Mosquito Biology, Surveillance and Control

A Pesticide Applicator Certification
Manual for Georgia

Second Edition

This manual was prepared by Elmer W. Gray, Public Health Extension Specialist,
University of Georgia Cooperative Extension Service.

A special thanks must be offered to Terry All, Dr. Carina Blackmore, Dr. Mark Blackmore, Dr. Roxanne Connelly, Dr. Rosmarie Kelly, Dr. Henry Lewandowski, Dr. Paul Guillebeau and Dr. Ray Noblet for their editorial efforts, advice and comments.

Table of Contents

Preface

This training manual is intended to provide the information needed to meet the standards of the Environmental Protection Agency for pesticide applicator certification and prepare applicators to take an examination developed by the State Department of Agriculture. Additional information in the form of publications and short courses can be obtained from the Cooperative Extension Service and the Georgia Department of Public Health.

This manual will provide information important to the control of mosquitoes, including:

- Effects of mosquito pests on humans
- Mosquito life cycles and habitats
- Recognition of pests and vectors
- Methods used to control pests and vectors
- Arbovirus surveillance
- Descriptions of other common pests

Introduction

Mosquitoes occur throughout the world, developing in almost every known aquatic habitat except swift currents and open bodies of water. Wherever they occur, they are, at best, an annoyance and, at worst, vectors of deadly diseases. Over 3,000 species of mosquitoes have been described worldwide and over 60 species are known to occur in Georgia. These species exhibit a wide range of habits and habitat preferences. Larvae are found in such diverse habitats as the grassy margins of ponds, standing water in fields and forests, catch basins and common yard debris. Eggs of different species may be laid singly or in rafts, on water or on damp soil where they hatch after subsequent flooding. Flight ranges for adult mosquitoes vary from a few hundred feet to more than one hundred miles with favorable winds. Hibernation or over-wintering in different species may be in the egg stage, as larvae or as adults.

Insects and other animals which are involved in the transmission of diseases, cause discomfort by biting or stinging, and/or cause annoyance by their presence are considered economic and public health pests. In this respect, mosquitoes are one of the most important groups. In Georgia, mosquitoes are known vectors of West Nile virus, eastern equine encephalitis virus, St. Louis encephalitis virus, LaCrosse encephalitis virus and dog heartworm. Large numbers of these pests are the source of almost constant annoyance in many parts of the State, particularly during the warmer months. In areas where mosquito annoyance is great, agricultures is impeded, recreational areas become virtually unusable and economic growth may be affected.

People do not wish to live in areas where mosquitoes interfere with living, and industry often is not willing to accept the losses resulting from the lowered efficiency of their employees. Consequently, considerable sums of money are invested annually in mosquito control in Georgia, yet annoyance caused by these pests continues to have a direct effect on the economy of the state. Approximately $125,000,000 is spent annually in Georgia in an effort to reduce and treat the effects of disease and nuisance caused by mosquitoes. Mosquitoes often have the greatest effect on the resort industry where salt marsh species pose an all too frequent threat to the economy of many coastal towns. As expected, four of Georgia's larger and most comprehensive mosquito control programs are located in coastal counties. However, mosquito suppression programs are active from the coast to the mountains and from the Savannah River south to the Alabama/Florida border.

In addition to the economic losses suffered as a result of annoyance, mosquitoes also threaten public health. Although malaria and yellow fever have been absent from Georgia for some time, other mosquito-borne diseases remain a problem. The introduction of West Nile virus into the state in 2001 has reminded us of the importance of mosquito-borne diseases. Public health officials have initiated a process to identify areas where arbovirus transmission is occurring. In addition to human issues, thousands of dogs die each year from dog heartworm, another mosquito-borne disease. When potential for a mosquito-borne disease outbreak is high, mosquito control becomes a priority.

Mosquitoes can be controlled by a number of methods. Larval habitat reduction through water management is a widely used and ecologically sound approach to mosquito control. This method involves many techniques for eliminating excess surface water or creating water circulation systems that allow predators access to the immature stages of the mosquitoes. Water management is often augmented by the application of insecticides. Insecticide applications reduce peak populations of mosquitoes rapidly, but are only a temporary solution. In emergency public health situations, the exclusive use of insecticides will produce short-term control when a rapid reduction in numbers is necessary or desirable. However, when mosquitoes occur over large areas, total reliance on insecticides for control without consideration of habitat reduction or an integrated control approach is costly and only provides temporary periods of relief from the targeted pest. Combining all available control methods in an "integrated control" program always provides the most efficient and effective results. Initially, this approach may require more time, work and expense, but in the long run it is more effective and efficient than a program based solely on the use of insecticides.

Essential to any mosquito control program is a thorough knowledge of the mosquito life cycles, habits, numbers and location. With such information and an awareness of the various methods of control, mosquito control operations can more effectively attack the weak points in a mosquito's life cycle. Of course, such a broad-based approach to control is founded on an effective and informed program of surveillance that provides evidence of specific problem areas. Before initiating a control program, one should consult the responsible state health department representatives, local mosquito control agencies and the Cooperative Extension Service for guidance and assistance.

History of Mosquito Control in Georgia

Mosquitoes and the problems they cause have been associated with some parts of Georgia since the arrival of the earliest English settlers. Fort King George was constructed in 1721 on the north branch of the Altamaha River, near the later developed town of Darien. Journal notations from the construction period for Fort King George describe "Musketos in their Vigour." Another report from 1744 from the same area reiterated the descriptions of large numbers of mosquitoes being present. The development of a rice growing culture and the importation of slaves to support it were quickly followed by regular outbreaks of malaria and yellow fever. Rice culture and the large areas of impounded water that were used to grow this crop also increased the number and quality of larval mosquito habitats.

In 1817 the City of Savannah, which also supported a large rice growing culture, approved an ordinance authorizing the City to buy the right of culture from wet to dry from the surrounding landowners. From 1817 to 1829 the City had expended $72,537 so that only dry rice field culture was practiced on the adjacent lands. City records show the health of its citizens was much improved. This successful reduction in mosquito breeding sites was likely the first time that local tax monies were expended to control mosquitoes in the New World. Yellow fever, vectored by the container breeder, *Aedes aegypti*, continued to plague coastal Georgia through out the 1800's. Particularly severe outbreaks occurred in 1859 and 1876 when 2.9 and 3.6 % of Savannah's population died.

The city of Savannah is located in Chatham County, a county that is one-third salt marsh. Consequently, large populations of the black saltmarsh mosquito, *Ochlerotatus taeniorhynchus*, and the brown saltmarsh mosquito, *Ochlerotatus sollicitans*, are often present. With organized mosquito control already being conducted in New Jersey and Florida, interested citizens in Chatham County approached the county commission to create a mosquito control program in the mid 1950's. A comprehensive, operational program was initiated during the 1957 mosquito season. Today Chatham County is the largest of the approximately 100 mosquito control programs in Georgia. In 2006, an estimated 9.0 million dollars were spent on mosquito abatement programs throughout the State.

Georgia Mosquito Control Association

The Georgia Mosquito Control Association (GMCA) was established in 1976 with Mr. Oscar Fultz of the Chatham County Mosquito Control Program serving as its first president. Today the association serves those interested in mosquitoes in Georgia by hosting an annual meeting each fall and serving as a resource of education and communication. The annual meeting provides an opportunity for anyone interested in mosquitoes to meet and enjoy friends and fellowship while attending presentations about a wide variety of mosquito oriented topics. In addition, sustaining members are on hand to provide a variety of information concerning mosquito control products, equipment and services. The meeting is open to the public and registration is required. Recertification credits for Pesticide Applicators licenses are available for attending the annual meeting. Membership information can be obtained at the annual meeting each fall or by contacting the Georgia Public Health Extension Specialist through the University of Georgia, Entomology Department. The association is served by a Board of Directors. The Board of Directors includes the President, Past President, Vice-President, Secretary-Treasurer, Commercial Representative, Extension Service Representative, Public Health Department Representative and three rotating Directors. The Board of Directors operate the Association and schedule and organize the annual meeting. The GMCA web site provides a vast array of mosquito information and contacts and can be found at http://www.gamosquito.org/.

Chapter 1. Classification and Biology

Learning Objectives

After study of the material in this chapter, you should be able to:

1. Recognize the scientific name of a mosquito.
2. Name the fours stages of mosquito development.
3. Understand how an insect key is used.
4. Differentiate between male and female mosquitoes.
5. Describe the three primary egg laying habits.
6. Recognize a mosquito larva.
7. Name the three body regions of a larva.
8. Describe the primary larval feeding technique.
9. Recognize a mosquito pupa.
10. Explain the emergence process from a pupa to adult.
11. Differentiate an adult mosquito from other common insects.
12. Recognize the body regions of an adult mosquito.
13. Understand the importance of flight range for adult mosquitoes.
14. Explain why knowing the pest species biology is important to control efforts.
15. Understand how long have mosquitoes been a problem in Georgia.

Mosquito Classification

In order to make it clear exactly which animal among the many kinds one is speaking or writing about, scientists have devised a system of classification and naming in which each kind of animal known to science is given a name consisting of two words. The first name is the name of the genus and is written with a capital letter. The second name is the species name and begins with a small letter. Together they form the scientific name which is always either italicized or underlined (to indicate italics).

The classification of the mosquito which transmitted malaria when it was present in the southeastern United States is shown below:

Kingdom - Animalia	(all animals)
Phylum - Arthropoda	(all animals with paired, jointed appendages and exoskeletons)
Class- Insecta	(all insects; three main body divisions and six legs)
Order - Diptera	(all two-winged flies)
Family - Culicidae	(all mosquitoes)
Genus - *Anopheles*	

Species -*Anopheles quadrimaculatus* Say (Say is the last name of the person who first described this species)

At the current time there are 63 known species of mosquitoes in Georgia, belonging to 12 genera. Worldwide there are over 3,000 species known, 174 of which occur in the United States. These mosquitoes inhabit a wide variety of aquatic habitats. The biology of each species is unique in some respect. Some of these distinctions, such as differences in larval habitat, host preferences and flight ranges, will be discussed in more detail in a section of this publication dealing with various species. The differences in appearance (morphological differences) will be discussed in the section on identification.

Identification of Adult and Larval Mosquitoes

Life History

Mosquitoes have four distinct stages of development: egg, larva, pupa and adult (Figure 1). This type of life cycle is described as holometabolous. Eggs of most species must be immersed in water to hatch, but may be deposited initially either directly on water or in locations subject to periodic flooding. Larvae and pupae are aquatic, while adults are active, free-flying insects. Overall, the aquatic and terrestrial habitats utilized by immature and adult mosquitoes are diverse, however each species typically has specific requirements or preferences.

Mosquitoes are usually collected as larvae or adults. It is important to determine what species are present and their relative abundance so that mosquito control personnel will know what their problem mosquitoes are and where they are developing. Only in this way can they most efficiently use the control tools available. Every person who works in mosquito control should be able to recognize the common problem species in their area.

Mosquitoes belong to the family of Culicidae within the insect order Diptera. Like all true flies, the adults have only one pair of wings rather than the usual two pairs found in most insects. Mosquitoes differ from other Diptera by: (1) having numerous scales on the edges and veins of the wings and (2) by females having mouthparts extended into a long proboscis which contains needle-like stylets. These piercing-sucking mouthparts are suited for penetrating the skin of the host and sucking blood. All mosquitoes may be separated from other closely related insects such as midges and crane flies by these two characteristics. It should be noted that while male mosquitoes have an elongated proboscis, they **do not** feed on blood. Males typically feed on the nectar of flowers and other sugars in the environment to produce energy for flight and mating. Female mosquitoes also feed on nectar and other sugars for flight energy, and usually require a blood meal prior to laying eggs.

Careful observation of mosquitoes will show that not all are the same size and color. Recognition of the differences between, or the presence or absence of, certain structures and markings (characters) is necessary for the identification of a particular mosquito. These characters may be arranged in a list or "key" so that by accepting or rejecting certain characters as they pertain to a specimen, one may narrow down the possibilities until the mosquito is identified. Mosquitoes sharing certain common characters are grouped into a genus and given a generic name such as *Aedes* or *Culex*. Mosquitoes which differ from one another within a genus are separated to species. Species or specific names are binomial (made up of two words), for example, *Aedes albopictus* or *Culex restuans*. Identifying mosquitoes to species can be a difficult task and usually requires a microscope and the use of a quality key.

Worldwide, over 3,000 species of mosquitoes are known. About 174 species representing 14 genera occur in the United States. Twelve of the 14 genera that exist in North America are present in Georgia, and 63 species are known to occur here. Important taxonomic reclassifications do occur during the course of time. Examples of these which have had an impact upon species nomenclature include the re-classification of *Mansonia perturbans* to *Coquillettidia perturbans* and more recent reclassification of many *Aedes* species to the genus *Ochlerotatus.* These changes occur when taxonomists believe that newly discovered anatomical differences or important characters warrant a regrouping.

Since most adult mosquito keys apply only to females, the sex of the mosquito must be determined prior to identification by examining the head (Figure 1). Male mosquitoes have bushy antennae and long palpi. Females have few bristles on their antennae and, with the exception of *Anopheles* mosquitoes, have short palpi.

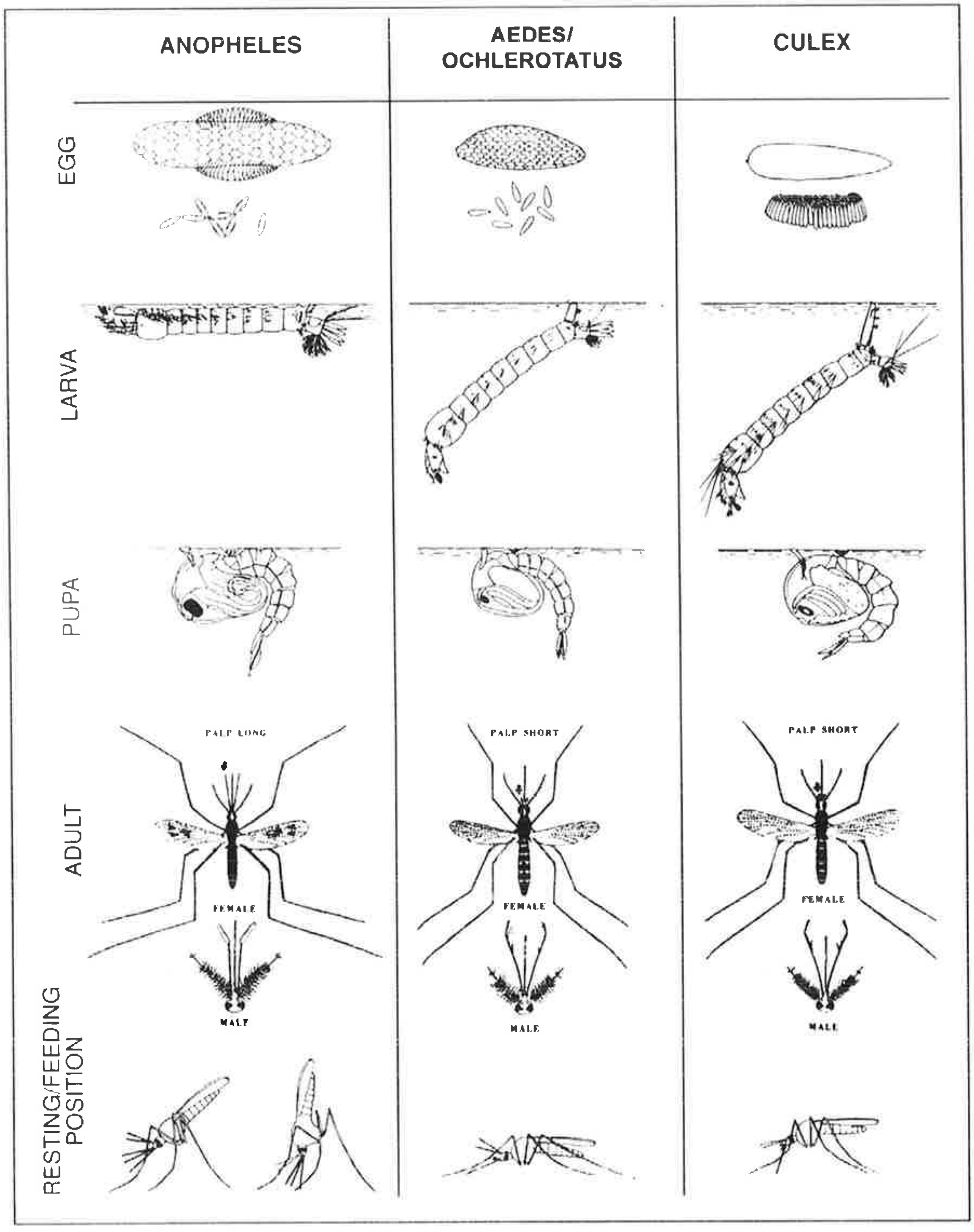


Figure 1. Mosquito life stages.

Each species of mosquito has certain specific morphological characteristics, as well as physiological characteristics and habits, which are distinctive to that species. Each species typically has a preferred egg laying site and a related larval environment, a normal flight distance and a preferred host to blood feed on (Appendix D). There is also a definite temperature tolerance at each stage of development.

This range of tolerated temperatures may be very wide or very narrow depending on the species and the time of the year. There is a maximum temperature above which the animal will die, a minimum below which it will die, and an optimum temperature at which maximum development takes place in a minimum amount of time. Both temperature and humidity are critical for adult mosquitoes. In most insects, the longer the optimum temperature is maintained, the more generations the insect will produce at a given location in a season.

Mosquito species in Georgia fall into one of three subfamilies: Toxorhynchitinae (genus *Toxorhynchites);* Anophelinae (genus *Anopheles);* or Culicinae (the other ten genera).

The larvae of *Toxorhynchites* are found in tree-holes or artificial containers. They are very large and predacious, feeding on other mosquito larvae and small organisms that occur in their larval habitat. They have an almost square head and the hairs on the thorax and abdomen arise from heavily chitinized plates. The females do not take blood as adult mosquitoes, feeding only on plant nectar and juices.

Anopheline larvae (Figure 1) are characterized by the absence of a siphon, and the presence of a palmate (palmetto-shaped) hair dorsally on each side of, at least, segments IV-VI of the abdomen. Anopheline larvae usually lie parallel to the surface of the water.

Culicine larvae always have a siphon. (Figure 1) which may or may not bear pecten, a row of spines; they do not have palmate hairs. These larvae usually lie with head downward at a 45 degree angle to the water surface.

With practice it may be possible to identify some species as adults or as fourth instar larvae with the unaided eye or a hand lens. However, because it is easy to misidentify mosquitoes in the field, samples should be taken into the laboratory to be verified under a microscope. A stereoscopic microscope to be used for adult and larval identification should have a magnification range of 10X to 40X, the lower power for use in sorting specimens that are readily identifiable and the higher power for detail work. Specific identification of difficult larval characteristics or male terminalia may require magnifications of up to 400X.

Developmental Stages

Eggs. Female mosquitoes select locations for egg deposition that will provide suitable conditions for larval development after the eggs hatch. Mosquito eggs are white when first deposited but darken within 12-24 hours (Figure 2). Most species' eggs appear similar when seen by the naked eye, with the exception of the *Anopheles* spp., whose eggs have lateral extensions that serve as floats attached to each side (Figure 1). When viewed with magnification, eggs of different species can be seen to vary from canoe-shaped to elongate or elongate-oval in shape.

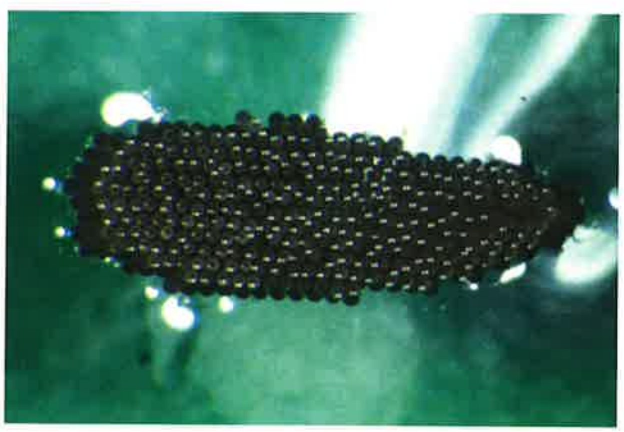


Figure 2A. A raft of *Culex* eggs.

Figure 2B. Individual eggs representative of many *Aedes* or *Ochlerotatus*. (Image courtesy of Roxanne Connelly)

Egg-laying characteristics follow one of three patterns: (1) eggs deposited singly on the water's surface: (2) eggs glued together to form rafts that float on the water surface; and (3) eggs deposited singly out of the water. To a degree, the physical characteristics of the eggs of each species are adaptations that reflect the egg-laying pattern. *Anopheles* and *Toxorhynchites* eggs are deposited singly on the water surface and float until they hatch two or three days later. *Toxorhynchites* eggs have projecting spines that trap air bubbles that keep them on the water surface, similar to the *Anopheles* eggs with their lateral extensions that serve as floats. *Culex, Culiseta, Coquillettidia* and *Uranotaenia* species glue individual eggs together to form a floating raft. As the eggs hatch, two or three days later, the raft breaks up and individual egg cases (up to 300 or more) remain floating on the water surface. The desiccation-resistant eggs of *Aedes, Psorophora, Ochlerotatus* and *Orthopodomyia* species are deposited out of the water and do not hatch until the area is later flooded. With these four genera, a wide variety of habitats are utilized and the environmental conditions needed for survival and subsequent hatching vary. *Orthopodomyia* and some *Ochlerotatus* species lay their eggs on the sides of tree-holes or other water containers just above the water surface. *Orthopodomyia* eggs hatch within two to three days and the larvae slide down into the water. Hatching occurs in some *Ochlerotatus* species only when the water level rises and eggs are flooded. Other *Ochlerotatus, Aedes* and all *Psorophora* species deposit their eggs on moist soil where they remain until exposed to certain environmental conditions and subsequently are covered with water. *Aedes, Psorophora* and some of the soil-deposited *Ochlerotatus* eggs hatch shortly after flooding, but other *Ochlerotatus* eggs must experience a protracted exposure to cold weather before flooding causes them to hatch. Some species have several generations each year, while other groups have only one. The eggs of some species can survive for 3 to 5 years if flooding does not occur. This characteristic is an important factor that contributes to the extensive mosquito populations that are sometimes common after hurricanes and floods.

Larvae. Mosquito larvae have three distinct body regions: head, thorax and abdomen (Figure 3C). The head is broad and somewhat flattened (Figure 3A), with lateral antennae attached near the anterior end. A pair of eyes is located laterally near the posterior margin of the head and mouthparts are attached anteroventrally. Mouthparts usually consist of a series of brushes and grinding structures, but in some predaceous species, they are adapted for grasping prey. The thorax is broader than the abdomen and somewhat flattened. The structure and numbers of hairs on both the head and thorax are used in the identification of species. The abdomen is elongate and cylindrical, consisting of nine well-defined segments. The first seven abdominal segments are similar, but the eighth and ninth (Figure 3B) are considerably modified. The eighth segment contains the respiratory openings, which are at the end of a prominent air tube, except in *Anopheles* where the openings are a pair of dorsal holes. The ninth segment consists of a cylindrical structure (anal saddle), a prominent fan-like brush, and two to four tapering membranous appendages (anal gills), which are involved in regulating osmotic pressure rather than respiration.

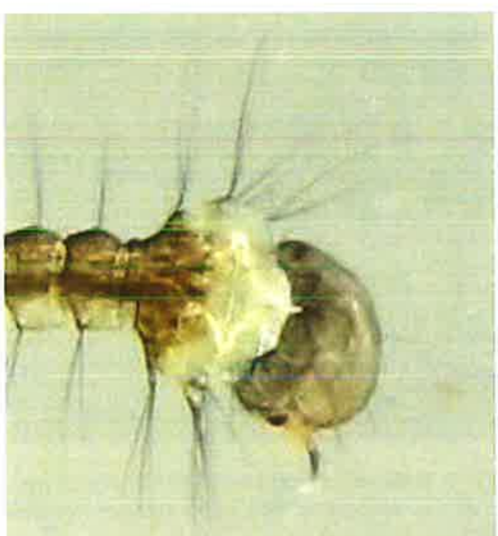


Figure 3A. Larval head and thorax. **(Photo by Stephen Luk)**

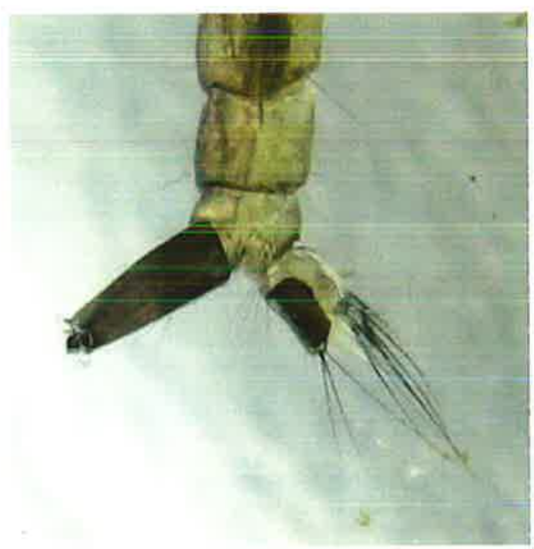


Figure 3B. The 8th and 9th abdominal segments of a Culicinae larvae. **(Photo by Stephen Luk)**

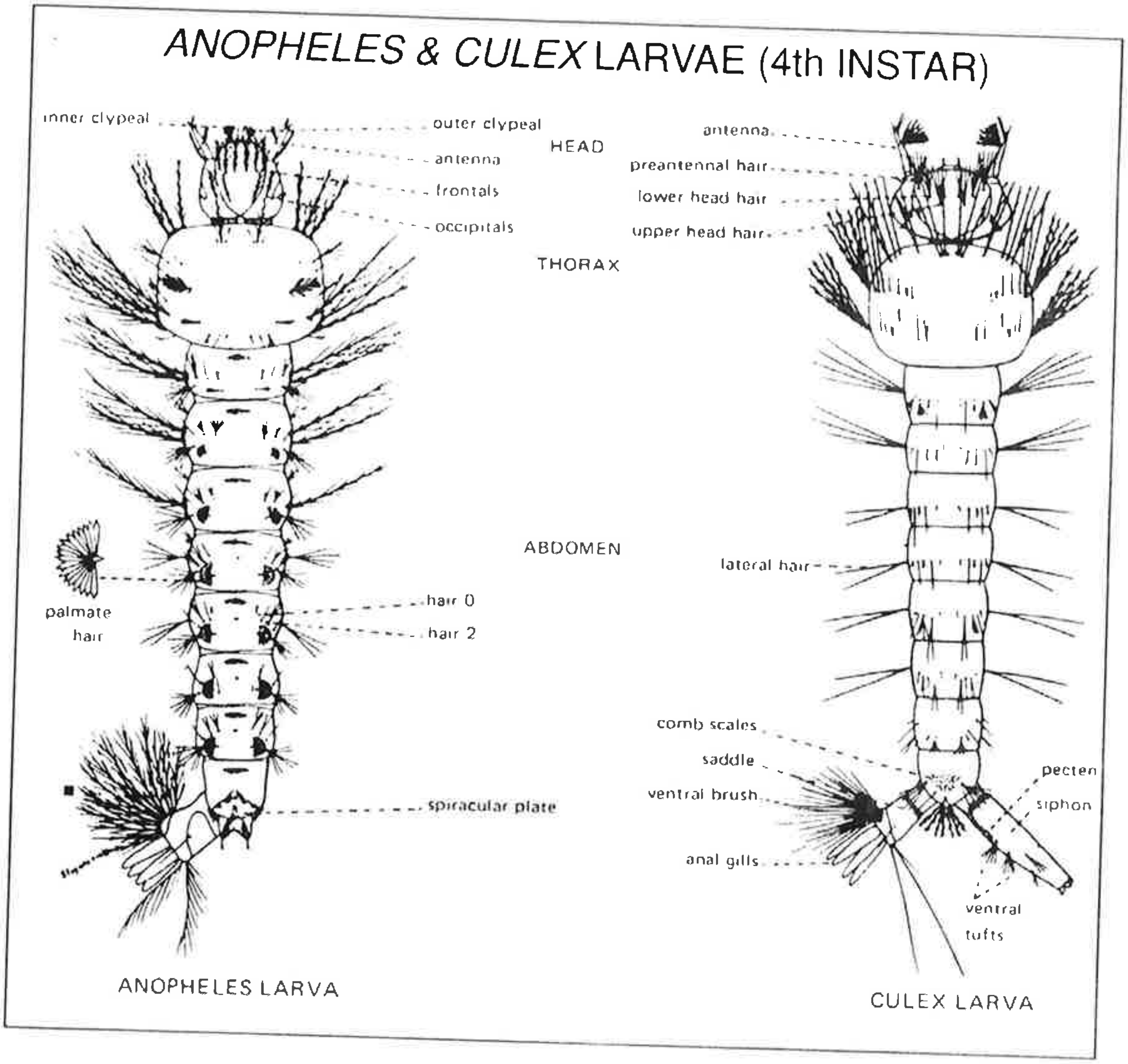


Figure 3C. Fourth instar of *Anopheles* and *Culex* larvae.

The locations in which mosquito larvae occur are determined by the sites selected for egg deposition by the female. Without exception, water is required for the full duration of larval and pupal development. Neither of these immature stages can survive desiccation. Vegetation is important as protection for larvae and pupae in many natural habitats.

The size and type of water accumulations (breeding sites) that support immature mosquitoes are highly variable, but have three common characteristics. The water: (1) is either stationary or slowly moving; (2) has a suitable food source for the larvae (bacterial, fungal, or algal growth and/or suspended organic particles); and (3) provides some protection from wind and waves either in the form of emergent vegetation or other wind-shielding features. Within these broad requirements, the specific type of water used by mosquito larvae is rather characteristic for each species but might vary widely from one species to another. Common larval habitats in Georgia are temporary pools caused by rain or stream overflow or tides, used tires, man-made debris and other water-collecting containers, storm sewer catch basins, roadside drainage ditches, cavities in trees and permanent ponds, marshes and lakes with emergent vegetation. The water in these locations may vary from fresh, to brackish, to salty, to highly polluted and have a broad spectrum of dissolved chemicals.

During larval development, mosquitoes pass through four stages or instars. At the end of each stage, the larvae shed their skins (molt) and increase in size. At the end of the fourth instar, larvae molt again and become pupae. The time for complete larval development at normal summer temperatures in Georgia is typically from five to ten days, but might take much longer at low temperatures or if food is not adequate. Larval feeding behavior is variable among the different species. However, most species are indiscriminate, filter feeders that ingest all suspended particulate matter that is small enough to be swallowed. Particles ingested typically range 1 – 50 microns.

The mouthparts of mosquito larvae are composed of a complex arrangement of spicules and setae that act as brushes, combs and sweepers often referred to in combination as mouth brushes. The combined action of these mouth brushes and other mouthpart movements create a current that moves food particles into the mouth. Most species also browse on algae, bacteria and fungi growing on submerged surfaces. Some species are predaceous and feed on other mosquito larvae and small aquatic invertebrates. Mosquito larvae stop feeding towards the end of the 4th instar; this attribute is important to keep in mind before applying larvicides which must be ingested to cause mortality.

Figure 4A. A "ball" of mosquito larvae. **(Photo by Omar Fahmy)**

Figure 4B. Mosquito larvae (Cx. Quinquefasciatus) **(Photo by Sean McCann)**

Mosquito larvae move about either by rapid flexures of the body or by slower propulsion due to the movement of mouth brushes. The first type of movement is used as a diving reaction to sudden light changes, water disturbances, or to move from the bottom up to the water surface. The slower brush propulsion moves the larvae along the surface or the bottom. Mosquito larvae typically assume characteristic positions in the water. All mosquito larvae are air breathers and, with some exceptions, spend an appreciable amount of time suspended from the surface in characteristic positions (Figure 4 A&B). *Anopheles* rest parallel to the surface, suspended by float hairs inserted into the surface film, with their respiratory openings exposed to the air. All other Culicinae, except *Coquillettidia* and *Mansonia*, hang at an angle from the surface with the tip of their air tube (siphon) inserted into the surface film. *Coquillettidia* and *Mansonia* obtain air by inserting their air tubes into the hollow roots of aquatic plants and never need to go to the surface to breath. Although larvae are heavier than water, they can rest just beneath the surface without muscular effort.

Pupae. Unlike most other holometabolous insects, mosquito pupae (Figure 5 A&B) can be very active and are often called "tumblers" because of their rapid, tumbling-like movement when disturbed. The pupal stage is typically a relatively short (two to three days), nonfeeding, transitional stage in which the adult develops within the pupal covering. The pupa has two body regions, an expanded cephalothorax and an elongate abdomen consisting of eight movable segments terminating in a pair of paddles. Projecting from the cephalothorax are two short, flared tubules (trumpets) surrounding the openings to the respiratory system. The trumpets are inserted through the water surface film and allow the pupae to breathe air directly. An exception to this is *Coquillettidia* pupae, which insert their trumpets into the hollow, air-filled roots of aquatic plants. Pupae in other genera are lighter than water due to an air cavity between the wings of the adult developing within the pupal exoskeleton. Consequently, pupae spend extended periods suspended just below the water's surface. If disturbed, they can move quickly by rapidly flexing the abdomen and its paddles, producing a diving, tumbling movement.

Figure 5A. Mosquito pupa.

When pupal development is completed, the adult ingests air that is present between the pupal exoskeleton and the developing adult exoskeleton, thus creating pressure that splits the dorsal cephalothorax of the pupa and allows the adult to emerge from the pupal skin. After emerging, the adult rests on the floating pupal skin until its body and wings dry and harden. At this moment it is critical for the pupae to be in a still and protected area. Excessive wind and wave action would drown the adult before it would have time to harden and fly away from the pupal skin. Mosquito control personnel have few options for controlling pupae and even less time to do it as a result of the short pupal stage in most cases. Surface film agents can be used to treat areas with pupae present.

Figure 5B. Mosquito adult and pupae.

Adults. The adult mosquito (Figure 6 A&B) is a small, fragile insect with a slender abdomen, one pair of narrow wings, three pairs of long slender legs and an elongate proboscis. Adult mosquitoes vary in length from slightly over 1/16 inch to about 1/2 inch. Adults have three distinct body regions: head, thorax and abdomen.

The almost spherical head (Figure 6B) is joined to the thorax by a narrow, membranous neck and bears a pair of large, compound eyes, a pair of antennae, a pair of palpi and the proboscis. 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 separate canal through which blood is ingested. The five-segmented palpi originate at the lower margin of the head near the proboscis and vary in size and shape. In female *Anopheles*, the palpi are as long as the proboscis. The mouthparts of the male are incapable of piercing the skin of humans or animals. The antennae, which arise on the front of the head between the eyes, are long, slender structures with 15 segments, only 14 of which are readily visible. Each segment except the two closest to the head bears a whorl of hairs that are short and sparse in females, but long and bushy in males. Antennae are believed to be organs of hearing and smell.

The thorax bears wings and legs and has a variety of scales and hairs or bristles on the upper surface and sides. The long, slender legs arise from the lower sides of the thorax and consist of five sections: a short conical coxa; a hinge-like trochanter; a long femur: a slender tibia; and a five-segmented tarsus. The first tarsal segment is the longest and often equal in length to the tibia. The fifth tarsal segment bears a pair of claws. If this segment is missing, identification can be more difficult for some species. All segments of the leg are covered with scales. The wings are long and narrow with longitudinal reinforcement structures called veins. They have a close-set row of long, slender fringe scales on the posterior margin. The wing veins are also clothed with scales, often of different colors that form distinct patterns. A pair of small, knobbed structures, known as halteres, are located behind the wings. These vibrate rapidly during flight and function as organs of equilibrium. Scales and scale patterns on the thorax, legs and wings, and the hairs and bristles on the sides of the thorax are all used in species identification. Therefore the less damage a specimen receives the easier identification will be. The elongate abdomen is nearly cylindrical and consists of ten segments, only eight of which are readily visible. The ninth and tenth segments are greatly modified for sexual function in both males and females. In Culicinae and Toxorhynchitinae species, the abdomen is covered with scales that often form characteristic markings. In Anophelinae species, abdominal scales are either absent or very sparse. The abdomens of *Aedes, Ochlerotatus* and *Psorophora* females are tapered apically, with the eighth segment withdrawn into the seventh; in all other U.S. genera, female abdomens are bluntly rounded at the apex (Figure 6B). The terminal abdominal segments of all male mosquitoes are greatly modified for copulation and are of value in species identification.

Figure 6A. ***Aedes aegypti*** **(Photo by James Gathany, CDC)**

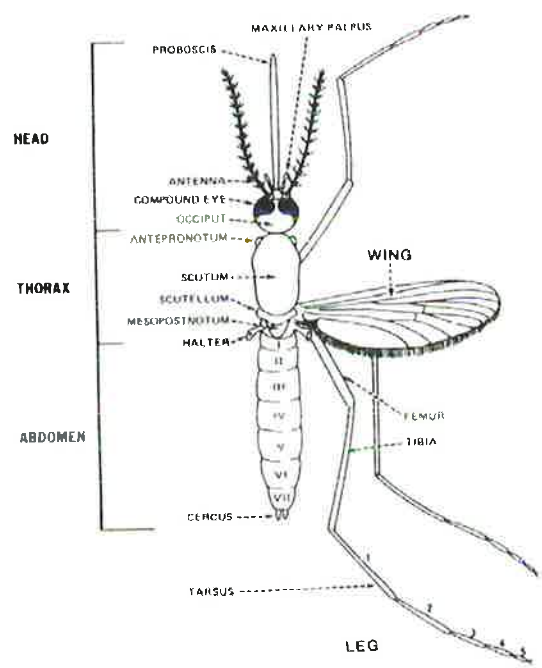


Figure 6B. The external anatomy of an adult female mosquito.

Adult Mosquito Characteristics

Some behavioral characteristics are common to most mosquito species, but few generalizations can be made. Adult mosquitoes (Figure 7 A&B) are terrestrial and capable of flight. Males' antennae have dense bristles, and their mouthparts are modified to suck nectar and plant secretions, where no piercing is required. Flight habits vary considerably. *Aedes albopictus*, (the Asian tiger mosquito) has become one of the most common mosquitoes in Georgia and is probably the most domesticated of all mosquitoes. This species breeds primarily in and around human habitations and flies short distances, usually a "block" or about 100-200 yards. Most anophelines have a maximum flight range of about 1 mile. However, other species such as *Ae. vexans* and *Ochlerotatus sollicitans* can fly 10 to 20 miles or more. Knowing the flight range of a pest species is critical to locating its larval habitats and targeting control efforts.

The male-female ratio in adult mosquitoes is normally 1:1. Males emerge from the pupal stage about 24 hours before the females and stay in the immediate vicinity until the females emerge. Surveillance work that captures many males is typically being conducted close to an emergence site. Mating usually occurs within 24-48 hours of female emergence, consequently the majority of the females in any population are fertile. Both males and females utilize nectar and other plant juices as energy sources; but only females take a blood meal (Figure 7C.) utilizing the protein from blood to produce their eggs. In a few species, females acquire enough protein during the larval stage to produce eggs when they become adults and do not require a blood meal to produce their first batch of eggs.

Mosquitoes exhibit considerable variation as to their preferred sources of blood meals. Some species prefer to feed on birds or domestic animals such as cattle or horses, while others seem to prefer humans. Because these preferences are not exclusive, many species will accept an alternate available host, which accounts for the transmission of encephalitis viruses from birds to humans or horses. 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

Figure 7A. Adult male mosquito.
(Photo by Ashley Bradford)

Figure 7B. A fully engorged *Aedes albopictus*.
(Photo by James Gathany)

eggs, and feeding again can be repeated many times in the life of a single female. Only one mating (Figure 7D.) by the female is generally required to fertilize her lifetime egg production. Mosquito longevity in nature is highly variable and dependent upon a number of environmental conditions. In general, males are much shorter lived than females, surviving for a few days to a week, while females may live for several weeks to months, depending upon the species and local conditions. Adults that hibernate can live for six months or more. Generally, mosquitoes remain inactive during the day, resting in cool, humid locations to minimize moisture loss. Typically, feeding and mating activity occurs from dusk through the night until just after dawn.

In order to understand the dynamics of mosquito-borne disease transmission and plan effective and efficient control measures for either disease or pest problems, it is important to be familiar with all aspects of the biology of the species present in the area. Among these facts are: the types of larval habitat utilized; seasonal population levels; how far they fly from their sites of origin; whether or not a given species can become infected with and later transmit the pathogen involved; whether a given species present in the area is actually infected with a pathogen at the time the disease is present in vertebrate hosts; the preferred host for blood feeding; and many other specific items of information. These types of specifics usually are unique for a given area. It is important to remember that very few things in nature are absolute and that exceptions can and do occur.

Figure 7C. Adult female mosquito feeding.
(Photo by James Gathany)

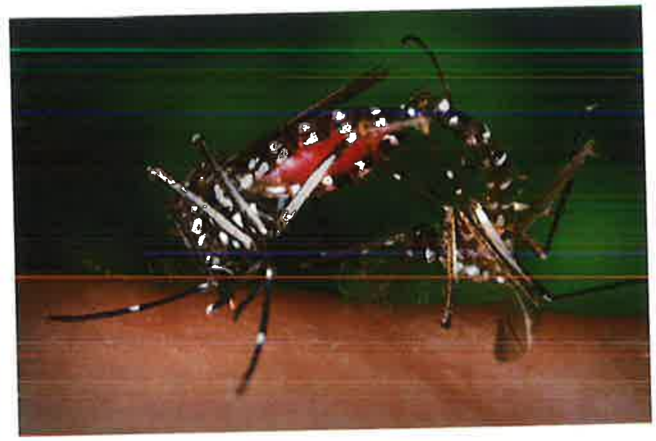


Figure 7D.Mating mosquitoes.
(Photo by James Gathany)

Figure 7E. An engorged mosquito takes flight.
(Photo by James Gathany)

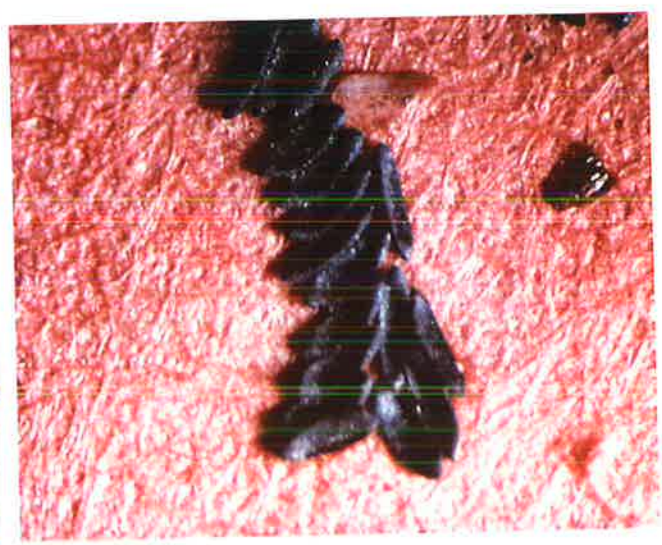


Figure 7F. *Ochlerotatus triseriatus* **eggs.**
(Photo provided by the CDC)

Chapter 2. Ecology and Identification

Learning Objectives

After study of the material in this chapter, you should be able to:

1. Name the four types of larval habitat classifications.
2. Recognize the importance of *Culiseta melanura* populations.
3. Describe the egg laying habits of typical flood water species.
4. Name the most important salt marsh mosquito in GA.
5. Describe the life history of *Aedes albopictus.*
6. Describe the unique features the *Toxorhynchites* sp.
7. Understand the importance of knowing the larval habitats of various pest species.
8. Understand the importance of accurate identification of a pest species.
9. Describe the life history and importance of *Culex quinquefasciatus.*
10. Recognize the historical importance of *Anopheles quadrimaculatus* in the Southeast.
11. Describe the unique features of *Psorophora ciliata.*
12. Name the two life stages that are primarily used to key specimens to species.

Ecologic and Bionomic Types of Mosquito Life Histories

Although all mosquitoes require water to complete the larval portion of their life cycle, the type and quality of the water required varies considerably among species. Some species seek only the clean water found in freshwater swamps or woodland pools, while others deposit their eggs on salt marshes or the enriched water of agricultural lagoons. Over 60 mosquito species are known to occur in Georgia and virtually every conceivable water source fulfills the larval habitat requirements of at least one species.

The water in which the larvae develop is referred to as the "larval habitat." In recent years, there has been increased emphasis on control procedures that are directed against the larval stage. Consequently, mosquito control workers should be able to associate the adult mosquito with its larval habitat. For example, initiating control procedures on a freshwater swamp will not eliminate a nuisance problem if the mosquito's larval habitat is elsewhere.

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, seasonal density and dispersal. The Centers for Disease Control and Prevention's Mosquitoes of Public Health Importance and Their Control proposes the following groups: (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 generally are found in bodies of quiet, fresh water exposed to sunlight and containing an abundance of surface vegetation and flotage at the air-water-plant interface. Typical habitats (Figure 8 A&B) are shallow margins of ponds, lakes and smaller impoundments, the defining characteristic being a degree of permanency. Such habitats are particularly suitable for *Anopheles* spp., *Coquillettidia* spp., *Culex salinarius, Cx. territans* 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, Coquilletidia* 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 generally is continuous in these species with several generations per year. Most *Anopheles* and *Culex* overwinter as adult females, but some, e.g., *An. walkeri,* may overwinter in the egg stage, while *Mansonia* and *Coquillettidia* overwinter as larvae attached to the roots of plants.

Figure 8A : A freshwater cattail swamp in Appling County, GA.

Figure 8B: A retention pond in Athens, GA.

Coquillettidia perturbans is an important freshwater swamp species that can cause considerable annoyance in some areas of Georgia. The larvae of this species have highly modified air tubes which are inserted into the roots of some aquatic plants. Air is obtained directly from the plant, and the larvae never come to the water surface. Permanent bodies of water with stands of cattails and other emergent vegetation often support large populations of *Cq. perturbans*. 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 (Figure 9 A&B) are similar to those in the permanent pool group, but they seem to be more often associated with pools of temporary nature as opposed to species with 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 *Cx. quinquefasciatus, Cx. restuans, Cs. inornata* and *Cs. melanura*. If water remains sufficiently long, anophelines frequently become established in later season, particularly such species as *An. crucians* and *An. punctipennis.*

Figure 9A. A freshwater swamp in Chatham Co., GA.

Figure 9B. Ruts under power lines in Baxley Co., GA.

Culiseta melanura, the black tailed mosquito, is a particularly important member of this group. The larval habitats for this mosquito are swamps and hardwood bottoms. *Culiseta melanura* does not typically bite humans, but transmits the eastern equine encephalitis virus from bird to bird. Other less host-specific species may then transfer the pathogen to humans.

The Floodwater Group

Floodwater species of mosquitoes of the genera *Aedes, Ochlerotatus* and *Psorophora* generally deposit their eggs singly on damp soil associated with salt marshes, grassy or woodland depressions, road side ditches or along vegetated shorelines that are intermittently flooded (Figure 10 A&B). When flooded after a period of desiccation, the eggs hatch if conditions (temperature, pH, oxygen concentration, etc.) are favorable; otherwise, the eggs might remain dormant and viable on the soil until a more favorable inundation. Typically, large numbers (broods) are produced during a hatching; larval development is uniform; and adults might appear as early as six days after flooding. Many of these pests will appear and disappear at varying intervals throughout the summer. Some species produce a single brood, particularly in northern portions of the country, but many species of *Aedes*, *Ochlerotatus* and *Psorophora* produce multiple broods in a given year. Floodwater mosquitoes typically overwinter in the egg stage. These species are particularly troublesome pests and some characteristically fly long distances from larval habitats, e.g., 5-20 miles in the case of *Ochlerotatus taeniorhynchus, Oc. sollicitans* and *Ps. columbiae.* The woodland species such as *Oc. atlanticus/tormentor* and *Ps. ferox* tend to remain near the larval habitat. Some important vectors and pest species in this ecologic group are *Oc. sollicitans, Oc. taeniorhynchus, Oc. atlanticus/tormentor, Ae. vexans, Ps. ferox* and *Ps. columbiae.*

Figure 10A. Roadside ditch in Oglethorpe Co., GA.

Figure 10B. Salt marsh in Glynn Co., GA.

The salt marsh mosquitoes are particularly important pests in this group. They typically develop in standing water which collects in depressions on coastal marshes after heavy rains or exceptionally high tides. The larvae are able to tolerate the high levels of salt which are found in the pools as the water evaporates. Populations of salt marsh mosquitoes appear and disappear at regular intervals during the summer, and their presence is directly related to the tidal flooding of the higher portions of the marshes. In most coastal areas there are four or more major floodings during the mosquito season. Because of the large acreage of habitat involved, salt marsh mosquitoes can emerge in unbelievably high numbers. Most of these species can travel many miles to locate a suitable host. The salt marsh mosquitoes directly affect the economy of Georgia's coastal resorts and consequently receive intense control pressures throughout their season, which can be lengthy on the coast. The most important salt marsh mosquito is *Oc. taeniorhynchus.* This mosquito may bite throughout the daylight hours and is a constant source of annoyance from late spring to late fall.

One of the most important and common freshwater species in this group is *Ae. vexans.* In years of heavy rainfall, the adults can cause annoyance all summer long. This species is very common in roadside ditches and bottomlands that hold water during wet periods.

The Artificial Container and Tree-Hole Group

Characteristic of this group are members of the genera *Aedes* and *Ochlerotatus,* with the more important being *Ae. albopictus* and *Oc. triseriatus. Aedes aegypti* was once an important member of this group in Georgia, but the introduction of *Ae. albopictus* has led to the near elimination of *Ae. aegypti* through competitive forces that are not completely understood. Neither of these species were originally native to Georgia, but *Ae. albopictus* is a more temperate species that may be more suited for Georgia's climate.

Aedes albopictus, the Asian tiger mosquito, was first found in Houston, Texas, in the 1980's in used tires and has become one of the most important urban pests in Georgia. While this species has demonstrated significant vector potential in its native habitats and in the laboratory, it has yet to be implicated as a major disease vector in Georgia. However, its role in LaCrosse Encephalitis virus transmission is an area of concern. Control of *Ae. albopictus* is difficult because this species is an aggressive daytime biter that is usually resting in foliage and other protected sites in the evening and is not significantly affected by the typical evening spray program. Homeowners need to be educated to reduce populations in their own yards by removing and emptying containers that can produce this species. Fortunately, this species has a rather limited flight range (300-500 feet) and is usually developing in close proximity to the adult population. Industrial sites and tire recycling operations (Figure 11 A) can produce tremendous numbers of this species if potential larval habitats are not eliminated or treated.

Aedes albopictus normally oviposit in artificial containers, whereas *Oc. triseriatus* usually oviposit in natural cavities containing water, such as tree holes, but their larvae are also frequently found in containers with heavy sediment or decaying leaves. Eggs are deposited 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 multiple broods occur.

Tree holes or rot cavities in trees and logs (Figure 11 B) can support significant populations of the tree-hole mosquito, *Oc. triseriatus.* This species can also be a fierce daytime biter in or near infested woods. The tree hole mosquito is the primary vector of LaCrosse encephalitis, a potentially serious viral disease of children. Habitats for this species can be eliminated by filling holes with sand, but often it is difficult to locate and fill significant numbers of tree holes.

This group includes not only the important *Aedes* and *Ochlerotatus* species mentioned, but also species of *Toxorhynchites* and *Orthopodomyia* as well, none of which are troublesome to humans. The larvae of *Toxorhynchites* are actually predaceous and often reduce pest species trying to develop in their habitats. Both male and female adult *Toxorhynchites* feed on flowers for nectar and can not bite humans.

Although not included in this group on the basis of ecology and bionomics, *Cx. quinquefasciatus* and *Cx. restuans* often oviposit in artificial containers of all types, particularly those rich in organic matter. Both of these Culex species appear to be important in the West Nile virus cycle and should be the focus of any residential mosquito management program.

The fact that many species are found in multiple habitat types and some in very specialized habitats illustrates the complexity of the problem faced by control personnel. While habitat association with many species is quite specific, others thrive in a variety of situations. Thus, the detection of adults of the previously mentioned species in routine surveys does not provide an immediate indication of the sole, or precise, site of the related larval habitats. These considerations only emphasize the premise that a quality mosquito control program has as its foundation a solid understanding of the biology of the mosquito species that occur in a particular locale.

Figure 11A. Commercial tire recycling site.

Figure 11B. Typical tree hole habitat.

Common Problem Species in Georgia

Identification

The need for accurate mosquito identification is an important aspect of an integrated mosquito control program (Figure 12). To efficiently and effectively reduce a pest population in an integrated manner, it is critical to properly identify the pest, so the corresponding larval habitats can be targeted for surveillance and control procedures. Mosquito identification, while challenging, is not as difficult as the identification of most other insect groups. Identification to the species is possible for both late instar larvae and adult females, the two most commonly collected stages of mosquitoes. Adult males are rarely identified because they lack the blood-feeding behavior of females.

Identification to species level exceeds the depth of this manual, but a variety of identification keys exist (See list below). Although some characters are observable with the naked eye, a dissecting microscope of 40X or more is typically required. One should also consider that in any identification, some characteristic markings might be damaged or obscured during the collection process. In such cases, knowing where the mosquito was collected is helpful for assisting the identification process. Included is a general key to the more commonly encountered mosquito genera of Georgia.

Suggested Mosquito Keys for use in Georgia:

Mosquitoes of the Southeastern United States (2013). Nathan D. Burkett-Cadena. The University of Alabama Press/Tuscaloosa.

Identification and Geographical Distribution of the Mosquitoes of North America, North of Mexico (2005). Richard F. Darsie, Jr. and Ronald A. Ward. University Press of Florida.

Keys to the Adult Females and Fourth Instar Larvae of the Mosquitoes of Florida (Diptera, Culicidae) (2003). Richard F. Darsie, Jr. and Charlie D. Morris. Florida Medical Laboratory, University of Florida and Sarasota County Environmental Health.

A Key to the Mosquitoes of North Carolina and the Mid-Atlantic States (1989). Marc Slaff and Charles S. Apperson. The North Carolina Agricultural Extension Service.

PICTORIAL KEY TO UNITED STATES GENERA OF FEMALE MOSQUITOES

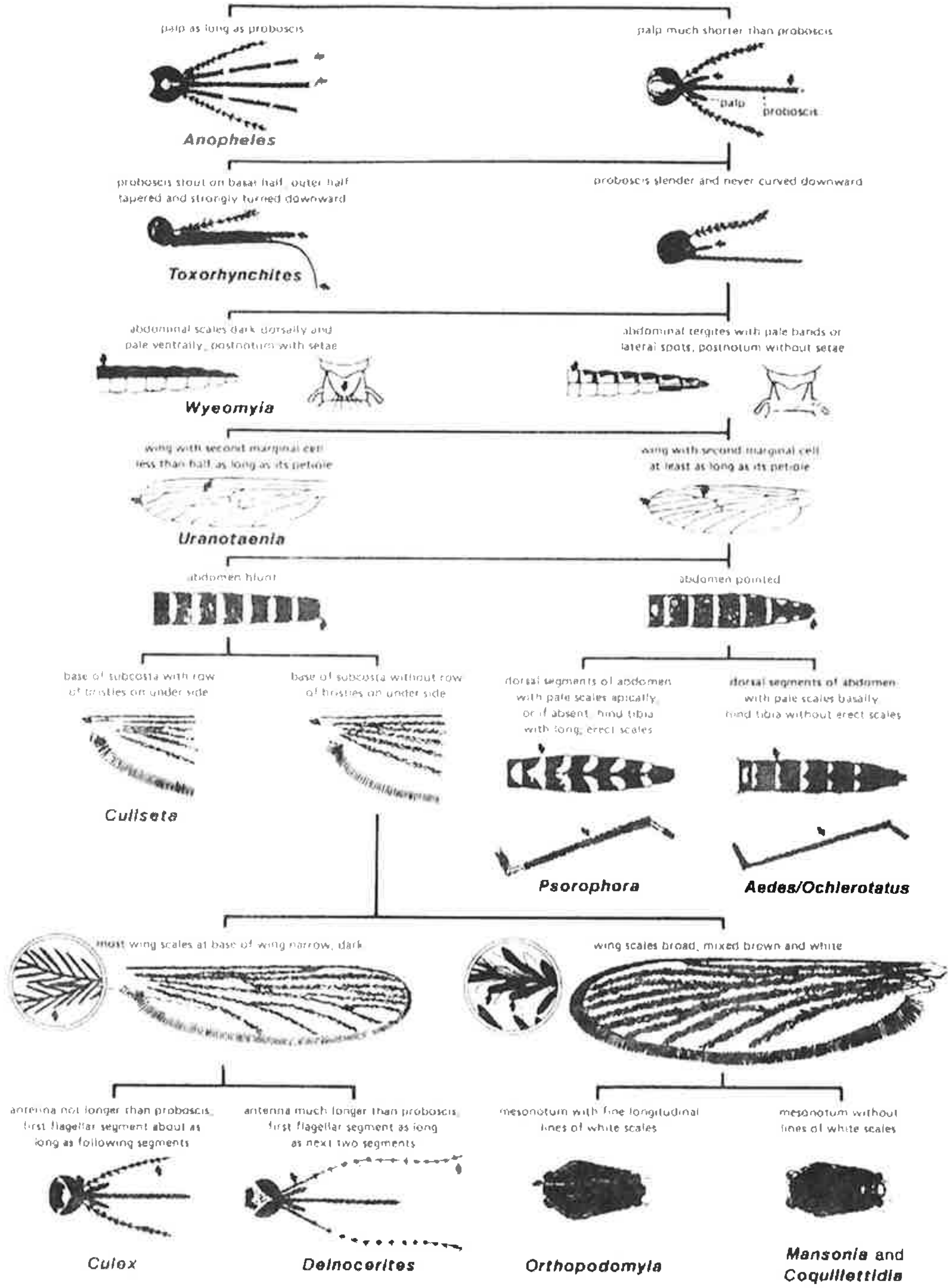


Figure 12. Pictorial key to United States genera of female mosquitoes.

As a result of the large geographic size of the state of Georgia and the recent introduction of West Nile virus, there is a tremendous amount of variability when considering the primary pest species for a particular region. However, in historical terms, the largest and most comprehensive mosquito control programs have developed in the coastal areas where large populations of salt marsh mosquitoes and human populations have coincided. In the coastal regions, the primary pest mosquitoes are the salt marsh species *Oc. taeniorhynchus* and *Oc. sollicitans.*

Ochlerotatus taeniorhynchus (Black saltmarsh mosquito) (Figure 13 A) is a small black and white mosquito with distinct narrow white rings on the tarsi and on the proboscis and has cross bands of white scales on the upper side of the abdomen. Wing scales are all dark. *Oc. taeniorhynchus* is the predominant species, produced in huge numbers along the coast of Georgia.

Oc. taeniorhynchus eggs are usually deposited on damp soil where ground vegetation is thick. Sod samples in Florida have yielded up to 100 million eggs per acre. The larval embryo is fully developed in about three days and ready to hatch as soon as it is flooded by the tides or rainfall. The longer the period is before hatching, the greater the chance of the embryo dying, although some of the eggs will hatch after many months. The length of time required for larval development depends on temperature and available food, and ranges from four days to four weeks. The pupal stage may last from 30 hours to several days, depending on temperature. Emergence from an active larval habitat may go on for several days. Mating occurs during the general flight activity of a newly hatched brood. The adult rests for at least six to eight hours and then after sunset a large number will migrate, possibly flying as far as 25 miles, usually downwind and parallel to the coast. Migration may continue a second or third night and then the brood settles down to feeding, resting and egg laying. Adults feed on nectar as an energy source.

A blood meal, taken only by females, serves as a source of protein for egg production, although some *Oc. taeniorhynchus* are capable of depositing their first batch of eggs without first blood feeding by utilizing protein carried over from the larval stage. This species is active chiefly after sunset. During the day the mosquitoes rest on the ground where grass or leaves offer a dark, moist, cool hiding place. However, if a stimulus reaches them, they will fly to it, which means if you go where they are in the daytime they will be stimulated to bite you.

Ochlerotatus sollicitans (Tan saltmarsh mosquito) (Figure 13 B), occurs along the coast of Georgia and in localized situations, may outnumber *Oc. taeniorhynchus. Ochlerotatus sollicitans* is somewhat larger than *Oc. taeniorhynchus* and can be recognized by the golden color of the upper side of the thorax and a longitudinal stripe of white or yellowish-white scales on the abdomen. The proboscis and tarsi also have wide pale bands. The wing scales are mixed light and dark. This species has a life history similar to that of *Oc. taeniorhynchus,* developing in the salt marsh, but the larvae have also been found in great numbers in coastal swales and inland in brackish waters. After their eggs have been dry for a week or two, they hatch within minutes if covered with water. 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. The adults usually rest during the day, but the females are persistent biters and will attack at any time of night or day. The exact seasonal distribution of the salt marsh species is dependent on the tides and rainfall, but usually each year they begin to emerge in large numbers in May and continue through October.

The adults of *Oc. 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 severe deterrent to 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 normally invade houses. *Ochlerotatus sollicitans* is considered to be an important bridge vector responsible for the transmission of Eastern equine encephalitis virus from birds to humans and horses.

After the two salt marsh species, *Aedes albopictus* (Asian tiger mosquito) (Figure 13 C) may be the state's most widespread nuisance species. *Aedes albopictus* was introduced from Asia into the Houston, TX area by 1985 (Sprenger and Wuithiranygool 1986) and has expanded its range throughout most of the Southeast. In most areas of Georgia, *Ae. albopictus* has replaced the related species, *Ae. aegypti* in areas where the two mosquitoes share breeding sites. Similar to *Ae. aegypti* in size, appearance, and habits, this mosquito can be identified by the single, silver, longitudinal line on the thorax and by the strongly contrasting silver and jet black body coloration. An aggressive daytime biter, *Ae. albopictus* is considered a major vector of dengue in Asia. While dengue is not currently present in Georgia, the introduction of this mosquito into the U.S. has some officials concerned about the increased potential for epidemics of this viral disease. *Aedes albopictus* is a competent vector of *Dirofilaria immitis*, the dog heartworm, and has been implicated in the transmission of LaCrosse encephalitis, which may become its most important disease association in Georgia. The mean development time for *Ae. albopictus* from egg hatch to pupation takes 5-10 days at temperatures near 25°C (77°F), but will take longer at lower temperatures or with a suboptimal food supply.

Aedes aegypti is a small, dark mosquito easily recognized by the silvery-white lyre-shaped marking on the thorax and the silvery-white bands on the tarsi. Historically, it was one of our most common domestic mosquitoes, laying its eggs on the sides of containers such as tin cans, tires, vases, small pools, tree-holes and yard plantings of certain bromeliads. Its numbers have been drastically reduced throughout most of the state by, as yet, unknown factors related to the more recent introduction of *Ae. albopictus.* The embryos develop in two to four days and will hatch when flooded. The cycle from egg to adult may be completed in 8-10 days in warm weather. The adults feed warily, often attacking the ankles and seldom flying more than a few hundred feet from the emergence site.

With the introduction of the West Nile virus into Georgia, the bird-feeding *Culex* group has taken on a more important role among the pest species of the state. The *Culex* mosquitoes all develop in fresh water habitats such as pools, ditches and ponds. *Culex quinquefasciatus* (Southern house mosquito) (Figure 13 D) larvae are often associated with foul water such as effluents of sewage treatment plants, which have been found producing these mosquitoes by the thousands. The larvae are also found in catch basins, cesspools, polluted ditches and ponds, and in containers holding water around homes and buildings. The adults are brown and medium sized, distinguished by having a pale basal band on each abdominal segment rounded on the apical margin so that the band is wider in the middle and narrower on each side.

This species lays eggs in clusters or rafts of 50-500. These rafts float on the surface of the water and hatch within a day or two in warm weather. Under typical summer conditions, 8-10 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. House mosquitoes typically only migrate short distances unless great numbers are produced. Ordinarily, when adults are present, larvae are found nearby. This species is 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. The females are said to show a preference for bird blood, but they often go into homes and feed readily on humans at night. In some areas of the country this species is the primary vector of St. Louis Encephalitis.

Culex quinquefasciatus is the primary vector of the West Nile virus in Georgia. As a result of this finding, there has been an intense push to control this species, which has proven very difficult. Locating larval habitats for *Cx. quinquefasciatus* has proven particularly challenging even for the state's best mosquito control experts. Storm drains in urban areas should be sampled diligently to determine their input to the local population and any areas receiving fecal contamination should also be carefully evaluated.

Culex nigripalpus is a small, dark-brown mosquito, with white lateral abdominal patches. It develops in permanent or semi-permanent waters where decaying leaves and vegetation are abundant. Larvae have also been found in brackish water. This species usually bites outdoors and will feed on humans and birds. It was formerly believed to be of little medical importance, but work conducted in Florida has demonstrated this species' importance in the West Nile virus cycle. This mosquito is readily taken in light traps and is considered a tropical species that is seasonally abundant in southern GA.

Culex restuans (White dotted mosquito) larvae occur in a variety of freshwater habitats, including areas of foul water, such as that containing decaying grass and leaves. While most common during cooler weather, a recent study in the Athens area demonstrated that this species was present throughout most of the summer as well. Females sometimes come into homes and bite after dark, but they are not a primary nuisance, preferring birds to humans. The adult is similar to *Cx. quinquefasciatus* except that the abdominal bands are straight on the apical margin and the thorax often has two small patches (spots) of pale scales. Separating this species from *Cx. quinquefasciatus* is very difficult for specimens that have been even slightly damaged in the collection process. It has been speculated that this species is important in the early season amplification of the West Nile virus in bird populations. Consequently, more emphasis should be placed on the reduction of this species than was previously considered.

Culex salinarius (Unbanded saltmarsh mosquito) larvae are often found in association with *Cx. nigripalpus* larvae, and are usually found in grassy pools of both fresh and brackish water, along lake margins and in marshes, cattail bogs, ponds and ditches. Emergences are concentrated in the cooler months. The females bite readily outdoors and sometimes enter buildings to feed on humans. The species is characterized by golden scaling on the entire seventh abdominal segment.

Aedes vexans (Inland floodwater mosquito) (Figure 13 E) is a very common floodwater/temporary pool species throughout most of the state. Larvae are found in rain pools, floodwaters, roadside puddles and practically all temporary bodies of fresh water. It usually feeds in shady places during the day, but is often particularly annoying at dusk and after dark. This species has narrow basal white rings on the tarsal segments and rather broad white bands on the abdomen, notched on the posterior border. Eggs are laid in moist depressions, especially those containing decaying organic debris. The eggs may hatch during the same season in which they are deposited, after the usual sequence of incubation, drying and flooding. In receding waters, larvae may frequently be concentrated so that 500 or more are found to each pint of water. Development of the aquatic stage requires 10-21 days, depending on temperature. Adults can commonly migrate long distances (5-10 miles) from their larval habitats. Studies in other states have shown that the adults can live for nearly 2 months. Adults are attracted to light, and both males and females are frequently taken in light trap collections.

There are three main problem *Anopheles* mosquitoes in Georgia. *Anopheles quadrimaculatus* is the most common and widespread member of a larger species complex consisting of five morphologically similar species. Although almost identical, they can be separated with great care and differ somewhat in their preferred habitat and range.

Anopheles quadrimaculatus (Common malaria mosquito) (Figure 13 F) was the primary vector of malaria in the southeastern United States. This species has probably been responsible for the transmission of almost all human malaria that has occurred east of the Rocky Mountains. The adults are fairly large, dark brown mosquitoes characterized by having four, more or less, distinct spots near the center of each wing. The palpi and tarsi are entirely dark. 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. This species will enter houses readily and feed upon humans, but they feed more frequently on other warm-blooded animals such as cows, horses, mules, pigs and chickens. Normally, most adults don't fly more than one-half mile from their larval habitat. Over most of the State this species spends the winter as fertilized adult females in caves, hollow trees, basements and other protected places. In most 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 peak during July and August and decline rapidly in September and October. Hibernating females may survive from 4 to 5 months.

Larvae are found primarily in stagnant, alkaline fresh water which has emergent or floating vegetation or debris. 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. The most favorable temperature for the development of this species is between 85° and 90°F, at which 8-14 days are required for development. The larvae can withstand low temperatures, but do not complete their development at temperatures below 50° to 55°F.

Anopheles crucians adults have distinct areas of pale scales on each wing. This species develops primarily in the slightly acidic waters of cypress swamps and in ponds and lakes. It has been found naturally infected with malaria, but is not considered an important vector of the disease since it apparently prefers to feed on large mammals rather than humans.

Anopheles punctipennis have wings conspicuously marked with spots of pale and dark scales. The palpi are entirely dark. This species is a relatively common mosquito whose larvae occur in a wide variety of permanent water habitats, but seem to prefer cool water. Adults of this species are typically the first anophelines to appear in the spring.

Coquillettidia perturbans (formerly *Mansonia perturbans)* (Irritating mosquito) is the most common and wide-ranging of the mosquitoes whose larvae breathe by piercing the roots or stems of aquatic plants with their siphon. Larvae are found in marshes, ponds and lakes that have a thick growth of aquatic vegetation. Many aquatic plants serve as host to this species, including water lettuce, water hyacinths and cattails. Larval development is unusually slow. The larvae that hatch in any one season do not ordinarily complete their development until the following spring, although multiple broods can occur in southern GA. Larvae may detach from their host plants and move about, but the larvae remain below the water surface during the entire larval period. The pupae also have breathing tubes adapted for penetrating plant tissues. The females bite during the daytime in shady, humid places, but are much more active in the evening and early part of the night. This species will readily enter houses and bite viciously and are strong fliers. This species is also suspected of being an important bridge vector of Eastern equine encephalitis (EEE) virus to horses and humans and may be the primary vector in many inland areas. *Coquillettidia perturbans* is a fairly large species with a golden brown coloration. They also have characteristic pale bands at about the outer third of both the hind femur and the hind tibia.

Culiseta melanura (Blacktailed mosquito) (Figure 13 G) is a smaller, very dark species that develops in small, permanent bodies of water, particularly in fresh-water swamps. The larvae develop in water beneath stumps and roots of trees in wooded swamps. Females feed chiefly on birds, and the species is considered to be the primary vector of Eastern equine encephalitis from bird to bird. Since it rarely bites humans, it is not the primary vector of EEE virus to humans.

Ochlerotatus atlanticus is a dark, medium sized, species which has a distinct median pale stripe running the length of the thorax. This mosquito lays its eggs on damp soil and the larvae develop in the shallow pools following rainfall. The adults bite readily, even in sunlight. It is often found in association with *Oc. infirmatus,* which has a broader pale stripe that extends only about two-thirds the way back on the thorax.

Ochlerotatus canadensis, (Woodland pool mosquito) is one of the first mosquitoes to appear in early spring. This species has pale rings both at the base and tip of the tarsal segments and can be a nuisance in some areas of the state during the spring, but rarely migrates far from its larval habitats. This species prefers low lying woodland pools with a bottom of dead and decaying leaves.

Ochlerotatus japonicus, (Asian bush mosquito) (Figure 13 H) is a medium to large mosquito that has recently been identified in Georgia. This mosquito is relatively easy to identify by its yellow lyre-shaped markings and a median yellow line on the scutum. This species seems to prefer rock pools or holes along rocky rivers and streams for larval habitats, but will utilize natural and artificial containers that are in the shade in forested areas. To date, this species has been identified in 12 counties in north-central and northeast Georgia and will likely continue to expand its range in Georgia. While the true vector potential of this species is unknown, in the laboratory it transmits several viruses effectively, thereby causing concern among entomologists.

Ochlerotatus triseriatus (Eastern tree-hole mosquito) (Figure 13 I) adults are blue-black and have silvery-white scales on the sides of its scutum. Larvae are usually found in water collected in rot cavities of trees, although they frequently occur in old tires and a variety of artificial containers, particularly those containing decaying leaves. Larval development appears to be rather slow; nearly a month is required to reach maturity. Near their larval habitat, these mosquitoes will attack humans during the day or early evening, and their bite is painful and lasting. Flight range is characteristically short, and this species is the primary vector of LaCrosse encephalitis.

Psorophora mosquitoes that commonly develop in flood-water habitats include *Ps. ciliata* (Gallinipper) (Figure 13 J), a very large, shaggy black and yellow species with conspicuous scales on the hind tibia. This species is one of the few mosquito species whose larvae feed on other aquatic insects, including other mosquito larvae. A fourth instar *Ps. ciliata* can consume three or four mosquito larvae/day. Larvae of this species are easily recognized in the field, as they are two or more times as long as larvae of most other species and they hang almost straight down from the water surface. The larval and pupal stages are brief, as is characteristic of this genus. *Psorophora ferox* (White-footed woods mosquito) (Figure 13 K) is a smaller purplish mosquito with conspicuously white tips on the hind legs (tarsal segments 5, 4 and part of 3). This species is a persistent and painful biter that attacks readily during the day. The larvae develop in temporary pools and are easy to recognize by their antennae which are longer than the head. *Psorophora columbiae* (formerly *Ps. confinnis*) (Dark rice field mosquito) (Figure 13 L) is a large black and white species distinguished by a pale subapical ring on each femur. *Psorophora columbiae* is one of the most troublesome pests in Georgia; it will bite viciously any time of the day or night, but is especially active at night. The adults emerge in huge numbers from improved pastures, woodland pools, roadside ditches, irrigation waters and temporary rain pools. Soil with low, rank vegetation seems to be ideal for egg deposition. When present in great numbers, they occasionally kill livestock and make it almost unbearable for people to remain outdoors.

Figure 13A. *Ochlerotatus taeniorhynchus*
(Photo by Sean McCann)

Figure 13B. *Ochlerotatus sollicitans*
(Photo by Sean McCann)

Figure 13C. *Aedes albopictus*
(Photo by James Gathany)

Figure 13D. *Culex quinquefasciatus*
(Photo by James Gathany)

Figure 13E. *Aedes vexans*
(Photo by Tom Murray)

Figure 13F. *Anopheles quadramaculatus*
(Photo by Sean McCann)

Figure 13G. ***Culiseta melanura***
(Photo by Omar Fahmy)

Figure 13H. ***Ochlerotatus japonicus***
(Photo by Omar Fahmy)

Figure 13I. ***Ochlerotatus triseriatus***
(Photo by James Gathany)

Figure 13J. ***Psorophora ciliata***
(Photo by Sean McCann)

Figure 13K. ***Psorophora ferox***
(Photo by Sean McCann)

Figure 13L. ***Psorophora columbia***
(Photo by Sean McCann)

Chapter 3. Mosquitoes as Vectors of Disease

Learning Objectives

After study of the material in this chapter, you should be able to:

1. Discuss the importance of mosquitoes besides their pure nuisance activity.
2. Name the major diseases the mosquitoes typically transmit in Georgia.
3. Recognize and understand the importance of the term encephalitis.
4. Describe the recent history of West Nile (WN) virus in the US.
5. Describe the typical transmission cycle of WN virus.
6. Name the primary vector of WN virus in Georgia.
7. Understand the importance of Eastern equine encephalitis (EEE) to mosquito control operators.
8. Describe the EEE virus transmission cycle.
9. Name the most important disease transmitted by mosquitoes world-wide.
10. Name the most important veterinary disease transmitted by mosquitoes in Georgia.
11. Recognize the economic importance of dog heartworm in Georgia.
12. Recognize that AIDS is not transmitted by mosquitoes.

Aside from the irritation and annoyance that mosquitoes inflict on humans and livestock alike, the threat of disease pathogen transmission is always present. Malaria, dengue, yellow fever and encephalitis are just a few major representatives of a long list of human diseases for which mosquitoes serve as vectors. Of these, several forms of encephalitis represent the greatest perennial threat in the U.S. Malaria and dengue are diseases occasionally imported by travelers, and yellow fever is now rare due to the availability of a highly effective vaccine.

The mosquito-borne viruses are classified on the basis of the organization of their structural, genomic, physiochemical, replicative and biologic properties. They also can be viewed in terms of the kind of disease symptoms they cause. In humans, the mosquito-borne viruses might cause no infection at all after the virus is delivered by a mosquito bite, or might cause infection with no apparent symptoms, or might cause acute disease of either systemic febrile illness (fever), encephalomyelitis (inflammation of the brain and spinal cord), hemorrhagic fever (bleeding and fever), or febrile myalgia and arthralgia (fever with muscle and joint pain, or arthritis). The case-mortality (fatality) rate tends to be low for those viruses that cause myalgia and arthralgia and fevers, although morbidity (illness) can be high. For the viruses that cause encephalitis or hemorrhagic fevers, morbidity and mortality rates can range from low to high, depending upon the virus and factors such as host age and immune status. After the acute phase, humans might die, recover fully, or recover from illness, but show various sequelae (after-effect of disease or injury), such as neurological problems after acute encephalitis. Long-term chronic infection with mosquito-borne viruses does not occur in humans, although consequences of infection might be long lasting.

West Nile (WN) Virus

The Disease

West Nile (WN) virus was first isolated in 1937 from the peripheral blood of a human in the West Nile province of Uganda in Africa. Since then, WN viruses have been reported from Africa, Europe, the Middle East, West and Central Asia, and, most recently, the United States and Canada. West Nile virus is very similar to St. Louis encephalitis (SLE) virus in many respects, but was unknown in the Americas until 1999, when it appeared in the northeastern U.S. While the precise mode of entry will likely never be known, the most plausible circumstances indicate that infected birds were imported, thereby introducing the virus to North America. More than 60 clinical human cases occurred in the New York City area in late summer of 1999, while subsequent serosurveys suggested that there actually had been several thousand subclinical human infections following a widespread die-off of American crows in the region. In 2001, the virus spread throughout the eastern U.S. and crossed the Mississippi River, by 2002 the virus spread over most of the United States and caused over 4000 cases and 277 deaths, to earn the designation as the worst mosquito-borne encephalitis outbreak on record. This record was surpassed in 2012 when 5,674 cases were reported with 286 deaths. West Nile virus was detected in mosquitoes, birds, horses and humans in Georgia for the first time during 2001.

The incubation period (the time from infection to onset of disease symptoms) for WN virus in humans is usually 3 to 14 days. Most people who are infected with West Nile virus do not have any type illness. An estimated 20% of the people who become infected develop West Nile fever: mild symptoms include fever, headache and body aches, occasionally with a skin rash on the trunk of the body and swollen lymph glands. Symptoms of the mild form of this disease generally last a few days. The symptoms of severe infection (West Nile encephalitis or meningitis) include headache, high fever, neck stiffness, stupor, disorientation, coma, tremors, convulsions, muscle weakness, and paralysis. Symptoms of severe disease may last several weeks, although some neurological effects can be permanent. An estimated 1 in 150 persons infected with the West Nile virus will develop a more severe form of disease.

Clinical signs of WN virus infection also have been observed in horses, even though most horse infections are asymptomatic. Horse mortality has run in the range of 25-30%. Fortunately, an effective horse vaccine is now available. Cattle, sheep and camels also can be infected with WN virus, but clinical symptoms and viremia capable of infecting arthropod vectors have not been reported from these hosts. Birds, however, do experience viremias capable of infecting arthropod vectors. Various species of free-ranging and domesticated mammals, domesticated birds and exotic bird species housed in zoos also have been infected.

Transmission Cycle

As with Eastern equine encephalitis virus and St. Louis encephalitis virus, West Nile virus exists primarily as an infection of bird populations and is transmitted from bird to bird by several species of mosquitoes (Figure 14). The principal route of human infection with West Nile virus is through the bite of an infected mosquito. Mosquitoes become infected when they feed on infected birds, which may circulate the virus in their blood for a few days. The virus eventually moves into the mosquito's salivary glands. During subsequent blood meals, the virus may be injected into humans and animals, where it can multiply and possibly cause illness. Mosquitoes are capable of transmitting the virus to another animal 10-14 days after feeding on an infected bird. Birds in the Corvidae family appear to be very susceptible to the North American strain of this virus, with crows and blue jays being the most susceptible. Epidemiologists quickly recognized this fact and publicized the importance of reporting dead birds to local health districts. This reporting system has proven important to identify areas where active virus transmission is occurring. West Nile virus has been isolated from ticks, mites, and ked flies, but the importance of non-mosquito arthropods as potential vectors to humans appears minimal.

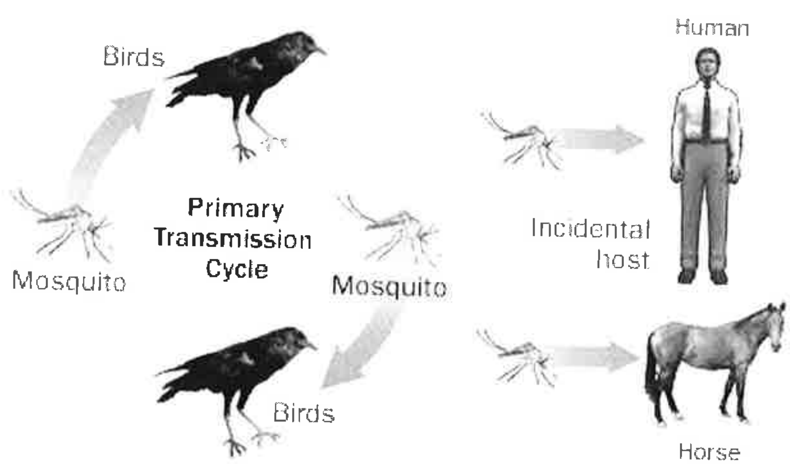


Figure 14. West Nile Virus cycle.
(Image from *American Family Physician*, Vol. 68 No. 4)

Mosquito Vectors

Mosquitoes serve as primary vectors of WN virus. In the United States, WN virus has been isolated from at least 36 mosquito species, primarily from three genera, *Aedes, Culex* and *Ochlerotatus*. However, evidence of WN virus in a mosquito species does not incriminate that species as a vector, or as playing a role in transmission. Isolation of WN virus from a mosquito is only an indication that the species has bitten a WN virus infected host. Vector incrimination requires additional information indicating that not only does the species feed on infected birds, but that the virus will develop and multiply in the species and that it will or can transmit the virus to the next potential host. Important vector (s) most likely to transmit WN virus in the United States are members of the *Culex* genus. It currently appears that *Culex quinquefasciatus* (southern house mosquito) is the primary vector of WN virus to humans in Georgia. *Cx. restuans* and *Cx. nigrapalpus* also appear to be involved as primary enzootic and avian epizootic vectors in Georgia. Another important bridge vector in the U.S. is *Cx. salinarius*, as evidenced by the 2000 epidemic on Staten Island, New York. Among the numerous other species that have produced WN virus positive pools are several common species in Georgia, including *Aedes albopictus, Ochlerotatus triseriatus and Ochlerotatus japonicus*.

Eastern Equine Encephalitis (EEE)

The Disease

Eastern equine encephalitis (EEE) virus is one of the most pathogenic among all of the mosquito-borne, encephalitis-causing viruses. The clinical disease is severe with a human-case fatality rate of over 50 percent (90 to 95 percent in horses). The type and severity of illness in humans depends upon the age and health of the individual. EEE can infect people of any age, but young children and infants are particularly vulnerable. Children, the elderly, immuno-compromised individuals and sometimes apparently healthy adults all can develop acute encephalitis with high fever, drowsiness, lethargy, vomiting, convulsions and coma. The case-fatality rate is especially high in children, and individuals who survive infection often show neurologic sequelae including mental retardation, behavioral changes, convulsive disorders, and/or paralysis. However, some survivors recover completely and show rapid and dramatic improvement from coma. Seldom are more than 20 or 30 human cases reported nationally in any given year, although localized groupings of human cases do occur.

Transmission Cycle

EEE is a viral infection maintained in nature by a bird-mosquito-bird cycle (Figure 15) similar to that of WN and SLE virus. The cycle primarily involves the fresh-water swamp mosquito, *Culiseta melanura*. Adult female *Cs. melanura* feed on birds in the swamp environment, or may leave the swampy area for more open areas to locate new hosts, returning later to oviposit. *Culiseta melanura* females are highly efficient vectors of EEE virus and transmit it primarily to swamp-dwelling, passeriform birds. More than 48 species of wild, native birds have shown evidence of infection. Replication of the virus produces a high viremic period in birds that lasts from two to five days. Mosquitoes taking bird blood meals during this period of high viremia can become infected. Once infected, mosquitoes remain infected for life. Birds, on the other hand, produce antibodies that eliminate the virus after a few days of infection. Some exotic bird species such as pheasants might become infected through pecking, thereby transmitting EEE virus by mechanical injection or inoculation from pheasant to pheasant.

Virus activity is confirmed by encephalitis monitoring programs conducted by health departments and mosquito control districts. These agencies periodically collect blood samples from wild birds or sentinel chicken flocks to detect antibodies produced after infection by the EEE virus. High antibody levels in young birds indicate recent circulation of the virus. Antibodies in older birds might be the result of infection the previous year or earlier. Periodic outbreaks among non-vaccinated equines also provide evidence of local EEE virus activity. Vaccines are available for horses, and annual booster shots are recommended. There are no vaccines available for human use. EEE virus is more prevalent in horses and susceptible domesticated birds such as emus than in humans, often with fatal outcomes. Deaths due to EEE virus infections have also been reported in red-winged blackbirds, house sparrows, whooping cranes and pheasants.

Horses, and probably humans, rarely develop viremia high enough to infect mosquitoes. Therefore, horses and humans are considered dead-end hosts that are not involved in the transmission cycle. Human and equine cases usually appear relatively late in the season after some period of summer amplification in birds. The mechanism of overwintering of EEE virus is unknown, although several possible methods exist, such as overwintering in mosquitoes, birds, reptiles, or hibernating vertebrates. The warm climate of Georgia could support an enzootic cycle of EEE virus because of high populations of overwintering birds and the potential vectors that are present during much of the year.

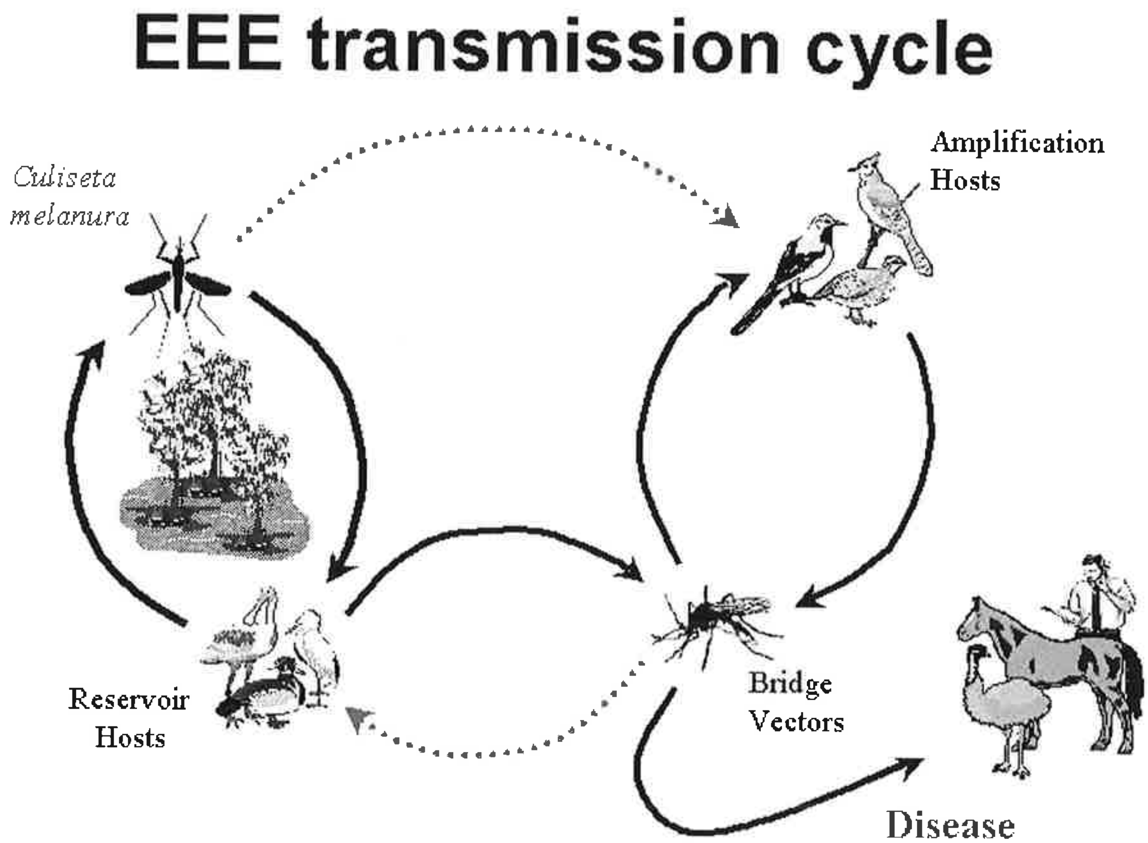


Figure 15. Eastern equine encephalitis transmission cycle.
(Image courtesy of Roxanne Connelly)

Mosquito Vectors

EEE virus has been isolated from several species of mosquitoes. However, the importance of individual mosquito species in transmitting the virus to humans and horses is not fully understood. Studies conducted in South Carolina in 1996-1998 isolated EEE from six different species of mosquitoes. These included *Anopheles crucians, An. punctipennis, An. quadrimaculatus, Coquillettidia perturbans, Cx. erraticus* and *Cs. melanura.* Species that could also be involved in EEE transmission in Georgia include *Ae. vexans, Cx. restuans, Oc. sollicitans, Oc. triseriatus, Orthopodomyia signifera* and *Psorophora ciliata.*

In the eastern United States, EEE virus occurs in a bird-mosquito enzootic cycle in swamps that support the biology of the enzootic vector *Cs. melanura.* The swamps comprising EEE virus foci are characterized in the southeastern distribution of its range by bald cypress, sweet gum, or tupelo trees, typical of swamp or bog ecosystems. Preferred habitats for aquatic stages of *Cs. melanura* are heavily shaded, permanent, fresh-water swamps and marshes containing cool, acetic water. The larvae generally develop in darkness or conditions of low light intensity and in situations where they can have contact with the soil. Such habitats include holes beneath tree roots and stumps, depressions formed by uprooted trees and the underside of root systems in aquatic plants.

Culiseta melanura eggs are laid in rafts late in the season. The larval stage undergoes diapause during the fall and winter months. Larvae are typically present every month of the year, but are difficult to find during the winter. Adult emergence begins in late April, and oviposition occurs from late May through October. Two or three adult emergence peaks occur during the year. *Culiseta melanura* feeds primarily on passeriform birds. Other birds and mammals are less frequent hosts and humans are rarely bitten. Reptiles might be an occasional source of blood. Adult females are most active during the evening twilight period, but some activity continues throughout the night. Very little adult activity occurs during daylight hours. Adult *Cs. melanura* can be collected in light traps and gravid traps. Adult females also are attracted to bird-baited traps and can be collected from artificial "resting boxes".

In some summers, for reasons likely related to weather patterns and the resulting density of mosquito hosts, EEE virus in its enzootic swamp setting becomes amplified to high levels so that epizootics develop. Certain mosquito species function as bridge vectors, particularly *Oc. sollicitans* in coastal areas and *Cq. perturbans* in inland areas. These vectors acquire the virus while feeding on viremic birds, later blood-feeding on mammals and transmitting the virus to them. *Ae. vexans,* one of our most common mosquitoes that can also develop in swampy environments, is not an efficient vector of EEE, but could become involved in the cycle when populations are high.

Coquillettidia perturbans is often an important bridge vector of EEE to horses and humans in Georgia. This species breeds prolifically in permanent bodies of water with emergent vegetation such as cattails. The eggs are laid in rafts on the water surface. The larvae, which are equipped with a modified air siphon tube, puncture and attach to the roots of cattails and other aquatic vegetation and derive oxygen from the plant. Unlike most mosquito larvae, this species does not have to surface to obtain oxygen and thus can remain among the roots underneath the water surface. This peculiar habit makes larval surveillance and control very difficult, if not impractical. Breeding continues throughout the warmer months, with several generations per year. The over-wintering stage is the larva. These mosquitoes are relatively strong flyers and may migrate some distance from their larval habitat. This species is active at night and rests on vegetation during the day. Peak feeding occurs at dusk and dawn. Feeding can occur during daylight when resting females are disturbed in shaded areas.

Status of Eastern Equine Encephalitis

Epizootics have been documented in the eastern United States since the 1930's, generally involving cases in horses and penned pheasants. The virus was first isolated from brains of horses that died during a 1933 epizootic along the eastern coast of the United States in Virginia, Delaware and Maryland. Disease in humans was first recognized in 1938 in Massachusetts. Generally, outbreaks involve many horse cases and very few human cases. Nearly all outbreaks involving human cases have occurred along the eastern coast of the United States. From 1964 to 2004, a total of 220 human cases of EEE infection were reported in the United States, with an average of 5 cases (range 0-15) per year. The greatest number of human cases occurred in 1959, when 36 were documented, mainly in New Jersey. Centers for Disease Control and Prevention's records go back to 1964, the first year that Georgia had a reported case, but this disease has surely occurred in Georgia since its earliest inhabitants. A total of 24 cases have been reported in Georgia since 1964, the second highest total in the country after Florida's 57.

There are a number of mosquito species, particularly *Cs. melanura,* capable of maintaining and transmitting EEE virus to birds in nature. Because *Cs. melanura* seldom bites humans, other mosquitoes such as *Cs. inornata, Cx. quinquefasciatus, Ae. albopictus, Ae. vexans, Oc. sollicitans, Oc. infirmatus, Oc. atlanticus* and *Cq. perturbans* are important in transmission from birds to humans and/or horses. Factors favoring infections in humans are the buildup of virus in wild-bird populations and a high density of adult mosquito vectors.

LaCrosse Encephalitis

The Disease

During the past several years there has been increasing recognition that LaCrosse (LAC) virus has become a serious and growing infectious disease problem in the United States. In many years, LAC virus accounts for more human disease than St. Louis encephalitis virus, western equine encephalitis virus and eastern equine encephalitis virus combined. In 1964, LAC virus was isolated from preserved brain tissue of a child who had died of encephalitis in 1960 in the vicinity of LaCrosse, Wisconsin. Historically, most cases of LAC encephalitis occur in the upper mid-western states (Minnesota, Wisconsin, Iowa, Illinois, Indiana and Ohio). Recently more cases are being reported from states in the mid-Atlantic (West Virginia, Virginia and North Carolina) and southeastern (Alabama, Mississippi, Georgia, South Carolina and Tennessee) regions of the country. LaCrosse encephalitis is suspected of having a broader distribution and a higher incidence in the eastern United States. Because no specific treatment for LAC encephalitis exists, physicians often do not request the tests required to specifically identify LAC virus infections and the cases are reported as aseptic meningitis or viral encephalitis of unknown etiology.

LaCrosse encephalitis virus activity is seasonal beginning in late May and extending into October, a period that coincides with peak mosquito populations. Disease onset in a majority of the cases occurs in August. The clinical syndrome ranges from a mild and transient aseptic meningitis to a severe encephalitis and death. LaCrosse encephalitis is primarily a disease of children under the age of 15. Most adult infections are thought to be sub-clinical. Clinical infections are more frequent in males and most reported cases have been associated with a rustic or rural environment. Complete recovery is usual but some post-encephalitic behavioral changes in the form of irritability, aggression, forgetfulness, speech changes and impaired scholastic ability have been reported. Unlike the other arboviral encephalitides that occur in the U.S., relatively few deaths have been associated with LAC virus.

Transmission Cycle

The natural transmission cycle of LAC virus (Figure 15) involves small mammals such as squirrels, chipmunks, field mice and rabbits as the primary vertebrate hosts and mosquitoes of the genus *Ochlerotatus* as the primary vectors. The animals become infected when bitten by infected mosquitoes. Propagation of the virus produces a viremic period in the animals, and mosquitoes feeding on the animals subsequently become infected. Once infected, the mosquitoes remain infected throughout their life. The virus can also be passed on to succeeding generations of mosquitoes transovarially (through the egg) and venereally from an infected male mosquito to the female and her eggs. Because male mosquitoes do not feed on blood, they must be infected transovarially. Hence, vertebrate reservoirs are not always essential to the persistence of LAC in nature because the mosquito itself can be a reservoir host. An infected female is able to transmit the virus at its first blood feeding without previously having taken an infectious blood meal. The disease is enzootic and usually occurs in localized foci where environmental conditions support both the mosquito vectors and the host animals. Human disease usually occurs when persons frequent these localized habitats.

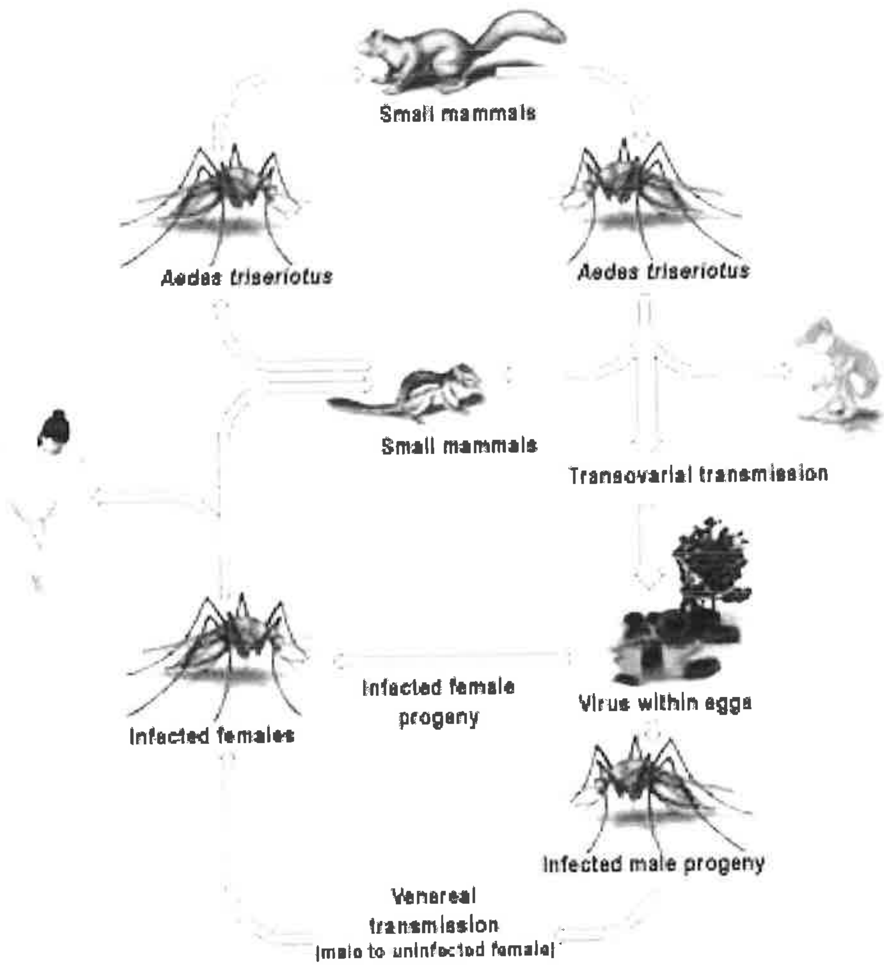


Figure 16. LaCrosse encephalitis transmission cycle.
(Image from ASM News, Barry Beaty)

Mosquito Vectors

The primary vector of LAC virus is *Oc. triseriatus*. Epidemiologic investigations of cases of encephalitis or aseptic meningitis of unknown origin often reveal LAC encephalitis and populations of *Oc. triseriatus* in the immediate vicinity of the infection. This species is the most widely distributed tree-hole mosquito in North America. Larvae develop in rot holes in many kinds of deciduous trees and in a wide variety of containers in which rain water and organic debris accumulate. These sites include tires discarded in wooded areas, barrels, tubs, tin cans and natural water containers such as ground pools and pitcher plants. Larval habitats of this species usually are in wooded areas or other shaded localities. The egg is the over-wintering stage. Eggs are deposited on the walls of tree-holes or other water containers just above the existing water levels and hatching occurs only when water accumulations in the container increase enough to flood the eggs, either during the year in which they are deposited or at a later time. Multiple generations can occur during the warm months of the year. Adults fly and feed mostly during early morning and early evening hours. The peak feeding activity is during late afternoon and early evening and biting usually stops when full darkness occurs. Adults normally are found in deciduous forests and woodlots, although they might become serious pests in residential areas near wooded localities and tire piles.

In Ohio and New York, LAC virus also has been isolated repeatedly from *Oc. canadensis*; however, the role of this mosquito as a vector to humans and its role in the enzootic cycle are not well understood. LAC virus also has been isolated from *Ae. albopictus* in Anderson County, Tennessee, and in Buncombe County, North Carolina.

Other Mosquito-borne Diseases

St. Louis Encephalitis (SLE). This disease is caused by a virus that has a natural transmission cycle involving several species of wild birds and a few species of mosquitoes. The virus is briefly present in the blood of infected birds, and mosquitoes ingest the virus when taking a blood meal. After one to two weeks at summer temperatures, longer at cooler temperatures, the virus multiplies and spreads to the mosquito salivary glands. It is then inoculated into the next host when the infected mosquito feeds.

Once infected, the mosquito can transmit the virus each time it takes, or attempts to take, a blood meal for the duration of its life. In the vertebrate host, usually a bird, the virus reproduces and must reach a certain concentration in the blood to infect susceptible mosquito species. In most cases, this level is reached less than a week after the infective bite occurs and lasts for only three to four days, after which the virus in the host blood is reduced below the level required to infect the mosquito. To become infected and later transmit the virus, a mosquito must feed on the infected vertebrate during this three- to four-day period.

In some species of birds the virus level that develops is much higher than in other species. Those with the higher levels are the most important sources of infection for mosquitoes. Also, some mosquito species are especially receptive and can become infected when feeding on blood with relatively low virus levels. These species are the most important in transmitting the virus to the vertebrates. The SLE virus does not multiply in some mosquito species and therefore is not transmitted by these species even if the mosquito has fed on an infected bird. Also, the virus does not develop to high enough levels in the blood of some dead-end vertebrates to infect even the most susceptible mosquito species that feed on these animals. Humans, nonhuman mammals and some bird species are dead-end hosts for SLE virus. There is no person-to-person transmission. Vertebrates, birds, humans or other mammals infected with SLE virus do not always exhibit disease symptoms. Birds, even those that develop high levels of virus in their blood, may not exhibit any symptoms.

The reaction of humans infected with SLE virus is quite variable and dependent on age, general health and other poorly understood characteristics. SLE virus affects the central nervous system. Infected humans may experience no noticeable symptoms, or symptoms may include the onset of fever, nausea and vomiting with severe headaches within five to seven days of infection. Severe symptoms may include temporary or permanent physical or mental disabilities, even death.

In general, the fatality rate is higher and the symptoms more severe in people over 50 years of age. In past epidemics, fatality rates among confirmed cases have ranged from 4 percent to 20 percent of infected individuals, with most deaths occurring in the older age groups. Studies conducted in epidemic areas indicate that for each person who developed symptoms of SLE virus infection (ranging from mild to severe), 80 to 800 infected people did not develop disease symptoms.

In the eastern and mid-western U.S., epidemics of SLE have occurred in relatively densely populated urban and suburban areas where suitable bird and mosquito species live in close association with humans. For example, *Cx. quinquefasciatus,* the southern house mosquito, is thought to be a primary vector of SLE virus in areas where there are many water-filled artificial containers that provide ideal larval habitats for mosquitoes amidst populations of birds such as sparrows and starlings that live and nest in or near human residences. Water-holding structures commonly associated with humans (storm-sewer catch basins, cesspools, sewage lagoons, open septic tanks, polluted drainage ditches and water runoff impoundments, failed septic systems, drain fields and effluent from sewage disposal plants) also can produce huge numbers of these mosquitoes during the warm months of the year. Rural areas may be highly susceptible to transmission when pastures and other extensive, temporary, freshwater habitats produce large populations of avian-feeding mosquitoes, for example, *Cx. nigripalpus.*

The probability of SLE virus transmission is in direct proportion to the number of SLE virus infected birds and the abundance of *Culex* mosquitoes. Mosquito agencies monitor virus activity by sampling the blood of wild birds or, more commonly, sentinel birds caged in the natural habitat. SLE outbreaks are most likely to occur from midsummer to early fall, with case detection continuing until cold weather reduces mosquito abundance. Outbreaks may be more closely related to water accumulation patterns than to total rainfall (for example, drought conditions cause polluted streams to pool and produce *Culex* mosquitoes). SLE occurs throughout the U.S. More than 200 deaths were attributed to SLE in

St. Louis alone in 1933. The number of reported cases ranged from a handful to more than 1,800 annually in the two decades following 1970.

In temperate zones, *Cx. quinquefasciatus* females overwinter in locations that are protected from weather extremes, such as outbuildings, attics, storm sewers and rodent burrows. All other stages are killed when exposed to freezing temperatures. After overwintering, females lay eggs in rafts of 40 to 500 on the surface of organically polluted water. At summer temperatures, eggs hatch in one to two days, and adult development is complete in eight to 10 days. In the cooler temperatures of spring and fall, this development might require two or more weeks. Mosquito development occurs throughout the warm months of the year, and populations typically increase throughout the summer, peaking in late August. Although this species feeds primarily on birds, there is some evidence that it may change its feeding habits in mid-August to September to feeding on other animals, including humans. This change of feeding habits, and favorable meteorological conditions, may explain in part why human outbreaks of SLE normally occur in late summer.

There is evidence that the virus can remain viable in overwintering *Cx. quinquefasciatus* adults and, presumably, be transmitted when they feed on susceptible vertebrates in the spring. Whether this is the primary overwintering mechanism is not yet known.

Malaria. On a worldwide basis, malaria remains the most important human disease transmitted by mosquitoes. It is estimated that there are 400 million human cases of malaria in the world (mostly in Asia and Africa), with more than 2 million human deaths annually. Most of those who die are children under 10 years of age. In Africa, more than one in every 20 children die from malaria.

It is believed that malaria was introduced into North America during colonial days. Tens of thousands of cases occurred in the U.S. before the 1930's, but there are no reliable statistics available for the period. It is estimated that as many as a million cases may have occurred in the U.S. during the Civil War. In the 1930's, approximately 100,000 cases were reported annually; however, in the early 1940's, the number of cases were reduced dramatically due to the work of public health agencies using DDT during and after World War II and the Tennessee Valley Authority (TVA) source reduction program.

Since the late 1950's, a few hundred to a few thousand new cases have been recorded annually, almost entirely attributable to travelers and military returnees from malarious areas. These cases were contracted outside the U.S., but symptoms appeared following re-entry into the country. Georgia has averaged 50-60 cases of imported malaria over the past few years. There are periodically documented cases of human malaria being transmitted in the U.S. from infected hosts to uninfected hosts by indigenous mosquitoes. As recent as 2003, there were 8 confirmed cases of locally acquired malaria in Palm Beach County, Florida. Antimalarial prophylaxis is effective, and most nonresistant forms of malaria are responsive to treatment.

Human malaria is caused by one of four species of *Plasmodium* (*ovale, malariae, vivax, falciparum*), a protozoan parasite that causes fever, chills, sweating and headache. If not treated, it may cause shock, renal failure, acute encephalitis, coma and death. The disease is transmitted by several species of *Anopheles* mosquitoes. In the eastern U.S., some members of the *An. quadrimaculatus* species complex are important vectors. Another species, *An. crucians,* is a vector also, but probably to a lesser degree.

Dengue. Dengue is a viral disease, commonly called "breakbone fever." It is often characterized by severe headache, pain behind the eyes, high fever, backache, pain in the joints and a severe rash with convalescence that may require several weeks. These symptoms generally occur five to six days after an infected mosquito has bitten a susceptible person. In uncomplicated cases, death rarely occurs. Four strains of dengue virus are recognized, each of which produces lifelong immunity against the infecting virus. Exposure to infection by a second strain of dengue virus in an already immune individual may result in a more severe form of dengue known as dengue hemorrhagic fever (DHF) with accompanying dengue shock syndrome (DSS). Increased incidence of DHF has been experienced in the Western Hemisphere in recent years, with outbreaks occurring in the Caribbean region.

Dengue epidemics were common in the 1800's and early 1900's in the U.S. Before 1980, the last major epidemic of dengue in the continental U.S. occurred in Louisiana in 1945 with 62 confirmed cases, but authorities estimated that there were probably several hundred unapparent and/or unreported cases. As recently as 2010, Key West, FL. experienced an epidemic of dengue with 66 cases being reported and an incidence rate of 330 cases for every 100,000 persons. This region will remain at risk to this disease as dengue transmission continues to rise across the Caribbean basin in 2013. Although dengue is not endemic now in most of the U.S., potential vectors are present in the southern U.S., and the virus is commonly imported in people entering the country from endemic areas. Conditions for dengue transmission are present, but it is unlikely that transmission would occur at the levels observed in the 1900's, when hundreds or thousands of cases are estimated to have occurred in some major cities.

Dengue is transmitted in the U.S. by *Ae. aegypti* in a mosquito-human-mosquito cycle. Other potential vectors include *Ae. albopictus* and *Oc. japonicus*. These **peridomestic** species are found in close association with humans, developing in natural and artificial water-holding containers around dwellings. After biting an infected person, the female mosquito requires eight to 10 days for viral development before it is capable of transmitting the virus to humans. Once infected, the mosquito remains infective for the remainder of its life. Presently, there is no vaccine available to prevent dengue infection.

Yellow Fever (YF). Yellow fever is caused by a virus closely related to the dengue virus. In fact, YF infections produce dengue-like symptoms in humans, but the effects of YF are normally much more severe. The fatality rate may reach 50 percent or more in epidemics. The virus is presently found in Africa and South America. It is absent from the continental U.S., where the last epidemic of YF occurred in New Orleans in 1905.

As with dengue, the YF virus is transmitted in urban areas by *Ae. aegypti*, with *Ae. albopictus* and *Oc. japonicus* as potential vectors as well. Unlike dengue, however, the probability of YF virus reaching the U.S. is low. This fact may be due, in part, to the fact that YF, along with cholera, smallpox and plague, is quarantinable. This means that the Centers for Disease Control and Prevention in Atlanta, Georgia, are continually monitoring outbreaks of YF in the Western hemisphere. Yellow fever vaccines are used to prevent disease in humans traveling to YF-endemic areas. They are also required of people moving from YF-endemic areas to YF-free areas where *Ae. aegypti* is present.

Dog Heartworm. Dog heartworm *(Dirofilaria immitis,* a filarial nematode) is a serious disease for all breeds of dogs in temperate and tropical climates. Infection rates in some states have been reported to be as high as 80 percent in dogs over 2.5 years old, and almost 100 percent in dogs over 5 years old that are left unvaccinated. The infection rate in cats is sufficient to be a veterinary concern. Humans can also become infected, but the worms are unable to develop or mature because humans are not their natural hosts. Wild canids, such as foxes and coyotes, probably serve as **enzootic reservoirs.** Several genera of mosquitoes can transmit the parasite to dogs *(Aedes, Anopheles, Culex, Ochlerotatus* and *Psorophora,* for example). In nature, *Cx. quinquefasciatus* is considered to be the most important vector. Other incriminated vectors of dog heartworm include *Ae. albopictus, Ae. vexans, Oc. taeniorhynchus* and *Cx. salinarius*. The recently introduced *Oc. japonicus* could also become involved in this cycle.

The life cycle of dog heartworm (Figure 17) involves two hosts: mosquitoes and dogs. Mosquitoes ingest the immature worms called **microfilariae** while taking blood from dogs. These immature worms develop through three larval stages in the mosquito in nine to 14 days. After they have developed into infective or third-stage larvae, the microfilariae are transmitted via the mosquito's mouthparts to a dog when the mosquito feeds again. The larvae grow and migrate through the host's subcutaneous tissues and large blood vessels and eventually enter the right ventricle of the heart. In the heart, the larvae grow into adult worms measuring approximately 11 inches for the females and 6 inches for the male. The adult female lays no eggs but produces microfilariae that circulate in the blood, completing the cycle.

In areas where dog heartworm disease is prevalent, dog owners should provide mosquito-proof sleeping quarters for their animals. Additionally, the owners should seek the assistance of a veterinarian to administer a program of chemical prophylaxis. It is estimated that approximately $1.2 billion is spent on heartworm prevention throughout the U.S. This would correspond to approximately $60,000,000 being spent on heartworm prevention in Georgia alone. As with most diseases, prevention is better than treatment, as it is estimated to cost approximately $1,000 to treat a case of heartworm, once infected. Fortunately, highly effective preventative medication is readily available and easily administered.

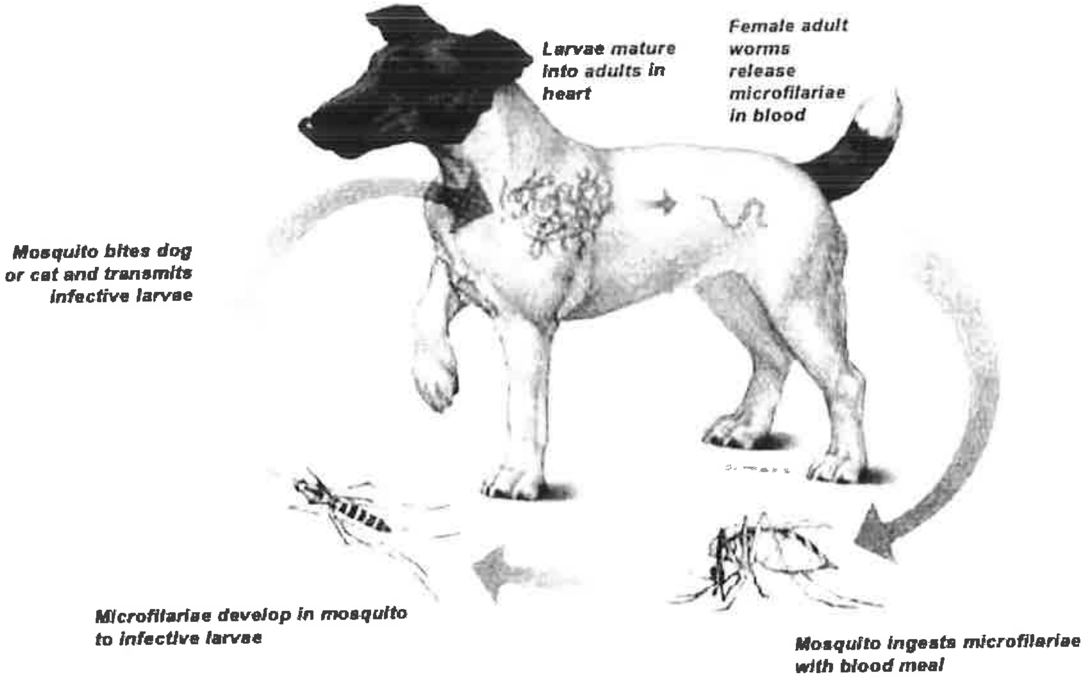


Figure 17. Heartworm transmission cycle.
(Image from *Oklahoma State University College of Veterinary Medicine*)

Acquired Immune Deficiency Syndrome (AIDS). When AIDS was initially discovered in humans, one of the first questions asked of public-health officials was: "Is the virus that causes AIDS (HIV) transmitted by bloodsucking insects?" There have been exhaustive laboratory tests conducted by the CDC and other similar agencies around the world using a wide range of blood-feeding insects and arthropods in attempting to answer this question. Currently, there is no scientifically based, credible evidence to suggest or imply that mosquitoes or other biting arthropods can transmit the virus to humans. Is that enough evidence to say that it is <u>impossible</u> for insects to transmit the virus to humans, either biologically or mechanically (for example, infected blood on the mouthparts)? While that question may not have been fully answered to the satisfaction of some members of the general public, it is safe to say that the involvement of blood feeding insects and other arthropods is biologically insignificant, if, in fact, it occurs at all.

Chapter 4. Integrated Mosquito Management

Learning Objectives

After study of the material in this chapter, you should be able to:

1. Name the five aspects of Integrated Mosquito Management.
2. Discuss the importance of sanitation in controlling container breeding mosquitoes around homes.
3. Describe the proper technique for using insect repellents.
4. Explain why the use of maps is so important to a comprehensive mosquito control program.
5. Understand the concept of larval and adult surveillance.
6. Name three types of adult surveillance.
7. Explain why source reduction is the best way to control mosquitoes.
8. List three modes of action for commonly used larvicides.
9. Name the most common type of adulticide application conducted today.
10. Explain why the calibration of adulticide machines is so critical.
11. Discuss the importance of insecticide resistance to a mosquito control operator.
12. List three larvicides and three adulticides.

The four overlapping aims of mosquito control are to prevent mosquito bites, keep mosquito populations at acceptable densities, minimize mosquito-vertebrate contact and reduce the longevity of female mosquitoes. All of these actions minimize the annoying and harmful effects of bites and blood loss and interrupt pathogen transmission (Mullen and Durden, 2002). The most effective and efficient manner to produce these results is usually based on a combination of the following practices: **Education/Communication, Surveillance, Source Reduction, Larviciding and Adulticiding**. The combination of these practices is called "integrated mosquito management". To use an integrated approach effectively, it is necessary to have a broad understanding of the insects to be controlled, factors which influence population size and the technologies available to control the pest.

Education/Communication

Organized mosquito control should include a clear and continuous public education and public relations program. Control effectiveness will depend in a large part on public support. This factor is particularly important today, when the container breeder, *Aedes albopictus* is often one of our most important pest species. The prerequisites to a successful program include proper planning, trained personnel and proper equipment. Of course, all of these are necessary for doing a good job, and the best public relations is good mosquito control.

Public relations is an educational process that should be a two-way activity. Mosquito control personnel should not only inform the public of their program but also listen to the public and learn what it expects. The public should be informed so that it:

1. recognizes the problems.
2. recognizes the cause of the problems.
3. knows the approach to correct the problems.
4. knows the reasons for successes or failures.
5. knows how to assist mosquito control personnel and help itself.

Mosquito control personnel should listen to the public so that they:

1. learn of problem areas.
2. learn which methods are acceptable and unacceptable to the people living in the problem areas.
3. obtain feedback as to the effectiveness of control efforts.

Public relations may be approached by:

1. person-to-person contacts, including phone calls, letters and home visits.
2. group contacts, including lectures, tours, field trips and school visits.
3. mass media activities, including radio, television, newspapers, movie advertisements and exhibits.

Professional mosquito control programs should explore all three approaches.

Information concerning mosquito control programs should also extend to other government agencies. Health departments, planning boards, road departments, environmental commissions and other state, county and municipal bodies may have interest in mosquito control projects and activities. It may be advantageous to discuss problems and tentative plans with these agencies. Water management projects especially should be planned so as to serve the objectives of all concerned agencies. Interagency cooperation is beneficial to a mosquito control program because an informed, cooperating outside agency then becomes another means of keeping the public aware of the benefits of mosquito control. The most important part of the education phase of an integrated program is to inform the public about the basic biology of mosquitoes and where and how they develop. A primary aspect of this information will involve the concept of premise sanitation.

Sanitation. The need to prevent mosquito development in water-holding containers around homes and businesses is well known and has received much emphasis in recent years. Each mosquito control director should use the media available to educate the general public about the need to ensure that buckets, cans, old tires, boats, tarps and other debris and possessions do not support mosquito development. Containers of all types and man-made structures such as cisterns, roof gutters and discarded tires are capable of producing large numbers of mosquitoes, including species that can transmit disease. Removal of debris and regular inspection, when conducted on a continuous basis, permanently reduces populations in such sites. Typically, mosquito control related sanitation efforts are best accomplished by homeowners and residents who through their own actions have created mosquito habitats around their homes. Mosquito control agencies often support educational programs that call attention to the hazards of mosquito populations and recommend individual efforts on residential-area cleanup. Amnesty programs for used tires, while expensive, are excellent programs that can permanently reduce the number of larval habitats in any community.

Education. A relatively new aspect of education and outreach involves targeting our youth through the public education system. There is a belief among public health specialists that sometimes the education of a child about mosquito biology and control is more effective than targeting their parents. Children are more impressionable and are more likely to act after seeing a presentation about mosquito abatement concepts. By teaching children early about the importance of eliminating standing water and mosquito biology in general, they are more likely to carry these concepts through to their parents and to their adult life. Other educational techniques involve showing educational previews at movie theaters prior to the main event and using mascots at community events to emphasize the importance of mosquito prevention and maintain community awareness.

Personal Protection. Preventing mosquito bites is the most important and effective way to negate the negative effects of mosquitoes and in particular, prevent disease transmission. The public must consciously adopt personal behavior practices that reduce the probability of receiving infective mosquito bites. For example, most, but not all, vectors are quite active during the **crepuscular** periods at sunset and dawn. This period is a time of day when attractiveness to mosquitoes should be minimized. Staying indoors as much as possible, especially if there is an alert situation in connection with mosquito-borne disease, is one way to avoid contact. If it is necessary to go outside, wear loose fitting, light-colored clothing (which is less attractive to mosquitoes and most biting flies), pants and long sleeves, and apply a repellent to the exposed skin - carefully following the manufacturer's directions on the label.

While there are a variety of products labeled as repellents, products containing DEET (N,N-Diethyl-meta-toluamide) continue to be the most common and are safe, effective and long lasting. There are a great number of products available that contain this material in varying concentrations. The most important aspect to remember about DEET is that it is very effective and a small amount of product goes a long way. Products are typically available with concentrations of active ingredient ranging from 5% - 100%. DEET is not typically recommended for children less than 2 months of age and products containing less than 30% DEET are recommended for older children. When applying any repellent to children, adults should put a small amount on their hands and then rub it onto the child while avoiding their hands, eyes and mouth. When people are removed from mosquito populations they should wash the skin that repellent has been applied to with soap and water, regardless of the product. Most people do not need the higher concentrations of DEET unless they are going to be exposed to extreme mosquito populations for an extended period with limited opportunities for reapplication. Under normal circumstances when people are only outside for short periods of time, the lower concentrations are just as effective as the higher concentrations. Complete coverage of all exposed skin is critical as mosquitoes are amazingly effective at locating untreated areas.

In 2005, the CDC revised their recommendations for mosquito repellents and added two materials: Picaridin (IR-3535) and Oil of Lemon Eucalyptus [p-methane 3,8-diol (PMD)]. The label for oil of lemon eucalyptus specifies that it should not be used on children under 3 years of age. When using any of these products, it is essential to follow the label instructions.

Surveillance

One of the most important elements of a successful mosquito control program is surveillance. Surveillance is the act of searching for mosquito habitats and populations. It involves determining the presence of mosquitoes, the identification of the species involved, and evaluating their relative abundance. The information provided by surveillance programs and a thorough knowledge of a mosquito's biology, habits, and habitats will provide a sound basis for targeting control efforts. Surveys are essential for the planning, operation and evaluation of an effective mosquito control program, whether for the prevention of mosquito-borne diseases or to reduce mosquito populations to levels permitting normal activities without undue discomfort. Initial surveys identify the species of mosquitoes present and provide general information on locations, densities and disease potential. With this knowledge, it may be possible to determine life cycles and feeding preferences; predict larval habitats, adult resting sites and flight ranges; and perhaps even make preliminary recommendations for control programs. Mapping of larval habitats is a critical aspect of any surveillance program.

The next step is to embark on a formal surveillance program in which routine monitoring of mosquito presence is conducted. A basic inspection program usually addresses adult and larval population densities and species composition, rainfall and tide monitoring, and larval habitat locations. This information not only can provide justification for source reduction and insecticide applications, but it also serves as an ongoing indicator of the effectiveness of these activities and continually adds to the database of knowledge concerning mosquitoes in the area. The data also may indicate that an insecticide application is not warranted. Such inspections do not determine the absolute population of mosquitoes, but they can show fluctuations in relative mosquito abundance and diversity over time in the various habitats visited.

Mapping. Reasonably accurate and comprehensive maps are essential in conducting a mosquito control operation. Maps provide information for field survey and suppression activities, program evaluation, and reporting. When large areas are involved, a master map may be needed for planning drainage and other field operations. The master map should indicate the treatment areas, the possible flight range of mosquitoes from larval habitats and the potential degree of penetration into populated areas. Larval and adult sampling stations can be indicated by symbols and numbers. Counts made at these stations at weekly or biweekly intervals provide information for current evaluation of the mosquito problem at any time by indicating the abundance of mosquitoes, species involved, flight range and habitat, and disease potential. This information identifies areas requiring high priority for treatment.

Narrative descriptions, sometimes necessary for exact location description, are simplified whenever possible. For example, "N.W. corner of 15th Street and Ninth Avenue" is a brief description that leaves no doubt as to the location. There may be some areas that are difficult to accurately describe (e.g., marshlands). However, maps can be subdivided into numbered or named areas for easy reference, and Global Positioning System (GPS) coordinates are very reliable. Some common methods of subdividing maps involve the use of geographical features, artificial grids or a combination of both to set boundaries on areas that are indexed for easy reference and filing. Maps should show elevations, streets, roads and railroads, as well as ponds, lakes, streams, sewage lagoons, flooded woodlots and other larval habitats. Maps can also be used for locating and plotting larval habitats and adult sampling stations. A variety of computer programs and mapping systems are now available. Budgetary constraints will often determine what technique or program is used, but any system is better than none!

Record Keeping. In order to avoid comparing dissimilar parameters, inspections should be consistent both in method and location. **Keeping clear, accurate records is as important as the data gathering itself**. Surveillance records are managed in a manner that ensures subsequent inspections can be conducted in a similar manner by others less familiar with the area. They usually include the inspector's name, date of inspection, sampling method and exact location in addition to the data collected.

Data recording forms and devices promote uniformity, which makes records easier to read, interpret and summarize, and serve as a reminder to the inspector to record all pertinent information. In the absence of data recorders, standardized formats lead to more consistently accurate transcription of the data into the permanent records.

Surveillance Options and Techniques

Before beginning a survey, obtain information about the general life history and habitats of the species known or suspected to be in the area. An experienced person may be able to spot the probable larval habitat in a specific area by rapid reconnaissance. These areas should be carefully numbered and marked on a map. Determining the specific larval development sites and establishing permanent larval sampling stations requires a more detailed inspection. Larval surveys to determine the exact areas in which the mosquitoes develop and their relative abundance are of particular value in control operations.

Oviposition Trap. Collections of mosquito eggs in oviposition traps are used to detect and monitor container breeding mosquitoes such as *Oc. triseriatus*, *Ae. aegypti* and *Ae. albopictus*. The oviposition trap can easily be made out of food cans (3-pound coffee cans) or pint jars painted black inside and outside. The traps are placed in shaded areas at a height no greater than 4 feet and filled with water and a few dried leaves placed at the bottom of the container. An oviposition **substrate** made of a strip of various materials (seed germination paper, muslin, formica, balsa wood, wooden tongue depressor, etc.) is then placed vertically inside the container with the water covering about half of it. **Gravid** females use this substrate to lay eggs just above the water level. Traps should be checked weekly to prevent them from becoming larval habitats. If larvae are found in the trap, the water should be dumped and the trap reset. The ovipositional substrate is periodically collected and returned to the laboratory in a plastic bag. Samples are kept cool and moist during transportation, taking care to avoid too much moisture, which could cause eggs to begin hatching. Eggs or the resulting 4th **instar** larvae are then identified.

Larval and Pupal Equipment. The standard monitoring tool for larval populations is the mosquito dipper. A white enameled or plastic dipper about 4 inches in diameter (1 pint or 350 ml capacity) is frequently used for collecting mosquito larvae (Figure 18 A&B). The handle of the dipper may be lengthened by inserting a suitable piece of wood dowel or PVC pipe. Specially designed dippers can be created so that their capacity can be directly related to the amount of water surface examined. Thus, the number of larvae per square foot or meter can be computed with reasonable accuracy.

Other tools used to monitor larval and pupal populations include turkey basters, disposable plastic pipetters, small fish nets and soup ladles. In addition, a quality, bright, flashlight is very helpful when monitoring tires or other darkened areas. Often when monitoring tires for mosquito presence or absence, a bright flashlight is the best option. Larval and pupal activity can be observed without disturbing the water and the debris contained therein.

Dip Procedure. Mosquito larvae of some species are usually found near surface vegetation or debris. In larger ponds or bodies of water, these larvae are ordinarily confined to the shoreline areas where it is necessary to proceed slowly and carefully in searching for mosquito larvae as disturbance of the water or shadows may cause the larvae to dive to the bottom. **Anopheline** larvae are collected using a skimming movement of the dipper with one side pressed just below the surface. The stroke is ended just before the dipper is full to prevent larvae from washing out of the dipper. Where clumps of erect vegetation are present, it is best to press the dipper into a clump with one edge depressed so that the water flows from the vegetation into the dipper. **Culicine** larvae such as *Ae. vexans* or *Oc. sollicitans* or species of *Psorophora* require a quicker chopping motion of the dipper, as they are more likely to dive below the surface when disturbed.

The inspector records the number of dips made and the number of larvae found, by **instar** if warranted, and transfers representative sample specimens by pipette into small vials of alcohol for later identification. With most species, it is possible to get a rough idea of the larval population by computing the average number of larvae of each species per dip. The number of dips required will depend on the size of the area and the relative larval density, but for convenience is often in multiples of 10. Inspection should be made at weekly or biweekly intervals during the mosquito season, as areas that are free of an abundance of larvae at one time may rapidly become heavily infested.

Inspections for certain species require variations in the procedure described above. For example, *Coquillettidia* larvae remain below the surface throughout much of their development attached by the **siphon** to the stems of emergent vegetation. These larvae are found by pulling up aquatic plants (cattail, sedges, pickerelweed, etc.), washing or shaking them in a pan of water, and searching the resulting muck and debris.

Inspection for *Oc. triseriatus* and *Ae. albopictus* populations involves searching tree holes and artificial containers such as tires. These containers are often too small for an ordinary dipper, but water can be transferred with a turkey baster or siphoned into a dipper or pan where the larvae can be observed.

Figure 18A. Common larval surveillance tools (left to right, soup ladle, common mosquito dipper, turkey baster and small fish net).

Figure 18B. Common mosquito dipper.

Adult Surveillance

Adult mosquito surveillance permits evaluation of the incidence of mosquitoes within residential areas where they might bite people and shows the relative abundance of various species. Using this information and reference material in relation to larval habitats and habits of the resident species, vector-control specialists can determine the need for a control program and conduct an effective search for larval development sites. Interpreting these observations also provides the justification for applying or withholding control measures.

Landing and Biting Collections. The required equipment for this method of adult mosquito survey is simple and inexpensive and consists of an ethyl-acetate charged kill jar (ex. pickle jar with approximately 1 inch of plaster of paris on the bottom, soaked with 1 tablespoon of ethyl-acetate), aspirator, pill boxes, cages for live collections, field data forms or notebook, pencil, flashlight and map.

Although most districts use battery-operated mechanical aspirators, a simple mouth-suction aspirator can be made from a section of plastic (or glass) tubing 12 inches long with an inside diameter of about 5/8 inch. Cover one end of the tube with a bobbinet or fine wire screening and then insert it into a piece of rubber tubing 2 to 3 feet long. Small pill or salve boxes are convenient for holding dead mosquitoes until they can be identified. A small piece of crumpled soft tissue or lens paper in the box will prevent subsequent damage to the specimens. Specimens that are stored for later identification should be adequately labeled and stored in an insect-proof box or stored with mothballs to prevent ants, roaches, beetles and other insects from eating the mosquito specimens.

Collecting mosquitoes as they bite or land on the surveyor's body is a convenient method of sampling populations. The subject sits quietly for a designated period of time, usually five to 10 minutes, collects the mosquitoes with an aspirator and places them in the collection jar for later identification. It should be pointed out that the mosquitoes do not have to actually bite to be counted. Also, if there is evidence of virus transmission in the area, this technique is not used in order to protect employees from mosquito-borne diseases. It is customary to make landing collections near sundown as this **crepuscular** period is the most active time for most mosquitoes. Some individuals are more attractive to mosquitoes than others, so the same person or bait animal should be used if possible throughout a survey. Make collections at about the same time of day and for the same duration, so that activity rates at different stations may be compared to show trends in mosquito abundance. In areas where mosquito-borne disease occurs, landing rates are preferable to biting rates.

Insect Sweep Net Collection. Use insect nets to collect mosquitoes from grass and other vegetation. This type of collection is valuable in assessing species that rest in these habitats during the daytime, such as *Ae. vexans* and *Oc. sollicitans.* Power vacuum collectors or aspirators perform the same function.

Bait Trap Collection. When other collection methods are inadequate, animal-baited traps, alone or with dry ice, can be used to trap mosquitoes. Make a portable mosquito bait trap from a 12-inch lard can or bucket with inwardly directed screen funnels and baited with young chickens, pheasants, house sparrows, other birds or about 2 to 3 pounds of dry ice wrapped in newspaper. Commercial traps are available that convert propane into carbon dioxide to achieve similar attraction. This type of collection provides information on the abundance of host-seeking female mosquitoes in the vicinity.

Truck Trap Collection. Some organized mosquito control districts use the basic truck trap, which consists of a large funnel-shaped frame covered with screen and mounted over the roof of a light truck with the entrance (larger) end forward. When driven at low speed (10 to 15 mph) for a fixed distance, mosquitoes caught in the collection bag represent a reasonably unbiased sample in terms of variables in attraction.

Daytime Resting Collection. Adults of most mosquito species are inactive during the day, resting quietly in dark, cool, humid locations. Although labor intensive, careful inspection of daytime shelters can indicate the population density of these mosquitoes. This method is especially useful for **anopheline** mosquitoes and is commonly used for collecting specimens in the *Anopheles quadrimaculatus* spp. complex. It is also helpful in estimating populations of some culicines such as *Culex quinquefasciatus.* Because this method does not rely on host-seeking behavior, it is considered to be less biased than others that may be selective for mosquitoes in certain physiological stages. Natural resting stations include houses, stables, chicken houses, privies, culverts, bridges, caves, hollow trees and overhanging banks along streams.

A few species of mosquitoes (e.g., *Anopheles* spp.) can be sampled using artificial resting stations such as the red box shelter, which is a wooden box 1 foot wide, long and deep, with one side open, painted flat black on the outside and red on the inside. Such stations are placed near the suspected larval habitats in shaded, humid locations, normally on the ground not facing east. Mosquitoes enter the shelters at dawn, probably in response to change in light intensity and humidity, and ordinarily do not leave until dusk. Specimens can be collected using an aspirator as described in the "Landing and Biting Collections" section.

Light Trap Collection. Light attracts many mosquito species, making it possible to use this response for sampling adult populations between dusk and dawn. Mosquito light traps attract adults from a considerable distance when they are placed in locations remote from competing light sources. To make the trap even more attractive, place a 2 pound block of dry ice wrapped in newspaper above the trap. The trap should be located 30 or more feet from buildings in open areas near trees and shrubs and away from other lights, areas open to strong winds and industrial plants giving off smoke or gas. Moonlight may reduce the effectiveness of the traps. The light should be 5.5 to 6 feet above the ground when mounted on a post or hung from a tree. Research has demonstrated that the height of the trap can affect what species are collected, thereby demonstrating the importance of consistency in trap usage and installation. The trap can be operated on a regular schedule from one to seven nights per week, being turned on just before dark and turned off after daylight. The specimens collected should be removed each morning for sorting and identification.

The New Jersey mosquito light trap (Figure 19) has been widely used in obtaining data on the density and species composition of mosquito populations. It is powered by 110 volts AC (a standard extension cord) and is placed near a continuous supply of power.

The battery operated Centers for Disease Control (CDC) Miniature Light Trap (Figure 19) was developed for portability to conduct live mosquito catches in remote areas where standard electrical power is not available. As the mosquitoes respond to the attractants, they are blown downward through a screen funnel into a killing jar or a mesh bag suspended below the trap. It collects a high percentage of mosquitoes in proportion to other insects and many more females than male specimens, a desirable feature in collecting mosquitoes for virus studies.

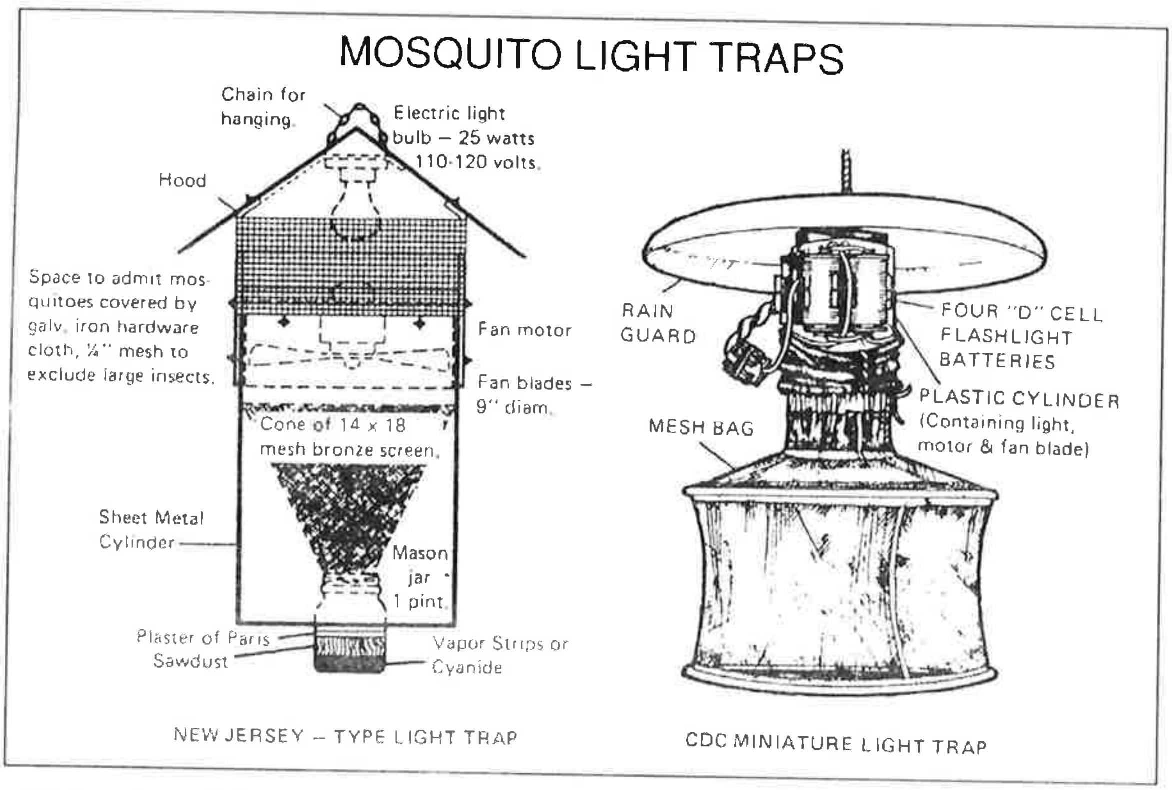


Figure 19. New Jersey light trap (left) and CDC miniature light trap (right).

Different species of mosquitoes have wide differences in their reactions to light. Light trap collections are often used to complement other methods of sampling mosquito populations. These traps can be converted to monitor densities of mosquitoes not attracted to light by removing the light and using only carbon dioxide as the attractant. With light as an attractant these traps have proven very useful in measuring densities of some of the culicine mosquitoes, such as *Oc. sollicitans, Ae. vexans* and

Coquillettidia perturbans. Some anophelines, especially *An. walkeri*, are also readily taken in light traps. The use of carbon dioxide only as an attractant collects large numbers of *Oc. canadensis*, *Oc. fitchii*, *Oc. stimulans* and *Oc. intrudens*. However, members of the *An. quadrimaculatus* species complex and *Cx. quinquefasciatus* and *Ae. aegypti* are seldom taken in significant numbers. Light trap collections may fluctuate with the dark and bright phases of the moon, being greatest during the dark phases. The effect of moonlight can be offset to some extent by placing traps in locations shaded from the moon.

Gravid Trap Collection. This trap has proven to be very effective in capturing large numbers of **gravid** *Culex* mosquitoes. Gravid traps are commonly available, light-weight, portable and run on one 6-volt gel cell rechargeable battery or four "D" cell batteries. One gallon of attractant (infusions made from grass, rabbit pellets, manure, etc.) placed in a black tray draws gravid females to the trap to oviposit. A standard infusion recipe is 1 pound of hay in 45 gallons of water allowed to age for 5 days. While flying above the attractant's surface, the mosquitoes are drawn into the collection chamber by an air current created by a motorized fan. The mosquitoes are captured live and then can be used for virus isolation studies or species density information. Gravid traps have proven highly effective in catching large numbers of *Cx. quinquefasciatus* for WNV surveillance studies in Georgia. Traps are commonly placed on the edge of vegetation interfaces and in protected areas where adults are expected to harbor.

Figure 20A. A Reiters/Cummings gravid trap in operation.

Figure 20B. Trap opened to show battery source, collections chamber (top removed) and switch/fan mechanism.

Figure 20C. A standard CDC gravid trap.

Using Mosquito Survey Data

Data from the preliminary reconnaissance surveys are correlated with reported disease prevalence or complaints of pest mosquitoes. Only after reviewing all of this information, can the health office or mosquito control supervisor 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.

Inspections that have been continued routinely once a mosquito control project is under way are used to evaluate progress. Success or failure of a mosquito control project cannot be measured in terms of the number of feet of ditches constructed or the number of gallons of insecticides used. While these statistics may be useful for some purposes, it is the actual density of mosquito populations that is significant. If the density is reduced to a satisfactory level, the routine surveys will reflect this reduction and document the accomplishment. On the other hand, if mosquito populations remain high, these results will spur intensified efforts to obtain the desired level of control. It is advisable to inspect some comparable untreated habitats, if they are available, at regular intervals to determine the normal fluctuation of various species throughout the season.

The correlation between mosquito annoyance and numbers captured in light traps has been established in many localities. In one state, 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. Landing rates of over 15/minute on the front half of the body for *Ae. albopictus* typically represent populations that would cause a general annoyance and reduce outdoor recreation. Similar criteria can be developed for other areas and also for various species. Meaningful action thresholds can provide justification for application decisions. However, meaningful action thresholds can not be established without accurate baseline information for the area in question.

Counts of mosquito larvae are a bit more difficult to correlate with pest problems or disease hazards. However, larval surveys reveal the specific sources of mosquito production. This information is invaluable to the control supervisor who can then apply effective **larvicides** to the proper sites at the correct times to keep adult mosquito populations below disease vectoring or annoyance levels. Data over a period of time may also serve to justify the use of permanent control measures, such as source reduction. Expensive operations, such as filling and draining, should be undertaken only when careful inspection of each area has shown its role in the production of the vector or pest species that are important in the locality.

Source Reduction

Source reduction ranges from the simple overturning of a discarded bucket or disposing of waste tires to complex water-level manipulations in marshes. The removal or reduction of larval mosquito habitat is the most effective and economical long-term method of mosquito control. These efforts often minimize or even eliminate the need for mosquito larviciding in the affected habitat and greatly reduce adulticiding in nearby areas. The topic of sanitation is covered under education/communication and should be covered as part of source reduction as well. Often times the primary mosquito pests encountered in communities are container-breeding species, particularly *Ae. albopictus*. The most effective technique to reduce their populations is through education and the elimination of larval habitats in communities and neighborhoods. Educational mailings and news clips should target individual home owners to inform them of the importance of eliminating standing water around a home or neighborhood. In particular, these materials would include information about the removal of used tires, maintenance of rain-gutters, emptying of buckets and other debris, checking tarps and plastics of all types for water holding depressions and in general **a constant vigilance toward the removal of standing water**.

Water Management. Prevention of mosquito development can be accomplished by removing surface waters from productive sites to reduce **oviposition,** manipulating shoreline water levels or flooding areas in which mosquitoes oviposit on the soil. These approaches have been used for decades and involve ditching, diking, daily water management manipulation and retrofitting of catch basins and storm drains to manage the aquatic habitat. However, experience has demonstrated these techniques can be harmful to the ecology of the affected habitats if practiced without due concern for the entire ecosystem. Consequently, permits are required to initiate new projects of this nature. Maintenance of existing schemes is often allowed without additional permits. Maintaining an open line of communication with local governmental regulatory agencies is critical.

An excellent example of the water management approach is **impoundment management** as practiced in coastal areas impacted by intermittent tidal activity. Salt marshes producing salt-marsh mosquitoes are impounded by construction of dikes to contain water pumped onto the marsh surface from the adjacent estuary. This eliminates oviposition opportunities for the salt-marsh mosquitoes on the impounded marsh and effectively reduces mosquito populations. For example, in Florida, 40,000 acres of impoundments have been constructed on the east coast, and a concerted effort has been made to manage these controlled marshes as natural resource sites. Rotational impoundment management (RIM) is a technique developed to minimally flood the marsh during the summer months and to use flap-gated culverts to reconnect impoundments to the estuary for the remainder of the year, thus allowing the marsh to support its many natural functions. While such impoundments usually control salt-marsh mosquitoes adequately, occasional influx of storm water runoff or rainfall can create freshwater-mosquito development problems in these impoundments.

The salt marshes are also good examples of a variety of ditching approaches for mosquito control. An acceptable form of salt-marsh source reduction is **open marsh water management** (OMWM). This is a technique wherein mosquito producing locations on the marsh surface are connected to deep water habitat (e.g., tidal creeks, ponding areas, deep ditches, etc.) with shallow ditches. Mosquito broods are thus controlled without pesticide use by providing access for naturally occurring larvivorous fish to the mosquito producing depressions or, conversely, by draining these locations before adult mosquitoes can emerge. Alternatively, OMWM can also provide hydrological connections between marsh and estuary that enhance natural resources, such as waterfowl and fisheries, and benefit mosquito control. The use of shallow ditching (approximately 3 feet or less in depth) rather than the deep ditching used in years past is considered more environmentally acceptable because with shallow ditches, fewer unnatural hydrological impacts occur to the marsh.

Larviciding

Elimination of sites where larvae are developing is the most effective intervention for suppressing mosquito populations. Because many sites cannot be controlled by source reduction, the next most effective intervention is larviciding. Several types of agents can be used to prevent mosquito larvae from emerging as adults. Ground or aerial applications of these agents to kill immature mosquitoes is typically more effective and target specific than adulticiding, although it is less permanent than source reduction. However, larviciding is often more time consuming and labor intensive than adulticiding and therefore is more difficult for smaller mosquito control programs to conduct effectively. Several types of agents in various formulations are labeled for mosquito larviciding, including biological control agents (Diptera-specific bacterial based products), insect growth regulators (IGR), conventional insecticides and surface film agents.

The timing of a **larvicide** application is dependent on the nature of the control agent. Conventional insecticides, for example, kill **larvae** at all stages and thus can be applied when convenient. Bacterial proteins must be consumed by the larvae and are usually applied well before the 4th **instar** to ensure that consumption occurs and effective mortality is produced. IGRs mimic an essential hormone present in high concentration in early instar larvae but in very low concentration in late 4th instar larvae. Exposure of 4th instar larvae to the IGR upsets the physiological **molting** process and kills mosquitoes in the subsequent **pupal** stage. IGRs can be formulated as slow release insecticides so that application in the 2nd or 3rd instar will result in an adequate exposure during the 4th instar. Monomolecular films are effective throughout the larval and pupal stage as a result of the reduced surface tension caused by these products. Larviciding oils kill larvae and pupae by suffocation because the insects are not able to obtain air through their **siphon** at the water's surface.

Each type of larvicide has specific applications where it may be more effective against one species or group or in a particular habitat than another. Each label (the label is the law when using pesticides) is different, and special attention must be given to a full understanding of the provisions of the label for each chemical being considered for use in mosquito control programs. The label prescribes application methods and rates, habitat restrictions, personal and environmental exposure limits, etc. Pesticide applicators must be knowledgeable of the label contents and abide by the label specifications.

Important characteristics for larvicides include specificity for mosquitoes, minimal impact on non-target organisms and, in many instances, ability to penetrate dense vegetative canopy. Larvicide formulations (e.g., liquid, granular, solid) must be accurately applied and appropriate to the habitat being treated. Larvicidal applications, when based on accurate surveillance data, are an important component of an integrated mosquito control operation. Accuracy of application coverage is important, as failure to expose even a relatively small portion of a larval habitat can result in the emergence of a large mosquito brood and lead to the need for immediate broad-scale adulticiding.

Biological Control. Biological control is the use of biological organisms or products to control pests, in this case insect pests. Biocontrol, as it is commonly called, is popular in theory because of its potential to be host-specific with few **nontarget** effects while being safe to the environment. The most widely used biological control agents are the various biological larvicides produced from the bacteria *Bacillus thuringiensis* subsp. *israelensis* (*Bti*). This bacteria is a common soil bacteria that produces protein crystals during its sporulation process. Research in the late 1970's demonstrated that when ingested by mosquitoes and black flies these proteins are converted to toxins and are highly efficacious. Today *Bti* is produced commercially and formulated in a variety of formulations, including liquid, granular and briquettes. Another biological larvicide is produced from the bacteria *Bacillus sphaericus*. This bacteria is similar to *Bti*, however the products have demonstrated a longer residual effect due to the actual growth of the bacteria in mosquito cadavers and the resulting additional production of proteins.

Both of these materials are being used by many mosquito districts due to their effectiveness, lack of non-target effects and acceptance by the public.

Larvivorous fish have been a longtime standard as biological control agents against mosquito larvae. Predaceous fish, such as *Gambusia affinis* and other top minnows *(Poeciliidae)* and killifish *(Cyprinodontidae)* that occur naturally in many aquatic habitats, can be collected (or in some cases propagated) and placed in permanent or semi-permanent water bodies for larval control. *Gambusia* can also be purchased from hatcheries in Georgia during the cooler months. It should be noted that *Gambusia* in particular, are extremely aggressive, and are not typically favored by fish and wildlife departments in natural habitats. The use of these fish is best suited for habitats not containing natural fish populations and with limited risks of overflowing into natural fish habitats.

Other biocontrol agents have been tested for use in mosquito control but to date have not generally been operationally feasible. These include the predaceous mosquito *Toxorhynchites,* predaceous copepods, the parasitic nematode *Romanomermis* and the fungus *Lagenidium giganteum.* Biocontrol certainly holds the possibility of becoming a more important tool and playing a larger role in mosquito control in the future when improved technology and more attractive economics may enhance its usefulness. Unfortunately, there is no basis for the often-claimed suppression of mosquito biting activity by bats or purple martins. Their predation is insufficient to significantly reduce mosquito densities.

Larviciding Equipment. One of the oldest methods of mechanical application of larvicides is by knapsack sprayer or by hand-operated granular applicator. In the interest of covering a larger area more quickly, manual application has been largely replaced by more mechanized methods, but the knapsack sprayer is still often used in urban areas, along drainage ditches and in catch basins where it is desirable to put a very localized application of insecticide. While both of these techniques are highly effective, the use of motorized backpack blowers for the application of granular products has become increasingly more common due to larger application zones and ease of operation. Except in roadside ditches and other areas readily accessible to vehicles such as trucks and ATV's, larviciding of large areas is usually done by application from airplanes and helicopters.

The introduction of WNV and the corresponding targeting of *Cx. quinquefasciatus* and the catch basin/storm drain habitats has lead to the development of a variety of innovative equipment and products. Included in these developments are devices that meter a preset amount of pellet or granular product into the catch basin habitat. Typically these devices are mounted on trucks and the resulting ease and efficiency result in large numbers of sites treated/day. Water soluble pouches and briquettes or ingots have also been developed with a particular goal of usage in the catch basin environment. Another product that is now available is an ultra-sonic device that has a probe that is inserted into a larval habitat and emits ultrasonic sound waves. These sound waves rupture the air bladder in larvae which results in larval death.

Adulticiding

Treatment of adult mosquitoes (adulticiding) is the most visible practice exercised by mosquito control operations. This option is usually reserved for managing mosquito populations that have reached the adult stage in spite of efforts to intervene in the larval stage or when such treatments have not, or cannot, be conducted. The tendency of poorly funded or misguided mosquito control organizations to use only **adulticiding** and bypass the other, often more effective, options available conflicts directly with accepted practice. However, there may be situations where small, rural towns situated in areas of vast larval habitats may find adulticiding to be their most cost effective technique for adult mosquito suppression. Nevertheless, adulticiding, when based on concurrent surveillance data, is an extremely important and effective part of the IPM approach when conducted at the appropriate label rates. Adulticides are often applied as **ultra-low-volume** (ULV) sprays in which small amounts (3 fluid ounces or less per acre) of insecticide are dispersed either by truck-mounted equipment or from fixed-wing or rotary aircraft. Ground or aerially applied thermal application of adulticides is also used in some areas, but to a much lesser degree.

Mosquito adulticiding with **ULV application** differs fundamentally from efforts to control many other adult insects. The fine ULV droplets (high concentration of active ingredient but very low dosage/acre) must drift through the habitat and contact flying mosquitoes in order to provide optimal control benefits. These applications are typically conducted between dusk and shortly after dawn, when most beneficial insects are resting. These tiny droplets are unlikely to impinge on objects larger than mosquitoes because those larger objects' physical characteristics and size cause the droplets to drift around rather than deposit on them. The very small flying mosquitoes, however, do not ward off the small droplets in this manner. Also, use of the fine ULV droplets means that there are literally millions more droplets to impinge on mosquitoes than there would be if larger droplets were used. The typically targeted size range for ground ULV applications is 10-25 microns with aerial applications targeting the 15-30 micron range. However, a variety of conditions and factors are involved in these ranges, including product, nozzle type and weather conditions to name a few. The most important consideration is to follow the product label recommendations.

Using the proper size range for the droplets makes it possible to increase control efficiency and decrease the risk of adverse impact to the environment and public health. The small droplets drift far beyond the point of release and settle in a widely dispersed manner on the ground, often after their toxicity has been degraded by hydrolysis. The relatively minuscule amount of toxicant in each droplet further protects against adverse impact.

Thus, while the technique lends itself to the criticism that non-target organisms can be impacted, adherence to the label specifications for droplet size in ground applications confines the possibility of adverse impacts to relatively few, small, **nocturnal** organisms. This is a constant consideration for control programs, especially those relying heavily on aerial adulticiding, for which the droplet size spectrum is somewhat larger. Extensive research coupled with multitudes of EPA studies demonstrate that when applied according to the label (the law), these applications have minimal or no effect on most non-target organisms.

Adulticiding Equipment. Control of adult mosquitoes is usually accomplished through the use of ultra-low volume (ULV) fogging as previously mentioned. A variety of fogging and spraying equipment is available including ULV machines, thermal fog generators and mist blowers, the "cold foggers." Both gas and electric powered ULV machines are available, with the electric powered machines having the benefit of being very quiet.

Aircraft equipped for conventional spraying or adapted for ULV applications are sometimes used throughout the state, both for larviciding and adulticiding. Helicopters are often used both for larviciding and adulticiding and may be used for larval surveys. The majority of aerial applications are conducted in coastal areas where extensive salt-marsh mosquito populations are possible.

Calibration of ULV Machines and Checking Droplet Size. Ultra-low volume (ULV) application of pesticides is a method whereby the insecticide, usually a technical or undiluted material, is broken up into very small droplets. Most equipment uses the airblast of a blower to break up the droplets and transport them away from the vehicle, but some machines use other methods to produce the small droplets. The primary reason a piece of equipment must be calibrated is to make sure it is operating in an effective manner and discharging insecticide in the correct amounts according to label recommendations of the particular insecticide.

The calibration of ULV equipment is relatively simple. Little equipment is needed; a timepiece, preferably a stop watch, and two containers - one in which to collect the insecticide and one for measuring. Obviously, when discharging only 1/2 to 4 fl. oz/min (15 to 125 ml/min) as with ULV sprayers, a measuring container calibrated for small amounts is required. A glass container marked in milliliters (ml) or tenths of a fluid ounce is ideal.

Generalized Calibration Procedure:

1. First, disconnect the insecticide line from the nozzle and place the tip of the line in a container to collect the discharge.
2. Start the machine and when it is operating at the desired pressure, etc., set the flow meter or digital readout about mid-scale of where you think it should be for the desired discharge.
3. While the material is being discharged into the collection container, move the discharge line to the calibrated measuring container for a predetermined time, usually 1 min.
4. At the end of that time, move the discharge line back to the collection container and record the amount that was discharged into the measuring container.

5. If the discharge is too much, reduce the setting and repeat the procedure; if it is too little, increase the setting.
6. Repeat the entire procedure as many times as necessary until the machine is dispensing the recommended volume per minute. Repeat at the same setting as a check. If the discharge is satisfactory, reconnect the insecticide line to the nozzle.
7. The recommended discharge in fluid oz/min for a particular insecticide is shown on the insecticide label.

The insecticidal distribution system of the ULV machine should be flushed with approximately one pint of isopropyl alcohol following each time the unit is used.

Once a ULV machine has been calibrated to deliver the correct dosage of an insecticide, it is necessary to determine whether the insecticide is being dispersed in the correct droplet sizes. Instructions for testing droplet size are given on some insecticide labels. Recent improvements in testing for droplet size include the use of a stand with a wooden arm to which slides are attached. The arm is dropped through the insecticide coming from the machine. This mechanism gives a more uniform deposition rate than waving the slides by hand; however, it works only with machines that use a blower to propel the droplets from the nozzle.

Since droplet size varies with flow rate, different formulations, and formulation pressure, as well as, to some extent, with temperature, it is important to check droplet size frequently. It is recommended that droplet size be checked each time the unit is put into service following repairs or maintenance. The droplet size should be verified every 100 hours of operation or as often as necessary to ensure it is producing droplets in the required range. Industry representatives are valuable resources when working with the proper calibration of equipment.

Calibration of Thermal Fog Equipment. Since thermal foggers discharge much greater volumes than ULV equipment, a larger measuring container must be used. Because of the low viscosity of the dilute insecticide solution, the temperature of the solution is not a factor in determining discharge rates.

Maintenance of Equipment. The importance of proper maintenance cannot be overemphasized. Machine breakdown is both annoying and expensive. Because timing is often of great importance in adult mosquito control, a machine failure can completely destroy the value of any specific operation. An instruction manual and a parts manual are available for each piece of equipment. These should be kept at hand and both the machine operator and the supervisor should be familiar with their contents. Thorough maintenance should be conducted during the winter period, when the operational demands of a mosquito control program are less.

Other Adulticide Applications. Barrier treatments, typically applied as high volume (low concentration) liquids with hand-held spray equipment using compounds with residual characteristics, are common in some U.S. locations and their use is growing. This technique may be one of the better options in neighborhoods infested with *Ae. albopictus*, where the elimination of all larval habitats is difficult. It has been reported that the treatment of shrubbery and vegetation that *Ae. albopictus* use as harborage is effective in suppressing localized populations. In addition, this technique is especially attractive to individual homeowners living near mosquito-producing habitats where residual chemicals applied to the vegetation along property borders can provide relief.

Space Sprays. Applications generated by portable ULV equipment often are used to provide indoor mosquito control in houses, tents, trailers, warehouses, etc. For small enclosures, commercial aerosol (bug bomb) applications are also highly effective. These applications require close review of the label to ensure the safety of inhabitants and pets when they re-enter after completion of the application. This technique relies on the movement of fine droplets throughout the enclosed space in order to impinge on the mosquitoes. Alternatively, in certain circumstances residual applications of insecticides are placed on interior walls to kill mosquitoes that subsequently rest on the treated surfaces. Residual treatments, common overseas, are not routinely used in the U.S. for mosquito control, but some insecticides are labeled for this usage.

Insecticide Resistance

Insecticide resistance is an increasingly important aspect of mosquito control. The limited number of insecticides registered for mosquito control and their corresponding modes of action only emphasize this matter. Insecticide resistance is defined by differences in susceptibility that arise among populations of the same species exposed to insecticides. Individual differences in susceptibility exist within each species. Individuals that are substantially less susceptible may be present, generally at low frequencies, in at least some insect populations. In the presence of an insecticide, it is these substantially less susceptible individuals that survive and reproduce. Hence, the development of a portion of a population of insects that are increasingly tolerant to a specific type of insecticide. Insect populations exposed to insecticides that have a similar mode of action for extended periods can be expected to develop resistance. Preventing this resistance is an important aspect of mosquito control today.

Insecticide resistance is usually first noticed when normal application rates fail to produce the expected level of mortality. It is extremely important when lower than expected mortality is observed that application rates, techniques and conditions are evaluated to assure that all aspects of an application are being conducted properly and are conducive to an efficacious application. If an operator is confident that insecticide applications are being conducted properly, there are a variety of techniques available to monitor and evaluate the level of insecticide resistance that is present in an insect population. For the purpose of this manual, we will not cover these techniques in detail. It is recommended that mosquito control programs that suspect insecticide resistance in a mosquito population contact the Centers for Disease Control or the Cooperative Extension Public Health specialist.

The risk of developing insecticide resistance in insect populations can be minimized by the use of Integrated Mosquito Management techniques. These practices try to reduce the need for insecticide applications. In addition, it is prudent to rotate the type of insecticide, active ingredient and corresponding mode of action of the insecticides used against an insect population. While this may necessitate the use of a more expensive product for some applications, the long-term benefits of preserving susceptibility far outweigh any short term costs.

Chapter 5. Pesticide Use, Risk, and Safety

For a comprehensive overview of pesticide safety please refer to your core category study guide.

Learning Objectives

After study of the material in this chapter, you should be able to:

1. Explain why following label instructions are so important.
2. Recognize the signal words on pesticide labels.
3. Understand what determines the risk level associated with a pesticide.
4. Discuss the safety levels of the various larvicides.
5. Recognize the two primary chemical classes used in adulticiding.
6. Understand the importance of pesticide safety.

Pesticide Use

Pesticides are used for temporary relief of a pest problem. For pesticides to be effective, special precautions must be taken in the selection, storage, handling, and disposal of these products. Most of this information is included on the product label. Law forbids use of any pesticide that is not in accordance with the label instructions. **The label is the law!** All pesticides for use as larvicides and adulticides must be registered with the EPA and the State of Georgia. An EPA registration number is present on the label of federally registered pesticides. Pesticide regulations in Georgia are administered by the Commissioner of Agriculture through the Pesticide Division of the Georgia Department of Agriculture.

Pesticides can be either "specific" or "broad spectrum." Specific pesticides are effective against certain insects or insects at particular stages. These types of insecticides are usually non-toxic to humans and other animals. Broad-spectrum pesticides can have deleterious effects on non-target organisms. Whether specific or broad-spectrum pesticides are used, the type pesticide and the timing, rate, and location of its application can minimize the effects on non-target organisms.

Signal words are used on the label of pesticides to describe how acutely toxic the pesticide is to humans. The word "danger" on the label indicates that it is a Category I pesticide, meaning that it is either very toxic or corrosive on contact with skin or mucous membranes. Pesticides labeled with a "danger" signal can also cause irreversible eye damage and even death with an oral dosage of just a few drops to a teaspoon. If the pesticide has the word "warning," the compound is moderately toxic and is classified as a Category II compound. Pesticides labeled with the "warning" signal word can cause death with an oral dose of 1 teaspoon to 2 tablespoons. "Caution" is used on the label to describe Category III and IV compounds that are slightly or practically non-toxic. Other information regarding use of protective equipment, environmental hazard, use directions, first-aid information, storage and disposal can be found on the label.

Pesticide Risk

Whether or not a substance poses a risk to humans or other organisms depends on two factors: how toxic the substance is and the amount to which an organism is exposed. The EPA considers both toxicity and exposure data in determining whether to approve a pesticide for use. Consequently, adverse health effects are not expected to occur when pesticide products are used in accordance with label directions.

The EPA requires that a series of tests be conducted for pesticides registered in the United States. These studies demonstrate how the organism reacts to a pesticide and how much of the pesticide is needed to affect the organism. The studies also describe those levels of the pesticide that do not cause harm. To determine any health concerns associated with pesticides, the EPA considers toxicity information and the amount of exposure from mosquito control activities such as ULV applications. Exposures from ULV applications can range from 1/100 to 1/10,000 of the amount that is anticipated to cause health concerns. The exposure assessment includes all routes of exposure (inhalation, dermal, diet and water) and also includes short-term and long-term exposures.

Most larvicides have very limited human exposure potential because the material is applied to habitats with water unsuitable for drinking or recreational purposes (i.e., ditches, ponds, marshes or flooded areas). Other factors that reduce exposure include the rapid dissipation and breakdown of the product and the relatively small amount of product used for area-wide application.

Pesticide Safety: Larvicides

- *Bacillus thuringiensis* subsp. *israelensis (Bti)* is a biological insecticide that is highly effective, yet virtually non-toxic to non-target organisms. This material is registered under various trade names such as Vectobac®, Aquabac® or Teknar®. These products are classified as slightly toxic to practically non-toxic, depending on the formulation. *Bacillus thuringiensis* subsp. *israelensis* forms a crystalline protein during the sporulation process that has proven to be highly insecticidal. This toxin damages the lining of the intestine and paralyzes the midgut of the mosquito larva by binding to receptors which are specific to insects and are not found in mammals.

- *Bacillus sphaericus (B. sphaericus)* is a biological insecticide registered under the trade name Vectolex®. *Bacillus sphaericus* produces a protein that acts in a manner similar to *Bti. Bacillus sphaericus* is classified as practically non-toxic. The advantage of *B. sphaericus* over *Bti* is a longer period of larvicidal activity. However, this material has a narrower range of susceptible target species.

- Methoprene is an insect growth regulator that is registered under the trade names Altosid® and Aquaprene™. As an insect growth regulator, methoprene disrupts the development of the larva into the adult. Methoprene has less specificity to other freshwater invertebrates than the *Bacillus* products, but is identified as practically non-toxic to humans and other mammals. Methoprene degrades rapidly in water.

- Temephos is an organophosphate insecticide that has been registered under the trade name Abate® for many years. Temephos interrupts the function of the nervous system by interfering with key enzymes controlling the synaptic transmission of nerve impulses. Temephos is slightly toxic to humans and other mammals. It is a broad-spectrum insecticide and as such can be highly toxic to other invertebrates, some birds, and fish if misused.

- Mineral oil and monomolecular films are used as larvicides and pupacides. These materials are practically non-toxic. Mineral oil (with an added surfactant) may be registered under various trade names such as Bonide® and Golden Bear® mosquito larvicides. These compounds block the breathing tubes of the larvae and pupae. Monomolecular films may be registered under various trade names such as Agnique® and Arosurf®. Monomolecular films spread across the water and decrease its surface tension. The reduction in surface tension causes the larvae and pupae to deplete their energy reserves trying to stay at the surface and consequently succumb to exhaustion. Adult mosquitoes also have problems ovipositing and emerging from waters treated with these products.

Pesticide Safety: Adulticides

Some of our most common adulticides are the pyrethroid-based insecticides. These products are synthetic derivatives of the pyrethrin insecticides which are developed from substances (pyrethrums) isolated from flowers of the chrysanthemum. Pyrethrins are fat-soluble and act on insects to interrupt transmission of nerve impulses. Humans quickly break down pyrethrins in the body; however, insects cannot break down pyrethrins as easily. Hence, pyrethrins have selective toxicity to insects. Pyrethrins can be combined with compounds (synergists) that increase their insecticidal activity up to 300 fold.

Pyrethrins are broken down in the presence of sunlight and do not persist in the environment. Pyrethroids are man-made chemicals with a similar mode of action to pyrethrums, but have increased chemical stability and effectiveness.

- Pyrethrins are a mixture of pyrethrum insecticides, and may be registered under various trade names such as Pyrenone® and Pyrocide®. Pyrethrins interrupt the function of the insect nervous system by interfering with the conduction of nerve impulses. Pyrethrins are slightly toxic to humans and practically non-toxic to birds. It is a nonspecific insecticide and therefore can be toxic to other insects and fish.

- Resmethrin is a pyrethroid insecticide that is registered under the trade name Scourge®. Resmethrin interrupts the function of the nervous system by interfering with the conduction of nerve impulses. Resmethrin exhibits very low mammalian toxicity, degrades very rapidly in sunlight, provides little to no residual activity and is practically non-toxic to birds. It is a nonspecific insecticide and therefore can be toxic to other insects and fish. Mosquito knockdown with ULV applications of resmethrin begins in approximately 5 minutes.

- Permethrin is a synthetic pyrethroid insecticide registered under various trade names such as Aqua-Reslin®, Biomist©, Kontrol®, Permanone® or others. Permethrin acts in the same manner as resmethrin and is slightly toxic to humans and practically non-toxic to birds. It is a nonspecific insecticide and therefore can be toxic to other insects and fish.

- Sumithrin (d-phenothrin) is a synthetic pyrethroid insecticide, and it may be registered under various trade names such as Anvil©. Sumithrin exerts a toxic effect in the same manner as resmethrin. Sumithrin is practically non-toxic to humans and other mammals. It is a nonspecific insecticide and therefore can be toxic to other insects and fish.

Organophosphate insecticides act on the nervous tissue to prevent breakdown of a substance called acetylcholine, which is responsible for nerve conduction. Organophosphates are nonspecific regarding their toxic effects on other insects and vary in their toxicity to humans and other mammals. Fish might also be sensitive to organophosphate poisoning.

- Malathion is an organophosphate and a longtime standard in the field of mosquito control. The primary product that is widely available is Fyfanon©, although other brands may be available in some areas. Malathion is toxic to other insects and fish, but is only slightly toxic to humans and other mammals.

- Chlorpyrifos is an organophosphate registered under the trade name MosquitoMist©. Chlorpyrifos is highly toxic to other non-target insects and fish, but is slightly toxic to humans and other mammals.

- Naled is an organophosphate, and it may be registered under various trade names such as Dibrom® and Trumpet®. Naled is toxic to other non-target insects, humans, animals and fish. Naled is the least persistent of the organophosphates used for mosquito control.

The use of proprietary or trade names mentioned above does not constitute an endorsement of that product.

If you suspect that exposure to a pesticide has affected the health of you or someone else, seek a medical provider for assistance. Take the product label and MSDS (Material Safety Data Sheet) to the medical provider for assistance in making an accurate diagnosis and providing effective medical care.

Pesticide Safety Overview. Pesticides are generally poisonous chemicals that can injure or kill non-target plants and animals, including people, if they are handled improperly. The seriousness of these facts can not be over stated. It is imperative that the instructions on the label be followed closely. Once again, the label is the law concerning pesticides. Consequently, it is imperative that employees be properly trained in the handling, use and storage of pesticides.

Chapter 6. Program Operation

Learning Objectives

After study of the material in this chapter, you should be able to:

1. Discuss the responsibilities of a Mosquito Control Director.
2. Recognize the importance of continuing education.
3. Describe issues important to actually planning mosquito control operations.
4. Recognize common legal issues relevant to mosquito control operations.
5. Understand the importance of maintaining good public relations.
6. Discuss techniques to minimize honey bee exposure.

Responsibilities of a Mosquito Control Director

It is the duty of the Director to plan, supervise, and direct the execution of the county, district or community arthropod control program. Consequently, the Director is responsible for every aspect of the working program, including:

(1) Determining the extent of the problem and locating the larval habitats.

(2) Planning appropriate abatement activities and projects and to alleviate the problems.

(3) Preparing and submitting monthly reports for approval.

(4) Purchasing equipment and materials, providing for maintenance, and maintaining inventory records.

(5) Hiring and assigning necessary personnel.

(6) Assuring that all work is carried out in a safe, effective and efficient manner in compliance with Federal, State, and Local laws and all regulations pertaining to mosquito control.

(7) Evaluating the results the program achieves and providing for surveillance of larval habitats in the county or district.

(8) Establishing good public relations for mosquito control.

(9) Continually improving knowledge and abilities through participation in local and national associations, meetings and publications.

A mosquito control director must be able to depend on the abilities and integrity of the supervisors and equipment operators. The supervisor of a crew operating heavy equipment or applying insecticides must give the crew clear and complete instructions, must see that all safety precautions are adhered to, and that all equipment is kept in good condition.

In the final analysis, the success of a program often depends on the correct application of insecticides, on the ability and willingness of the applicator to use the materials and equipment as instructed and to immediately report malfunction of equipment, so the correct dosage is applied without endangering either the applicator, the public or the environment. It is important for every ground equipment operator and pilot to know how to safely use the equipment, how to calibrate and check it and how to maintain it. Accurate record keeping is essential for evaluating the effectiveness and efficiency of insecticide applications and is required to abide by all applicable laws and regulations.

Continuing Education

In order to do the best possible job in any profession, it is necessary that employees know of new methods and materials that can help them to better accomplish their purpose. Each new employee should be fully trained for the job they were hired to do, know what they are expected to do, how they are to do it and why. It is good practice to have reminder and updating courses on insecticide usage and safety practices for all employees. This is especially important for employees holding pesticide applicators certifications, as this license is renewed through recertification credits. A multitude of training and educational opportunities are routinely available in Georgia and the surrounding states.

The director of the program should keep up with new developments in mosquito control through reading technical journals and pamphlets, by talking with representatives of equipment and chemical companies, and by belonging to and attending meetings of associations in the field. One of the most useful journals for directors is the Journal of the American Mosquito Control Association (AMCA). Annual meetings of the AMCA and the Georgia Mosquito Control Association (GMCA) also are sources of new ideas and facilitate the exchange of information and ideas with other directors and operators.

Planning the Project

Before any control effort is made, the director must understand what the problem is in the area. The director needs to determine what species are involved, the level of annoyance from mosquitoes, and where they are developing. Even after the initial survey, routine checking (surveillance) will be needed because of seasonal variations in the fauna, because of changes in the topography, and as a means of evaluating how control efforts are progressing.

To assess the problem, larvae and adults are collected throughout the area. Larval collections are usually made with a long-handled dipper and counts are based on the number of larvae per dip. The larvae are usually preserved in alcohol for later identification in the laboratory.

It is very important to know the exactly of each collection. Collecting sites can be identified by an address, such as "in fish pond at 634 Lane Avenue," by description such as "in pasture pond at intersection of State Road 84 and U.S. 1," or a map of the control district may be marked into a grid pattern with each square assigned a number and/or letter. Additional data on the collecting site such as a list of dominant vegetation or evidence of gross pollution is useful. In marshes, larval dipping is sometimes done from a hovering helicopter, making it possible to check larval habitats not otherwise accessible to the inspector.

Adult mosquito surveys are most often conducted with light traps. The New Jersey trap is operated with 110 volt power, (common household electricity) and is still a good choice when convenience and long-term monitoring from a permanent site are important. New Jersey traps, however, tend to collect larger organisms, i.e., beetles, moths and frogs, which can damage the collection and make identifications difficult (Figure 19). The CDC miniature light trap, (Figure 19) baited with dry ice which releases carbon dioxide, will usually capture much larger numbers of mosquitoes and may attract some species which do not usually come to the New Jersey trap in significant numbers. CDC traps are compact and highly portable, but are operated by batteries which need fairly frequent recharging or replacing. It should always be kept in mind that traps are selective, no matter what kind is used, and merely indicate what species are present and their relative abundance.

Other methods of judging the extent of the mosquito problem include pants leg landing rate counts - the number of mosquitoes which land per minute - and collecting by aspirator in fixed resting stations such as culverts, sheds or houses. The number of telephone complaints received by the mosquito control office is also an index of the magnitude of the problem, but should be relied upon only when followed up by inspection or when taken from individuals who have proven reliable.

In locating larval habitats and in planning source reduction projects, the director must have accurate knowledge of the topography of the district or area. This information would include the size and position of streams, lakes and roads and the elevation throughout the area. In addition, the Director will want to know the location of recreation areas, wildlife areas, state and national parks, large bridges, towers and power lines. Among the maps which will be especially useful are: shaded relief maps, road maps, population maps, soil maps, drainage maps and aerial photographs. Plans for engineering projects for mosquito control can be shown as map overlays, and areas to be sprayed by plane can be marked on the maps for the pilot's use.

Legal Aspects of Mosquito Control

Performance of control measures on private property typically requires permission of the owner. In cases where the owner will not control arthropod development on their property and refuses to permit the mosquito control district to do so, it may be necessary to pursue legal action. However, it is always best to settle this kind of problem out of court if possible.

The Federal Insecticide, Fungicide, and Rodenticide Act of 1972 requires that the Environmental Protection Agency be certain that all personnel handling hazardous or restricted chemicals be trained to do so correctly and safely, and that they be certified as pesticide applicators by a responsible state or federal agency. Some states are moving towards requiring all public health applicators to be certified regardless of the type of pesticide being applied. By increasing the educational level of a program's operational staff, supervisors help assure more accurate and effective applications and represent the mosquito control profession in a more informed and professional manner.

The state agency that administers the certification is appointed by the governor of each state. In Georgia, the Department of Agriculture has been designated as the lead agency, and shall be responsible for certifying commercial pest control operators. The law requires that every person applying pesticides for arthropod control for pay be certified or be supervised by a certified applicator.

A mosquito control director must be familiar with, and abide by, a number of laws and regulations with reference to providing for the safe use of pesticides and machinery by their employees. The Director cannot stress too much the importance of good safety practices. He/she should see that the applicators read and understand pesticide labels, that they wear and maintain appropriate personal protective equipment (PPE), that they follow the recommended procedures in storing and mixing chemicals and in disposing of empty containers, that they are well trained in proper operation of equipment, and that they know and use good driving habits. In addition, the Director should make sure an Emergency Action Plan is in place in case of a spill or accident. This plan would include who the employee should call in case of a spill or accident, assuring that PPE and a spill kit was available and that the employees are properly trained.

Other aspects of managing the personnel of a mosquito control district include securing adequate insurance for the district and meeting the requirements of the Social Security Act, "Right to Know" law, and the Occupational Safety and Health Act (OSHA).

Public Relations and Dealing with Negative Impacts

Public relations are the methods and activities employed by an individual, organization, corporation or government to promote mutual dialogue and a favorable relationship with the public. To build a truly effective mosquito control program, the general public must be made aware of the need for mosquito control, the methods by which it is accomplished, and the need for their support and cooperation. How well a program is explained to the public can influence the amount of tax money the program receives, as well as the cooperation received from land owners on whose property it is necessary to work. It will influence the concern and cooperation citizens give in trying to keep their premises free of receptacles which could become larval habitats.

The public image of a mosquito control district is created in three ways - through public coverage such as newspaper stories and radio and television announcements and programs, by talking before civic organization, schools and other groups, and by dealing with individuals through telephone calls, letters or personal contact.

The word "relations" in public relations indicates that a relationship should exist, that the process involves an exchange of information to and from the public. Telephone calls and letters from the public give the director an indication of where mosquitoes are present in annoying numbers, how the public is reacting to the control measures being used, and what the public wants done that isn't being done. This is invaluable information and the Director should use it to full advantage. The Director should not, however, rely solely on telephone complaints to define the problem, but should follow-up on complaints through inspection and surveillance.

In addition, every employee of the district should be aware that the image they create as they go about their job determines how the public feels about mosquito control. Courtesy and safety in driving, patience and consideration in dealing with questions and problems, and care when working on other people's property will give the public a favorable view of the program.

Wherever a large-scale mosquito control program operates, some negative impacts, both real and perceived, will occur. Groups that occasionally oppose some or all mosquito control activities include environmental organizations, beekeepers, public lands managers, aquaculturists, organic farmers, concerned citizens, and chemically sensitive or chronically ill individuals.

A mosquito control director has a responsibility to work with these groups to achieve a compromise acceptable to all concerned. The first step is always to open the lines of communication and to develop trust. Often, the main problem is a lack of understanding on both sides. Through education the concerned party may better understand the need for, and minimal impact of, control operations and the mosquito control director may realize how small changes in the operation may significantly decrease the possibility of adverse effects. Beekeeping is a good example. Honey bees are susceptible to organophosphates such as the adulticides naled and malathion, and the larvicide temephos. As a result, adulticiding during times of high bee activity and larviciding over bee yards may have an impact on the honey bee populations. Most aerial adulticiding is now performed early in the morning before bees leave the hive to forage, or in the evening or at night when bees are back in the hives, thus minimizing any impacts. In addition, mosquito control personnel advise local beekeepers as to which areas will have high, low or no aerial activity, allowing them to locate their bee yards in "safe" areas. Beekeepers are encouraged to inform mosquito control employees when they plan to move their hives. If mosquito control employees are aware of bee yards in or close to areas regularly treated, they can tailor the operations to avoid impacts on the bees, such as switching larvicides from Temephos to a safer material, such as Methoprene or *Bti*.

Many mosquito control programs maintain a listing of concerned citizens. Often these individuals understand the need for mosquito control operations, but are fearful of exposure to any chemicals, despite education and assurances from scientific experts. In most cases the solution to this problem is simple: a personal call or website posting informing them prior to any spray operation in their area. They can then take whatever precautions they deem necessary to avoid exposure, and then feel mosquito control has made an effort to work with them.

Chapter 7. Other Arthropods of Public Health Importance

Learning Objectives

After study of the material in this chapter, you should be able to:

1. Recognize a Chironomid midge as opposed to a mosquito.
2. Describe the illness known as delusory parasitosis.
3. Understand the importance of ticks and how to avoid them.
4. Describe the life history of biting midges and why they are so difficult to control.
5. Discuss the larval habitats of the stable fly.
6. Describe the best way to control house flies.

Mosquito control directors are often asked for identification of, advice, and help in controlling arthropods other than mosquitoes. Usually questions are about insects which bite or sting, but concern also is shown about arthropods which are annoying because of their abundance.

Among the insects which are frequently reported as annoying are the midges (Chironomidae) which sometimes emerge from the lakes and ponds of coastal Georgia in such huge numbers that they make outdoor living impossible and may even be a traffic hazard. These insects superficially are very similar to mosquitoes, but they do not have scales on their wings and the adults cannot bite or suck blood. It is usually difficult for an individual to control these insects. A mosquito control district can, however, cover a large enough area with adulticides to give temporary relief. Effective operational midge control is conducted by controlling the midge larvae in the habitats where they occur on a community-wide basis.

Inside homes there are sometimes populations of booklice (Psocidae) large enough to create annoyance by crawling on the skin. These insects are not true lice and do not bite.

A difficult problem that entomologists and doctors sometimes face are people who are convinced that insects are crawling on, biting, or burrowing into their skin, when no arthropod can be identified. This situation is commonly termed **delusory parasitosis or Ekbom Syndrome**. Often the sensation associated with crawling insects is related to medication interactions or other medical problems. These situations require careful examination of all aspects of the patient's environment. Sampling with clear packing tape can be attempted to try to collect the unseen pests. If no arthropods are collected, medical referrals should be encouraged. Unnecessary pesticide applications should be avoided.

Certain insects and arachnids are feared because they can give a painful bite or sting. Those which inject a venom by biting include the black widow spider and the brown recluse spider (rare in Georgia). Those which inject a venom by stinging include scorpions, wasps, bees and fire ants; the venom produces irritation at and around the site of the injection. When the person is allergic to the venom, more severe reactions may result, including anaphylactic shock and even death. If a person feels sick or short of breath following an arthropod bite of any type, prompt medical care is recommended.

Urticating caterpillars inject their venom through hollow body hairs. When a person brushes against the hairs, venom passes from blades at the base of the hair into the skin of the individual producing a very painful sting. The puss moth caterpillar, saddleback, and Io moth caterpillar are the most commonly encountered stinging caterpillars. The urticating caterpillar is often to blame when we are outdoors working with vegetation and get a burning irritation on our skin and see no pest. Often we can brush against one and not know or see the insect, but still feel the effect.

A number of insects which shed wing scales or hairs cause allergic reactions such as itching and dermatitis in sensitive individuals.

The dog fly (stable fly), biting midges, horse or deer flies, fleas, chiggers, ticks and bird mites do not inject a venom when biting, however, their saliva may be very irritating, resulting in itching welts for extended periods. Most of these arthropods do not usually transmit diseases, with the exception of ticks which can transmit a number of disease organisms.

A few fly larvae have been known to survive internally in man, but these cases are usually the result of accidental infestation and occur infrequently. However, a variety of flies may occasionally lay their eggs in wounds or in the nostrils of man, and the maggots can cause a very serious health problem if not promptly treated by a skilled physician.

The role of mosquitoes in disease transmission has been discussed previously. However, a number of other insects are also involved in the spread of human diseases.

Some examples of mechanical or passive transmission of diseases would include the spreading of "pink eye" or conjunctivitis by eye gnats, the spread of typhoid and intestinal diseases by house flies and the potential spread of pathogenic and food poisoning organisms by cockroaches.

Aside from mosquitoes, the arthropod vectors of diseases most likely to be encountered in Georgia are ticks and fleas. Although endemic typhus, spread by rat fleas, was once widespread in the State, it is no longer a concern here.

Rocky Mountain spotted fever, Lyme disease, the human ehrlichioses and tuleremia are human diseases which are vectored by ticks. The usual vector of Rocky Mountain spotted fever, the American dog tick, *Dermacentor variabilis,* occurs in Georgia and the disease is relatively common in the State. Lyme Disease is caused by a bacterial spirochete and is found primarily in the northeast and pacific coast areas of the U.S. The disease is vectored by Ixodid ticks. The human erlichioses are a complex of tick-borne rickettsial diseases that are generally mild, but may become serious if not treated early. Cases of tuleremia do occur, but in Georgia most of these have been traced to dermal contact with infected rabbits, and not tick bites.

A few cases of tick paralysis have been recorded in Georgia, usually in children who were found to have one or more ticks attached near the hairline on the neck. Careful removal of the ticks has been followed by a swift recovery from the paralysis. Tick control is often difficult due to the large areas that would need to be targeted. Tick avoidance is the public's best option. Keeping trails mowed, such that grass and vegetation does not contact one's legs will significantly reduce tick contact. Tucking pant legs into socks and the proper use of repellents will also help. Repellents containing permethrin can be used on clothing when ticks and chiggers are a concern. As always, follow label instructions.

Mosquito control directors should learn to recognize the more common of these annoying or dangerous arthropods, and should be able to provide information on their life histories and control when requested.

Control of Other Arthropods by Mosquito Control Districts

In instances where insects other than mosquitoes breed in such numbers as to be a serious nuisance or a health hazard to the public, the mosquito control district will often be called on to control these insects or other arthropods. The most frequent problems encountered are biting midges (no-see-ums), stable flies (dog flies), midges (blind mosquitoes), house flies and other filth flies, and eye gnats.

Biting Midges (Figure 21)

These pests have several common names in Georgia including no-see-ums, biting midges, punkies, and sand flies. True sand flies belong to a different group of diptera and should not be confused with these pests. Biting midges of the genus *Culicoides* are a pest in many areas of Georgia, although the coastal species cause more annoyance than the freshwater species. Biting midges lay their eggs on damp organic materials such as the surface of mud near swamps and marshes, decaying leaf litter and manure. Areas adjacent to extensive salt marshes often experience the worst pest problems. Larval development is temperature dependent, typically requiring 14-25 days. The pupal stage typically requires 2-3 days. Adults are not typically strong fliers with flights of over 1/2 mile rare. Much research has been directed toward finding

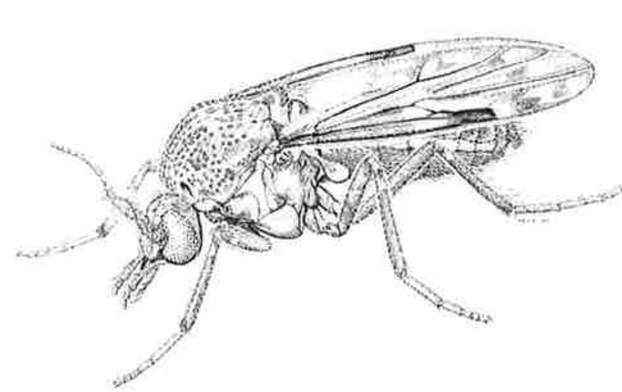


Figure 21. Biting midge.
(Image reproduced with the permission of the Minister of Public Works and Government Services Canada, 2007)

methods and materials to control these pests, but no really satisfactory method has been found except water management. The ideal, and actually the only solution, is to keep their larval habitats flooded completely, or to fill them and construct bulkheads at the shoreline.

When biting midge adults are a problem in populated areas, it is possible to fog or spray and kill them, but new adults move in from the periphery so rapidly that relief is very temporary and the results do not always justify the cost. Unless the problem can be built out by impounding or filling, the only real solution at the present time is for people to try to remain inside air-conditioned buildings when populations are high. If the flies get indoors, household aerosols will give control. Homeowners can also use floor or ceiling fans to reduce nuisance due to the weak flying traits of these pests. It is also helpful to treat screens with barrier products and install the finest screen possible if these pests are a persistent problem. Repellents offer some protection for several hours when one must be outside, but do not repel these insects as well as they do mosquitoes. Fortunately, these insects are seasonal in nature.

Stable Flies (Figure 22)

Also known as dog flies, stable flies are a major pest in some coastal areas. These flies have a known flight range of up to 70 miles, although a major pest problem would likely be produced at a much closer proximity. Sometimes called "biting house flies" due to their similar size and appearance, these flies are quickly identified by their bayonet-like proboscis and painful bite. Fortunately, this fly is not a significant vector of disease.

Larval development typically occurs in decaying organic matter associated with stables, feed lots and decaying seashore vegetation. Stable fly larvae should be controlled, where possible, by management of these plant and animal wastes to eliminate the larval habitat without the use of sprays. This objective can be achieved by spreading materials thinly so they dry quickly. Stable flies developing in decaying seashore vegetation can cause significant nuisance populations on beach areas. Some areas use adulticide applications to suppress populations when a significant nuisance is observed.

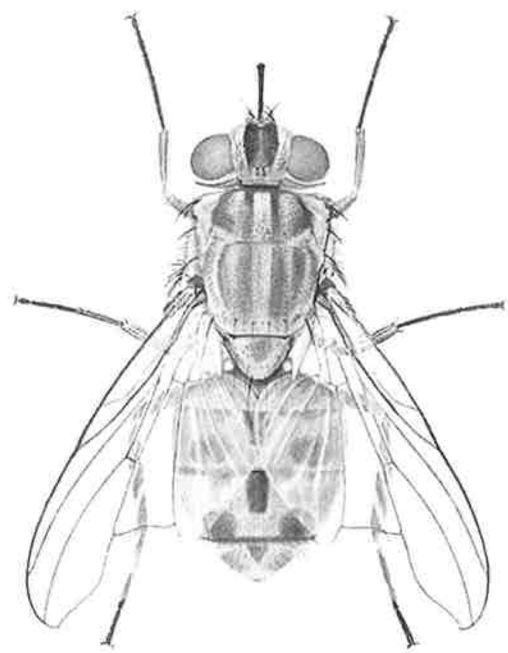


Figure 22. Stable fly.
(Image from *Flies and Disease* Volume 1, Princeton University Press)

Chironomidae (Figure 23)

These mosquito-like insects do not bite, nor carry disease. They are a nuisance only when they emerge in such large numbers that they make outdoor activities unpleasant or impossible, or where they come to homes in such huge numbers, attracted by the lights, that they enter every time a door is opened. Most complaints about midges come from coastal resort communities with man-made lakes. Organic pollution, including sewage treatment effluents, canning wastes and fertilizer carried by runoff, is often responsible for the heavy production.

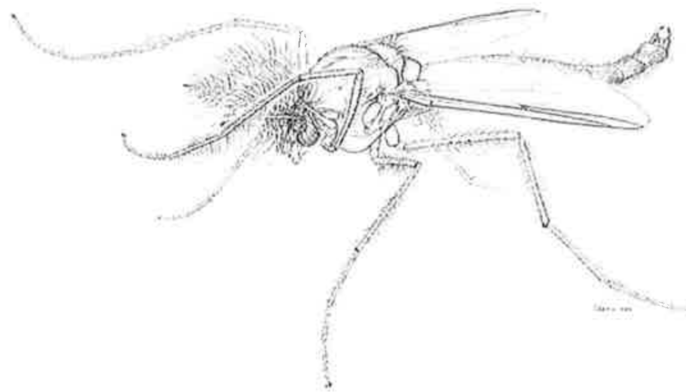


Figure 23. Chironomidae.
(Image reproduced with the permission of the Minister of Public Works and Government Services Canada, 2007)

Midge control in Georgia is relatively rare, with only a few organized attempts. Current control practices involve the use of larvicides targeting the larval stage in the bottom substrates of ponds where they develop. Active ingredients with labels for midge control include methoprene, *Bti* and temephos. The surface film agent, Agnique can also be used with respectable levels (~70% reductions) of control. In general, midge control is relatively expensive as compared to mosquito control, due to the increased levels of active ingredient required to produce mortality in the larval substrates. Mosquito adulticides will temporarily reduce populations, however, repopulation is usually quick, due to the unabated larval development. Research continues trying to develop more effective larvicide formulations for these pests.

Flies (Figure 24)

House flies are one of our most common insects and are characterized by their sponging mouthparts and a thorax that bears four narrow black stripes. House flies and other filth flies are capable of developing in almost any warm, moist organic matter such as animal manure, garbage or decomposing foods. Filth flies have been shown to carry a wide variety of diseases, often related to their feeding habits and their subsequent contact with human food materials. Control of filth flies is best accomplished by good sanitation, and arthropod control districts are usually only called in when an unusual situation causes a problem population - such as an improperly managed landfill. Larval control can be effective, as is done in agricultural situations. House flies have developed resistance to many of the chlorinated hydrocarbon and organophosphate insecticides. It is best to consult the most recent recommendations for control before treating for flies. The use of plastic trash bags is highly recommended when flies are a problem, as well as the proper maintenance and use of window and door screens.

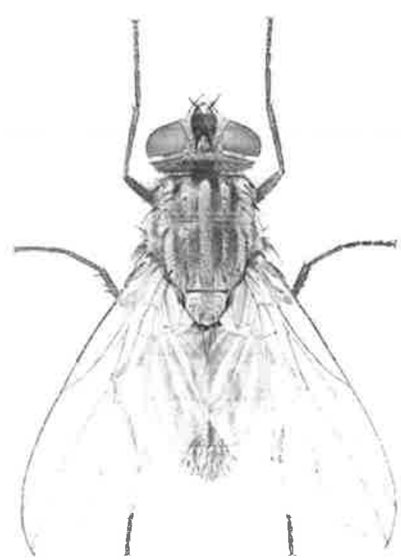


Figure 24. House fly.
(Image from *Flies and Disease* Volume 1, Princeton University Press)

Eye Gnats (Figure 25)

Until the last decade, eye gnats were only a localized and temporary problem in the State. However, with conversion of vast tracts of woodlands into farms for growing soybeans and other crops, eye gnats have come a problem of major proportions in some areas. Larval development occurs in moist, sandy soils, with freshly plowed fields that had organic matter turned in being the most productive sites. Adult populations typically peak in the spring and fall. With eye gnats, as with many problem insects, adulticiding offers, at best, temporary relief. Newly emerged adults quickly reinfest the sprayed areas. IGR compounds show promise in current research for control of the larval stage.

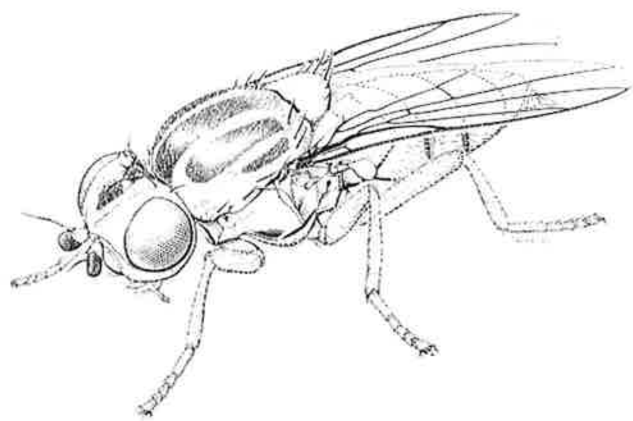


Figure 25. Eye gnat.
(Image reproduced with the permission of the Minister of Public Works and Government Services Canada, 2007)

Miscellaneous Insects

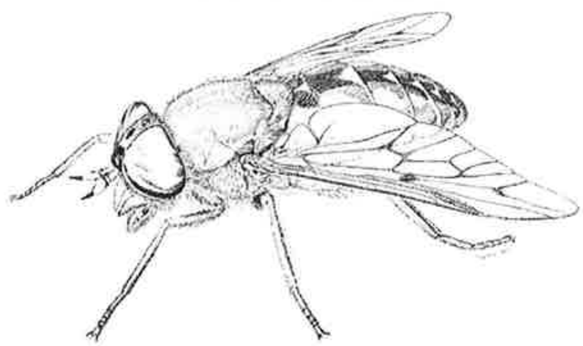
Mosquito control districts receive numerous calls from private citizens seeking information on how to control certain household pests, such as fleas, roaches, ticks, etc. It is good public relations to have additional information at hand to give them. Questions which deal with agricultural insects may be referred to your county extension agent.

Appendix A. – Mosquito Related Flies & Gnats

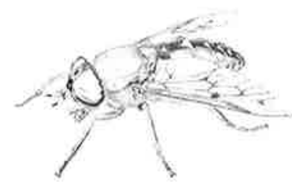
Right column represents a relative size progression.

Tipulidae – crane fly

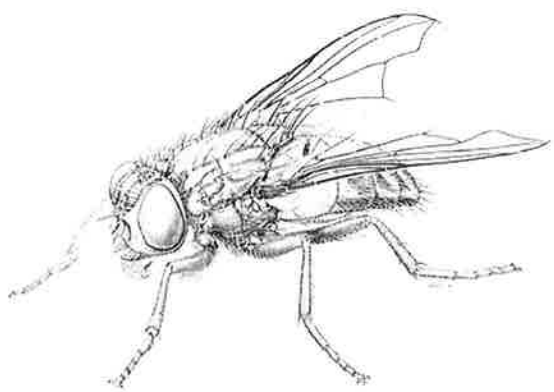
actual size 3/8 – 2 1/2 inches (8 – 65 mm)



Tabanidae – deer fly



actual size 3/8 – 1 1/8 inch (9 – 28 mm)

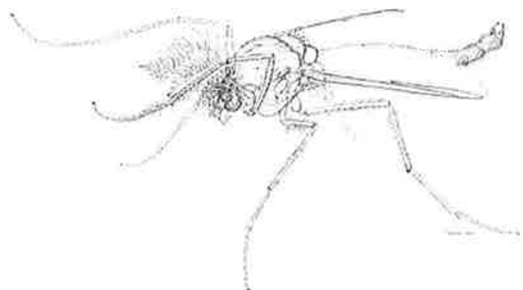


Muscidae – house fly

actual size 1/8 – 1/4 inch (3 - 6 mm)

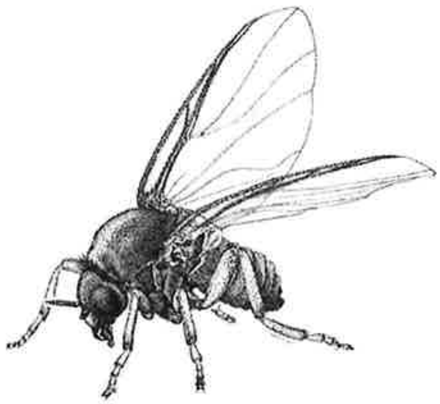
Culicidae – mosquito

actual size 1/8 – 1/2 inch (4 - 13 mm)



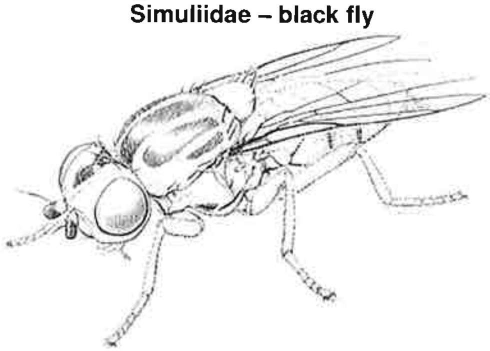
Chironomidae - midge

actual size 1/16 – 3/8 inch (1 – 10 mm)



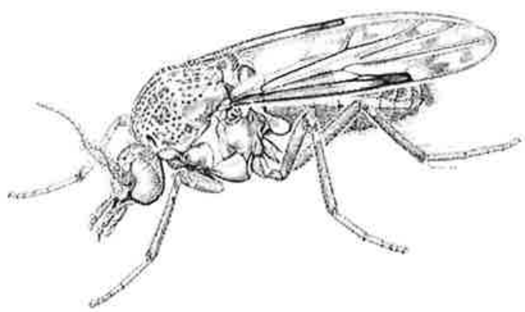
Simuliidae – black fly

actual size 1/16 – 1/8 inch (2 – 4 mm)



Chloropidae – eye gnat

actual size 1/16 – 1/8 inch (2 – 4 mm)



Ceratopogonidae – biting midge

actual size 1/32 - 1/16 (.5 – 2 mm)

Appendix B. Accepted Abbreviations of Mosquito Genera

Aedes	*Ae.*
Anopheles	*An.*
Coquillettidia	*Cq.*
Culex	*Cx.*
Culiseta	*Cs.*
Deinocerites	*De.*
Ochlerotatus	*Oc.*
Orthopodomyia	*Or.*
Psorophora	*Ps.*
Toxorhynchites	*Tx.*
Uranotaenia	*Ur.*
Wyeomyia	*Wy.*

Appendix C. Definitions of Key Mosquito-Related Words

Abatement..................The process of reducing the amount of a specific thing (mosquitoes).

Abdomen.....................The last of the three main body regions of a mosquito.

Adulticide....................Treatment to kill adult mosquitoes.

Ague..........................Malarial fever, or any other severe recurrent symptom of malarial origin.

Amplification................ The increase of a disease agent in an ecosystem when susceptible wild animals become infected after being bitten by infected mosquitoes, thereby increasing the likelihood that more mosquitoes will become infected.

Antennae.................... A pair of long, jointed, sensory organs attached to the front of the head. The female mosquito's antenna has only a few fine, short hairs sticking out at each joint. The male mosquito's antennae have many coarse, long hairs sticking out at each joint.

Anterior...................... Front; in front of.

Anteroventral............... In front and underneath or on the lower side.

Antibody.....................Proteins that are produced by the host in response to exposure to an antigen.

Antigen.......................Anything that produces an immune response (example: virus, bacteria)

Aphasia...................... Loss of power of expression by speech, writing, or signs, or of comprehending spoken or written language, due to injury or disease of the brain centers.

Apically...................... Pertaining to or located at the apex (narrowed or pointed end): distal.

Arbovirus.....................Viruses that are maintained in nature through biological transmission between susceptible vertebrate hosts by blood-feeding arthropods (e.g., mosquitoes, ceratopogonids, and ticks).

Arthropod vector.......... Member of the phylum Arthropoda, including Crustacea, Myriopoda, Insecta, and Arachnoidea, which carries pathogenic organisms.

Artificial containers....... Anything that can hold water and act as a breeding site for mosquitoes; a rain catcher.

Aseptic meningitis ....Inflammation of the brain or spinal cord where pathogenic organisms are absent.

Basal ....Relating to, situated at, or forming the base, often referring to an insect body part that is located nearest to the thorax.

Bioassay........................A test to determine the toxicity of a substance on an organism.

Cephalothorax ....The body region formed by fusion of the head and thorax in Arachnida and Crustacea and mosquito pupae.

Cerci ....A pair of appendages sticking out of the tip of the abdomen of mosquitoes.
Cerebrospinal fluid ....Fluid of the brain and spinal cord.
Coxa ....The basal segment of the leg.
Crepuscular...................Active in the twilight (dawn and dusk).
Culicidae ....The scientific family name of the mosquito.
Debris.............................An accumulation of material, sticks, leaves, etc.
Desiccation.....................The act of drying up. Some mosquito species deposit their eggs in a dry area. These eggs are able to survive dry conditions and will hatch when exposed to water.
Diapause ....A period of biological quiescence or dormancy; an interval in which development is arrested or greatly slowed.
Diptera............................The order of insects that includes two-winged flies, gnats, and mosquitoes.
Dorsal.............................Top or uppermost; pertaining to the back or upperside.
Edema.............................An accumulation of an excessive amount of fluid in cells, tissues, or serous cavities.
Egg raft...........................A group of eggs deposited by a single female mosquito that are stuck together and float on the surface of water.
Encephalitis ....Inflammation of the brain.
Encephalomyelitis ....An acute inflammation of both brain and spinal cord.
Endemic ....Presence of a disease in a human community at all times, but occurring in only small numbers of cases.
Entomology ....The scientific study of insects.
Enzootic ....Affecting animals in a specific area/community in a constant or routine manner.
Epidemic ....Infection/disease spreading rapidly in a human population.
Epidemiology ....The field of science dealing with the relationships of the various factors that determine the frequencies and distributions of an infectious process, a disease, or physiological state in a human community.
Epizootics........................An infection/disease attacking a large number of animals at the same time.
Equine ....Pertaining to horses.
Exoskeleton ....A skeleton or supporting structure on the outside of the body.
Febrile ....Relating to fever.
Femur..............................The third leg segment of an adult insect, located between the trochanter and the tibia.
Flotage............................Material that floats.
Halteres...........................A pair of small knobbed structures located on the last segment of the thorax, formed from a modified hind wing. They are the balancers of flies and mosquitoes.
Holometabolous............Development that produces drastic changes in form during growth from an immature to adulthood.
Insecticide ....A chemical or biological formulation used to control insects.
Instar ....Any one of the larval stages of an insect between molts.
Larva ....(pl. larvae) The aquatic feeding stage of immature mosquitoes.
Larvicide ....Treatment to kill mosquito larvae.
Lateral ....Of or pertaining to the side (that is, the right or left side).
LD_{50} ....The dose of an active ingredient that is expected to cause death in 50% of the test animals treated.
Meningoencephalitis .....Inflammation of the brain and its membranes.
Metamorphosis............ A change in form during insect development (e.g., from larva to pupa to adult).

Microfilariae................. The first stage larvae of filarial nematodes. Ingested by mosquito during blood meal from vertebrate host.
Midgut......................... The middle portion of the insect alimentary (or digestive) tract.
Molt............................. Shedding of the exoskeleton as part of the growth process.
Moribund.......................Dying.
Necropsy....................... Autopsy; an examination and dissection of a dead body to determine cause of death or the changes produced by disease.
Neurologic sequelae...... A pathologic condition resulting from a disease of the nervous system; persistent or lasting damage after recovery.
Organophosphates....... A class of insecticides that contain phosphorus; they are initially toxic but degrade quickly when exposed to air and light.
Osmotic....................... Relating to diffusion through a semi-permeable membrane.
Overwintering.............. Surviving through the winter. (See diapause).
Oviposition.................. The act of laying or depositing eggs.
Ovitrap..........................A surveillance tool, typically a black jar or cup, used to induce oviposition and monitor the associated species.
Palpi............................ A pair of sense organs extending from the head of a mosquito, above and at the sides of the proboscis.
Passeriformes.............. An order of birds that includes perching birds and songbirds such as jays, blackbirds, finches, warblers, and sparrows.
Pathogen..................... Any disease-producing microorganism or material.
Peridomestic............... Living around human inhabitations.
Pesticide......................A chemical or biological material used to control pests.
Predaceous................ Living by seizing or taking prey; predatory, feeding on others.
Posterior...................... Situated behind, caudal, the hinder parts of the body.
Proboscis.................... Mosquito mouthparts that are formed into a long slender beak. It is attached to the front of the head between the eyes, below the palpi and antenna.
Propagation................. Reproduction; generation.
Pupa............................ (pl. pupae) The aquatic non-feeding stage of immature mosquitoes.
Pyrethrins....................Insecticides that are derived from the extract of chrysanthemum flowers.
Pyrethroids..................Synthetic (man-made) forms of pyrethrins.
Pyrethrums..................The plant extract that contains pyrethrin I and pyrethrin II collectively, called pyrethrins.
Receding......................To draw back, as floodwaters returning to the stream channel.
Residua........................ (Singular- residuum) Residue or remainder.
Resistance.................. The level of immunity that an organism has for a particular substance.
Scales.......................... Flattened, thin body covering growing out of a mosquito's cuticle, the noncellular outer layer of the body wall. When they are long and slender, they are called hairs. Heavy hairs are called bristles. When these are heavy and pointed, they are called spines. When they are flattened out and thin, they are called scales.
Scientific name............ The proper name used by scientists to refer to any plant or animal.
Scutellum.................... A small plate-like growth. It is part of the thorax, posterior to the scutum.
Sequelae......................(Singular-sequela) morbid condition following or as a consequence of a disease.
Serology...................... The branch of science dealing with blood serum, especially with specific immune or lytic serums.
Seropositive................ Showing positive results on serological examination, indicating the host has been exposed to the agent in question and has developed a detectable immune response
Serosurvey..................Looking at a population to determine the prevalence of exposure to a given pathogen.

Siphon........................The breathing tube of a mosquito larva.

Species...................... A category of biological classification ranking immediately below the genus or subgenus, comprising related organisms or populations potentially capable of interbreeding.

Spiracles.....................An external opening of the tracheal system, or breathing pores through which a mosquito breathes. An adult mosquito has two on each side of the thorax. The front spiracle (mesothoracic) is a character used in identification. Concerning larval mosquitoes, the spiracles of the meso- and metathorax and abdominal segments I-VII are rudimentary and non-functional. Post abdominal spiracles of abdominal segment VIII are functional.

Subclinical.................. Without clinical manifestations; said of the early stages, or a slight degree of a disease.

Susceptible..................Easily affected by diseases or poisons, not resistant.

Tarsal segment............ One of the five segments of a mosquito's tarsus.

Tarsus........................ (pl. tarsi) The leg segment of the adult mosquito immediately distal to the tibia to which the tarsal claw attaches at its apex.

Tegula........................ A small bump on the underside of the base of the wing of a *Culiseta* mosquito. It has a number of small bristles.

Thorax........................ The middle portion of the adult mosquito to which one pair of wings, one pair of halteres and three pairs of legs are attached.

Tibia........................... The fourth segment of the mosquito leg, between the femur and the tarsus, equivalent to a human's shin.

Translucent..................Semi-transparent; almost clear enough to see through.

Transmission.............. The transfer of a disease.

Transovarian.............. transmission The mechanism whereby virus is transferred directly from an infected mosquito to her offspring through the egg.

Trochanter...................The second segment of the mosquito leg, between the coxa and the femur.

Trumpets.................... Two breathing tubes of the mosquito pupa.

Tumbler......................A common name for a mosquito pupa. Pupae are called tumblers because of the way they move in water.

Vector........................ An insect, or other arthropod, that can carry a disease from one animal to another animal (or human).

Viremia.......................The presence of high levels of virus cells in the blood.

Viremic...................... The presence of virus in the blood.

Virus...........................One of a group of minute infectious agents, with certain exceptions not resolved in the light of a microscope, and characterized by a lack of independent metabolism and by the ability to replicate only within living hosts.

Water........................ *Fresh* - Clear, clean water of recent occurrence.
Stagnant - Water that has set in one place for a long time.
Foul - Water that is contaminated with filth of various kinds.
Polluted - Water that contains a large amount of sewage and similar material.

Wriggler......................A common name for a mosquito larva. Larvae are called wrigglers because of the way they move in water.

Appendix D. Characteristics and Field Guide of Georgia Mosquitoes

Note: This table indicates the possibility that many species can potentially vector diseases not common in Georgia or not commonly detected during normal surveillance activities. The efficiency with which this happens actually might be extremely low. This is referred to as vector competence. Genetic, chemical, and physiological traits that vary by species will affect the window of time that a virus remains viable for transmission in a given species. Species such as *Anopheles crucians, Coquillettidia perturbans, Culex quinquefasciatus, or Culiseta melanura* generally are more competent vectors. Species such as *Aedes vexans* exhibit lower competence, but sheer population numbers increase the odds of an infected individual being present. Other species, such as *Aedes cinereus,* exhibit a low degree of competence and low population density, and the odds of an infected individual being present is much lower.

Scientific Name		Associated Pathogens	Feeding Preference Time/Host	Habitat	Eggs	Broods/Year	Over-wintering Stage	Effective Flight Range
Genus	Species							
Aedes	*aegypti*	DEN, WN, YF	Daytime Mammals	Containers, especially wooden, with walls at least in part other than soil; tree holes; shade; fairly clean water over decaying leaves	Singly within 1 inch of water line, on water surface in foul water, or on floating wood in clear water	Several		500 feet to < 0.5 mile
	albopictus	CV, DEN, DHW, EEE, JC, KEY, LAC, POT, TEN, WN, YF	Daytime Mammals, wild & domestic animals, birds	Artificial containers, tree holes	Singly above the water line	Several	Eggs	300 feet to < 0.5 mile
	cinereus	DHW, EEE, JC, LAC, WN	Daytime Mammals	Woodland pools, bogs, marshes	Singly on low, damp surface	One		Limited
	vexans	EEE, CV, JC, POT, WEE, WN, DHW	Crepuscular & Night Mammals & Birds	Temporary pools; floodwater	Laid in or on soil in low lying areas	Several	Eggs	1 to 15 miles

Scientific Name		Associated Pathogens	Feeding Preference Time/Host	Habitat	Eggs	Broods/Year	Over-wintering Stage	Effective Flight Range
Genus	Species							
Anopheles	*atropos*	WN	Crepuscular & Night	Salt marsh; saline water to undiluted sea water, brackish				1 to 5 miles
	barberi	WN	Mammals	Tree holes, stump holes, artificial containers	Singly on water surface	2 or more	Larvae	
	bradleyi	DHW	Crepuscular & Night	Pools of brackish water near the coast; margins of fresh water ponds and marshes	Singly on water surface	Several	Adult females	1 to 2 miles
	crucians	EEE, JC, Malaria, TEN, VEE, WN	Crepuscular & Night Mammals, birds	Ponds, swamps, semi-permanent and permanent pools; prefers acidic waters	Singly on water surface	2 or more	Larvae	1 to 2 miles
	georgianus			Hoof prints in seepage areas in pastures; in potholes; and in sluggish swamps				
	maverlius (*quadrimaculatus* complex)							
	punctipennis	CV, DHW, EEE, JC, KEY, Malaria, SHV WN	Day & Night Mammals	A wide variety of ground water accumulations which are cool & clean including stream pools, woodland pools & ditches	Laid singly on water surface	Several	Adult females	1 to 2 miles, typically less
	quadrimaculatus	CV, DHW, EEE, JC, Malaria, TEN, WN	Crepuscular Mammals, Occas. birds and reptiles	Permanent fresh water with herbaceous surface growth, flood waters, grassland pools, lake margins	Singly on water	Several	Adult females	0.5 to 1 mile
	smaragdinus (*quadrimaculatus* complex)							
	walkeri	DHW, Malaria, WN	Night Mammals, wild & domestic animals	Fresh water with emergent vegetation, artificial containers	Singly on water surface	Several	Eggs	1 to 2 miles
Coquillettidia	*perturbans*	CV, EEE, TEN, VEE, WN	Crepuscular Mammals, birds, amphibians, occas, reptiles	Permanent bogs, marshes with heavy aquatic vegetation, (e.g., cattail, sedges, water hyacinth, swamp loosestrife, arrow arum, and buttonbush), drainage ditches, lake margins	Rafts on water	One irregular	As larvae attached to plant roots for oxygen supply	1 to 5 miles

Scientific Name: Genus	Scientific Name: Species	Associated Pathogens	Feeding Preference Time/Host	Habitat	Eggs	Broods/Year	Over-wintering Stage	Effective Flight Range
Culex	*coronator*	SLE, WNV	Crepuscular Birds & horses	Temporary pools & artificial containers	Rafts on water	Several	Adult female	0.25 to 1 mile or more
	erraticus	WN	Night Birds, mammals	Grassy margins of ponds marshes & lakes, woodland pools	Rafts on water	Several	Adult female	0 to 0.25 mile
	nigripalpus	DHW, EEE, SLE, TEN, WN	Crepuscular Opportunistic	Ditches, flooded fields, grassy pools, & marshes of semi-permanent or permanent nature; occas. in wheel ruts, leaf axils of plants, & artificial container; best described as floodwater	Rafts on water	Several		1 to 5 miles, typically less
	peccator			Stream pools & marshes	Rafts on water	Several	Adult female	
	pilosus			Grassy pools, swamps, plant parts	Rafts on water			
	pipiens/ quinquefasciatus	DHW, EEE, FIL, SLE, WEE, WN	Crepuscular & Night Birds, mammals	Foul ground water & containers	Rafts on water	Several	Adult female	0.25 to 1 mile or more
	restuans	DHW, EEE, SLE, WEE, WN	Crepuscular & Night Birds; rarely bite mammals	Ditches, woodland pools, containers; usually associated with foul water (high organic content)	Rafts on water	Several	Adult female	1 to 2 miles
	salinarius	EEE, SLE, WN	Crepuscular & Night Birds, mammals	Fresh or foul pools, ditches; salt marshes, containers, lake margins	Rafts on water	Several	Adult female	0.25 to 5 miles
	tarsalis	EEE, SLE, WEE, CE, WN	Crepuscular & Night Birds, mammals	Clean or foul ground water; containers	Rafts on water	Several	Adult female	Up to 17 miles
	territans	EEE, WN	Crepuscular & Night Cold-blooded vertebrates esp. frogs	Semi-permanent to permanent clean ground water pools	Rafts on water	Several	Adult female	0 to 1 mile

Scientific Name		Associated Pathogens	Feeding Preference Time/Host	Habitat	Eggs	Broods/Year	Over-wintering Stage	Effective Flight Range
Genus	Species							
Culiseta	*inornata*	EEE, SLE, WEE, WN	Large mammals	Ground/woodland pools, brackish & alkaline; artificial containers, drainage ditches	Rafts in pasture pools, semi-permanent water	One or more	Adult female	Up to 1 mi or more
	melanura	CE, EEE, HJ, WN	Crepuscular & Night Birds; infrequently on mammals and reptiles	Heavily shaded sites with uprooted or decaying trees in permanent freshwater hardwood swamps (pH 5.0); tree root cavities or stump rot holes	Rafts on water surface	Several	Larvae	0.5 to 2 miles
Mansonia	*dyari*			Permanent bogs, marshes with heavy aquatic vegetation (especially water hyacinth and water lettuce)		Several		
Ochlerotatus	*atlanticus/ tormentor*	KEY, TEN, WN	Crepuscular & Day	Temporary pools in woodland and open fields				0.25 to 0.5 mile
	atropalpus	WN	Mammals	Rock and masonry pools	Singly above water level	Several	Eggs	Limited
	canadensis	DHW, EEE, JC, WN	Crepuscular & Day Birds, mammals, amphibians, reptiles	Temporary shaded woodland pools, drainage ditches, freshwater swamps	Singly on low, damp surface	One	Eggs	0 to 0.5 mile
	dupreii			Temporary woodland rainwater pools, grassland pools			Eggs	
	fulvus pallens		Crepuscular, day & night	Small pools, woodland pools				2 to 5 miles
	grossbecki			Flooded woodlands (woodland pools)		One	Eggs	
	hendersoni		Mammals	Tree holes, containers, prefer canopy of trees	Laid above water level	Several	Eggs	± 1 mile
	infirmatus	CV	Crepuscular & Day	Woodland pools, grassland pools, lake margins				0.25 to 1 mile
	japonicus	WN, Den,	Daytime, Crepuscular & Night, Mammals	Rock holes along river, tree holes, artificial containers including tires	Singly above the water line	Several	Eggs and larvae	0 to 0.25 mile
	mitchellae		Mammals	Temporary rain pools			Eggs	

Scientific Name		Associated Pathogens	Feeding Preference Time/Host	Habitat	Eggs	Broods/Year	Over-wintering Stage	Effective Flight Range
Genus	Species							
Ochlerotatus (cont.)	*sollicitans*	DHW, EEE, JC, WEE, WN	Crepuscular & Day Mammals, birds	Salt & brackish marshes	Singly on ground	Several	Eggs	5 to 100 miles or more
	sticticus	JC, DHW	Crepuscular, Day & Night Mammals	Floodwater pools in river floodplains	Singly on low, damp surfaces	One, possibly more	Eggs	Up to 7 miles
	taeniorhynchus	CV, DHW, EEE, VEE, WN	Crepuscular, Night & Day Large mammals, humans	Salt marshes, especially those supporting mangrove & pickleweed; inland brackish-water swamps	Inner part of tidal zone and slightly above normal high tide	Multiple and continuous	Eggs	2 to 40 miles
	thibaulti		Crepuscular, Night & Day	Hollow butts of gum trees in floodplains; woodland pools		One		
	triseriatus	DHW, LAC, SHV, WN	Crepuscular Indiscriminate	Tree holes (prefer basal part of tree); containers	Laid singly above water level	Several	Eggs	0.5 to 1 mile
	trivittatus	CV, DHW, JC, SHV, TVT, WN	Crepuscular Mammals	Floodwater, woodland pools & grassland pools	Singly on damp, ground depressions	Several	Eggs	Up to 0.5 mile
Orthopodomyia	*alba*		Probably birds	Tree holes, containers	Singly on walls just above water line	Probably one	Larvae	
	signifera	WN	Birds	Tree holes, containers	Singly on walls just above water line		Larvae	
Psorophora	*ciliata*	SLE, WN	Crepuscular, Night & Day Mammals (predaceous cannibalistic as larvae)	Unshaded temporary rain pools	Damp earth or edge of container	Multiple	Eggs	1 to 5 miles or more
	columbiae	CV, VEE, WN	Crepuscular, Night & Day Mammals	Unshaded temporary rain pools	Ground depressions	Multiple	Eggs	1 to 8 miles
	confinnis=columbiae		Mammals	Temporary shallow ground pools rice fields, and woodland pools	Ground depressions	Multiple	Eggs	5 to 10 mi or more

Scientific Name		Associated Pathogens	Feeding Preference Time/Host	Habitat	Eggs	Broods/Year	Over-wintering Stage	Effective Flight Range
Genus	Species							
Psorophora (cont.)	*cyanescens*		Mammals	Transient ground pools in fields, woodlands, or near dwellings	Ground depressions	Multiple	Eggs	Several mi
	discolor		Mammals	Temporary shallow ground pools, rice fields, and woodland pools	Ground depressions	Multiple	Eggs	
	ferox	DHW, WN	Crepuscular & Night Mammals	Temporary rain-filled pools, particularly in or near thickets; in overflow pools along streams	Damp earth in low areas subject to flooding	Multiple	Eggs	1 to 2 mi
	horrida		Mammals	Temporary rain-filled pools	Damp earth in low areas subject to flooding	Multiple	Eggs	
	howardii		Crepuscular & Night Mammals	Unshaded or partly shaded temporary rain-filled pools, drainage ditches	Damp earth in low areas subject to flooding	Multiple	Eggs	1 to 2 mi
	mathesoni		Mammals	Temporary rain-filled pools	Damp earth in low areas subject to flooding	Rarely more than one	Eggs	
Toxorhynchites	*rutilus*	none	Not a blood feeder	Rot holes in trees or stumps; containers that contain leaves and sticks; larvae are predaceous	Singly on water surface	Multiple	Larvae	Seldom leaves vicinity
Uranotaenia	*lowii*		Reptiles and amphibians	Various ground pools		Several		
	sapphirina	WN	Reptiles and amphibians	Semi-permanent & permanent water with emergent or floating vegetation exposed to sunlight	Rafts on water surface	Several	Adult females	Up to 8 miles
Wyeomyia	*haynei*			Water-filled leaves of pitcher plant				
	smithii		Rarely humans	Water-filled leaves of pitcher plant	Leaves of pitcher plant	Several	Larvae	

Abbreviations: CE - California Encephalitis virus; CV - Cache Valley virus; DEN - Dengue virus; DHW - dog heartworm; EEE - Eastern Equine Encephalitis virus; FIL - Filariasis; HJ – Highlands J: JC - Jamestown Canyon virus; KEY - Keystone virus; LAC - Lacrosse Encephalitis virus; POT - Potosi virus; SHV - Snowshoe Hare virus; SLE - St. Louis Encephalitis virus; TEN - Tensaw virus; TVT -Trivitattus Encephalitis virus; VEE - Venezuelan Equine Encephalitis virus; WEE - Western Equine Encephalitis virus; WN -West Nile virus; YF - Yellow Fever virus.