie, R. F., Jr. 1986. "The identification of *Aedes albopictus* in the Nearctic region" J. Am. Mosq. Control Assoc. 2:336-340.

Darsie, R. F., Jr. and R. A. Ward. 1981. "The identificaiton and geographic distribution of the mosquitoes of North America, north of Mexico." Mosquito Systematics Suppl. 1:313 pp.

de Barjac, H. and D. J. Sutherland (eds.). 1990. Bacterial Control of Mosquitoes and Black Flies. Rutgers University Press, New Brunswick, NJ. 352 pp.

Elmore, C. M. and R. W. Fay. 1958. "*Aedes sollicitans* and *A. taeniorhynchus* larval emergence from sod samples." Mosq. News 18:230-233.

Elmore, C. M. and H. F. Schoof. 1963. "Dispersal of *Aedes taeniorhynchus* near Savannah, Ga." Mosq. News 23:1-7.

Evans, B. R. 1992. Mosquito control: commercial and government agencies, pp. 405-410 in K. S. Delaplane, 1992 Georgia Pest Control Handbook, Coop. Ext. Serv., Univ. of Georgia, Athens, GA.

Fay, R. W. and A. S. Perry. 1965. "Laboratory studies of ovipositional preferences of *Aedes aegypti*." Mosq. News 25:276-281.

Ferrigino, F., P. Slavin, and D. M. Jobbins. 1975. "Saltmarsh water management control." Proc. 62nd Ann. Meet. NJ Mosq. Exterm. Assoc.

Francy, D. B., C. G. Moore, and D. A. Eliason. 1990. "Past, present, and future of *Aedes albopictus* in the United States." J. Am. Mosq. Control Assoc. 6:127-132.

Freier, J. E. and D. B. Francy. 1991. "A duplex cone trap for the collection of adult *Aedes albopictus*." J. Am. Mosq. Control Assoc. 6:127-132.

Fritz, G. N., S. K. Narang, D. L. Kline, J. A. Seawright, R. K. Washino, C. H. Porter, and F. H. Collins. 1991. "Diagnostic characterization of *Anopheles freeborni* and *An. hermsi* by hybrid crosses, frequencies of polytene X chromosomes, and rDNA restriction enzyme fragments." J. Am. Mosq. Control Assoc. 7:198-206.

Gerberg, E. J. 1970. Manual for Mosquito Rearing and Experimental Techniques. J. Am. Mosq. Control Assoc. 5:viii, 109 p.

Gershwin, I. J., M. E. Gershwin and J. Kritzman. 1974. "Human pulmonary dirofilariasis." Chest 66:92-96.

Grimstad, P. R. 1988. "California group virus disease." pp. 99-136 in T. P. Monath, The Arboviruses: Epidemiology and Ecology. Vol. II, CDC Press, Boca Raton, Fl.

Gubler, D. J. 1988. "Dengue", pp. 223-260 in T. P. Monath, The Arboviruses: Epidemiology and Ecology. Vol. II, CDC Press, Boca Raton, Fl.

Harmston, F. C. and L. J. Ogden. 1971. "Evaluation of mosquito control problems associated with improved soil and water management practices in irrigated mountain meadows." Proc. 11th Annu. Meet. N. W. Mosq. Vector Control Assoc. pp. 3-10.

Harmston, F. C., G. R. Schultz, R. B. Eads, and G. C. Menzies. 1956. "Mosquitoes and encephlaitis in the irrigated high plains of Texas." Pub. Hlth. Rep. 71:759-766.

Harwod, R. F. and M. T. James. 1979. Entomology in Human and Animal Health. Macmillan Company, New York, NY. 548 pp.

Hawley, W. A. 1988. "The biology of *Aedes albopictus*." J. Am. Mosq. Control Assoc. 4 (supp. 1):1-39.

Hess, A. D. and C. C. Kiker. 1943. "Water level management for malaria control on impounded waters." J. Natl. Malar. Soc. 3:181-196.

Hester, P. G., M. A. Olson, and J. C. Dukes. 1991. "Effects of Arosurf MSF on a variety of aquatic nontarget organisms in the laboratory." J. Am. Mosq. Control Assoc. 7:48-51.

Horsfall, W. R. 1956. "A method of making a survey of floodwater mosquitoes." Mosq. News 16:66-71

Jakob, W. L. 1973. "Developmental inhibition of mosquitoes and the house fly by urea derivatives." J. Med. Entomol. 10:452-455.

Jenkins, D. W. 1964. "Pathogens, parasites, and predators of medically important arthropods, annotated bibliography." Bull. WHO 30.

Johnston, J. G., J. W. Weaver, and W. D. Sudia. 1973. "Flashlight batteries as a power source for CDC miniature light traps." Mosq. News 33:190-194.

Kettle, D. S. 1990. Medical and Veterinary Entomology. C. A. B. International, 845 N. Park Avenue, Tucson, AZ 85719. 664 pp.

Kilpatrick, J. W. 1967. "Performance specifications for ultra-low volume aerial application of insecticides for mosquito control." Pest Control 35(5):80, 82, 84.

Lacey, L. A. and C. N. Lacey. 1990. "The medical importance of riceland mosquitoes and their control using alternatives to chemical insecticides." J. Am. Mosq. Control Assoc. Suppl. 2:1-93.

Laird, M. 1988. The Natural History of Larval Mosquito Habitats. Academic Press, London.

Laird, M. and J. W. Miles. 1983. Integrated Mosquito Methodologies. Vol. 1. "Experience and components from conventional control." Academic Press, New York, NY.

Laird, M. and J. W. Miles. 1983. Integrated Mosquito Methodologies. Vol. 2. "Biocontrol and Other Innovative Componenets and Future Directions." Academic Press, New York, NY. 444 pp.

Leahy, F. F. 1985. The Pyrethroid Insecticides. Taylor and Francis, London. 440 pp.

Ludlam, K. W., L. A., Jachowski, Jr., and G. F. Otto. 1970. "Potential vectors of *Dirofilaria immitis*." J. Am. Vet. Med. Assoc. 157(10):1354-1359.

Marten, G. G. 1990. "Elimination of *Aedes albopictus* from tire piles by introduction of *Macrocyclops albidus* (Copepoda, Cyclopidae)." J. Am. Mosq. Control Assoc. 6:689-693.

Mitchell,, C. J. 1991. "Vector competence of North and South American strains of *Aedes albopictus* for certain arboviruses: a review." J. Am. Mosq. Control Assoc. 7:446-451.

Mitchell, C. J., M. L. Niebylsky, G. C. Smith, N. Karabatsos, D. Martin., J. P. Mutebi, G. B. Craig, Jr., and M. J. Mahler. 1992. "Isolation of Eastern equine encephalitis virus from *Aedes albopictus* in Florida." Science 257(5069):526-527.

Monath, T. P. (ed.). 1980. St. Louis Encephalitis. APHA, Washington, DC. 680 pp.

Monath, T. P. (ed.). 1988. The Arboviruses: Epidemiology and Ecology. 5 vols. CRC Press, Boca Raton, FL.

Monath, T. P. 1988. "Yellow Fever." pp. 139-231 in T. P. Monath (ed.). 1988. The Arboviruses: Epidemiology and Ecology. Vol. V. CRC Press, Boca Raton, FL.

Moore, C. G., R. G. McLean., C. J. Mitchell, R. S. Nasci, T. F. Tsai, C. H. Calisher, A. A. Martin, P. S. Moore, and D. J. Gubler. 1993. Guidelines for Arbovirus Surveillance Programs in the United States. USDHHS, PHS, CDC, Fort Collins, CO. 83 pp.

Morris, C. D. 1988. "Eastern Equine Encephalitis." pp. 1-20 in T. P. Monath (ed.). 1988. The Arboviruses: Epidemiology and Ecology. Vol. III. CRC Press, Boca Raton, FL.

Mulhern, T. D. 1942. "New Jersey Mechanical Trap for Mosquito Surveys." NJ Agric. Exp. Sta. Circ. 421 (Reprinted in J. Am. Mosq. Control Assoc. 1:411-418, 1985).

Mulhern, T. D. 1974, 65 pp. A Manual for Mosquito Control Personnel. California Mosq. Control Assoc., Visalia, CA. 190 pp.

Narang, S. K., P. E. Kaiser, and J. A. Seawright. 1989. "Identification of species d, a new member of the *Anopheles quadrimaculatus* species complex: a biochemical key." J. Am. Mosq. Control Assoc. 5:217-224.

Neff, J. M., L. Morris, R. Gonzalez-Alcover, P. H. Coleman, S. B. Lyss, and H. Negron. 1967. "Dengue fever in a Puerto Rican community." Am. J. Epidemiol. 86:162-184.

Oaks, S. C., V. S. Mitchell, G. W. Pearson, and C. C. J. Carpenter. 1991. Malaria: Obstacles and Opportunities. National Academy Press, Washington, DC. 309 pp.

Otto, G. F. (ed.). 1989. Proceedings of the Heartworm Symposium '89. Washington, DC. Am. Heartworm Soc. 251 pp.

Pratt, H. D. 1948. "Influence of the moon on light trap collections of *Anopheles albimanus* in Puerto Rico." J. Nat'l Mal. Soc. 7:212-220.

Pratt, H. D. 1991. "Malaria control and eradication in the United States." pp. 56-60. Insect Potpourri: Adventures in Entomology. Sandhill Crane Press, Inc. Gainesville, FL.

Provost, M. W. 1959. "The influence of moonlight on light trap catches of mosquitoes." Ann. Entomol. Soc. Am. 52:261-271.

Provost, M. W. 1974. "Salt marsh management in Florida." Proc. Tall Timbers Conf. on Ecol. Animal Control by Habitat Mgmt. 1973, pp. 5-17.

Rathburn, C. B. and A. H. Boike, Jr. 1975. "Ultra low volume tests of several insecticides applied by ground equipment for the control of adult mosquitoes." Mosq. News 35:26-29.

Reeves, W. C. 1965. "Ecology of mosquitoes in relation to arboviruses." Annu. Rev. Entomol. 10:25-46.

Reeves, W. C. 1990. "Epidemiology and control of mosquito-borne arboviruses in California." 1943-1987. Cal. Mosq. Vector Control Assoc. Sacramento, CA. xiv + 508 pp.

Reisen, W. K. and T. P. Monath. 1988. "Western Equine encephalitis" pp. 89-137 in T. P. Monath (ed.). 1988. The Arboviruses: Epidemiology and Ecology. Vol. V. CRC Press, Boca Raton, FL.

Reiter, P., W. L. Jakob, D. B. Francy, and J. B. Mullenix. 1986. "Evaluation of the CDC gravid trap for the surveillance of St. Louis encephalitis vectors in Memphis, Tennessee." J. Am. Mosq. Control Assoc. 2:209-211.

Ross, H. H. and W. R. Horsfall. 1965. "A synopsis of the mosquitoes of Illinois (Diptera, Culcidae)." Ill. Nat. Hist. Surv. Biol. Notes No. 52, 50 pp.

Service, M. W. 1976. Mosquito Ecology: Field Sampling Methods. John Wiley & Sons. New York-Toronto. 583 pp.

Splinter, W. E. 1976. "Center-pivot irrigation." Scientific American, April 1976, pp. 90-98.

Stone, A., K. L. Knight, and H. Starke. 1959. A Synoptic Catalog of the Mosquitoes of the World (Diptera, Culicidae). Thomas Say Foundation, Entomol. Soc. Am., Washington, DC. vi + 358 pp.

Sudia, W. D. and R. W. Chamberlain. 1967. Collection and Processing of Medically Important Arthropods for Arbovirus Isolation. CDC, PHS, USDHEW, Atlanta, GA. 29 pp.

Sudia, W. D. and V. F. Newhouse. 1975. "Epidemic Venezuelan equine encephalitis in North America: a summary of virus-vector-host relationships." Am. J. Epidemiol. 101:1-13.

Sudia, W. D., V. F. Newhouse, C. H. Calisher, and R. W. Chamberlain. 1971. "California group arboviruses: isolation from mosquitoes in North America." Mosq. News 31:576-600.

Thom, W. M. 1942. "A suggested treatment for the elimination of surface cracks on hydraulic fills." Mosq. News 2:73-102.

Trapido, H. and P. Galindo. 1956. "The epidemiology of yellow fever in Middle America." Exper. Parasitol. 5:285-323.

Tsai, T. F. 1991. "Arboviral Infections in the United States." Inf. Dis. Clin. North Am. 1991, 5:73-102.

Tsai, T. F. and C. J. Mitchell. 1988. "St. Louis encephalitis." pp. 113-143 in T. P. Monath (ed.). 1988. The Arboviruses: Epidemiology and Ecology. Vol. IV. CRC Press, Boca Raton, FL.

U. S. Department of Agriculture (USDA). 1967. Mosquito Prevention on Irrigated Farms. Agr. Handbook No. 319, Supt. of Documents, U. S. Gov. Printing Office, Washington, DC. 32 pp.

U. S. Public Health Service, Federal Security Agency and Tennessee Valley Authority. 1947. Malaria Control on Impounded Water. Supt. of Documents, U. S. Govt. Printing Office, Washington, DC. 422 pp.

Ventura, A. K., E. E. Buff, and W. J. Ehrenkrantz. 1974. "Human Venezuelan equine encephalitis virus infections in Florida." Am. J. Trop. Med. Hyg. 23:507-512.

Walton, T. E. and M. Grayson. 1988. "Venezuelan equine encephalitis." pp. 203-231 in T. P. Monath (ed.). 1988. The Arboviruses: Epidemiology and Ecology. Vol. IV. CRC Press, Boca Raton, FL.

Watts, D. M. S., S. Pantuwatana, G. R. DeFoliart, T. M. Yuill, and W. H. Thompson. 1973. "Transovarial transmission of LaCrosse virus (California Encephalitis Group) in the mosquito *Aedes triseriatus*." Science 182:1140-1141.

World Health Organization (WHO) 1974. Expert Committee on Filariasis. World Health Org. Tech. Rep. Ser. No. 542, 54 p.

World Health Organization. 1975. Manual on Practical Entomology in Malaria. World Health Organization, Geneva, Switzerland. Part I:1-160, Part II:1-191.