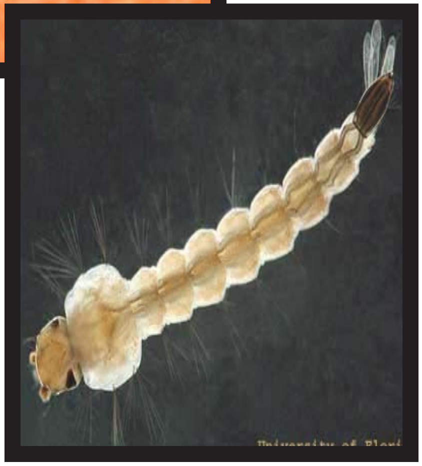
# MARYLAND PESTICIDE APPLICATOR TRAINING MANUAL

## PUBLIC HEALTH
## MOSQUITO CONTROL



# MARYLAND PESTICIDE APPLICATOR TRAINING MANUAL

# CATEGORY 8 - PUBLIC HEALTH
## Mosquito Control

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# INTRODUCTION

Throughout history mosquitoes have occupied a position of importance as a pest of mankind, but not until the late 19th century were these insects identified as the agents responsible for the transmission of some of man's most devastating diseases. During subsequent years, knowledge of the relationship of mosquitoes to these diseases has expanded, along with the knowledge of methods for controlling these disease vectors. This has provided a means for reducing, or eliminating, these diseases in many areas of Maryland and the United States.

This manual will provide pesticide applicators seeking certification in the Public Health Category (Category 8) of pest control with the necessary information in preparing for the certification examination. The importance of mosquitoes to human health in both Maryland and the United States is covered as part of this manual, along with the basic information on mosquito identification, biology and control. Upon completion of the certification process applicators should be able to provide a high level of mosquito control service to the public and customers.

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**“Mosquitoes remind us that we are not as high up on the food chain as we think.”**

**Tom Wilson**
**American Humorist**

# CHAPTER ONE

## GENERAL PRINCIPLES

### Scientific Classification

In order to properly identify living organisms and learn more about them, it is important to become familiar with the way they are classified. Biologists arrange animals into groups on the basis of traits which they share with other animals and their genetic relationships with each other. This orderly way of classifying animals forms the basis of the field of study called taxonomy. Modern scientific taxonomy is based on physical characteristics (such as mouthparts, patterns, size, or the structure of body parts) and on genetic characteristics. Some key characteristics are basic to taxonomic descriptions. Others are not part of the basic description, but correspond to evolutionary relationships upon which taxonomic classifications are based.

The field of study called systematics focuses specifically on the evolutionary relationships between living organisms. A Swedish scientist named Carolus Linnaeus laid the foundation of modern systematics with a work called *Systema Naturae*, which he published in 1758. Linnaeus wrote in Latin, the international language at the time, and Latin continues to be the basis of most scientific names. Sometimes the names of the various taxonomic categories are converted into forms that are more comfortable to everyday English; for example, instead of Insecta we usually just say insect.

Linnaeus designed his system of classification so that each animal and plant that he described had one and only one correct name that would not be shared with any other organism. Then he laid out a method for organizing all these named organisms into a series of related groups, based on their similarities and differences. In essence, it became a type of filing system, with the top levels including many different kinds of organisms and the lowest levels containing but a single type of plant or animal. This hierarchical Linnaean system uses clearly defined shared characteristics to classify organisms into each group represented by these different levels.

The most important categories in this hierarchical system, from higher and more inclusive to lower and more specific, are kingdom, phylum, class, order, family, genus, and species. A kingdom is one of the highest primary divisions into which all organisms are placed. Living organisms are divided into the plant kingdom, the animal kingdom and several smaller kingdoms of microscopic life. All forms of animals are part of the Animal Kingdom. Each kingdom is then divided into smaller units called phyla (the plural is phylum). The phyla, Arthropoda includes the insects. The animals in this phylum, the largest group of the animal kingdom, are the invertebrates, the insects and their relatives and their relatives. Arthropods also include spiders, mites, ticks, millipedes and centipedes, all of which characteristically have jointed legs and:

- a body made of segments that are grouped or fused together;
- legs, antennae and other appendages attached in pairs, and;
- a hard or tough external covering, the exoskelton, with some pliable or soft parts. The exoskeleton holds the body together and gives it shape, performing the same function as a mammal's bony internal skeleton.

Arthropods are further divided into classes such as Arachnida, Myriapoda and Insecta. Members of each class have characteristics which they share with other members of their class, but which generally are not found in members of the other classes. The class Arachnida includes spiders, mites scorpions, ticks and daddy longlegs. These arthropods usually have mouthparts with two prominent structures (pedipalps) and needlelike piercing fangs, or chelicerae. They have four pairs of legs and two body regions. The mouthparts and legs are attached to the first region, and the reproductive organs and digestive system are contained in the second region.

The class Myriapoda is made up of two groups: millipedes and centipedes. The millipedes have many segments and are wormlike, are cylindrical with short antennae and two pairs of legs per segment. Centipedeas also have many segments and are wormlike, but they appear more flattened and have one pair of legs per segment, long antennae and hind legs (all legs of the house centipede are long).

The class Insecta contains the insects, in which the adults have three body regions: head, thorax and abdomen (Figure 1.1). The head bears a single pair of antennae. The thorax bears three pairs of legs and usually one or two pairs of wings. The abdomen contains most of the digestive system and reproductive organs.

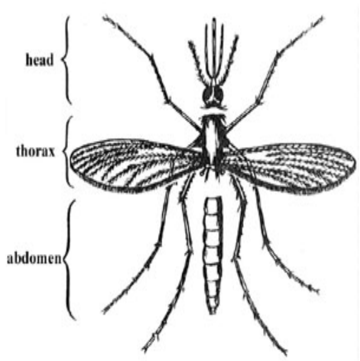



Figure 1.1. Adult insects have three body regions. The heaf, thorax and abdomen.

The class Insecta is divided into orders, which are distinct groups whose members look very much alike, for example, Lepidoptera (butterflies and moths), Coleoptera (beetles), or Diptera (flies and mosquitoes). Orders are then subdivided into families, which in turn comprises several or many genera (the plural is genus). Each genus is subdivided into species which are closely related. A family usually contains more than one genus, and each genus usually includes more than one species. Animals that share the same genus are very similar and probably evolved from a common ancestor. The species is the most fundamental unit and contains a single type of animal. Species of animals can be thought of as a specific kind of animal.

Species are always given two-word scientific names. The first word identifies the genus name (the first letter is always capitalized) and the second word is the species name (always lower case). Both names are written in italics, or underlined, as in *Ades vexans*.

Well-known species may also have nonscientific names called common names Figure 1.2). An example would be *Ades albopictus* which is commonly called the Asian tiger mosquito. Common names reveal what people think about the organism and their ideas about how they are related to each other. Some common names match scientific taxonomy very closely while other common names divide animals into more groups than scientists do, especially when they are very familiar to us, or important in our lives. Other animals are lumped together using similar common names in spite of very different biological histories. Despite the possibility for confusion, common names are a widely recognized way of referring to animals. However, they lack the universal recognition needed for accurate identifications and scientific research. To reduce this confusion, reference books and field guides list the scientific name in addition to the common name. Scientific names are included in order to indicate the animal's scientific classification.

Figure 1.2. Scientific name - *Ades albopictus*. Common name - Asian tiger mosquito.

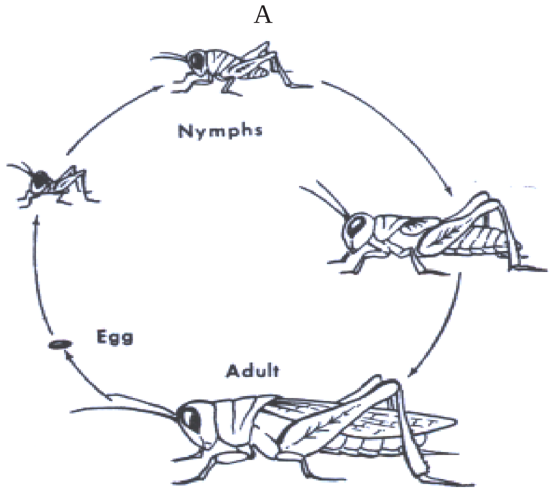
## Basic Insect Biology

Insects and mites are distantly related and, therefore, share some similarities. They usually have jointed legs and a tough outer skin during one or more of their life stages. They both must shed their skins several times in order to grow and become adults. Insects and mites can be distinguished by the number of body regions, legs, wings and antennae each possesses. Adult insects usually have three body regions (head, thorax and abdomen), three pairs of legs and one or two pairs of wings on the thorax, and one pair of antennae on the head. Adult mites, usually have one conspicuous body region, four pairs of legs, no wings and no antennae.

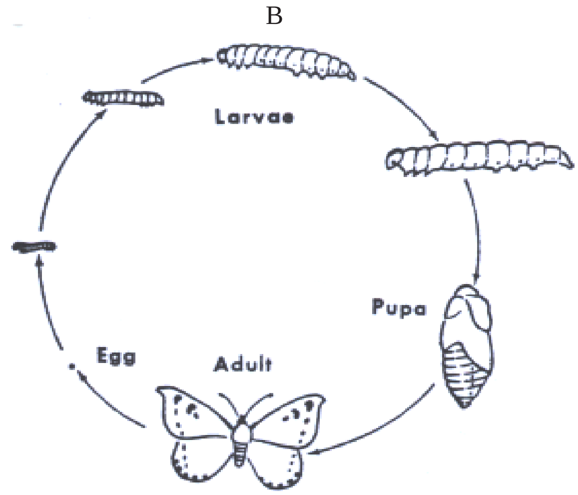
### Characteristics

Structural characteristics of the mouthparts vary dramatically among insects. In addition to the filter-feeding mechanisms found in some aquatic forms, there are four basic types of insect mouthparts: chewing, sponging, piercing-sucking and siphoning. Adult mosquitoes, for example, have piercing-sucking mouthparts, whereas mosquito larvae swallow everything that is small enough to pass through their filter-feeding mouthparts. Among the blood-feeding species, the females are universally blood feeders, but the males may or may not feed on blood, depending on the genus.

Figure 1.3




**Gradual Metamorphosis**. Newly hatched insects (nymphs) resemble the adult insect but are smaller, and the wings are not obious. These insects change shape gradually. Each time they shed their skins they grow and enlarge their wings. Nymphs and adults usually feed on the same food source. Mite developmkent is similar, but legs are added instead of wings.




**Complete Metamorphosis**. Newly hatched insects do not resemble adults. They have worm-like bodies with no external sign of wings and are called larvae. Like nymphs, larvae must also shed their skins to grow. Each larvae changes into a pupa before it can change into an adult. Wings usually are visable on the resting pupal stage, which does not feed and usually remains hidden. Adults eventually emerge from the pupal skins.

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## Life Cycles

Most insect reproduction is sexual, that is, an egg cell from the female develops only after fertilization by a sperm cell from the male of the same species. However, some insect and other arthropod species are asexual and have reproductive mechanisms that do not require a sperm cell.

**Growth and development**. The exoskeleton of the arthropod body can expand only a little, at the pliable or soft places. It does not grow continuously, but in stages. A new, soft exoskeleton is formed under the old one, then the old one is shed, or molted. The new exoskeleton then expands while it is still soft so that it becomes larger than the old one and allows the animal to grow. It hardens and darkens in a few hours. After the molting process, the arthropod resumes its normal activities.

Most arthropods hatch as tiny individuals and increase in size through this molting process, keeping the same appearance until they become adults. A spectacular and very important exception occurs in insects. The class Insecta is divided into groups according to the way the insects change during their development. This technical term for this change is metamorphosis, which means “change in form.” The three main types of metamorphosis are:

- ❑ Simple metamorphosis. This group, which includes silverfish, makes no drastic change in form from juvenile to adult. Its members simply hatch and grow larger by molting periodically. Only a few insect orders are included in this group.

- ❑ **Gradual metamorphosis** (Figure 1.3 A). This group includes inpart, cockroaches, crickets, grasshoppers, boxelder bugs and earwigs, which hatch from eggs as nymphs that resemble the adult form but do not have wings. Some of the orders have many species and include many pests. Nymphs and adults are often found together and usually eat the same food.

- ❑ **Complete metamorphosis** (Figure 1.3 B). Insects that develop by complete metamorphosis undergo a complete change in appearance from juvenile to adult. Insect species that undergo complete metamorphosis number more than all of the other species in the entire animal kingdom. This group includes mosquitoes, flies, fleas, beetles, moths, butterflies, ants, bees and wasps.

Insects with complete metamorphosis hatch from eggs as larvae (Figure 1.4 A) (grubs, maggots and

Figure 1.4


Larval (A) and pupal (B) growth stage of *Ades albopictus* (Asian tiger mosquito).

caterpillars). The larval stage feeds, grows and continues its development without changing form through a number of molts until it becomes mature. It then changes into a pupa (Figure 1.4 B), which is often immobile . During the pupal stage, change and body rearrangement occurs, for example, development of wings and legs, resulting in transformation into the adult stage. Reproduction occurs during the adult stage.

The developmental stages of insects with complete metamorphosis support rather than compete with each other. It is as if two or three completely different animals with different needs and habits represent a single species. The larvae feed and live in one habitat and sometimes leave that area to pupate a short distance away. The adults emerge, require a different food source and live in another area, perhaps returning to the larval feeding sites only to lay eggs. For this reason, pest management specialists must manage species with complete metamorphosis according to where the different developmental stages live and how they behave. The reader will need to pay special attention to the growth cycle, behavior and harborages (areas where insects or other pests remain safely hidden during their periods of rest) for each insect.

# Study Questions – Chapter One

1. Organisms classified based on:

2. How many scientific names are given to each organism?

3. How many body regions does an adult insect have, and what are they?

4. What is the most fundamental unit of classification?

5. Insects have how many pairs of legs?

6. Mosquitoes have what type of mouthparts?

7. What is metamorphosis?

8. What are the life stages found within complete metamorphosis?

# CHAPTER TWO

## MOSQUITO CONTROL HISTORY

Mosquitoes occur nearly worldwide (everywhere except Antarctica) and are found in rainforests, deserts, mountain meadows, marshes and coastal swamps, suburbs, inner cities and the Arctic tundra. Ancestors of the presently known 3,450 species of mosquitoes date back to the age of the dinosaurs and the prospect is favorable for their survival for the next 200 million years.

Mosquitoes are small (a typical mosquito weighs about 2.5 milligrams – about 20,000 to a pound), but their impact can be large. The record high mosquito attack rate is about 9,000 bites per minute. That fantastic attack rate was fortunately recorded on the Arctic tundra where few people are found. At that intensity of mosquito bites, it would take about two hours for a human to lose half his blood volume and die. Mosquitoes and the diseases they carry have affected world history. For example, if it were not for the death of 85 percent of French soldiers in Haiti from yellow fever (a disease transmitted by mosquitoes) in 1803, it is doubtful that Napoleon would have sold the Louisiana territory to the United States and settlement of the American west may have taken a much different course. Mosquitoes also had significant impacts on the Roman legions, and the armies of Alexander the Great and Attila the Hun. In the South Pacific during World War II, mosquito-borne disease debilitated more troops than did the bullets and bombs. In addition to disease, the pestiferous nature of mosquitoes leads to human annoyance that often results in uncomfortable conditions for outdoor workers, reduces the enjoyment and profitability of outdoor recreation and can decrease land values. It has been said that were it not for air conditioning and mosquito control, the state of Florida would still have a higher population of alligators than people.

Figure 2.1. Oil treatment to mosquito breeding wetland sites.

The current technology and high standard of living in the United States allows the implementation of effective mosquito control efforts where and when they are needed. The public's interest in mosquito control is currently at an all time high because of renewed concern about mosquito-borne disease as a result of the national outbreak of West Nile virus (WNV) since 1999. Local jurisdictions are receiving mosquito control service through public agency programs and communities are contracting for service with private pesticide applicators at an unprecedented rate.

### History of Mosquito Control in Maryland

Mosquitoes have a long and colorful history in Maryland. Colonial accounts of coastal settlements contain numerous mentions of "gnats and flys" troubling people and livestock by their persistent attacks in large numbers (gnats is the term the English commonly use to denote mosquitoes). Early attempts of "control" consisted largely of "smudge pots" (smoky fires) and numerous forms of personal protection.

The life cycle of mosquitoes was not generally understood by biologists until the 1800's and the relationship between mosquitoes and such diseases as malaria and yellow fever was not discovered until the late 19th century. Understanding the life cycle and discovering the association between mosquitoes and disease led to worldwide mosquito control efforts in the 20th century.

Early mosquito control efforts in Maryland began at the local level and were principally aimed at drainage of swamps and marshes near towns and cities. In 1905, the University of Maryland conducted a survey of mosquitoes in Maryland. This survey was under the supervision of Dr. Thomas B. Symons and Bulletin 109 of the Maryland Experiment Station provides information on the general distribution of mosquitoes in Maryland and a general discussion of methods of control. Between 1909 and 1932 little active mosquito control work was carried out in Maryland. Communities which did carry out control projects during this period included the City of Baltimore, the towns of Chesapeake Beach, Gibson Island and Salisbury. These projects included the digging of drainage ditches, filling of wetlands and the spraying of oil on mosquito breeding wetlands (Figure 2.1).

The Maryland Pest Mosquito Control Project was authorized on December 8, 1933 with the State Entomologist, Dr. Ernest N. Cory, in charge of the operation. This project, made possible by money from the federal government for work relief projects during the Great Depression, resulted in coordinated efforts between the Federal and State Civil Works Administration, the Bureau of Entomology, the Maryland Department of Health, the State Roads Commission, the State Conservation Department and local jurisdictions. The resources allocated for this work included 2,000 laborers, 48 supervisors and $30,000 for materials. Drainage projects were initiated at Chesapeake Beach, Annapolis, Cambridge, College Park, Ocean City, Westminster, Baltimore County, Salisbury, Talbot County, and the Pocomoke River Swamp. The mosquito control projects continued through the 1930's. The greatest amount of work occurred in Worcester County, where most of the salt marsh areas were ditched by 1940. Statewide, during this time, over 3,000,000 feet (586 miles) of ditches were dug by hand for mosquito control in Maryland.

The entry of the United States in World War II generally halted large scale mosquito control projects in Maryland. Local control efforts were undertaken during the 1940's, but without government support, these were small in scale and temporary in duration.

In 1956, the Maryland General Assembly authorized the use of $213,690 State general funds for anti-mosquito work for the 1956/1957 fiscal years under the direction of the University of Maryland, State Board of Agriculture and the State Entomologist, Dr. George Langford. This action of the General Assembly, with the support of Governor J. Millard Tawes, was in response to large populations of pest mosquitoes in the tidewater areas of Maryland and an outbreak of eastern equine encephalitis which affected people and livestock. During the summer of 1956, 82 communities in 11 counties contracted with the University of Maryland for "temporary work" (application of oils for larvae and DDT and BHC for larvae and adult mosquitoes) and/or "permanent work" (ditching and filling). The counties and communities were required to pay at least 50 percent of the total cost for temporary work and at least 25 percent of the cost for permanent work. Total local funds provided by the communities or counties for mosquito control in the summer of 1956 was $46,936.80.

Funds for mosquito control have been allocated by the Governor and the Maryland General Assembly in the State's budget each year since 1956. In 2004, over 2,204 communities participated in the mosquito control service provided by public agencies. During fiscal year 2005, a total of $3,160,174 was allocated for public agency mosquito control operations in Maryland. This includes $2,110,174 in State funds and $1,050,000 in local funds. An additional $78,051 in federal funds through a grant from the Maryland Department of Health and Mental Hygiene was provided for mosquito-borne disease surveillance. The Maryland Department of Agriculture provides mosquito control service to communities in 19 Maryland counties and the City of Baltimore. In Calvert County, service is provided by the County Department of General Services. In Caroline County and Queen Anne's County, mosquito control is a function of the counties' Public Works Departments. No mosquito control service is currently provided in Garrett County because the mountainous terrain is not favorable to mosquito breeding.

**Time Line of Mosquito Control Efforts in Maryland**

| | |
|---|---|
| 1600 – 1900 | No mosquito control |
| 1905 | First survey of mosquitoes in Maryland by Dr. Symons, State Entomologist. |
| 1909 – 1932 | Local mosquito control drainage projects in Baltimore, Chesapeake Beach, Gibson Island and Salisbury. |
| 1935 – 1940 | Pest Mosquito Control Project initiated under the direction of State Entomologist Ernest Cory. This was a combination mosquito control and employment project during the Great Depression. |
| 1941 – 1955 | Local control efforts, but no permanent program in place. |
| 1945 | 180 horses die from eastern equine encephalitis (EEE) on the Eastern Shore. |
| 1956 | Two human cases and 75 horse cases of EEE on the Eastern Shore. Maryland General Assembly approves Governor Tawes' proposal to provide funds for a statewide mosquito control project under the direction of the State Entomologist and the University of Maryland. |
| 1973 | The Maryland Department of Agriculture (MDA) is created and legislative responsibility for mosquito control is transferred to MDA from the University of Maryland. |
| 1975 | St. Louis encephalitis outbreak occurs in Central Maryland and the Eastern Shore. Ultra low volume equipment replaces mist blowers for mosquito adulticiding. Maryland begins open marsh water management for salt marsh mosquito control. |
| 1977 | Aerial spraying becomes a routine component of mosquito control operations. |
| 1989 | Eastern equine encephalitis (EEE) outbreak kills eight horses and one human on the Eastern Shore. |
| 1991 | Open marsh water management program is stopped by environmental regulations. |
| 1996 | Maryland purchases an Aztec aircraft for mosquito control spraying to replace contractual aerial spraying services. |
| 1999 | West Nile virus is first detected in Maryland in one crow from the City of Baltimore. |

| | |
|---|---|
| 2003 | Maryland experiences the largest outbreak of mosquito-borne disease recorded in the State with 73 cases of West Nile virus illness in people (8 deaths) and 234 horse cases (78 horse deaths) plus three horse deaths from EEE. |
| 2005 | Maryland purchases a Beechcraft King Air airplane and begins use of night vision technology to improve aerial spraying capability. |

## Study Questions – Chapter Two

1. What is responsible for the most recent increase in public demand for mosquito control in the Unitrd States?

2. What led to the worldwide mosquito control efforts in the 20th century?

# CHAPTER THREE

## MOSQUITO BIOLOGY

Mosquitoes are in the family Culicidae of the order Diptera, the true flies, and are similar in appearance to other flies. The **anophelines** (*Anopheles* spp. only) differ from the **culicines** (all other mosquito genera occurring in the U.S.) in many physical and behavioral characteristics (Figure 3.3).

Mosquitoes pass through four distinct stages in their life cycle: egg, larva, pupa and adult (Figure 3.2). Large numbers of mosquitoes can hatch simultaneously under the proper conditions. In rapidly developing broods, survival of the immature stages can be quite high, but estimates for many species indicate that immature survival is normally less than 5 percent. But 5 percent of millions represents a sizable number. Irrespective of population densities, if they transmit disease or preferentially feed on humans, which many species do, they become appropriate targets for control activities. This chapter deals with the **bionomics** of mosquitoes which is key to understanding the best methods to conduct surveillance and subsequent control of specific species.

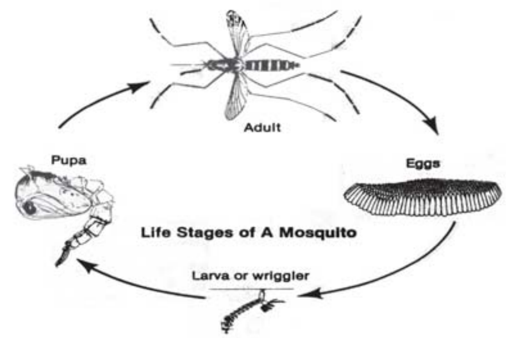



Figure 3.2. Life cycle of the mosquito: egg, larva, pupa and adult.

## Developmental Stages

### Immature Stages

**Eggs**. Mosquito eggs are white in color when first deposited but darken to appear glossy black within 12 to 24 hours. Most species' eggs appear similar when seen by the naked eye, with the exception of the *Anopheles* spp., whose eggs have floats attached to each side. When viewed with magnification, eggs of different species can be seen to vary from canoe-shaped to elongate or elongate-oval in shape (Figure 3.1). Some species lay eggs singly, and others glue them together to form rafts. The incubation period (elapsed time between oviposition and readiness to hatch) is dependent on environmental and genetic factors and varies considerably among different species.

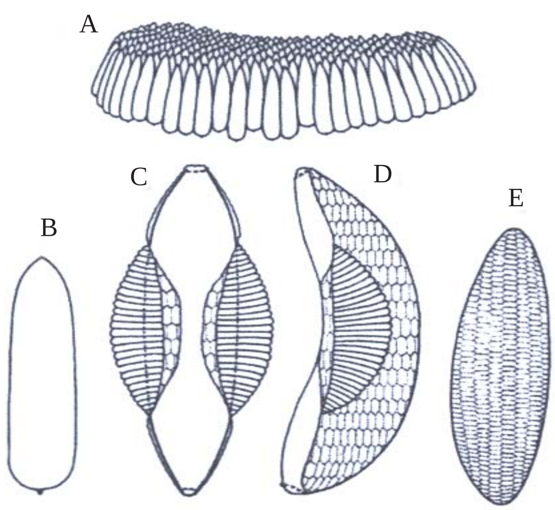



Figure 3.1. Eggs of mosquitoes. A - Egg raft of *Culex*. B - Single egg of *Culex*. C - Egg of *Anopheles* (top view). E - Egg of *Aedes* or *Ochlerotatus*.

Permanent water and standing water species deposit their eggs directly on the water surface, and these may hatch in one to four days depending on temperature. Floodwater and many container-breeding species deposit their eggs on moist soil or other wet substrates. These eggs may hatch within a few hours after being flooded, or the fertilized egg may remain in the embryonic state for up to a year or more depending on environmental conditions (temperature, length of daylight, etc.) and genetic (species) factors. These quiescent eggs accumulate over time due to continued oviposition by blood-fed females. When temporarily flooded, they hatch, along with more recently deposited eggs. Populations can attain large numbers quickly this way. Some mosquito species typically have several generations per year, or mosquito season, while other species will produce only one generation per year.

**Larvae**. Larvae (wigglers or wrigglers) of all mosquitoes live in water. Near the last abdominal segment in most species is a siphon or air tube that serves as a respiratory apparatus when the larva

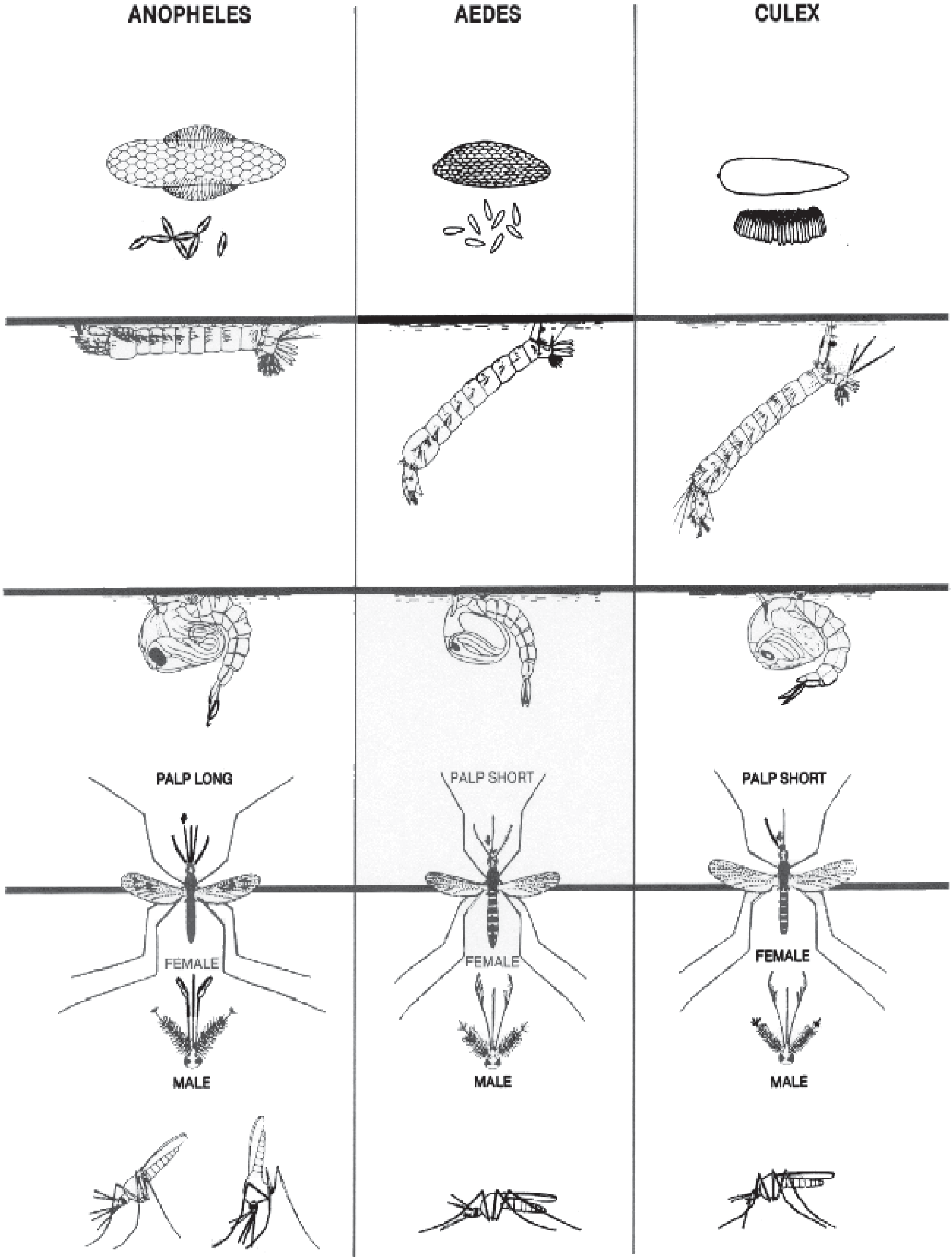



Figure 3.3. Characteristics of the developmental stages for the Genera *Anopheles*, *Ades* and *Culex*
(Communicable Disease Center, Atlanta, Georgia)

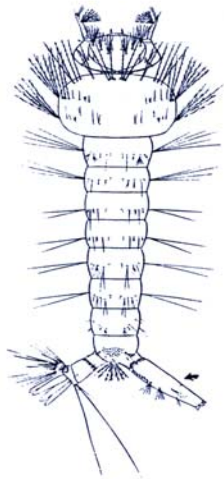



Figure 3.4. Larva of *Culicine* mosquito. Note prominent air tube.

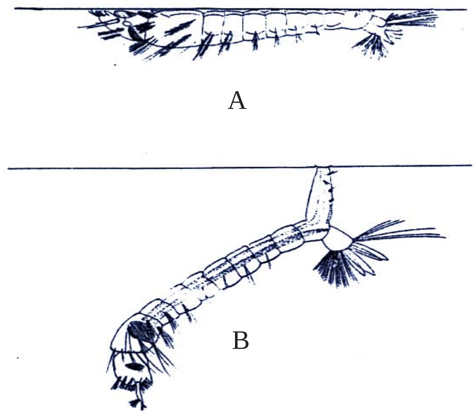



Figure 3.5. Feeding/resting positions of mosquito larvae. A - *Anopheles*; B - *Culicine*.

suspends vertically below the water surface (Figure 3.4 and Figure 3.5 B). Larvae of *Anopheles*, however, breathe through clusters of palmate hairs on the abdomen, which cause them to lie parallel to the water surface when not diving (Fig. 3.5A and Fig. 3.6).

Mosquito larvae are generally filter feeders, ingesting anything smaller than about 10 microns by vibrating their mouth brushes and sweeping in particulate matter and microorganisms from the surrounding water.

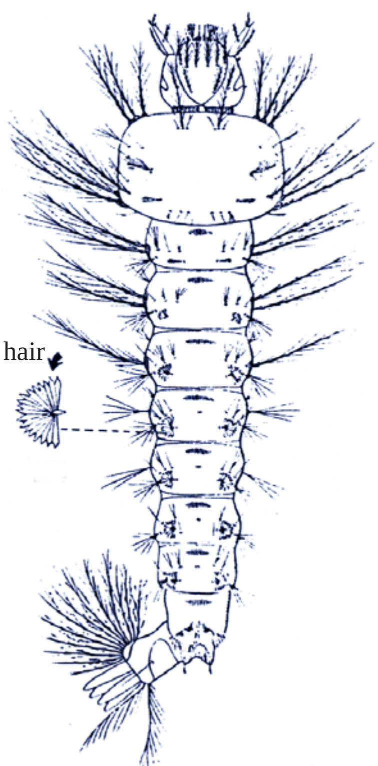



Figure 3.6. Larva of *Anopheles* mosquito. Note lack of air tube and presence of palmate hairs.

Many mosquito larvae can also "graze" algae and microorganisms, such as bacteria, from particulate matter found in their habitat. Two mosquito species in Maryland are predaceous as larvae, feeding on other mosquito larvae and small invertebrates. *Toxorhynchites rutilus septentrionalis* is commonly called the cannibal mosquito because of its preference to feed on other larvae. *Psorophora cliate*, or gallinipper*, is another predaceous larvae. The cannibal mosquito and the gallinipper are the largest mosquitoes found in Maryland because of their high protein larval diets.

Mosquito larvae have an external skeleton that allow limited expansion as the larvae grow. To accommodate the growth of larvae, old external skeletons, commonly called "skins", are shed. This process is called moulting. The exoskeleton is larger than the moulted "skin" and allows for continued growth. The interval between moults is called an **instar**. Mosquito larvae go through four instars. The larva emerging from a hatching egg is a 1st instar, after the first moult, the larva becomes a 2nd instar and so on until the 4th instar stage is reached. The 4th instar larvae is the largest. The fourth larval molt results in the pupal stage. Depending on species and environmental conditions, larval development from egg hatch to the pupal stage may take as little as four days up to several weeks. A few species such as some *Anopheles*, *Coquillettidia perturbans* and *Culisetta melanura* overwinter as larvae.

Appendix 1 and 2 provides a pictorial key to mosquito larvae found in the United States.

*Due to its large size and the preference of the adult mosquito for feeding on animals such as cattle, mules and horses, old farmers joked that this mosquito could take a "a gallon (of blood) each nip (bite)", hence the name gallinipper.

**Pupae**. Unlike most insect pupae, mosquitoes can be very active in the pupal stage (Figure 3.7) and are often called "tumblers" because of their rapid, tumbling movement when disturbed. Mosquito pupae breathe through two respiratory "horns" when at the water's surface and do not feed, relying on fat reserves stored as larvae. In the pupal stage, there occurs a transformation from the aquatic larva to the terrestrial adult mosquito. This process typically takes 2 to 3 days to complete.

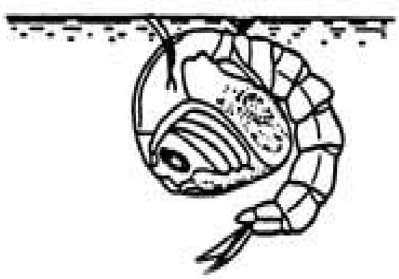


Figure 3.7. Mosquito pupa.

## Adult Mosquitoes

Adult mosquitoes (Figure 3.8) appear to be small fragile insects with three body regions: head, thorax and abdomen. They have one pair of narrow wings and six slender legs. Depending on species, size varies, but a typical mosquito is about ¼ inch in length and weighs 2.5 to 5 milligrams.

About equal numbers of male and female mosquitoes emerge from the pupal stage. The males typically emerge first and wait for females to emerge 12 to 24 hours later. A female mosquito will mate only one time in her lifetime, but will be able to lay several batches of fertile eggs as a result of that mating. Male mosquitoes compete to mate with as many females as possible. Only female mosquitoes bite and most (but not all) species require a blood meal before laying eggs. Male mosquitoes feed only on plant nectar.

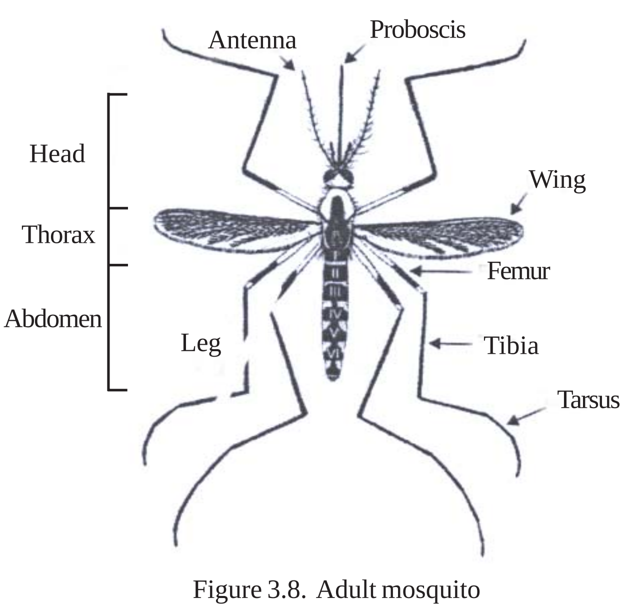



Figure 3.8. Adult mosquito

Flight distances of mosquitoes vary widely. Some species, such as *Aedes aegypti* and *Aedes albopictus*, fly only a few hundred feet from their domestic breeding sites while others, such as salt marsh mosquitoes, can fly 20 miles or more. Most mosquitoes have a flight range of 1 to 5 miles. Female mosquitoes typically travel greater distances (varies from hundreds of feet to 20 miles or more) from breeding sites and live longer than males. Why do mosquitoes move around so much? It is probably a combination of factors:

(1) searching for a suitable host for a blood meal;

(2) an instinctive drive to expand to new territory; and

(3) the effect of wind and weather.

Mosquitoes show great variation in their preferences for the animals from which they take blood meals. Some species feed exclusively on birds, others only on small mammals and a few species prefer to feed only on humans. Many mosquito species may show a preference for a certain group of animals, but will readily feed on another if the preferred host is not available. This nondiscriminatory blood feeding behavior accounts for the transmission of encephalitis viruses from birds to humans and horses. A few species, such as *Culex territans*, feed only on cold-blooded animals and are not pests or involved in any known disease transmission cycle. One mosquito species in Maryland, *Toxorhynchites rutilus septentrionalis*, does not feed on blood of any type, and adult males and females of this species feed only on plant nectar or plant juices. Some mosquito species feed only during the daytime while others are active only at night. As a general rule, daily activity is greatest for most mosquito species in the periods just after sunset and just before sunrise.

The female mosquito requires two or more days to digest a blood meal, lay a batch of eggs and begin to search for another blood meal. This cycle of blood feeding, laying eggs and feeding again can be repeated several times in the life of a female mosquito. How long can a mosquito live? One to two months is the maximum longevity during the spring, summer and fall months, but species that survive the winter by hibernating as adults may live five to six months. Most adult mosquitoes will die before they are three weeks old. Hot, dry weather is the leading cause of death of most mosquitoes and an extended period of such weather will result in a shortened life span of most mosquitoes. Humid conditions favor longer life spans, as does cool (but not freezing) air temperature. The longevity of a mosquito's life is an important factor in understanding the epidemiology of mosquito-borne disease. The longer a mosquito lives and the more times she feeds on blood, the greater the chance of being infected with a disease-carrying organism and transmitting the disease in a subsequent blood meal.

## Mosquito Breeding Habitat Types

Those casually acquainted with mosquitoes may believe that all types are much the same and, indeed, the similarities between species are considerable. There are, however, many differences in appearance from species to species and even among some varieties within species. These morphological differences, especially notable in the larval and adult stages, permit accurate identification of most species. Behavioral differences permit various species to occupy numerous ecological niches with relatively little overlap. Thus, knowledge of the source or breeding habitat of mosquitoes can provide strong clues to their identification.

Mosquito control requires knowledge of the behavioral and larval habitat differences among species in order to plan and carry out a treatment program. The trained worker first identifies the problem species. With identity established, useful correlations are immediately available, such as the type of breeding habitat and where to search for larvae. A working knowledge of the behavior and of habitats frequented by various species aids in determining the kinds of survey and control strategies best suited for the task.

Mosquitoes are not adapted to life in moving waters, but they can occupy the quiet pools and seepage areas near flowing streams. Aquatic environments differ chiefly in the chemistry of the water (acid or alkaline; fresh, salt or brackish). These environments may be natural or man-made and may also differ in the amount or type of vegetation present and the amount of sun or shade. *Coquillettidia perturbans*, for example, are found in association with specific aquatic plants — especially cattails. *Wyeomyia* spp. are found in association with bromeliads and pitcher plants. In this regard, the distinctive egg-laying habit of each species of mosquito determines its larval habitat. Although some species use more than one type of habitat, most mosquitoes can be categorized in general terms by their preference for either permanent water, floodwater, transient water or artificial container and tree-hole habitats. These categories can be combined into two major larval habitat categories: standing water (permanent and transient) and floodwater (including natural and artificial containers).

**Standing water species** deposit their eggs (either singly or cemented together in groups called rafts) on the surface of permanent or transient pools of standing water. They usually produce several generations (broods) each year and overwinter or survive harsh environmental circumstances as mated, engorged females. In contrast, **floodwater species** deposit their eggs out of the water but in locations subject to periodic flooding, such as damp soil in depressions or inside tree holes and artificial containers. They produce one to several broods annually and overwinter or survive harsh environmental circumstances in the egg stage. Mosquitoes are adaptable to changing environmental conditions and are thus associated with multiple habitat types.

The **Standing Water Group** - These mosquito species are generally found in quiet freshwater or brackish water habitat exposed to sunlight, with abundant surface vegetation. Typical sites are shallow margins of ponds or smaller lakes and stormwater management sites. Mosquitoes of the genera *Anopheles*, *Coquillettidia* and some species of *Culex* (primarily *salinarius* and *territans*) are found in habitats where water is present for several weeks or longer. These species lay their eggs directly on the water surface, singly for *Anopheles*, or in rafts for *Culex* and *Coquillettidia*. Breeding is usually continuous, with several generations a year. Flight ranges for these mosquitoes are relatively short, within 3 miles or so of the breeding area, except for *Coquillettidia*, which is a stronger flier that can travel more than 10 miles.

Freshwater and brackish water marsh: Mosquito species often found in these marshes include *An. walkeri*, *An. crucians*, *Cx. nigripalpus*, *Cx. salinarius*, *Cx. tarsalis*, *Cx. erraticus* and *Cq. perturbans*.

Lakes and Ponds: Larvae may be found throughout a lake or pond when floating or emergent plants are present. But, where vegetation occurs only in a narrow band along the lakeshore, larvae are confined to this littoral zone. Lake/pond species include *An. crucians*, *An. quadrimaculatus* spp. complex, *An. walkeri*, *Uranotaenia sappharina*, *Cx. salinarius*, *Cx. erraticus*, and *Cq. perturbans*.

Swamps: Swamps differ from marshes principally in vegetation type. Marshes are dominated by grasses or rushes. Swamps are dominated by trees and shrubs. The most common species of mosquito larvae found here are *An. crucians*, *An. quadrimaculatus* spp. complex, *Cs. melanura*, *Oc. canadensis*, and *Cq. perturbans*.

The **Temporary Water Group** - This group contains *Culiseta*, some *Culex*, and occasionally *Anopheles* species. Their habits are similar to those of permanent water species, but they are more often found in pools of a more transient nature as opposed to ponds, lakes or permanent wetlands. Typical habitats are roadside ditches, grassy pools, backed up creeks, ruts and puddles. Species associated with this group are *Cs. melanura*, *Cx. pipiens*, *Cx. restuans* and *Cx. salinarius*.

Salt or brackish water ditches: The ditches adjacent to saltwater marshes contain many species of grasses and support a large mosquito fauna, including *An. Bradleyi*, *Cs. inornata* and *Cx. salinarius*.

Borrow pits and canals: These man-made bodies of open water produce more mosquitoes as they silt-in and become overgrown with vegetation. They yield *An. quadrimaculatus* spp. complex, *Cs. inornata*, *Oc. canadensis*, *Cx. quinquefasciatus*, *Cx. restuans*, *Cx. salinarius*, and *Cq. perturbans*.

Freshwater drainage ditches: In pastures, at the bottom of road shoulders and in lowland groves, freshwater ditches will often yield the following species of mosquito larvae: *Cx. pipiens*, *An. crucians*, *An. walkeri*, and *Cx. restuans* .

Polluted water: Sewage disposal settling ponds, animal waste lagoons, impoundments holding waste water from food processing or animal processing sites, ditches receiving sewage runoff from human or animal waste, and abandoned swimming pools and storm drains all are high in biological nutrients and are important sources of *Cx. pipiens* and *Cx. quinquefasciatus*.

The **Floodwater Group** - The genera associated with this group are *Aedes*, *Ochlerotatus* and *Psorophora*. These species lay their eggs singly on damp soils which are intermittently flooded, such as woodland (vernal) pools, salt marsh depressions or irrigated fields. If conditions are right, eggs hatch after being flooded. Otherwise, they remain dormant and viable on the soil until a more favorable flooding event. Often, the eggs must go through a period of drying before hatch. These hatchings can produce large broods since larval development is uniform and during the summer adults frequently emerge less than a week after hatching occurs. This can result in a very large population of adults and, consequently, large pest problems for surrounding populated areas.

Some species produce a single brood per year, but many species have multiple broods. They all overwinter as eggs. Some species fly long distances from breeding areas (from 5-20 miles or more), while others stay close to their woodland habitats. Many species in this group are important vector or pest mosquitoes, including *Ae. vexans*, *Oc. candensis*, *Oc. sollicitans* and *Ps. columbiae*.

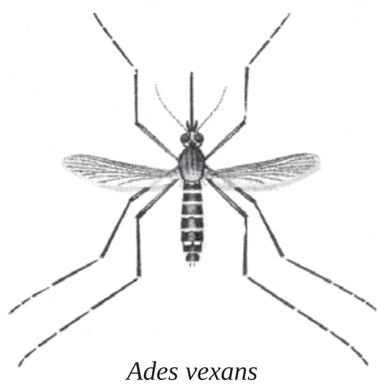
Tidal marsh: Salt-tolerant herbaceous plants and typical salt grasses dominate this type of habitat. Extensive areas are often covered by a single plant species such as *Distichlis spicata*, *Spartina patens*, or *Spartina alterniflora*. *Oc. sollicitans*, *Oc. taeniorhynchus* and *Oc. cantator* are the most numerous floodwater mosquitoes found breeding in Maryland tidal marshes.

Rain and floodwater pools: These pools form the breeding place for a large number of species, especially *Aedes*, *Ochlerotatus*, and *Psorophora*. The pools disappear in dry weather and support no true aquatic vegetation, though usually a layer of leaves and other detritus settles on the bottom. Mosquito species found in this habitat include *Oc. atlanticus*, *Oc. infirmatus*, *Oc. mitchellae*, *Oc. sticticus*, *Oc. tormentor*, *Ae. vexans*, *Ae. cinereus*, *Ps. ferox*, and *Ps. columbiae*.

The **Tree-Hole and Artificial Container Group** - The species in this group are in the genera *Aedes*, *Ochlerotatus*, *Toxorhynchites* and *Orthopodomyia* and have specialized habits. Eggs are laid singly on the inside wall of the treehole or container, at or above the waterline, or in dry containers which have previously been flooded. The eggs hatch when flooded. These species overwinter as eggs, or occasionally as adults, and produce several broods per year. Several species in this group are important vector or pest mosquitoes, including *Ae. albopictus* and *Oc. japonicus*. Several *Culex* species, although not normally grouped here, will breed readily in artificial containers of all types.

Because of their association with artificial containers, human habitation and their vector abilities, *Cx. pipiens* and *Ae. albopictus* are important targets of urban and suburban mosquito control programs. *Ae. albopictus* has also become a major pest mosquito in some rural areas of Maryland.

## Bionomics for Species Common in Maryland



*Ades vexans*

***Aedes vexans*** is the most widespread pest species in the world, and the most widespread of the *Aedes* species in the United States. It is generally a medium size dark brown mosquito but can be highly variable in size and markings. It has narrow white basal bands on all tarsi, and white basal bands on the abdomen, with an inverted dark v-shaped notch on segments 3, 4 and 5.

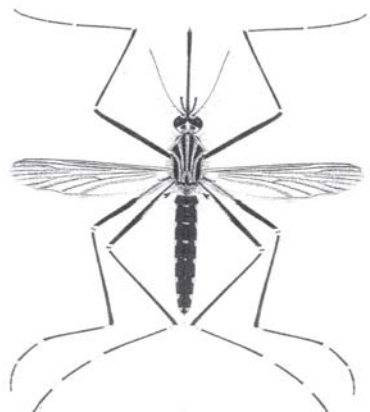
The females are persistent biters at dusk and after dark, and they will bite during the day in shady areas. Adults are strong fliers, commonly found several miles from their larval habitat. Females can be long-lived, sometimes surviving for 2 months. The species overwinters as eggs, laid on the ground in the fall. The eggs hatch when water in flooded areas reaches about 70$^{o}$ F. The eggs hatch in installments , with not all hatching during the first flooding. The larvae are found in floodwater areas, such as woodland pools, tire ruts, ditches or rain-filled meadows and depressions. They will breed in practically any temporary fresh water, and larvae do not show a preference for shade or sunlight within their habitat. Emergence of adults usually begins in May and continues, with several generations, through late September or early October.

Females are readily attracted to light traps (baited or unbaited) and to humans during landing rate counts. This species is a very common and serious pest species. Its vector potential is considered high. California encephalitis (CE), St. Louis encephalitis (SLE), Eastern Equine encephalitis (EEE) and West Nile Virus (WNV) have all been isolated from field collected *Ae. vexans*. It is also considered a primary vector of dog heartworm.

***Aedes albopictus*** is an exotic species, imported from Japan into the United States in 1985. The common name of this species is the Asian tiger mosquito due to its striped appearance. It has spread very quickly throughout the U.S. by laying eggs in used tires, which are then transported all over the country. It is small to medium in size, very dark black, with bright white stripes on the legs, head & thorax. The last 2 tarsal segments on the hind legs are white.

Tiger mosquitoes are persistent biters, attacking primarily during the day. They tend to bite low to the ground and the adults are easily disturbed when blood feeding. They readily enter buildings and cars. They are weak fliers, remaining within several hundred yards of their breeding areas. They readily feed on humans, domestic animals and birds. The species overwinters as eggs, or occasionally as adults in sheltered areas. Eggs are laid in dry containers, or just above the waterline in those with water. Hatching occurs when the eggs are flooded. Tiger mosquitoes breed exclusively in holes in trees, bamboo shoots or man-made containers of all kinds. In Maryland, this species shows a strong preference for breeding in containers, particularly tires. They can adapt to a very wide range of confined water areas and can develop in very small amounts of water. Egg laying, development, and emergence are continuous if conditions are favorable with multiple generations per year. The population of adult tiger mosquitoes builds throughout the summer months, usually peaking in early September.

Female tiger mosquitoes are not readily attracted to baited or unbaited light traps, but can be collected in Fay Prince traps and in landing rate counts. They can cause severe nuisance problems in urban and suburban areas and are difficult to control due to their containerized life habits. In other countries, they are vectors of dengue and yellow fever. In Maryland, they have been implicated in urban transmission of WNV. EEE and CE viruses have been isolated from them in other states.

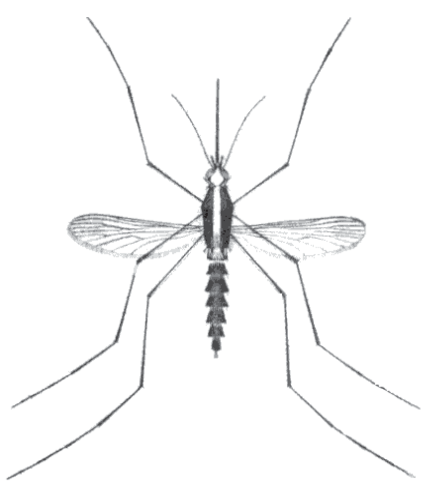


*Ochlerotatus japonicus*

***Ochlerotatus japonicus***, another imported Asian species, is relatively new in Maryland and many of its habits are not yet known. It was first discovered in the U.S. in 1998 from light traps in New Jersey and New York. It has now been found in at least 20 states and Canada. This species is a medium sized brown mosquito with yellow lyre-shaped markings on the thorax. It has an unbanded proboscis and palps, banded legs, and its last 2 tarsal segments are dark.

Adults can be collected from late April through late October. Unlike the Asian tiger mosquito, females do not seem to be aggressive human biters,. Flight range, as with other container breeders, is short. Egg laying and larval habitat are similar to *Ae. albopictus*, but *Occhlerotatus japonicus* can also be found in rock pools and occasionally in non-contained areas such as tire ruts or cement catch basins.

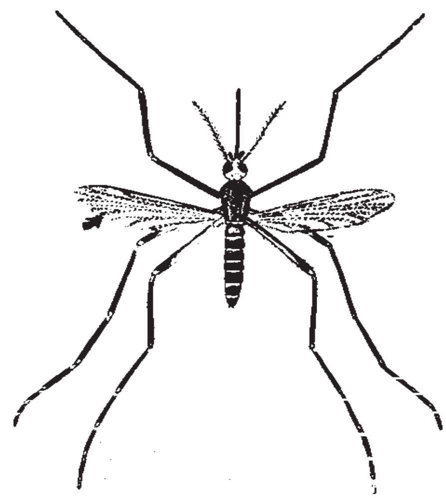
This species is somewhat attracted to light traps, but apparently not to humans in landing rate counts. Laboratory studies show it has tremendous vector potential for WNV and several other mosquito-borne viruses; however, its role in natural transmission of these viruses is not yet known.



*Ochlerotatus atlanticus*

***Ochlerotatus atlanticus*** can be extremely numerous in coastal plain areas under certain conditions. It is a medium sized, dark brown mosquito with no banding on the proboscis or legs and very little, if any, banding on the abdomen. The thorax has a conspicuous, wide, whitish-yellow stripe down the center.

Larvae are found in temporary pools in woodlands or open fields. Females are persistent biters even during daylight hours in shade or occasionally in sunlight. This species can become a serious nuisance in coastal areas after heavy rains.



*Ochlerotatus canadensis*

***Ochlerotatus canadensis*** is widely distributed throughout the U.S. and is very common in Maryland early in the season. It is a medium sized dark mosquito. The tarsi have white bands at the basal and apical ends of the segments.

Females are general feeders, attacking a variety of mammals, reptiles, amphibians, and feeding to a lesser extent on birds. They are our most abundant early season mosquito, the first to appear in the spring and usually are not commonly found after late June, but under favorable conditions can reappear in large numbers in late summer and early fall during wet years. Adults can live for several months. They rarely fly far from their larval habitat, generally remaining in the woods, and are aggressive biters in the shade during the day and at night. This species overwinters as eggs, which hatch very early in the year. First instar larvae can often be found in January or February. Egg hatching is staggered throughout the spring. There is usually one generation per year, however, large flooding events in the summer or fall can trigger another brood. Larvae develop mainly in leaf-lined woodland pools but they may use any early season temporary water areas.

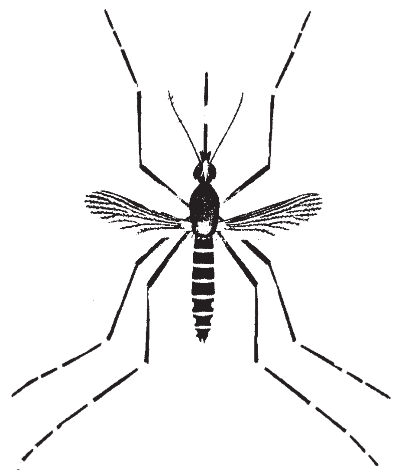
This species is readily collected in light traps and landing rate counts. It can be a serious pest in wooded areas, along with being an efficient vector of dog heartworm and it may also be a vector of viral disease.

*Ochlerotatus sollicitans*

***Ochlerotatus sollicitans*** is the dominant salt marsh species along the northern and mid-Atlantic seaboard of the United States. Adults are large and robust. They have a banded proboscis and legs, and intermixed dark and pale scales on the wings. The thorax is covered on the sides with dense patches of white scales and on top with brown, yellow, golden, and white scales. There is a longitudinal white stripe down the center of the abdomen.

Females are general feeders, attacking humans and a variety of animals. They are very strong fliers, sometimes traveling 50 miles or more. Females bite primarily at twilight (dusk more than dawn) but will readily attack during the day if hosts enter their habitat. The species overwinters as eggs laid in depressions in the high salt marsh. Eggs are laid singly on a moist substrate or on plants in marshes above the daily tide line, where they remain until being flooded with heavy rainfall or very high tides. Eggs hatch when flooded, usually all at once, and the larvae often cluster in dense balls. Larvae are found in pools in the high marsh as well as dredge spoil areas and mine tailings. Adults emerge 4-10 days after egg hatch, frequently in huge swarms. There are several generations per year, with adults active from May through October.

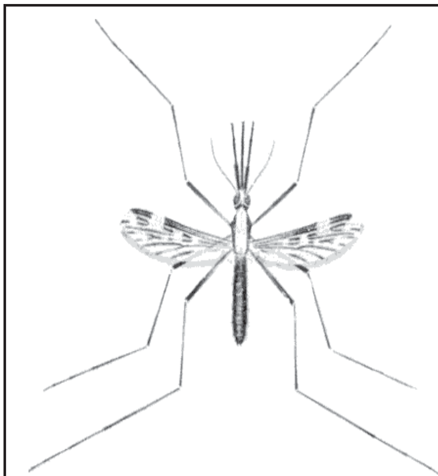
This species is readily collected in light traps and landing rate counts. It is a tremendous pest species all along the Atlantic coast and an important bridge vector of EEE, transmitting the virus from birds to horses or humans. WNV, SLE, CE and dog heartworm filaria have all been isolated from this species.



*Ochlerotatus taeniorhyncus*

***Ochlerotatus taeniorhyncus*** can be found all along the Maryland coast in salt marsh areas. It is a very dark, small species with white bands on proboscis and legs. It has white abdominal bands with white markings towards the sides of the last several segments.

This species is a fierce and persistent biter, feeding mainly at dusk and after dark, or during the daytime in shade. It is a strong flier and its habitat is similar to *Oc. sollicitans,* although it will breed in freshwater pools near salt marshes as well. It can develop rapidly from egg to adult, and has several generations per year. Larvae often congregate in dense balls .

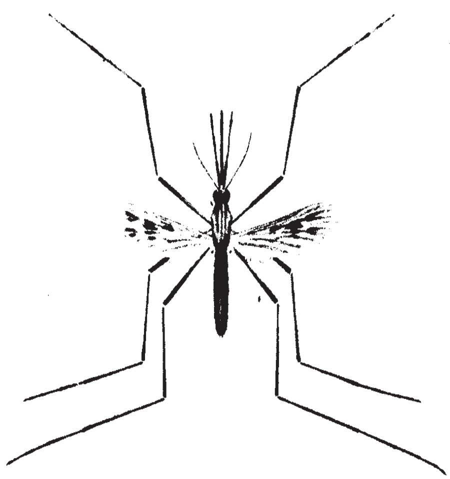


*Anopheles punctipennis*

This mosquito is an abundant and serious pest near salt marshes, and uncontrolled, it can have major economic impacts. It is a vector of dog heartworm, but is not considered a major vector of the viral encephalitis diseases.

***Anopheles punctipennis*** is a fairly large mosquito with long legs. All *Anopheles* have palps as long as their proboscis. *An. punctipennis* has 2 conspicuous pale areas on the front edge of the wing.

Females are active only at night and are vicious biters after dark. They can fly up to a mile from their larval habitat. Adult females overwinter in sheltered hibernacula such as caves, culverts or basements. They emerge in the spring to lay eggs. Eggs are laid singly on the water surface. Larvae are found in permanent or semi-permanent pools such as ponds, woodland pools, swamps, stream margins, or large ruts and puddles.



*Anopheles quadrimaculatus*

***Anopheles quadrimaculatus*** is widespread east of the Rocky Mountains. It is a fairly large, dark brown mosquito with long legs, and wings with 4 darker patches of scales near the center. It is the most important vector of human malaria in the eastern United States.

Adult fertilized females overwinter in tree hollows, caves, basements, etc. They may emerge from hibernation and take bloodmeals on warm winter days. Females are not strong fliers, staying within ½ mile to 1 mile of breeding areas. Larvae are found in ponds and swamps with aquatic vegetation or floating debris, rice fields, and edges of creeks or streams. They are most abundant in shallow water. They hide in the floating vegetation to avoid predators and can also change color to mimic that of their habitat. Adult females are inactive during the day, hiding in dark sheltered spots and feeding only after dark. There may be up to 10 generations per year.

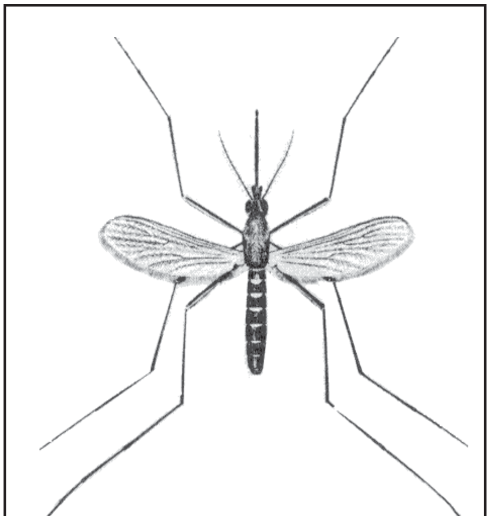
Adult females are only slightly attracted to light traps and can be taken in landing rate counts only outside of lighted areas. It is best collected from its daytime resting locations in livestock barns or outbuildings by use of an aspirator. This species is the most important U.S. vector of malaria east of the Rockies and may be a major vector of dog heartworm. It is also a significant pest of humans and livestock. *An. quadrimaculatus* will enter homes to attack humans.

*Anopheles crucians*

***Anopheles crucians*** is a medium-sized brown species. The tip of the wing is white, with three dark spots on the anal vein and the front margin of the wing is dark-scaled. This species is most numerous in the lower Eastern Shore of Maryland. It breeds in acidic freshwater swamps and ponds. It feeds on people, pets and livestock and will readily enter barns and houses in search of a bloodmeal. This mosquito is most active at dusk and at night, but will attack on overcast, cool days. This species overwinters as adults and larvae.

Another species, ***Anopheles bradleyi***, also occurs in brackish water habitats in Maryland marshlands. The adults are not taxonomically distinguishable from *An. crucians* and they share similar characteristics. However, the larvae of *An. bradleyi* are more likely to be found in saltwater and brackish water marshes.

***Culex pipiens*** is a medium sized light brown species which lacks distinctive markings; however, it does have white bands on the abdominal segments. It

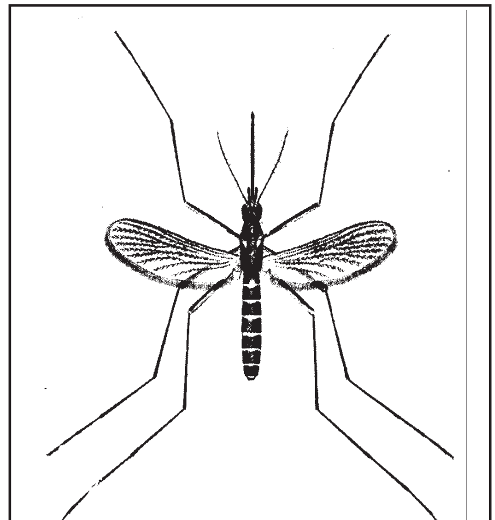


*Culex pipiens*

is indistinguishable from *Culex quinquefasciatus* (which also occurs in Maryland) and is difficult to separate from *Culex restuans* (Figure 3.8)if the specimens are older or the scales have been rubbed off at all.  It is known as the common house mosquito and is widespread in the U.S.

Females feed mainly on birds and much less often on mammals. Although there are reports in some urban areas of it being a pest species, this confusion may occur where *Cx. pipiens* and *quinquefasciatus* overlap. The inseminated female overwinters in hibernacula such as caves, culverts, basements, or other warm places. Eggs are laid on the water surface in rafts of up to 250 eggs. Larvae can be found in just about any standing water, particularly water that has a high organic content. They breed in clear grassy puddles, catch basins, street gutters, drains, ditches, mulch dumps, sewage treatment plants, and containers. Adults usually fly less than a mile from breeding areas and are active only at night. They commonly enter houses.

Females are not strongly attracted to light traps unless the traps are baited with $CO_2$, but are attracted to gravid traps. This species is an important urban bird vector of SLE, a known vector of Western Equine encephalitis (WEE) and is also implicated in the transmission of WNV, EEE and CE. It can also transmit avian malaria, bird pox, dog heartworm and filariasis.



*Culex restuans*

***Culex restuans*** is a medium sized, brown mosquito, that is difficult to distinguish from *Cx. pipiens*. If specimens are in good condition, *Cx. restuans* will have 2 light spots at the highest point of the thorax (Figure 3.8).

This species reaches its largest numbers in the spring and early summer, with fewer present in the late summer and early fall. Larvae are found in a wide range of habitats including ditches, stream edges, woodland pools, grassy pools, and artificial containers.

Some say that females can be persistent biters while others contend they rarely attack humans. *Cx. restuans* is an important vector of bird to bird transmission of WNV.

***Culex salinarius*** is a medium sized, brown mosquito, similar to *Cx. pipiens* and *restuans* but with many pale scales on the last 1 or 2 abdominal segments

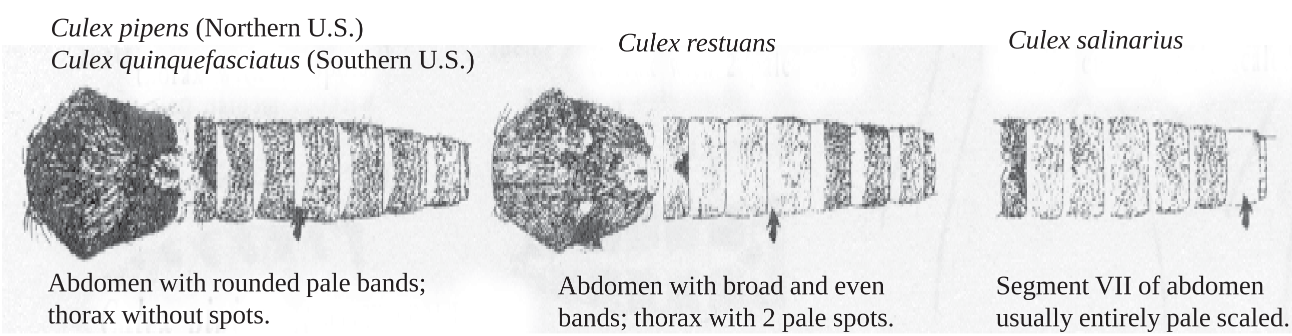
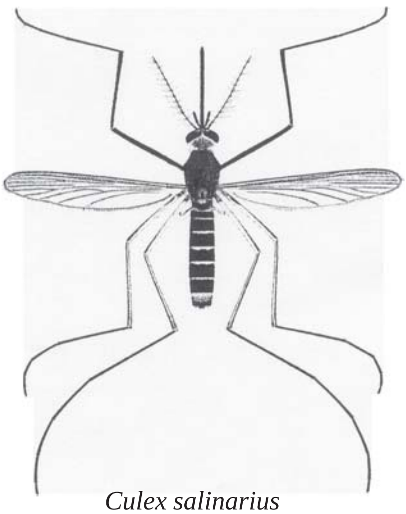



Figure 3.8. Abdominal charteristics for *Culex pipens*, *Culex restuans* and *Culex salinarius.*



*Culex salinarius*

(Figure 3.8). This species is widespread in coastal plain areas, occurring in extremely large numbers in large marshlands bordering the Chesapeake Bay and coastal bays of Maryland.

Females bite readily at dawn, dusk and for several hours after sunset. They are active through the night and will occasionally enter houses. They are general feeders, biting birds, mammals, reptiles or amphibians. They will fly farther than their other *Culex* relatives, up to 5 miles. There are several generations per year, with females laying egg rafts on grassy pools of fresh or brackish water. Their larval habitat often contains emergent or decaying vegetation and includes lake margins, ponds, swamps, marshes, ditches, and containers. This species overwinters as adults but hibernacula can be hard to find.

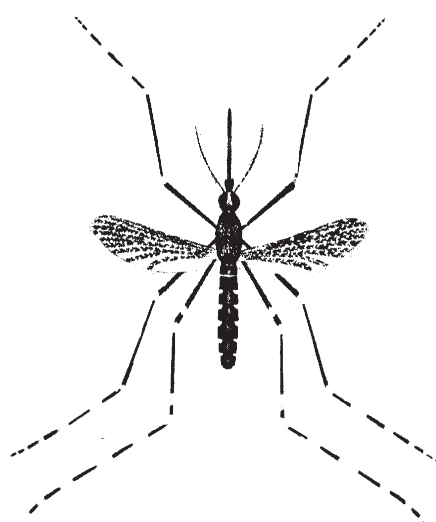
Females are attracted to light traps, both nonbaited and baited with $CO_2$. This species is an important pest since it readily bites humans. It is an efficient vector of SLE and WNV. Control of *Cx. salinarius* is often difficult due to dense vegetation found in their larval habitat. This vegetation offers protection from both predators and pesticides.

*Culex melanura*

***Culiseta melanura*** is a medium sized, dark brown species which resembles *Culex* species but has a longer proboscis and longer legs. It also has tufts of dark setae on the underside of the wing at the base of the subcostal vein, and spiracular bristles are present. This species is widely distributed in the coastal plain of Maryland, predominately in association with large swamps.

Females rarely bite humans, feeding almost exclusively on birds. They are not strong fliers, generally remaining within a mile of their swamp habitats, however, longer flights have been observed. Eggs are laid in rafts in very sheltered areas in swamps, often in deep tree crypts (areas under the roots of fallen trees). Larvae develop in their dark subterranean crypts, making them difficult to find since their crypts are sometimes not visible from above ground. This species overwinters as 2nd, 3rd and 4th instar larvae. Larger larvae will pupate in late April and adults can be flying by early May. There are several generations per year, producing several population peaks during the summer. Females are most active at dusk and dawn.

This mosquito is the most important bird to bird vector of EEE in the eastern United States, playing a vital role in maintaining the virus in bird populations. It also transmits WEE and CE in bird populations and WNV has been isolated from it in Maryland.

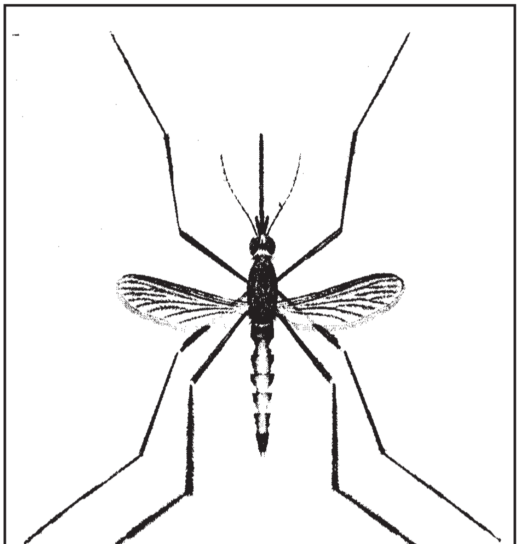


*Coquillettidia perturbans*

***Coquillettidia perturbans*** is a large mosquito with a banded proboscis and legs. Its wings are covered with flat broad scales, intermixed dark and light, giving it a speckled appearance.

Females bite primarily at night but will attack during the day in shady areas. They are general feeders and moderate fliers (up to 2 miles). There are probably 2 generations per year. Females lay eggs in rafts on water in ponds, lakes or swamps with heavy vegetative cover (cattails, pickerelweed, loosestrife, water lettuce, arrowhead, etc.). The larvae and pupae have breathing structures modified into a cutting edge and they attach directly to the roots and stems of aquatic plants where they obtain their oxygen from the plants. Larvae develop slowly. Pupae come to the surface to emerge into adults. Otherwise, the larvae and pupae remain submerged, making them very difficult to find, collect and control.

Females are readily attracted to light traps. They are persistent, vicious biters, and readily enter houses to feed on humans. This species is the bridge vector (from birds to mammals) of EEE, and WNV has been isolated from it in nature.

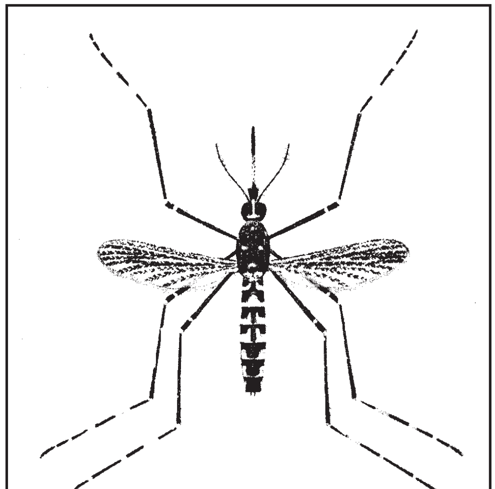


*Psorophora ferox*

***Psorophora ferox*** is a large, very dark mosquito with a bluish-purple metallic sheen. It has large erect setae on its legs which give it a shaggy appearance and the last 2 tarsal segments on the hind legs are entirely white, giving it the common name of the white-footed mosquito.

Females are rarely found far from their woodland breeding areas, although they will come out into the sun to bite. Larvae develop in temporary rain-filled pools in wooded areas and floodplains. They develop very rapidly and there can be many generations per year, depending on the amount and frequency of rainfall. Adults can be found from early May through early October. The life span of adults is short, rarely longer than 10 days.

This species is an important pest mosquito following heavy rains. Females are very persistent, vicious biters and will readily attack during the day or night, even in sunny open areas. It is not believed to be a vector of any disease.

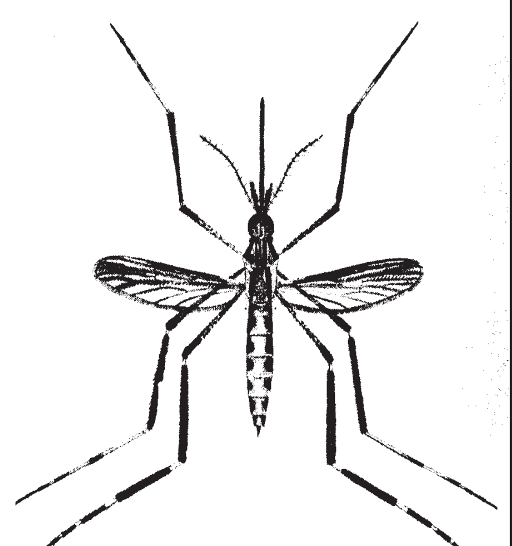


*Psorophora columbiae*

***Psorophora columbiae*** is a large, dark mosquito with banded legs and proboscis. Its wing scales are broad, intermixed dark and light. It has apical abdominal bands in an inverted-V shape on several segments and a narrow white band near the tip of each femur. The front aspects of its front femurs have laddered white stripes. This species is widespread in the U.S., especially in the southeast where it breeds in rice fields.

*Ps. columbiae* is a general feeder, feeding on any warm-blooded animal, and is a persistent fierce biter, attacking day or night. It will readily enter houses. A strong flier, it can be found up to 8 miles or more from it's larval habitat. Eggs are laid on the ground and hatch when flooded. This species can develop very rapidly, often completing their life cycle within 4 or 5 days. Larvae can be found in temporary rain-filled pools, grassy ditches and swales, ruts, puddles, and irrigated pastures and fields. They are most often found in open unshaded places with vegetation. Depending on conditions, there can be many generations per year. This species overwinters as eggs deposited on soil.

Females are readily attracted to light traps or landing rate counts. They can cause extreme annoyance in humans, making it almost impossible to remain outside. However, adults are short-lived and typically die-off within two weeks after emergence. They can severely reduce milk production and weight gain in livestock and when present in great numbers, have been known to kill livestock when found in extremely high numbers. SLE, CE and WNV viruses have all been isolated from this species, but it is not believed to be a good vector of these viruses. *Ps. columbiae* were important vectors of Venezuelan equine encephalitis virus during an outbreak of VEE in Texas in 1971.



*Psorophora ciliata*

***Psorophora ciliata*** is very large, with long, dark, erect setae on its legs, giving it a shaggy appearance. The hind tarsi are banded, there are patches of broad yellow or white scales on the sides of the thorax, and the top of the thorax has a narrow golden stripe.

This species is a persistent, very painful biter, attacking any time a host ventures into its habitat. It does not fly far from its breeding habitat. Females lay eggs in cracks or depressions in the soil. These eggs probably do not hatch until the following season. Larvae are found mostly in sunny temporary rain-filled puddles. Larvae hang nearly vertically from the water surface and are predaceous, often feeding on other mosquito larvae. They develop very rapidly.

This mosquito is common but only occasionally seen in large numbers. It can be a pest even in small numbers because of its size and its painful bite. Adults are short-lived and it is not a known vector of disease.

***Toxorhynchites rutilus septentrionalis*** is a very large metallic blue and yellow mosquito. Its proboscis is long and curved strongly downward. It is distributed widely within the U.S. but is rarely found in large numbers. It is one of our most beautiful mosquitoes, does not feed on people or animals, and is a biological control agent of other mosquitoes.

This species does not need a bloodmeal to develop eggs, consequently, it does not bite. Adults feed solely on nectar and plant juices. Its flight range is very limited. Females lay eggs singly on the water surface in tree holes or artificial containers where the larvae, which are predaceous, can be found feeding on other species of mosquitoes. They are most often found in tree holes and tires. Larval development is slow, taking from several weeks to 6 months.

Because *Toxorhynchites* are predaceous as larvae and the adults do not feed on animals, they have been used in some areas of the U.S. as biological control agents. They are reared in the laboratory and then released in areas with large numbers of tires, but their overall usefulness is limited.

Maryland is home to 62 mosquito species. Only a few of the more common and more important species are discussed above. The complete list of the species that have been found in Maryland follows on the next page. In addition, Appendix 3 and 4 provides a pictorial key to common female mosquitos found in the United States.

# MOSQUITO SPECIES KNOWN TO OCCUR IN MARYLAND

1 _Aedes aegypti_*
2 _Aedes albopictus_*
3 _Aedes cinereus_
4 _Aedes vexans_*

5 _Ochlerotatus aurifer_
6 _Ochlerotatus atlanticus_*
7 _Ochlerotatus atropalpus_
8 _Ochlerotatus canadensis_*
9 _Ochlerotatus cantator_*
10 _Ochlerotatus dorsalis_
11 _Ochlerotatus excrucians_**
12 _Ochlerotatus fitchii_
13 _Ochlerotatus fulvus pallens_
14 _Ochlerotatus grossbecki_
15 _Ochlerotatus hendersoni_
16 _Ochlerotatus infirmatus_
17 _Ochlerotatus japonicus_*
18 _Ochlerotatus mitchellae_
19 _Ochlerotatus punctor_
20 _Ochlerotatus sollicitans_*
21 _Ochlerotatus sticticus_*
22 _Ochlerotatus stimulans_
23 _Ochlerotatus taeniorhynchus_**
24 _Ochlerotatus thibaulti_
25 _Ochlerotatus tormentor_
26 _Ochlerotatus triseriatus_
27 _Ochlerotatus trivittatus_

28 _Anopheles atropos_
29 _Anopheles barberi_
30 _Anopheles bradleyi_*
31 _Anopheles crucians_*
32 _Anopheles earlei_
33 _Anopheles perplexens_
34 _Anopheles punctipennis_*
35 _Anopheles quadrimaculatus_*
36 _Anopheles walkeri_*

37 _Culiseta annulata_[1]
38 _Culiseta impatiens_
39 _Culiseta inornata_
40 _Culiseta melanura_*
41 _Culiseta minnesotae_
42 _Culiseta morsitans_

43 _Culex erraticus_
44 _Culex pipiens_*
45 _Culex quinquefasciatus_*
46 _Culex restuans_
47 _Culex salinarius_*
48 _Culex territans_

49 _Coquillettidia perturbans_*

50 _Orthopodomyia alba_
51 _Orthopodomyia signifera_

52 _Psorophora ciliata_**
53 _Psorophora columbiae_**
54 _Psorophora cyanescens_
55 _Psorophora discolor_
56 _Psorophora ferox_**
57 _Psorophora horrida_
58 _Psorophora howardii_
59 _Psorophora mathesoni_

60 _Toxorhynchites rutilus septentrionalis_

61 _Uranotaenia sapphirina_

62 _Wyeomyia smithii_

[1] _One specimen of this European species was collected near the Port of Baltimore in the 1960's._

* Pest and/or Disease Vector
** Pest Only

## Study Questions – Chapter Three

1. Describe the life cycle and developmental stages of mosquitoes.

2. How do larval mosquitoes differ from adult mosquitoes?

3. What do larval mosquitoes eat?

4. How do mosquito larvae breathe?

5. Describe the principle body parts of an adult mosquito.

6. Which sex of mosquito feeds on blood?

7. In general, what time of day are adult mosquitoes most active?

8. How do the egg-laying characteristics of standing water mosquito species differ from those of floodwater mosquito species?

9. Describe five types of standing water mosquito breeding habitats found in Maryland.

10. Name three genera of mosquitoes in Maryland associated with floodwater habitat for egg-laying and larval development.

11. How often do mosquito larvae molt?

12. Why is *Aedes albopictus* difficult to control?

13. Name two species of mosquitoes found in Maryland that are "exotic" or immigrant species originally found in Asia.

14. What is the dominant salt marsh mosquito found in Maryland and along the northern and mid-Atlantic seaboard of the United States?

15. Why is *Anopheles quadrimaculatus* an important species in Maryland?

16. *Culiseta melanura* does not bite humans, so why is it an important mosquito in Maryland?

17. What peculiar characteristic makes the larvae and pupae of *Coquillettidia perturbans* so difficult to find and control?

# CHAPTER FOUR

## MOSQUITOES AS VECTORS OF DISEASE

Worldwide, mosquitoes are responsible for the transmission of disease to millions of people each year. These diseases include encephalitis, dengue, yellow fever, malaria and filariasis. In the past, most of these diseases have had significant impacts to public health in the United States. All these diseases, with the exception of dengue, have occurred in Maryland. Currently, only mosquito-borne viruses causing encephalitis and filariasis (dog heartworm) are known to occur in Maryland.

It is important to remember that mosquitoes do not transmit diseases by a simple mechanical transfer of a disease organism from one animal to another. An example of a mechanical transfer of disease would be a hypodermic needle shared by drug abusers that can spread HIV or hepatitis.

The mosquito-disease agent cycle is much more complicated than simple mechanical transmission. An encephalitis virus not only survives in the mosquito for several days, it multiplies a thousand fold in the mosquito body and moves to the salivary glands, ready to be injected into a new host when the mosquito takes her next blood meal. The filarial worm that causes dog heartworms undergoes developmental changes in the mosquito necessary in the cycle of transmission. Even more complicated is the malarial parasite that undergoes a sexual cycle in certain species of *Anopheles* mosquitoes which requires 7 to 20 days and culminates with the invasion of the mosquito salivary gland with numerous microscopic sporozoites that are injected in a new host during the next blood meal.

The reason that not all species of mosquitoes are good, or competent, vectors of disease is because of the complicated nature of the relationship between mosquitoes, the disease organism and the animals fed on by mosquitoes. To be a good vector, a mosquito must provide an internal environment that is favorable to the survival, replication and transmission of the disease agent. The mosquito must also blood feed on animals that are suitable to the survival and replication of the disease organism. The relationship between certain mosquito species, disease organisms and vertebrate hosts of the various diseases has evolved over thousands of years.

### Mosquito-borne Encephalitis

Encephalitis is a disease affecting the central nervous system. There are six major types of mosquito-borne encephalitic virus known to occur in the United States: California encephalitis (CE), Eastern equine encephalitis (EEE), St. Louis encephalitis (SLE), Western equine encephalitis (WEE), West Nile virus (WNV) and Venezuelan equine encephalitis (VEE). Of these, CE, EEE, SLE and WNV are known to occur in Maryland.

The viruses that cause eastern equine, St. Louis and West Nile encephalitis are normally transmitted from bird to mosquito to bird and less commonly from bird to mosquito to human. The bird-mosquito-bird transmission is known as the **endemic** cycle and is the way the viruses are perpetuated in the environment. The transmission of the virus to a person by the bite of an infective mosquito is known as the **epidemic** cycle. The virus group that causes California encephalitis is normally transmitted by mosquitoes among small mammals (chipmunks, squirrels and rabbits) and occasionally transmitted to people.

Human cases of mosquito-borne viral infections range from inapparent or mild to very severe illness which may permanently damage the central nervous system or cause death.

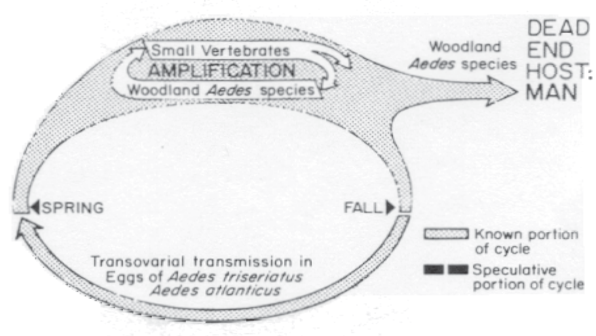



Figure 4.1. California Encephalitis (CE) group virus cycle in U. S. LaCrosse and Keystone Subtypes.

## California Encephalitis

CE (Figure 4.1) is caused by a number of related virus subtypes: California, La Crosse, Keystone and Trivittatus. CE is found across the United States, but most human cases occur in the Midwestern states. Human disease typically occurs in late summer and usually in children under 16 years of age. *Ochlerotatus triseriatus* is believed to be the primary mosquito vector of this disease.

CE virus has been isolated from mosquitoes in Maryland, but it is believed to be rare and not a concern to public health. The piedmont and mountain areas of Maryland have the greatest likelihood of the occurrence of CE.

## Eastern Equine Encephalitis

EEE (Figure 4.2) is found along the Atlantic and Gulf coasts of the United States and in limited areas of the Mississippi River valley. In Maryland, EEE is most frequently found in the southern Eastern Shore region and the Patuxent River basin. Cases of EEE affecting people in Maryland usually occur August thru October. Young children are the most susceptible age group. EEE is the most deadly of the North American mosquito-borne viral diseases, with a 50 to 75 percent human fatality rate and severe central nervous system impairment for the survivors. Fortunately, this is a rare disease in humans with 10 human fatalities recorded in Maryland during the period 1956 thru 2004.

EEE is a very serious disease in horses, game farm pheasants, and ratites (emus) with a fatality rate of up to 90 percent for these animals. In 1984, EEE virus caused the deaths of seven endangered whooping cranes at the Patuxent Wildlife Refuge in Laurel Maryland.

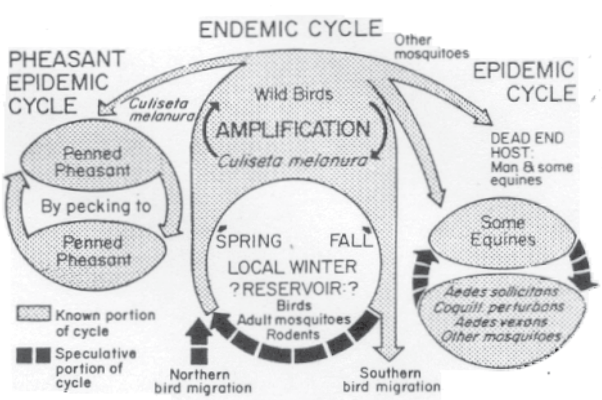



Figure 4.2. Eastern Equine Encephalitis (EEE) virus cycle in U. S.

Vaccines provide good protection against EEE disease in horses, ratites and cranes.

The bird to bird cycle (endemic cycle) of EEE virus is maintained by *Culisetta melanura*, a mosquito which breeds in freshwater swamps. Other mosquitoes that are important in the transmission of EEE virus to horse and people are *Coquillettidia perturbans*, *Oc. canadensis* and *Oc. sollicitans*.

## St. Louis Encephalitis

SLE (Figure 4.3) is found throughout the United States, but the majority of human cases have occurred in the Mississippi and Ohio River valleys and in Florida. This disease primarily affects people older than 50 years of age. Case fatality range from 2 percent to 20 percent. Most infections of SLE in humans do not result in illness and many mild cases result only in a fever and a feeling of tiredness.

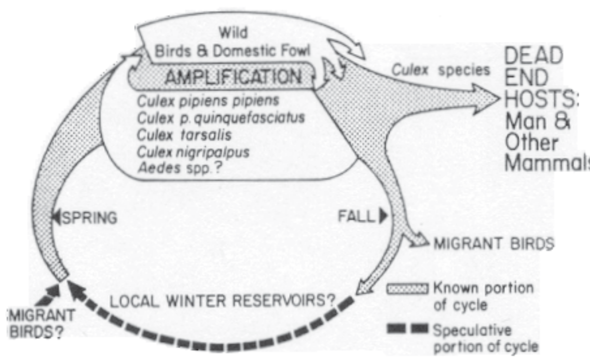



Figure 4.3. St. Louis Encephalitis (SLE) virus cycle in U. S.

SLE is maintained in nature in a bird to bird cycle. Birds do not suffer ill effects from the virus. *Culex* mosquitoes are believed to be the vector of SLE among birds and people. *Cx. pipiens* is the most important vector of SLE in most of the United States. In Florida, *Culex nigripalpus* is the most important vector. *Cx. salinarius* is also a competent vector of SLE.

The most significant outbreak of SLE occurred in 1975 when almost 1,800 human cases were reported from 30 states. During the 1975 epidemic, Maryland recorded 10 cases: Baltimore City (4), Prince George's County (4), Queen Anne's County (1), and Talbot County (1).

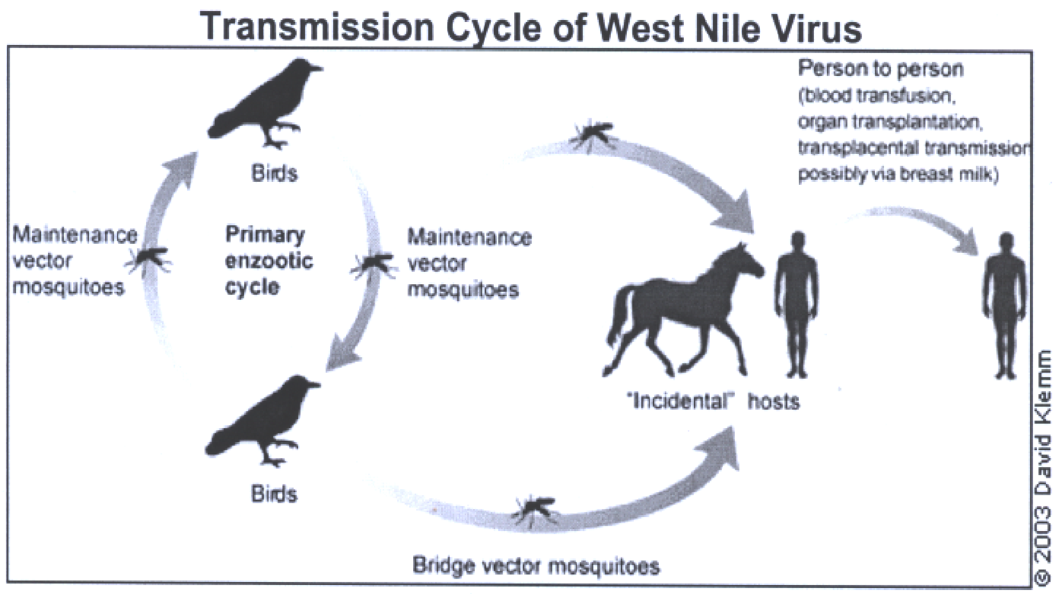



Figure 4.4. Life cycle of West Nile virus.

## West Nile Virus

WNV (Figure 4.4)has been know to cause epidemics among people since it was first described in Uganda, Africa in the 1930's. WNV was first found in the United States in 1999 during an outbreak of disease involving humans, birds and horses in the New York and New Jersey region. The introduction and spread of WNV in North America has caused the largest outbreak of mosquito-borne disease in the United States in the past 60 years. During the period 1999 thru 2004, WNV caused 16,284 clinical cases of disease and 582 deaths in the United States, according to the Centers for Disease Control and Prevention (CDC). In a few years, the disease spread from a small area on the east coast of the United States to each of the 48 contiguous states, Canada and Central America.

In Maryland, WNV was first found in October, 1999 in a dead crow recovered in Baltimore City. The first human case of WNV illness occurred in 2001. Between 2001 and 2004 there have been 131 clinically documented cases of human illnesses in Maryland caused by WNV infection, including 17 fatalities.

Like most other encephalitic viruses, WNV is maintained in a bird to bird cycle. However, unlike native viruses, WNV causes high mortality for certain birds, most notably crows, jays, hawks and owls. Bird migrations are believed to be responsible for the rapid spread of WNV across North America.

More than 30 species of mosquitoes have been found carrying WNV in the United States. *Culex* mosquitoes appear to be the most important vector, but other species are also considered important transmitters. In Maryland, *Cx. pipiens*, *Cx. restuans*, *Cx. salinarius*, *Aedes albopictus* and *Aedes vexans* have been collected from nature infected with WNV and are species of concern as potential vectors. *Cs. melanura* has also been found infected with WNV in Maryland and may be a factor in bird to bird transmission.

West Nile virus disease in humans in Maryland typically occurs in late summer (August thru September) and most seriously affects people older than 50 years of age. Most people bitten by a WNV infected mosquito will not show any sign of illness. Of those who become clinically ill, about 70 percent will display mild symptoms including fever and lethargy and about 30 percent will suffer central nervous system involvement resulting in meningitis or encephalitis. The national fatality rate has generally been 2 to 5 percent.

Horses are also susceptible to WNV infection. As in humans, illness is caused by impairment of the central nervous system. Several thousand horses have died from WNV infection across the U. S. In 2003, 234 Maryland horses were clinically diagnosed with WNV illness and 75 of these cases were fatal. Fortunately, an effective vaccine is available to protect horses from WNV disease. Since the introduction and acceptance of this vaccine, the case rate of WNV disease in horses has decreased significantly.

## Dengue

Dengue is a viral disease transmitted from person to person by mosquitoes. Mosquitoes obtain dengue virus from the blood of infected persons. The virus multiplies in the mosquito which is able to infect another person 7 to 14 days after the initial infection. Mosquitoes remain infective for the rest of their lives. Dengue is present worldwide in tropical and subtropical areas and occurs along the Gulf Coast of the U.S. The World Health Organization estimates there are 50 to 100 million cases of dengue infection each year.

Dengue is also called break-bone fever because it can cause severe joint and muscle pain. Health experts have known about dengue fever for more than 200 years. In the late 18th century, an outbreak of dengue occurred in Philadelphia, Pennsylvania. Currently, there is a small risk for dengue outbreaks in the continental United States. During the period 1980 thru 2004, dengue was detected 6 times in south Texas. The Texas cases were associated with dengue epidemics in northern Mexico. In 2001 and 2002, local transmission of dengue by *Ae. albopictus* was detected in Hawaii.

People emigrating or traveling to the U.S. from dengue endemic areas provide the potential to bring the disease to the United States on a broader scale. From 1977 to 2004, a total of 3,806 cases of imported dengue were reported in the United States. It is likely that many more cases, with unapparent or mild illness, were unreported. There is no vaccine to protect against dengue. Ongoing surveillance and proactive mosquito control programs are the best methods to minimize the risk of dengue to public health.

## Yellow Fever

Yellow fever is a viral disease that is transmitted to humans by mosquitoes. Unlike most encephalitic viruses, yellow fever virus is not maintained in a bird to bird cycle. The virus is generally transmitted from person to person by mosquitoes. The most important mosquito in this transmission cycle is *Aedes aegypti*, commonly known as the “yellow fever mosquito”.

The last epidemic of yellow fever in the United States occurred in 1905 in New Orleans. Epidemics of a disease with symptoms consistent with yellow fever were frequently reported during the 18th and 19th century in the United States. A yellow fever epidemic in Philadelphia, Pennsylvania in 1793 killed almost 5,000 people. Other epidemics occurred as far north as Boston, Massachusetts. In Baltimore, Maryland, a yellow fever epidemic began at Fell’s Point and spread throughout Baltimore in September, 1800, killing 1,197 people.

Yellow fever attacks all ages of people and results in mortality rates ranging from 20 percent to 80 percent. The virus attacks the liver and heart. It does not cause encephalitis. During the Spanish-American War of 1898, less than 900 U. S. soldiers died in battle, but over 5,000 died of disease, primarily yellow fever. This led to the creation of the Yellow Fever Commission, headed by Walter Reed. Reed and his assistants proved conclusively in 1900 that the disease was spread by *Aedes aegypti* and that the key to controlling the disease was the control of the mosquito. One of Reed’s primary assistants was Jesse Lazear. Mr. Lazear allowed yellow fever infected mosquitoes to feed on him as part of the experimental protocol. Lazear became ill and died of yellow fever. Doctor Lazear’s grave is in London Park Cemetery, Baltimore.

As a result of the Yellow Fever Commission’s work, an extensive *Aedes aegypti* control program was begun in the United States which virtually eliminated the disease within a few years. The United States model of controlling yellow fever by controlling the mosquito vector was copied in several other countries. A human vaccine was subsequently developed that provides protection against yellow fever, but includes adverse side effects.

## Malaria

Malaria is an ancient scourge of mankind. The malaria parasite (one of four species of *Plasmodium*) is transmitted from person to person by the bite of anopheline mosquitoes. Two anopheline species in the United States are vectors of human malaria. These are *Anopheles freeborni* in western states and *Anopheles quadrimaculatus* in the east.

Malaria was a common, widespread disease throughout much of the United States until the 1940’s but has been virtually eliminated since the early 1950’s. However, it is still one of the most important communicable diseases on a worldwide basis. The World Health Organization reports that nearly 3,000 children die each day from malaria out of the total annual malarial deaths of 1.5 million people and 200 million cases. Malaria continues to be a severe problem for many nations.

In the United States, malaria peaked in extent by 1870 when only parts of Maine, northern Wisconsin, northern Minnesota, the Appalachian Mountains and the dry and mountainous areas of the west were malaria free. Malaria gradually declined from the late 19th century through the 1920’s. A spike in malarial activity occurred in the United States during the 1930’s, probably as a result of the Great Depression, because malaria was and is primarily a disease of rural poor areas with substandard housing conditions. In 1935, the United States experienced an estimated 135,000 cases of malaria and 4,000 deaths.

A series of events led to the virtual elimination of malaria from the United States. During the depression years, work camps were established specifically to drain swamps and marshes that were mosquito breeding grounds. There was a shift in population from rural areas to cities, where malaria is rare. Insecticide use by the general public also became more common. However, the greatest campaign against malaria was launched by the U. S. Government which deployed a battery of health professionals and entomologists to rid the nation of malaria as an important element of national defense during World War II. Most military training posts were located in the southern United States in order to have year round weather favorable for training troops. Unfortunately, these areas were also infested with malaria. Government sponsored malaria eradication programs around military installations were highly successful and set the model for use by civilian programs around the country. These programs in the 1940's through the early 1950's relied on source reduction to drain *Anopheles* breeding swamps and the use of residual insecticides such as DDT which effectively eliminated malaria from the United States.

## Dog Heartworm

Dog heartworm is a disease caused by the parasite *Dirofilaria immitis*, a filarial worm (Figure 4.5). It is a very common disease of dogs and occurs in other animals, including cats, but rarely affects humans. The parasite is a long, thread-like worm that invades the heart of an infected dog and, if left untreated, will kill the animal by blocking blood flow and function of the heart. The early life stage of the parasite is microscopic in size and circulates freely in the blood of infected animals. Mosquitoes ingest the microfilariae stage of the parasite when feeding on infected animals. The heartworm microfilariae develop to juvenile worms in the mosquito. The juvenile heartworms are transmitted to an animal by the bite of a mosquito.

The best method of protecting pets from heartworm infection is through regular examinations by a veterinarian and providing preventative medication to the animals. Even dogs that are "house dogs" need the protection provided by the preventative medication that kills the juvenile heartworms before they can mature to adults and cause harm to the heart.

Heartworm is endemic throughout Maryland and may be transmitted by mosquitoes year round. Many common mosquito species are implicated as vectors, but three of the most important are *Aedes albopictus*, *Cx. salinarius* and *Oc. canadensis*.

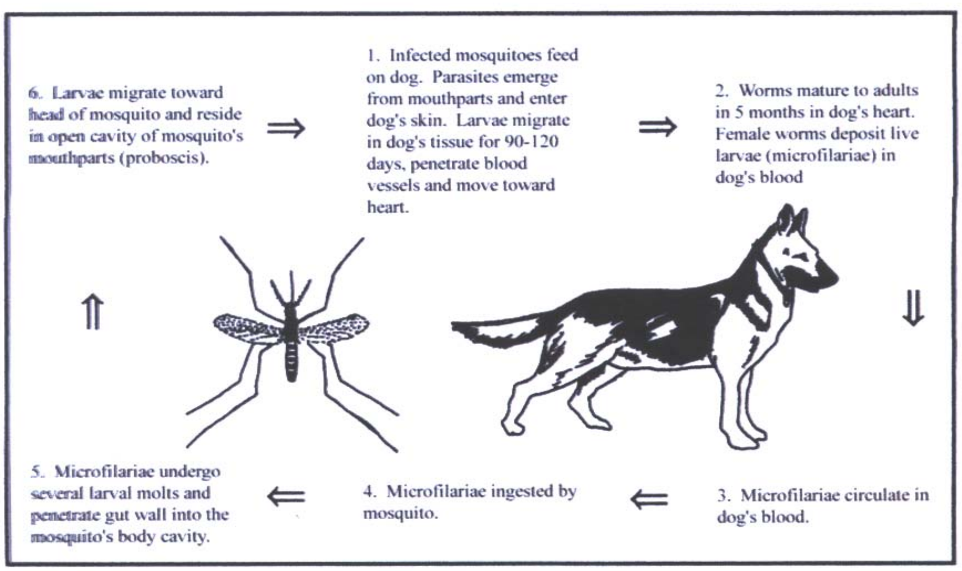



Figure 4.5. Life cycle of the dog heartworm.

# Study Questions – Chapter Four

1. Which mosquito-borne diseases are known to currently occur in Maryland?

2. What body organs of humans are most adversely affected by encephalitis viruses transmitted by mosquitoes?

3. Which mosquito-borne virus in Maryland causes the highest mortality rate in infected people?

4. Which mosquito-borne virus currently causes the greatest number of human illnesses in the United States?

5. What genus of mosquito is the most important vector of West Nile virus?

6. Of eastern equine encephalitis virus, St. Louis encephalitis virus and West Nile virus, which causes the highest mortality of birds?

7. Which age group of humans is most susceptible to West Nile virus?

8. Which age group of humans is most susceptible to eastern equine encephalitis virus?

9. Which mosquito species is commonly called the yellow fever mosquito? Is this species found in Maryland?

10. What are the two primary vector mosquito species of malaria in North America north of Mexico?

11. What body organ of a dog is most adversely affected when the dog is infected by *Dirofilaria immitis*?

12. What is the best method to control or prevent dog heartworm disease in pets?

# CHAPTER FIVE

## METHODS OF MOSQUITO SURVEILLANCE

Surveillance is the cornerstone of an effective mosquito control program. Initial **surveys** identify the species of mosquitoes present; provide general information on locations, dates and degrees of mosquito infestations; and the location of major breeding sites. Subsequent **inspections** monitor mosquito densities and can be used to choose the most appropriate control technique and to measure the effectiveness of the control program over time.

### Larval Mosquito Surveillance

Inspection for mosquito larvae is an important part of a control program. The equipment needed to conduct these inspections is simple and consists of waterproof boots, a white one pint dipper with an extended handle, jars to hold collected larvae, data entry forms (Figure 5.1) and maps (Figure 5.2) to accurately denote where larvae are found.

Mosquito larvae will dive to the bottom of the pool of water they inhabit if a shadow is cast over them or heavy footsteps cause ground vibrations. Therefore, it is necessary to proceed slowly and carefully in the search for larvae. Larvae can often be seen resting on the surface of an undisturbed pool of water. Dips should be taken quickly and smoothly to cause as little disturbance to the water as possible. Splashing and plunging of the dipper should be avoided as this will cause larvae to dive and disperse in an escape pattern.

Field data sheets should include the date and location of the inspection, the depth of water in the breeding sites, a description of the site, the number of dips taken and the total number of larvae collected. Larvae can be identified in the field by veteran inspectors, or returned to the laboratory for identification by a technician or taxonomist.

Culicine larvae will often occur in dense clusters. Anopheline larvae are more solitary and widely dispersed and almost always are found in dense emergent or floating vegetation. *Coquillettidia* larvae require special collection techniques because they are not free swimming, but are found attached to the roots

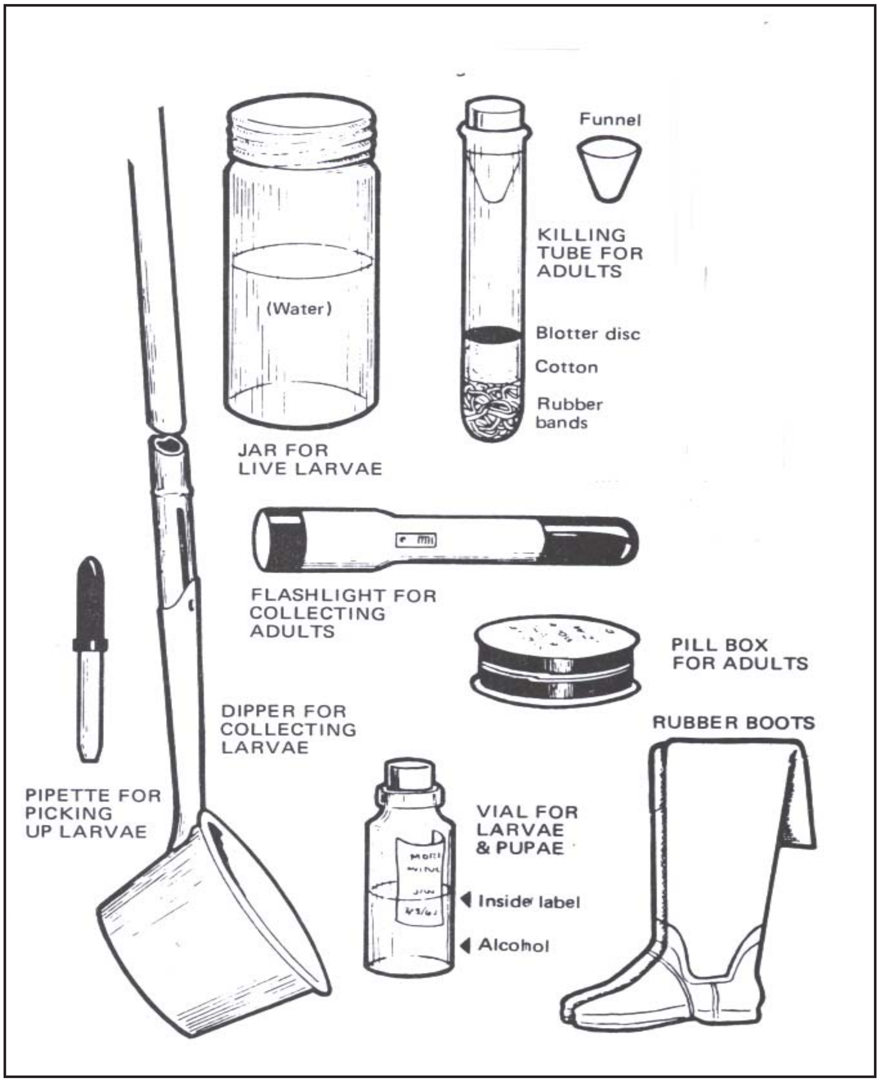



Figure 5.1. Surveillance equipment used for adult and juvenile mosquitoes.

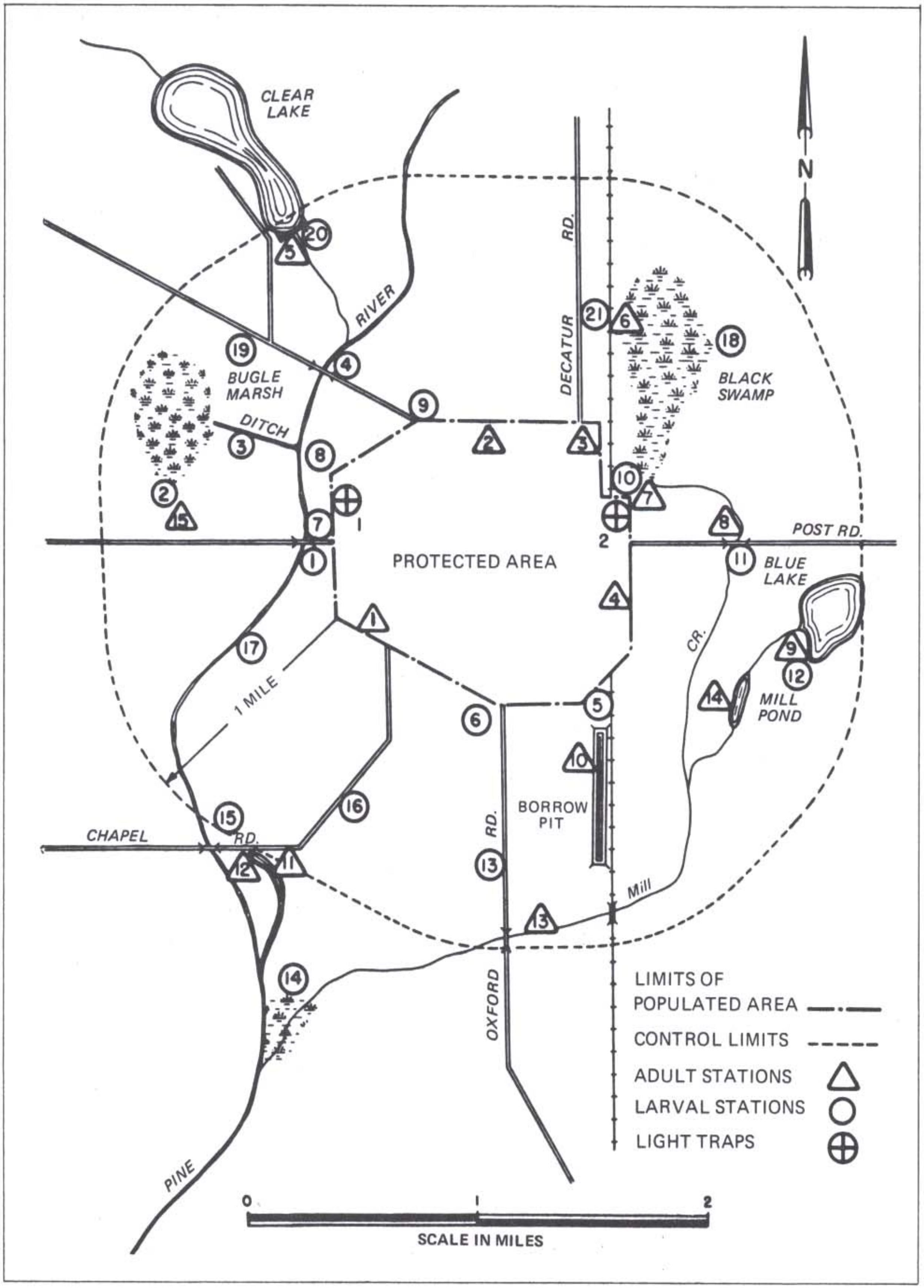



Figure 5.2. Schematic map showing mosquito sampling locations.

Figure 5.3. Above - Conducting mosquito larvae survey using a dipper. Below - Close up of mosquito larvae in dipper.

of aquatic plants in shallow water. These plants must be pulled from the ground or root-mat and the attached larvae washed off the roots in a bucket of water. The contents of the bucket are screened through a 16 mesh sieve to find the larvae. Surveys for *Aedes albopictus*, *Aedes aegypti* and *Culex pipiens* must be conducted in time-consuming site to site inspections. An **index** of domestic mosquito breeding can be expressed as the number of sites where larvae are found divided by the total number of premises inspected.

## Adult Mosquito Surveillance

Entomologists have devised numerous ways to collect adult mosquitoes. A description of the most common methods used in the United States and specific techniques used in Maryland are described below.

### Landing Rate Counts

The simplest method to assess the number of human-biting mosquitoes in an area is the landing rate count. The person conducting the count walks into the survey area to disturb the mosquitoes and "announce" the presence of a potential bloodmeal. Of course, inspectors cannot use any type of mosquito repellent while taking the counts. The inspector begins the count a minute or so after arriving at the site and counts the number of mosquitoes landing on his/her arms, legs and front of the body from chest to waist. The duration of the count may be from one to five minutes, depending on mosquito abundance. Procedures for the counts must be standardized so that accurate comparisons can be made between different areas and to measure the fluctuations in mosquito numbers in an area over time.

Mosquitoes can often be identified during the landing rate count by experienced personnel. Mosquitoes can also be collected, using a mouth aspirator or a battery powered aspirator and returned to the laboratory for identification.

Landing rate counts are low in cost, provide rapid feedback of information, selectively sample human-biting mosquitoes and allow rapid assessment of mosquito numbers over a large area in a relatively short period of time.

Landing rates are most often used to determine the infestation level of pest mosquitoes. Due to the potential hazard to inspectors, landing rate counts are discouraged when mosquito-borne disease is known to be active in Maryland.

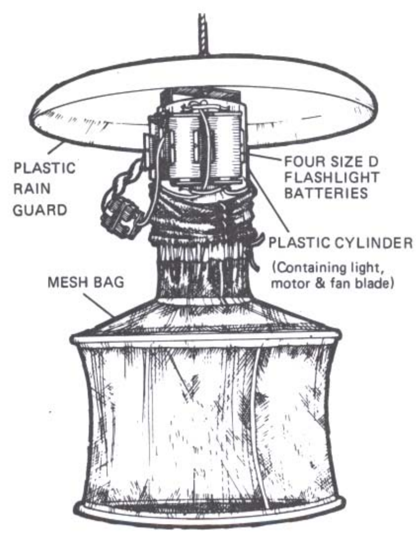



Figure 5.4. CDC miniature light trap.

### CDC Light Trap

The Centers for Disease Control and Prevention (CDC) developed a lightweight battery operated trap (Figures 5.4 and 5.5) for adult mosquito surveillance.

This is the most common collection device used in Maryland.

CDC traps are used to monitor pest mosquito populations and disease vectors. The traps can be used with a small light bulb attractant only or the light can be augmented by the addition of five pounds of dry ice. Use of dry ice will increase the number and species of mosquitoes collected because the carbon dioxide given off as the dry ice evaporates is a strong attractant to most female mosquitoes in search of a blood meal. The dry ice is placed in an insulated cooler with a 2 quart capacity and placed near the trap.

CDC traps are very easily used in a wide range of situations from remote wetlands to the inner city. They can be placed in tree canopies to collect bird-feeding *Culex* or at ground level for tiger mosquitoes. Typically the trap is placed approximately five feet above the ground. When used for tiger mosquito collection, it is best to remove the small light bulb and use the dry ice attractant only.

Mosquitoes collected in CDC traps are held in a fine mesh bag and remain alive for several hours. Mosquitoes are collected after the trap has operated for 12 to 24 hours and are returned to the laboratory for counting and identification.

The CDC style trap has been found to collect a wider range of mosquito species and a greater number of specimens more efficiently than other trap styles evaluated under Maryland conditions. Collections from CDC traps are generally “cleaner” than from larger light traps because the CDC traps collect fewer moths and beetles due to the smaller light bulb. The incidental catch of non-mosquitoes can be further reduced if the light bulb is removed and dry ice is the only attractant.

Figure 5.5. Battery operated CDC miniature light trap.

The record high mosquito trap catch in Maryland was in August 1989 when over 80,000 salt marsh mosquitoes were collected with a dry ice baited CDC trap on the Eastern Shore.

A

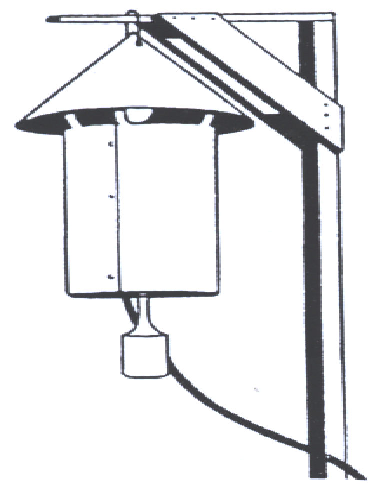
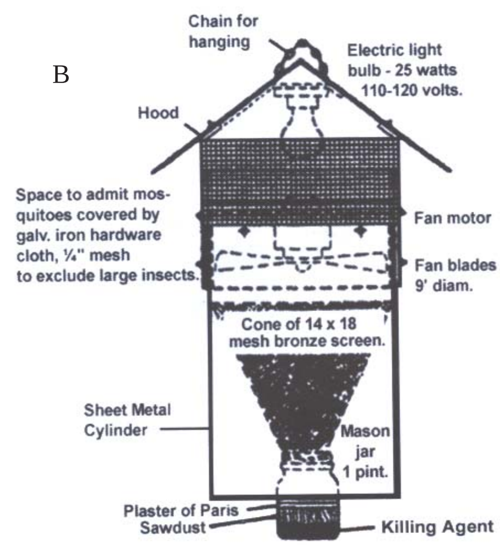


Figure 5.6. (A) New Jersey light trap, (B) Cross-section of a New Jersey light trap.

B




## New Jersey Light Trap

The N. J. light trap (Figure 5.6) was commonly used in Maryland until the early 1990’s when CDC traps largely replaced them. N.J. traps are still used in some areas and have proven themselves over time as a rugged, durable piece of equipment.

The N.J. light trap is heavy and is usually placed at one location for season-long operation. This trap must operate from a 110 volt electrical outlet, thus it can not be easily used in remote areas. The primary attractant of this trap is a 25 watt white light bulb. As mosquitoes are drawn to the light, a strong fan pulls them into the trap where they ultimately are deposited in a killing jar. Many non-mosquito insects are attracted to this trap due to the large amount of light emitted from the bulb and the presence of large moths and beetles often results in damage to the mosquitoes and identification becomes very difficult.

### Gravid Traps

This type of trap is selective for *Culex* females seeking to lay eggs. It consists of a one gallon container, which contains water and fermenting organic matter, a fan and a collecting bag. *Culex* mosquitoes are pulled into the trap bag by the fan, where they are held alive. The gravid trap is battery operated and portable.

The gravid trap is relatively selective for the collection of ovipositing *Culex* females and is reported to be a valuable surveillance tool to monitor for the occurrence of West Nile virus and St. Louis encephalitis virus in the mosquito population. Collections with this style trap are relatively low in number and few virus-positive mosquitoes have been recovered in gravid trap collections in Maryland. The attractant water composition for different species of *Culex* must be varied. The concoction used to attract *Cx. pipiens* smells very much like sewage and causes objections if placed too close to residences. *Cx. restuans* are best attracted to an oak leaf and grass slurry and *Cx. salinarius* is most attracted to a salt grass infusion.

### Fay-Prince Traps

This style trap was developed by Mssr. Fay and Prince to sample populations of *Ae. albopictus* and *Ae. aegypti*. Both species are difficult to collect with mechanical traps.

The Fay-Prince trap is battery operated and lightweight. Mosquitoes are attracted to a pattern of black and white squares on the trap and when close to the trap are pulled into a collecting bag by a small fan. This style trap is placed near the ground in an open, shaded location. The number and diversity of mosquitoes collected with this style trap are low, but can be significantly increased by the addition of dry ice attractant.

### Resting Boxes

Resting boxes (Figure 5.7) are 12 inch cubes which are open on one side. The interior of the box is painted red and the exterior is black. Mosquitoes are attracted to the box as a daytim resting site. The boxe should be placed on ope ground and grouped i clusters. This type o collection device is goo for collecting blood fe *Culisetta melanura* fo EEE investigations.

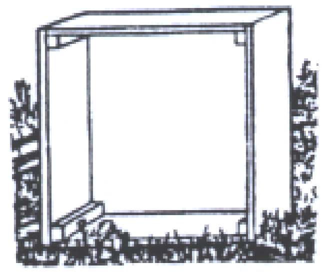


Figure 5.7. Resting box.

Other day-time resting sites can also be sampled for mosquitoes. These include culvert pipes, underside of bridges, hollow trees, crawl spaces of buildings, poultry houses and barns, etc.

### Sweep Netting

Sweep netting is an active collection technique which does not require mosquitoes to be attracted to traps. An insect collecting net is used to sweep through grass and other vegetation where mosquitoes rest during the day. Battery powered vacuum insect collectors can also be used.

These collections may yield a variety of mosquito species, but will also collect numerous other insects that are in the vegetation.

## Other Surveillance Techniques

In addition to sampling for larvae and adults, some mosquito control agencies survey for mosquito eggs. Culex egg rafts are readily visible floating on the water surface. For floodwater mosquitoes, samples (6” x 6” x 1” deep) of sod from potential mosquito breeding sites can be collected and flooded to hatch eggs contained in the sod. Eggs can also be separated from the soil and debris in the sod sample using a specialized egg separator machine. An oviposition trap, which consists of a black plastic cup in which a wooden tongue depressor covered with red felt paper is placed, is often used to monitor for the occurrence of *Ae. albopictus*.

An index of adult mosquito infestation can be developed by monitoring telephone or walk-in complaints by the public. By monitoring the number of calls, the area for which the complaint is registered and description of the problem (time of day of mosquito activity, biting habits of the mosquito, etc.), an assessment of neighborhood mosquito problems can be documented for follow-up visits by an inspector.

# Study Questions – Chapter Five

1. What is the cornerstone of effective mosquito control?

2. What is the basic tool used to collect mosquito larvae?

3. True or false? Anopheline larvae are commonly found in dense clusters and Culicine larvae are more solitary.

4. In conducting a community assessment, what is a common way of expressing an index of the intensity of mosquito breeding?

5. What is a landing rate count?

6. What is the most commonly used collection device for adult mosquitoes in Maryland?

7. Why is dry ice used in combination with light traps for adult mosquito collection?

8. When collecting the Asian tiger mosquito with a light trap, it is best to remove the light bulb from the trap and use dry ice as the only attractant. (True or False)

9. What is the major disadvantage of using a New Jersey light trap for adult mosquito surveillance?

10. Resting boxes are best used to collect daytime active mosquitoes. (True or False)

11. Public complaints about mosquitoes are of no value to a mosquito control agency. (True or False)

# CHAPTER SIX

## METHODS OF MOSQUITO CONTROL

Mosquito control is an important element of protecting public health and maintaining or improving the quality of life by reducing populations of pest mosquitoes. The responsibility for carrying out mosquito control programs rests largely with state, county and local governments, but private contractors are increasing their participation in mosquito control in response to public requests for service. The Federal government's role in mosquito control is to assist states in emergency situations, provide training, regulate the safe and effective use of pesticides and regulate activities in wetlands.

The **primary goal** of mosquito control is to minimize the risk to the public from mosquito-borne disease, but control of pest mosquitoes is also an important function. Indeed, it is the public demand for pest mosquito control that sustains most long-term mosquito control operations. In areas with minimal pest mosquito populations, public awareness of and demand for mosquito control is low and, due to limitations of financial and human resources and competing priorities, there usually are no organized mosquito control programs. When mosquito-borne disease unexpectedly occurs in areas without existing mosquito control service, a "crisis mentality" often results, with a portion of people desperately wanting mosquito control to avoid disease while others fear the consequence of applying pesticides. Due to the competing public perceptions under such circumstances, an effective mosquito control response is almost impossible to deliver. It is ironic, therefore, that during outbreaks of mosquito-borne disease, people living in areas with moderate to high mosquito populations and on-going control programs have a lower risk of becoming ill from a mosquito bite than people living in communities with few mosquitoes and no on-going control program. This has been the experience in many communities across the United States during the recent outbreak of West Nile virus.

Mosquito control does not mean mosquito extermination. Even the best control programs cannot eliminate mosquitoes. For accountability and measuring success, a mosquito control program must establish goals, develop a strategic plan to achieve the goals and adhere to guidelines for implementing various control activities. Successful programs utilize a variety of mosquito control options that are integrated to meet local needs. Most mosquito control programs in the United States today use the **integrated pest management** (IPM) strategy to achieve their goals. A working definition of IPM for mosquito control is, the use of a combination of biological, chemical, educational and physical methods to maintain targeted species or populations of mosquitoes below levels likely to cause:

(1) an increased risk of mosquito-borne disease in humans and domestic animals, and/or;

(2) unacceptable pest annoyance to the majority of people living in an area of concern.

Surveillance of mosquito populations and mosquito-borne disease pathogens is an essential element of an IPM program. IPM is not anti-pesticide, but uses pesticides in a prescribed manner according to all applicable laws, regulations and community standards.

### Mosquito Control Program Goals

The goals of state and local government-supported mosquito control programs in Maryland are to:

1. Reduce the risk of mosquito-borne disease affecting people and domestic animals.
2. Maintain the mosquito population below a level that causes unacceptable annoyance to people.
3. Have no adverse impact on the environment as a result of mosquito control activities.

### Public Education

To be most effective, mosquito control programs must be understood and supported by the people receiving the service. People who are informed about mosquito biology and control are more likely to keep their properties free of mosquito breeding areas and to support control efforts. For these reasons, public education is vital to the success of a mosquito control program.

To reach the public, work with established organizations such as schools, agricultural extension offices, civic associations and park officials. Examples of public education programs for these groups are: a grade school program targeted to a specific grade level; workshops for teachers, community officials or park personnel on general mosquito control or on specific subjects (i.e., tiger mosquitoes, what communities can do to help control mosquitoes); day-long teacher workshops (teach the teacher and they will teach many more students than you could reach); and explanations to the general public of how a mosquito control program works.

Other education activities include:

- ❑ Approach media outlets (TV, radio, newspapers) to see if they will run information on the program as a public service. Have something prepared or have a person who can explain the topic in a clear, concise manner, and in easily understandable terms. For TV spots, have live larvae (and pupae and adults, if possible) available to add interest. Try to tie your program or one aspect of the program into some subject already in the news. When dealing with newspaper reporters, carefully explain any scientific terms used.

- ❑ Encourage communities who are active in the program to publish information about mosquito control in their newsletter so that all community residents have access to information about the program and know whom to contact about questions or complaints.

- ❑ Set up an exhibit at local events such as fairs, community days, health fairs, shows, etc. as this will increase public awareness. Stress personal responsibility: i.e. use of repellents, home repair and maintenance of properties. Whenever possible, include live mosquito larvae with the exhibit. It draws people in and many people have no idea what mosquito larvae look like.

- ❑ Get permission to put an exhibit in a library, school, park office or nature center. Be creative about reaching as many different groups of people as possible, particularly with regard to container breeding species common around homes.

- ❑ Produce brochures or handouts, both general and targeting specific subjects. Have a flier or brochure with general mosquito and program information. Use posters or bookmarks with targeted subjects (i.e. fish, ditches, container breeding, "tiger" mosquitoes, or any other subject you can use).

- ❑ If your agency has a website, use it to get information out to the public. If there are mailings concerning budget or billing information to communities or individuals, contact the company or orginization doing the mailing to include handouts with information on the mosquito control program.

- ❑ If funds are available, produce a short public service announcement (i.e. "Help control mosquitoes in *your* yard") for distribution to local cable access channels and to civic groups. Check with other mosquito control agencies - they might already have something you can use with permission. Make a video about how to do a yard inspection for mosquito breeding areas and distribute copies of the video to homeowner groups for use at their community meetings.

When developing an exhibit for public education, make it interactive (i.e. pushing a button that results in something lighting up, or opening a door to see the answer to a question). Having live specimens of the different mosquito developmental stages is a very good interactive prop. Another example would be to have mosquito fish which can be fed larvae. The more interesting the exhibit, the more the public will learn and the longer they will retain the information.

Most importantly, make sure that all mosquito control staff are well-informed and courteous. Also, make sure that they can answer the public's questions and concerns and can give presentations at meetings. Finally, respond to complaints promptly, and give advice on a wide variety of problems.

## Personal Protection

The public should be encouraged to individually take what ever action is possible in order to reduce their exposure to mosquitoes. Some simple actions on the part of many people can dramatically impact the annoyance and public health aspects of mosquitoes.

These include:

- Remove water holding containers from around the home, clean roof rain gutters, change water in bird baths daily, fill in water-holding depressions, ensure that ditches are free-flowing and taking any other action in order to reduce mosquito breeding near the home.
- Keep screens in good repair in order to keep mosquitoes outside.
- Minimize outdoor activities when and where mosquitoes are most active.
- If contact with mosquitoes is likely, wear loose fitting, light colored clothes, long-sleeved shirts, pants and include a hat and gloves in areas of high infestation.
- Use an EPA registered insect repellent, and always use it as directed by the product label. Parents should consult their pediatrician before applying a repellent to young children.

## Source Reduction

Elimination or reduction of mosquito breeding sites by physical alteration or management of water is termed source reduction. This is one of the oldest, most proven methods of control. The short-term actions of unclogging a blocked ditch, filling a shallow depression, properly planning a stormwater management project, or removing a pile of scrap tires (Figure 6.1) lead to long-term effects of preventing the occurrence of mosquito breeding at that site in the future. Source reduction commonly requires the filling, deepening, draining or management of water levels of known mosquito breeding sites, proper design and maintenance of man-made ponds and reservoirs, management of aquatic vegetation and removal or destruction of containers such as tires and trash. Projects can range from complex and expensive wetland management projects to as simple an act as a homeowner emptying a water-holding container in their backyard (Figure 6.2).

Figure 6.1. Scrap tires provide an excellatant source for mosquitoes to breed.

Figure 6.2. Containers that can hold water are also excellant mosquito breeding sites.

Source reduction was, at one time, the cornerstone of mosquito control in the United States. Large ditching projects in tidal marshes and freshwater wetlands effectively eliminated large populations of mosquitoes. Community drainage ditches were well maintained to ensure rapid runoff of water following rainstorms. Low-lying ground with abundant shallow pools of surface water were filled and graded for housing lots and other development. Such filling occurred on a large scale in and near cities and towns. Much of the area now covered by large east coast cities such as Baltimore, Boston, Philadelphia and New York were at one time swamps and marshes that were filled as the cities expanded. Although preparing the ground for development was the primary reason for the filling, mosquito prevention was also realized.

Some source reduction activities are no longer possible in the United States. The value of wetlands has been fully documented during the past 50 years and the importance of wetlands for a variety of reasons has reversed the thinking of decades ago that wetlands were wastelands. The filling or draining of wetlands is no longer justifiable, or legal.

Large source reduction projects are still carried out in Maryland, although not as commonly as in the past. These projects typically occur on tidal marshes and utilize a technique known as **open marsh water**

**management** (OMWM) to control the salt marsh mosquito group (*An. bradleyi*, *Cx. salinarius*, *Oc. canta*tor, *Oc. sollicitans* and *Oc. taeniorhynchus*). An OMWM project constructs a system of ditches and ponds that create additional aquatic habitat, increase fish populations and increase the frequency of tidal inundation, all of which aid in the control of mosquitoes Figure 6.3). OMWM projects require review and approval by federal and state environmental agencies. Additionally, permission must be obtained from landowners to allow the alternations resulting from an OMWM project.

Figure 6.3. Open marsh water managfement OMWM) creates a system of ditches and ponds that create additional aquatic habitat, increase fish populations and increase the frequency of tidal inundation, all of which help in the control of mosquitoes.

OMWM requires a great deal of expense, specialized equipment and trained personnel. All projects must be justified as being of cost-benefit to the program by controlling a large number of mosquitoes over a period of several years. The resources necessary for a comprehensive OMWM program are not currently available in Maryland and the prospect for reviving this program is not favorable due to the cost and unpredictability of obtaining federal and state permits.

Source reduction on natural wetlands occurs less commonly now as compared to the past, but opportunities for source reduction in "created wetland" mosquito breeding environments are greater than ever. The created, or man-made, category of wetlands includes roadside ditches, stormwater basins, dredged material disposal sites, catch basins or street drains, ornamental ponds, abandoned swimming pools, tire ruts, tire dumps, improper grading at construction sites, etc. Proper design and maintenance of these types of mosquito breeding habitats can effectively eliminate conditions favorable for mosquito breeding.

Containers of all types produce large numbers of mosquitoes, especially tiger mosquitoes. In urban and suburban environments, containers may be the primary source of most of the mosquito problem. These range in size from flower pots, bird baths and buckets up to boats stored in the backyard, poorly maintained swimming pools and flooded basements. Removal of unnecessary containers and regular inspection reduces the mosquito problem. To be successful, this control initiative should be combined with a public education program to enlist the interest, support and participation of the public because the scope of backyard breeding sites is extremely large and is beyond the ability of mosquito control workers to effectively monitor and control.

## Biological Control

Biological control is the destruction of mosquitoes by predators, parasites or pathogens (diseases). Fish have been used in numerous control efforts for the successful control of mosquito larvae. By far, the fish species with the greatest record as a destroyer of mosquitoes is *Gambusia affinis*, commonly known as the **mosquito fish** (Figure 6.4). *Gambusia* have been distributed worldwide as a result of their mosquito-eating prowess.

Other potential biocontrol agents of mosquito larvae include viruses, protozoans, parasitic nematodes, flatworms, fungi, copepods, the predaceous mosquito *Toxohynchites*, dragonflies and aquatic beetles and certain species of salamanders. Unfortunately, numerous research projects have failed to demonstrate that these agents significantly affect mosquito populations to the extent commonly documented as a result of fish predation.

There are also many predators that will opportunistically eat adult mosquitoes. The most notable ones from this list of predators of adult mosquitoes are bats and purple martins. Unfortunately,

Figure 6.4. Mosquito fish, *Gambusia*.

there are no documented studies to support the often claimed ability of bats and birds to significantly reduce mosquito populations.

Bacterial toxins such as *Bacillus thuriningiensinsis israelensis* and *Bacillus sphaericus* are not true bio-control agents. These bacteria are used to produce spores, under optimized highly controlled conditions, which are toxic to mosquito larvae. However, the live bacteria are not able to impact mosquitoes under field conditions. The spores produced and formulated for use by industry are properly called biorational pesticides.

Biological control is often a controversial topic. The use of *Gambusia* has become a highly regulated activity. In some areas of the United States, *Gambusia* is listed as an **invasive species** and its use is prohibited. In Maryland, a permit from the Department of Natural Resources is needed to stock *Gambusia* for mosquito control and only the *Gambusia* species native to the Chesapeake Bay, *G. holbrooki*, can be released. *G. affinis* cannot be released in Maryland. *Gambusia* are considered an undesirable species in certain locations because they are capable of adversely affecting threatened or endangered species of fish and amphibians due to their efficiency as predators. There had been a great deal of activity in the 1950's thru the 1960's in importing exotic fish and other biological control agents of mosquito larvae to the United States for incorporation in control programs. The practice of importing foreign species for release in waters of the United States is now prohibited.

## Control by Pesticides

The use of insecticides is an essential element of most IPM mosquito control programs in Maryland. Use of pesticides for mosquito control in the United States was developed during the World War II era. In the early years of use, insecticides were widely applied for control of mosquito larvae and adults and the results were so dramatic in their effectiveness that the practice received widespread public and political support. However, the indiscriminate, widescale use of organochlorine and arsenical insecticides for the control of agricultural pests, mosquito control and other uses possibly caused environmental and human hazards. However, the readily apparent results of improved crop yields, reduction of human and animal diseases and greatly improved human comfort caused many to discount negative impacts such as toxicity to wildlife, accumulation of pesticides in the food chain, and development of resistance in some insect pest populations.

The risks of pesticide use were not widely questioned until the early 1960's when the popular book ***Silent Spring*** by Rachel Carson greatly increased public concern about the use of pesticides. The use of pesticides in mosquito control may have contributed to the environmental issues raised in *Silent Spring*, but compared to agricultural use, mosquito control pesticides are applied at much lower rates. The scientific accuracy of *Silent Spring* is controversial. However, there is no question that the book greatly affected public concern and political action regarding the use of pesticides.

The **risks** and the **benefits** of pesticides must be considered and evaluated in a systematic manner before they reach the market. It is during the risk analysis stage of development that appropriate safeguards for the use of the product are addressed. These safety measures are then incorporated into the product label in order to protect human health and the environment.

In the United States, the Environmental Protection Agency (EPA) is delegated the responsibility of registering pesticides. The risk analysis by EPA is rigorous and on-going. EPA requires studies and evaluations that take years to complete and costs millions of dollars in research and development before a pesticide can be registered for use. When used according to label directions, currently registered pesticides will have a minimal risk to public health or the environment.

The use of insecticides in mosquito control programs often come under close scrutiny because applications are applied directly into residential areas and sensitive natural environments such as wetlands. The adulticides registered for mosquito control use are applied at levels 100 to 10,000 times below the rates that would be cause of concern about exposure risk for the general public, or the environment. In addition, the use of currently registered mosquito control pesticides does not appear to have adverse effects to non-target species when used according to label directions, except in the case of small flying insects that are similar in size to mosquitoes may be impacted if they are present when mosquito adulticides are applied.

In Maryland, the use of pesticides is regulated by both state and federal laws that are enforced by the Maryland Department of Agriculture's Pesticide Regulation Section.

When pesticides are used as part of a mosquito control sprogram, consideration should be provided to those individuals in the public who object to the use pesticides due to health, or economic concerns. Individuals suffering from multiple chemical sensitivity comprise a small, but significant percentage of the population. If they are exposed to even a small amount of pesticide it may cause them to have a serious health related reaction. Mosquito control programs are not required by Maryland law to notify or make accommodations for chemically sensitive individuals. However, applicators making pesticide applications as part of mosquito control programs need to be aware of these individuals concerns and it is highly recommended that accommodations be made, such as notifying them prior to spraying or avoiding their residences when spraying. This is the policy of MDA's Mosquito Control Program.

Other sensitive sites such as bee hives, organic farms, and aquaculture operations must also be considered prior to the application of mosquito control **adulticides**. Beekeepers must be notified before applying an adult mosquito control insecticide in areas where hives are located, or to areas where the bees are known to forage. Locations with registered beehives should be avoided, or if an adulticide must be used make the application after sunset and before sunrise when the bees are not actively foraging. Beekeepers also need to be advised that the hives should be covered in order to minimize their exposure to spray drift.

Aquaculture operations should not be larvicided without the permission of the owners and pyrethroid insecticides should not be applied near aquaculture sites due to the high toxicity of this class of insecticide to aquatic organisms.

Registered organic farm operations should not be sprayed for mosquito control unless there is a documented risk of mosquito-borne disease. If spraying must be conducted the owner of the organic operation must be notified prior to the application. Many of these concerns can be minimized, or alleviated, by achieving a good larval control program by helping to reduce the use of adulticides that will be appreciated by the public and decrease the potential of environmental impacts.

The application of pesticides for mosquito control is part of an overall integrated control program that utlizes a combination of several control techniques. Pesticides should only be applied as a result of a surveillance program that substantiates the need for the application due to mosquito population levels that could result in a significant pest problem and/or increased risk of mosquito-borne disease. The population level at which point a pesticide application may be warrented is called an **action threshold**. Action threshold's are set based on a predetermined population level that once exceeded will result in an increased risk of mosquito annoyance or out break of mosquito-borne disease. The use of pesticides should never be scheduled unless the data collected from the surveillance program justifies their use.

The pesticides used in the Maryland mosquito control program are selected according to the following characteristics:

(1) minimal risk to human health and the environment when used according to label directions;

(2) efficacy in controlling mosquitoes;

(3) differing modes of action between insecticides in order to minimize the potential for a mosquito population developing resistance to a class of insecticides, and;

(4) affordability of the products.

However, the use of pesticides for mosquito control is considered a temorary form of control. This is due to the fact that it is unreasonable to expect the complete elimination of the next generation of mosquitoes by treating the current generation. This process may have to be repeated time after time, and holds true for the chemical treatment of both immature and adsult populations of mosquitoes. The need for temporary chemical control can be reduced by implementing permanent control measures whenever possible.

## Mosquito Larvicides

A **larvicide** is a pesticide applied to water to kill immature mosquitoes, or prevent the successful emergence of adult mosquitoes. Larviciding (the act of applying a larvicide) is more site specific than adulticiding and is the preferred control method using pesticides. However, larviciding requires greater resource assets than adulticiding in terms of both funding and the need for specially trained personnel. In addition, larvacides have a relatively short time frame in which they can be successfully applied.

Larvicides are available in four formulations that include:

(1) liquid concentrates that are generally diluted in water;

(2) granules that are a dry formulation (less than ¼ inch in size) and ready to apply;

(3) briquets that are another type of dry formulation that is much larger in size than granules and is designed to provide a slow, extended release of the active ingredient, and;

(4) wetable powders which is a dry formulation that must be mixed with water prior to application.

There are several materials labeled for the control of mosquito larvae. These larvicides are avaialble in the following classes of pesticides:

(1) oils and monomolecular films of alcohol that suffocate larvae and pupae;

(2) conventional insecticides such as, organophosphates that kill the larva by disrupting their nervous system;

(3) insect growth regulators (IGR) and chitin synthesis inhibitors. IGR's disrupt the normal growth of larvae. They do not kill the larvae, but prevents their successful emergence into adults, and;

(4) bacterial toxins that kill larvae as a result of large ulcers that develop in their digestive system after being eaten.

In Maryland, no oils or organophosphate products are currently used as mosquito larvicides.

The timing of the larvicide application is dependent on the nature of the product that will be used. Conventional insecticides will kill larvae at all stages and thus can be applied whenever convenient. Bacterial toxins must be consumed by the larvae and are usually applied well before the 4th instar to ensure that consumption by the larvae occurs. IGR's mimic an essential hormone present in high concentrations in the early instar larvae but in very low concentrations 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. IGR's can be formulated as slow release insecticides so that applications can be made in the 2nd or 3rd instar, resulting in an adequate exposure to the material during the 4th instar. Chitin synthesis inhibitors affect the ability of the larvae to reattach their muscles to the exoskeleton during the molting process and thus are effective throughout the entire larval stage. Monomolecular films prevent the insect from remaining at the surface of the water by reducing surface tension. Under these conditions larvae and pupae deplete their energy reserves trying to stay at the surface and succumb to exhaustion. Nonpetroleum oils kill both larvae and pupae by suffocation because the insects are not able to obtain air through the siphon at the oily surface.

The insect growth regulator methoprene is the most commonly used larvicide in the Maryland program. Methoprene is an insect growth hormone mimic that prevents the successful emergence of adult mosquitoes, but does not kill mosquito larvae. As previously discussed, larvae develop normally through the first four instars, but the pupae fail to mature into completely developed adults due to the artificially high level of juvenile hormone (methoprene) which inhibits the development of the adult characteristics. To be effective, methoprene must be present in sufficiently high concentrations at the critical fourth instar. These mosquitoes generally die after a prolonged time in the pupal stage. This is due to their depleted food reserves that eventually leads to their death due to starvation and is not the result of a direct toxic impact of methoprene. There are several formulations of methoprene including liquid, granular and brickets. The liquid and granular formulations have a very short time period in which they provide control (3 to 5 days) while the briquet formulations provide a slower release of methoprene over a longer period of time (1 to 5 months).

Bacterial toxins include *Bacillus thuringiensis israelensis* (B.t.i.) and *Bacillus sphaericus*. These bacterial spores must be eaten by mosquito larvae in order to be effective. B.t.i. formulations are most effective when they are applied to relatively clean water containing low to moderate populations of early instar (1st to 3rd instars) larvae of *Anopheles* and floodwater mosquitoes. The efficacy of B.t.i. is greatly reduced in water that contains a high level of organic matter and nutrients. It is generally ineffective when applied to 4th instar larvae, and in addition the control of *Culex* by B.t.i. is also generally ineffective.

*Bacillus sphaericus* is the active ingredient contained in pesticide products sold as Vectolex®. Vectolex is the most effective against populations of *Culex* and performs well in both clean and polluted water. However, Vectolex is less effective against floodwater mosquitoes. Under the conditions of long-term flooding, stagnant flow and when populations of *Culex* larvae reoccur, Vectolex provides a short to moderate level of residual larvicidal activity.

Each larvicide has it's own specific characteristics associated with it and as a result it may be more effective against one group or age class of mosquitoes over another product that has different characteristics. As a result, applicators must be careful to choose the product that is best suited to the particular conditions in which they will be applying the pesticide. For example, the briquet formulations of methoprene will provide long-term control, but are expensive and best suited for use in sites that are known to be chronic breeding locations. In addition, larvicides must be accurately applied and appropriate for the habitat being treated. They must also be applied at the right time and used against susceptible species of mosquitoes.

Another important consideration when using laracides, is to make sure that the application site has received a thorough coverage. This is important when larviciding because the failure to treat even a small portion of a community's mosquito breeding habitat can result in the emergence of a large number of adult mosquitoes that could lead to the need for immediate broad-scale adulticiding. Larviciding is the most effective under the following general conditions:

(1) when treating large areas of breeding habitat with aircraft; and

(2) when mosquito breeding is confined to specific small areas, such as roadside ditches or stormwater areas that can be easily treated by ground equipment.

The application of larvacides is important to the success of an IPM program, and must be based on accurate surveillance data. Information obtained from the larval surveys is invaluable to the control supervisor who can then apply effective larvacides to the right places at the right time in order to keep adult mosquito populations below disease-vectoring or annoyance levels.

These larval counts are then compared to predetermined action thresholds to see if the application of a larvacide is warrented. If the sample contains a larval count that meets, or exceeds, the action threshold the application of a larvacide is justified.

Maryland's action thresholds for pest mosquitoes have been set at 1 mosquito larva per dip in community-based breeding locations (ditches, catch basins, etc.) and 5 larvae per dip in large wetland areas.

However, larviciding is generally not effective for the control of tiger mosquitoes due to the numerous, difficult-to-find breeding locations for this species. Elimination of breeding containers by source reduction is the most effective method for controlling tiger mosquitoes.

## Mosquito Adulticides

Adult mosquito control, when coordinated with a good surveillance program, can be an important part of an IPM program and may be essential to protect public health during an epidemic of mosquito-borne disease. However, reliance on adulticiding as the only type of mosquito control is a poor practice that should be avoided, or utilized only to stop an on-going public health emergency characterized by the known occurrence of mosquito-borne disease within a controlled area. The ground or aerial application of pesticides to kill adult mosquitoes is usually the least efficient mosquito-control technique and is the last resort in their control.

Nevertheless, adulticiding, when based on concurrent surveillance data, is an extremely important part of the IPM approach when undertaken with the appropriate labeled amount of insecticide. Adulticides are most often applied as **ultra-low-volume (ULV)** sprays (Figure 6.5) in which very small amounts (3 fluid ounces or less per acre) of the insecticide is applied by ground vehicles or aircraft. ULV technology applies a relatively high concentration of insecticide at a very low rate. Very small droplets (15 to 100 microns) are produced by specialized ULV technology and application equipment, that can include high performance aircraft. These droplets are intended to remain suspended in the air for several minutes, drifting in the air currents in order to come in contact with flying or resting adult mosquitoes. Adult mosquitoes are then killed upon contact with these materials. The use of ULV spraying results in millions of these small spray droplets being dispersed into the target area. This is normally established on a per acre basis. The large majority of these spray droplets never come in contact with adult mosquitoes, and as a result they will eventually settle on vegetation, the soil or other objects where they will rapidly degrade in the presence of water, sunlight and micro-organisms into non-toxic substances. In addition, there is not any residual activity from the insecticides used in ULV spraying that can kill or repel mosquitoes. ULV spraying is typically done in the very early morning, or in the evening, when the wind speed is low, mosquito activity is high and

Figure 6.5. Ultra low volume spray application.

most beneficial insects are resting. For some species of mosquitoes, ULV spraying after sunrise is also effective. This is particularly true for tiger mosquitoes (which actively fly only during daylight hours), salt marsh mosquitoes, and a few other species that are also active during daylight hours.

The degree of control that results from the use of ULV adulticiding is variable. This is dependent on the completeness of coverage, amount of vegetation present, species of mosquito and formulation of insecticide. In urban areas and older suburban communities, truck ULV spraying can be very effective. This is due to the grid pattern established by the layout of the streets that provides a guide for the spray truck's route resulting in a uniform coverage of the area. In rural areas, or modern suburbs, with irregular street patterns and cul-de-sacs, ULV sprays from truck-mounted equipment cannot achieve complete coverage. As a result, the control efficacy in these type of areas is much less than the areas that have a grid of parallel roads. Aircraft can also be used to perform ULV spraying and are typically equipped with state-of-the-art global positioning systems (GPS) which virtually assure complete and accurate coverage of spray zones.

The efficacy that results from ULV spraying from ground equipment typically ranges from a 50 percent to a 90 percent reduction in the adult mosquito population. While the efficacy resulting in ULV spraying from aircraft generally ranges from a 90 percent to a 99 percent reduction in adult mosquito populations.

Using the proper size range for the droplets makes it possible to increase control efficiency and decrease the risk of adverse impacts 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 use of ULV applications lends itself to criticism that nontarget organisms can be impacted, adherence to the label specifications for droplet size in ground applications confines the possibility of adverse impact to a relatively few small, nocturnal organisms. This is a constant consideration for mosquito control programs, especially those relying heavily on aerial adulticiding, for which the droplet size spectrum is somewhat larger. Extended experience coupled with EPA studies demonstrates that when applied according to the label directions (the law), these applications have minimal, or no effect, on most nontarget organisms.

**Barrier treatments**, are typically applied as high volume (low concentration) liquids with hand-held spray equipment using compounds with residual characteristics. This application method is common in some areas of the United States and its use is growing. This technique is especially attractive to individual homeowners living near mosquito-producing habitats where residual chemicals are applied to the vegetation along property borders providing relief to the residents.

**Space sprays**, that are 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 structures 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 there are some insecticides labeled for this use.

Action thresholds are also established for the control of adult mosquitoes. Once these predetermined levels of mosquito counts are reached the use of an insecticide (adulticide) may be warrented in order to control the mosquito population. The following is a list of the action threshold criteria that has been established by the Maryland Department of Agriculture (MDA) for their adult mosquito control programs under normal pest suppression conditions:

- ❑ For pest suppression by truck-mounted ULV sprayers – a landing rate count of 5 mosquitoes in 2 minutes and/or a light trap collection of 20 female mosquitoes per night from an unbaited trap, or 40 females from a $CO_2$ baited trap.
- ❑ For pest suppression by use of aircraft – a landing rate count of 12 mosquitoes per minute and/or an unbaited light trap collection of 100 female mosquitoes per night.

The following criteria have also been established by MDA as the action threshold levels for conducting mosquito suppresion programs involving mosquito-borne diseases:

- ❑ For disease suppression by truck-mounted ULV sprayers – a landing rate count of 1 mosquito per 2 minutes and/or a $C0_2$ unbaited light trap collection of 10 female mosquitoes per night.
- ❑ For disease suppression by use of aircraft – determined on a case by case basis in consultation with local health departments.

All insecticides used for ULV spraying are liquid formulations containing a relatively high concentration of active ingredients. Natural pyrethrins, synthetic pyrethroids and organophosphates are the classes of insecticides most commonly used as mosquito adulticides in the United States. All of the insecticides kill adult mosquitoes by disrupting the insects nervous system. In Maryland, two pyrethroid insecticides are currently used for truck ULV spraying: (1) permethrin and (2) phenothrin (also known as sumithrin). Both of these products are **synergized** with piperonyl butoxide (PBO) which allows smaller doses of the insecticide to be effective in killing adult insects. Permethrin and phenothrin products are relatively non-toxic to humans, wildlife and other non-target organisms at the rates applied for mosquito control. However, like all other pyrethroids, permethrin and phenothrin can be toxic to fish and other aquatic species at low use rates. As a result, there may be specific use restrictions on the product label when using these products in areas that are near wetlands, lakes, streams, rivers, ponds, and similar sites.

The only organophosphate currently used in the Maryland mosquito control program is naled. Naled requires specialized training and equipment in order to properly store, transport and load the product due to its alkaline corrosiveness and toxicity when handled in large quantities. Due to these concerns, naled is used only in the aerial spraying program. Naled is the most effective mosquito adulticide used in Maryland's program and is the only mosquito adulticide that is specificaly labeled where it can be applied directly over water and wetland areas.

Before applying any pesticide, be sure to exercise all precautions and follow proven application methods in order to minimize the possibility of a problem, or accident, from occurring. **ALWAYS READ AND FOLLOW THE LABEL DIRECTIONS.**

### Repellants

In the strictest sense, repellents are not insecticides, but they are classified as a type of pesticide. For perasonal protection outdoors, repellents may be quite effective if they are properly applied. Many of the commercially available repellents currently on the market are formulated as creams, lotions, and aerosol sprays.

In addition to the proper application of repellents, their effectiveness is dependent on other factors, such as the active ingredient, formulation, percentage of active ingredient, the activity of the person, and even the skin chemistry of the person using the repellent. The label instructions need to be carefully followed in order to obtain good results and avoid hazards to your health.

## Toxic Materials Permit

In Maryland, mosquito control, including larviciding, generally requires a Toxic Material Permit (TMP) from the Maryland Department of the Environment, Water Management Administration, Industrial Discharge Permits Division. The permit is required for any homeowner, farmer, local government, or other person who wants to control aquatic life in ponds, ditches, or waterways by the deliberate use of a toxic chemical (e.g. mjosquito control, algae control). The also includes mosquito control in natural wetlands, ditches, stormwater sites and similar sites. However, a TMP is not required for larviciding swimming pools, bird baths, or artificial containers. As part of the application process, the following information must be provided:

(1) method in which the pesticide will be applied;

(2). the pesticide that is proposed for use, and;

(3). proposed schedule of applications.

If in doubt if a TMP is required, it is best to check with the Maryland Department of Environment, and not apply larvicides before confirming the need for obtaining a TMP. Appendix 5 provides a copy of the Toxic Materials Permit application.

## Monitoring For Effectiveness Of Control

The results from mosquito control efforts are not measured by the number of fish stocked, amount of public education information given out, feet of ditch dug or the number of acres sprayed with insecticides. The measure of effectiveness is determined by whether or not the goals established for the program have been met. These goals are to:

(1) reduce the risk of mosquito-borne disease;

(2) keep mosquito populations below the pest threshold levels, and;

(3) protect the environment.

Public and political support for mosquito control programs will continue only if these goals are consistently achieved.

Evaluating the results obtained from the control efforts is an important element of any mosquito control program. Conducting field evaluations of the effectiveness is relatively easy and extremely valuable. One example would be to determine if public education efforts result in fewer problems with tiger mosquitoes in a community? This question can only be answered by conducting periodic breeding index inspections and comparing results to an original breeding index survey conducted prior to the public education efforts.

Another example would be determining the effectiveness of stocking *Gambusia* in a stormwater pond. This can be best determined by compairing the results of mosquito larval dipping inspections obtained pre- and post-stocking of the *Gambusia*. It is also important to monitor stocked sites on a regular basis in order to determine how the fish are doing ( i.e., did the prolonged freezing weather last winter kill the fish?, or has the habitat degraded over time to the point where the fish can no longer survive?).

**Quality control** evaluations of insecticides should be done regularly in order to evaluate the degree of reduction to mosquito populations following spraying. If the ground-based spraying of roadside ditches does not result in a 100 percent control of mosquito larvae, there is a problem. The problem could be caused by:

(1) resistance to the insecticide;

(2) improper equipment calibration or performance, or;

(3) operator error.

For truck and aircraft ULV adulticide spraying, frequent checks should be made by program supervisors to determine it's effectiveness by conducting pre- and post- spraying landing rate counts or trap collections. If populations of adult mosquitoes are not greatly reduced by the ULV spraying and the desired results are not being achieved, a reason for the failure needs to be determined and corrected.

In addition, periodic evaluations of mosquito populations need be conducted in order to ensure that the insecticides being used are still effective and the mosquitoes have not developed a resistance to the pesticides. Resistance testing is best done in the laboratory in order to reduce the variables usually found in field evaluations. However, it is important to use field collected mosquito larvae and adults from areas that have a history of insecticide use for conducting this laboratory testing. Regular evaluations of adult mosquitoes for resistance to synthetic pyrethroid insecticides is especially important, since insects are known to develope resistance mechanisms to this class of pesticides in a relatively short period of time.

## Application Equipment

Insecticide application equipment for most mosquito control falls into two categories: granular applicators and liquid sprayers.

Application equipment ranges from small hand-held devices to sophisticated delivery systems mounted on aircraft. When selecting application equipment it should fit the situation in which it will be used and deliver the pesticide as intended without incident. A piece of equipment that was designed for, or used in another pesticide application program should not be used if a potential exists for an improper, unsafe or illegal application. In addition the component parts of the equipment such as spray tanks, pumps, agitators, nozzles, and hoses should be selected on the basis that they will apply the pesticide in a safe and effective manner. Proper maintenance and cleaning of the equipment is important in order to insure that it will continue to properly apply the pesticides over a long period of time. The accurate calibration of all application equipment prior to each use is also essential.

### Granular Application Equipment

Basically, all granular applicators are containers with adjustable openings in the base of the unit through which a controlled amount of granular insecticide may pass. They may be manually operated or power assisted. Some may be equiped with agitators or auger feeds to assist in producing a uniform flow rate. Granular application equipment is frequently used in larviciding programs.

**Horn Seeders** - The horn seeder is the simplest device for applying granules. The horn seeder is comprised of a canvas bag which is slung over the applicators shoulder and has a tapered, telescoping wand or tube attached to the lower front corner of the bag. Granules are then dispersed as the operator's arm (and wand) move in a horizontal figure eight fashion. Application rates may be altered by adjusting the opening at the base of the wand or by changing the speed at which the operator walks (Figure 6.6).

Figure 6.6. Granular application using a horn seeder.

**Cyclone Spreaders** - These spreaders are the second type of manually operated granular applicators. These are cylinders with an adjustable slot in the base through which granules fall onto a rotating disc and are dispersed by centrifugal force. The disc is rotated by gears which are activated by turning a crank handle. The rate of dispersal may be altered by controlling the size of the slotted opening, or by changing the walking speed of the operator.

Both the cyclone-type spreader and horn seeder are commonly used in treating small, isolated larval habitiats such as woodland pools.

**Granule Blowers** - The power assisted, granule blower has a feed tube that meters the granules from a hopper into a high velocity stream of air, which exits the hopper through a nozzle or spreader. These units may be back-pack size or truck mounted. The speed of the air stream may range from 75 to 150 miles per hour. Similar blowers are also utilized in helicopter delivery systems where the forward air speed of the aircraft is high enough to provide adequate pressure for proper distribution of the granules. In fixed-wing aircraft, where the payload is greater, this type of equipment may also use "ram-air" spreaders that use air pressure developed by the forward speed, propeller-wash, or both.

## Liquid Application Equipment

Liquid formulations for mosquito control can be applied in sprays that range in droplet size from less then 5 microns (fogs) to 250 microns (mists). Although the actual number of equipment types is numerous, there are seven basic ways of applying liquid formulations for mosquito control.

**Compressed Air Sprayers** - One of the most common sprayers for treating small areas is the 1 or 2 gallon compressed air sprayer (Figure 6.7). The liquid contents contained in the spray tank are put under pressure by a hand compressor (pump) or motor driven compressor. The air pressure that is created then forces the liquid through the nozzle as a spray. Compressed air sprayers are used for applying larvacides to small habitats such as catch basins or woodland pools. Some larger compressed air sprayers may be mounted on aircraft.

Figure 6.7. Compressed air sprayer.

**Hydralic Sprayers** - In hydraulic sprayers, the insecticide flows from a tank through a pump. From the pump, the insecticide, which is now under considerable pressure, flows through a delivery line or hose until it is released through a nozzle. In some sprayers, pressure of up to 600 pounds per square inch (psi) may be reached. Hydralic sprayers range in size from a back-pack with a trombone sprayer to units that are mounted on trucks or aircrafts. This equipment is most often used for treating large mosquito habitats.

Figure 6.8. Back-pack mist blower.

**Turbines or Mist Blowers** - Turbines or mist blowers (Figure 6.8) work similar to the hydralic sprayer, except air carries the insecticide to the target. A hydralic pump delivers the insecticide through a tube or nozzle into a high-volume, high velocity column of air that has been produced by the turbine. It is the column of air that carries the insecticide to the target. These sprayers range in size from a motor powered back-pack to those that are mounted onto trucks. This type of sprayer is used to apply both larvacides and adulticides over large aeras.

**Ultra-Low Volume (ULV) Sprayers** - Ultra-low (ULV) volume sprayers (Figure 6.9 A) were developed to eliminate the need for using great quantities of petroleum oil diluents as is necessary with thermal fogger's. The ULV units were originally constructed by mounting a modified vortical nozzle on a thermal fogger's forced air blower. Most of the nozzles are based on a design patented by the U.S. Army. The insecticide is then applied as a technical material, or in moderately high concentrations (as is common with the pyrethroids). This results in the application of very small quantities of the insecticide per acre, and as a result is referred to as ultra-low volume. ULV has been a technique used for insect control in agriculture, forestry, and public health programs for some time, particulary by aerial applications. In agriculture, this rate is less than 36 oz./acre, but in mosquito control ground adulticiding operations it rarely exceeds 1 oz/acre. The optimum size droplet for mosquito control using ULV is in the range of 5 to 15 microns.


Figure 6.9 A. Truck mounted ULV sprayer.


Figure 6.9 B. Truck cab mounted flowmeter for ULV sprayer.

The effectiveness of ULV is dependent upon the production of very small or "fine" droplets in much larger numbers than with convential methods of application. These fine droplets are produced by introducing air with a high velocity into a swirl chamber along with the liquid insecticide that has a low pressure. There is a shearing action of the air that takes place within the chamber which results in the production of extremely fine, relatively uniform droplets.

Since ULV involves the use of higher than normal concentrations of the insecticide and lower than normal rates of application, this information must appear as part of the product labeling in order to avoid misuse of the product.

Other disadvantages of ULV in comparison to convential mist type applications are poor residule life, creates a chemical slick if over sprayed, the necessity to wear protective equipment, there is a certain degree of fire and explosion hazard as compared to convential space sprays, and making the application at a time when the area is unoccupied. Some additional disadvantages that may be factors if a gasoline-powered spray unit is used is the production of carbon monoxide and noise from the motor. Because the droplet size is critical in ULV applications the equipment must be maintained and operated at the specified pressures and flow rates. At the present time there is not a pracitical way for determining the droplet size quickly in the field.

The advantages of ULV application include shorter treatment time and lower fire and explosion hazards than foggers. Other more debatable advantages include deeper penetration of the insecticide into mosquito harborage, a more thorough flushing action, and a more effective use of the insecticide.

To obtain the best results with ULV spraying you should:

- ❑ Follow label directions.
- ❑ Follow all safety precautions.
- ❑ Keep the equipment well maintained. The engine should run evenly at the proper speed and should be kept well tuned. The flow rate or pressure must also be correct.
- ❑ Direct the application into harborage areas so the maximum penetration is obtained along with increasing the potential for the pests to come in contact with the insecticide.
- ❑ Use only those pesticides registered for use in ULV spray equipment.
- ❑ Wear an approved respirator and goggles.

ULV is used for applying adulticides and the units are either portable or truck mounted.

**Thermal Foggers** - Thermal foggers create a fog with the insecticide. This is done by introducing an oil based insecticide formulation into a heated chamber which causes an immediate vaporization of the oil. Thermal foggers are only used to control adult mosquitoes.

**Rotating Cylinder Applicators** - This type of application uses high speed (10,000 rpm's or more) rotating cylinders to break up the liquid insecticide as it passes through a permeable sleeve that has openings between 5 and 60 microns in size. It then passes through either one or a series of screens, or between two closely speced discs. This type of equipment can be mounted on trucks or aircraft. It is mainly used in adulticiding programs. Some vehicle mounted units have an air blower system to assist in the movement of the produced aerosol cloud away from the vehicle.

**Aerosol Bombs, Burnt Coils or Sticks** - Aerosols or "bug bombs" consist of an insecticide and propellant in a presurized container. Since they are normally purchased as a unit from the manufacturer, they are used without further mixing. Aerosol bombs are not very economical and are only used in small, confined areas. Some of these insecticide formulations may be classified as a restricted use pesticide. Burnt coils or sticks are formulated so that when lit they release the insecticide into the air with the smoke particles.

# Study Questions – Chapter Six

1. What is the greatest value of a public education program in mosquito control?

2. Name five things that people can do to reduce exposure to mosquitoes.

3. What is source reduction as it applies to mosquito control?

4. What biological control agent has been used in more programs and more successfully than any other?

5. What four factors are considered in the selection of a pesticide for a mosquito control program?

6. What is a larvicide?

7. What four classes of insecticides are used as mosquito larvicides?

8. How do bacterial toxins kill mosquito larvae?

9. What is a Toxic Material Permit?

10. What does ULV mean in regard to pesticide application?

11. Why is it important to evaluate the level of mosquito reduction as a result of applying a pesticide?

12. What is the simplest type of application used to apply granules?

13. What are some of the important considerations that must be followed when using a ULV sprayer in order to obtain good application results?

# GLOSSARY

**Abdomen -** the last part of an insect's body (behind the head and the thorax); this section contains the reproductive organs and most of the digesticve system.

**Action threshold -** a population of mosquitoes, as detected by surveillance techniques, that meet or exceed predetermined levels that result in an increased risk of mosquito annoyance or mosquito-borne disease.

**Adult -** a full-grown, sexually mature insect, mite or other animal.

**Adulticide -** an insecticide that is toxic to the adult stage of insects.

**Anopheline -** a mosquito of the genus *Anopheles*.

**Arbovirus -** a virus borne by an arthropod such as a mosquito.

**Atomize -** to break up a liquid into very fine droplets.

**Barrier treatment -** application of a pesticide in a strip alongside or around a structure, a portion of a structure, or any object (for example, shrubbery), usually leaving a residual deposit on the treated surfaces.

**Bionomics -** the ecology, behavior and life history of an organism.

**Biorational -** a biological pesticide such as the toxins produced by bacteria that are used to control mosquito larvae.

**Class -** a group of similar orders withina phylum, such as the Class Insecta, or similar chemicals, based on molecular structure and mode of action.

**Crepuscular -** active at twilight (dawn and dusk).

**Crypt -** a hidden chamber, or depression, in the ground that can hold water, often found around tree roots or rock piles.

**Culicine -** mosquito species other than those found in the genus *Anopheles*.

**Dead-end-host -** an infected host from which a susceptible vector cannot acquire the virus.

**Definitive host -** see "primary host".

**Diurnal -** active during the day.

**Dipterans -** members of the insect order Diptera (flies and mosquitoes).

**Endemic -** a disease that exists continually in reservoir hosts in a geographically defined area.

**Enzootic reservoir -** a host for a disease organism that cycles in nature without involving humans.

**Epidemic -** the occurance of more cases of human disease in agiven area, during a specific time period then would normally be expected to occur.

**Epizootic -** a disease outbreak in nonreservoir, nonhuman animals.

**Exoskeleton -** the hard or tough external covering of arthropods to wichy their muscles are attached and which serves the same function as the bony skeleton of humans.

**Family -** a group of related genera within an order.

**Floodwater -** temporary water that is likely to persist long enough for mosquitoes to complete their immature stages.

**Genus (genera) -** a group of species considered more closely related to one another than to members of another genus (plural is "genera"); the first word in the sceintific name of a species is the name of the genus.

**Gravid -** the state of a female invertebrate that contains developing or mature eggs.

**Halteres -** knoblike balancing structures located behind the wings in the insect order Diptera.

**Harborage -** areas where insects or other pests remain safely hidden during their periods of rest; harborage sites are usually near food and water sources.

**Head -** the first part of an insect's body; the head bears a single pair of antennae and other sensory organs, such as compound eyes.

**Host -** any animal or plant in or on which another lives for nourishment, development or protection.

**Hibernacula -**the place in which an animal or insect hibernates or overwinters.

**Impoundment management -** manipulation of flooded aquatic habitats in a manner that minimizes both ecological change and mosquito development.

**Instar -** the developmental stage of an insect larva between molts.

**Integrated pest management (IPM) -** is the use of a combination of biological, chemical, educational and physical control methods in order to maintain targeted species or populations of mosquitoes at acceptable levels.

**Intermediate host -** a host in which asexual stages of the parasite or disease pathogen are found.

**Larva (larvae) -** the form that hatches from the egg in the development of an insect that undergoes complete metamorphosis (plural is "larvae"; after several molts that allow increases in body size, the larva transforms into a different form (pupa) before reaching its final form, the adult.

**Larvicide -** an insecticide that is toxic to insect larvae.

**Metamorphosis -** the physiological process that causes the striking changes in shape and structure that occur as an insect progresses from one stage in its life cycle to the next.

**Micron -** a unit of measurement used to describe the size of spray droplets. One micron is equal to1/ 1,000,000 of a meter.

**Mode of action -** the mechanism by wich a pesticide intoxicates an organism.

**Molt -** the process of shedding the outer layer of skin.

**Nocturnal -** active at night.

**Nontarget -** any plant, animal, or other organism that is not the object of a pesticidal or other control application.

**Open marsh water management -** a form of water management that preserves the ecology of aquatic habitiats and encourages natural predators and events to control mosquito larvae.

**Order -** a group of related families within a class.

**Ovitrap -** a trap designed to attract females to deposit eggs.

**Oviposition -** egg laying.

**Parasite -** an organism that derives nourishment from another at the other's expense, but without immediately killing it.

**Pathogen -** a disease-causing organism.

**Phylum (phyla) -** the primary divisionof the animal kingdom into smaller groups for classification, examples are Arthropoda and Chordata (plural is "phyla").

**Piercing-sucking -** one of the basic types of insect mouthparts; insects with piercing-sucking mouthparts (female mosquitoes, for example) pierce tissue to gain access to fluids such as blod.

**Primary host -** the host in which a parasite or pathogen completes the sexual portion of its life cycle; also "definitive host".

**Pupa (pupae) -** an immature stage, between the larva and the adult, in insects that undergo complete metaporphosis (plural is "pupae".

**Reservoir -** one or more host species that is infected by and tolerates the development or multiplication of a disease-causing pathogen without suffering serious harm.

**Scientific name -** the two-word name for a species derived from Latin or Greek words; the first word identifies the genus, the second the species; scientific names are underlined or italicized, as in *Ades vexans*, and only the first letter of the genus is capitalized.

**Setae -** bristles or hair.

**Siphon -** a breathing tube used for respiration by larvae of most mosquitoes.

**Siphoning-** one of the basic types of insect mouthparts; insects with siphoning mouthparts (male mosquitoes, for example) have tubelike mouthparts through which they ingest plant nectar.

**Source reduction -** the elimination or reduction of mosquito breeding sites by physical alteration or management of water sources.

**Space spray -** a pesticide applied in the form of aerosol droplets that remain suspended long enough to impinge on insects and other pests, used both inside and outdoors.

**Species -** a group or population of individuals capable of naturally interbreeding to produce viable offspring; the word "species" is both singular and plural; "spp." is the accepted abbreviation for more than one species.

**Standing Water -** permanent water, such as ponds, lakes, pools, etc.

**Sylvan -** literally, of the woods or forest; the word "wild" can be substituted without significantly changing the meaning.

**Synergized -** the interaction of two or more agents so that their combined effect is greater than the sum of the individual effects of each agent.

**Target -** an area, building, animal, plant or pest that is to be treated with a pesticide.

**Tarsus (tarsi) -** the last segments of an insect's legs; the "feet" of an insect (plural is "tarsi").

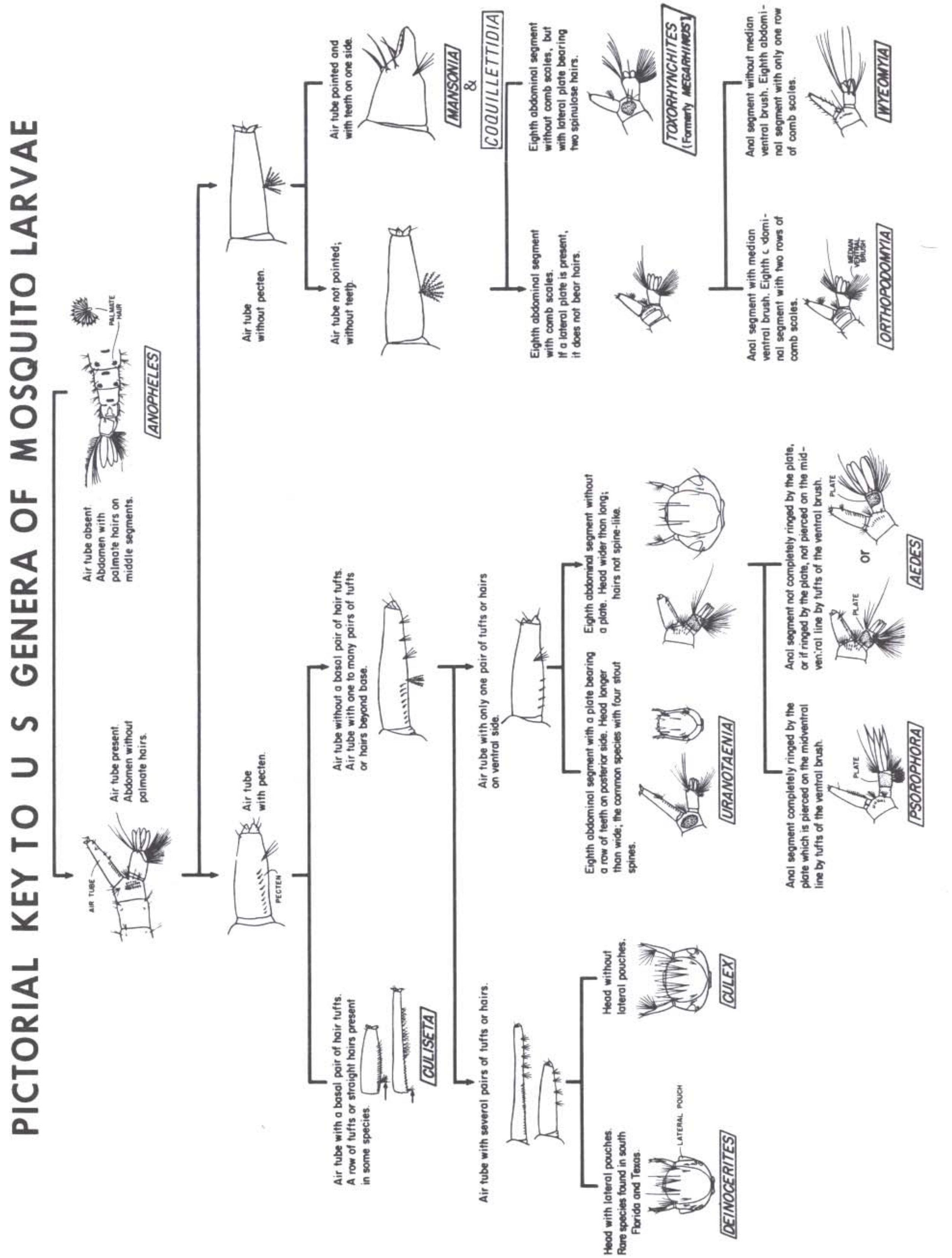
**Thorax -** the middle part of an insect's body (between the head and abdomen); this section bears three pairs of legs and usually one or two pairs of wings.

**Ultra low volume (ULV) application -** ultra-low volume; a spray application of a pesticide that is almost pure active ingredient; it is sprayed in extremely small amounts ( in fine droplets that impinge on small flying insects) over a large area (usually only a few ounces per acre and not more than a half gallon per acre).

**Vector -** an animal, usually an athropod, capable of transmitting a disease-causing agent or parasite from one host to another.

**Zoonosis (zoonoses) -** a disease that cycles in nature to nonreservoir hosts without involving humans (plural is "zoonoses").

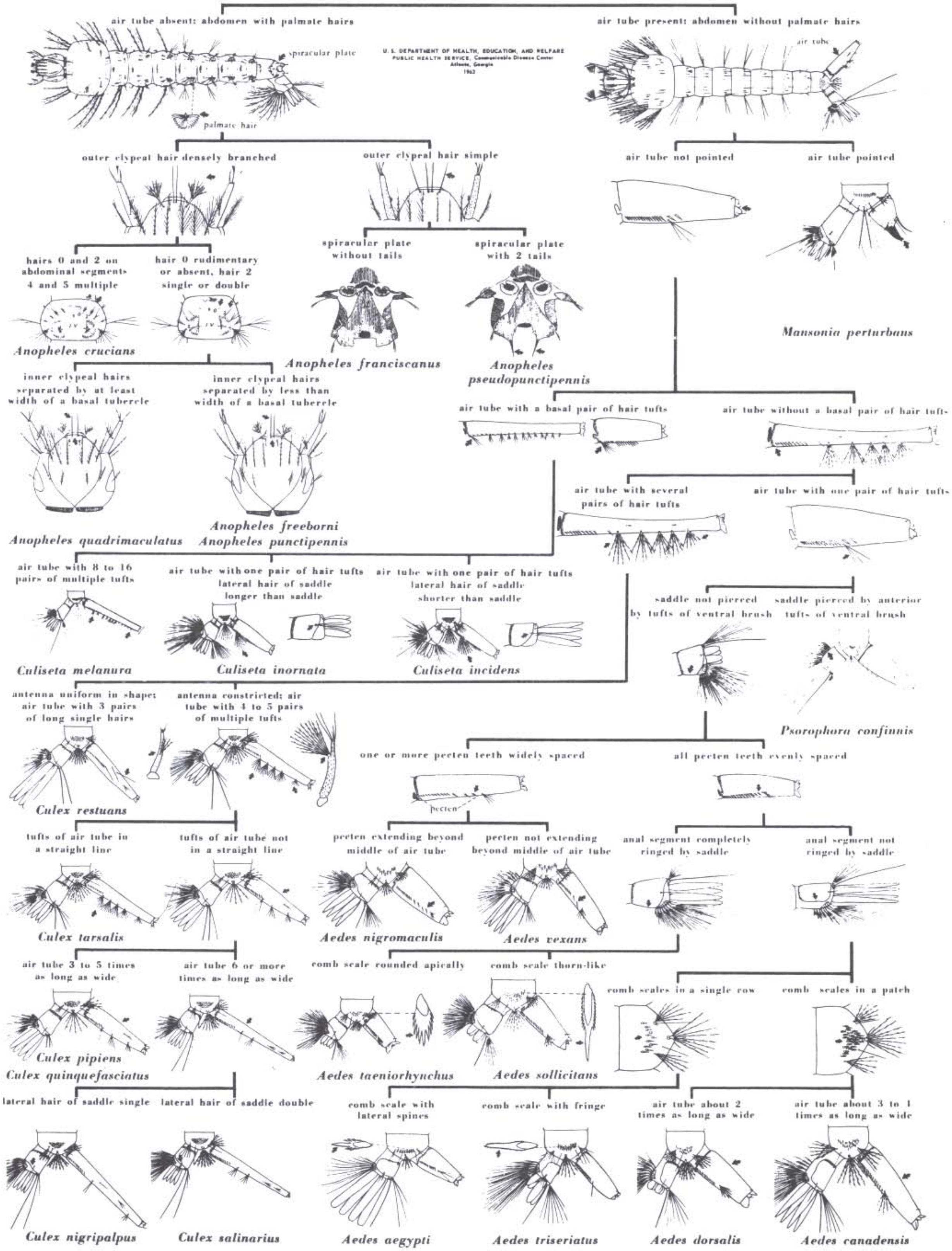
# Appendix 1


PICTORIAL KEY TO U S GENERA OF MOSQUITO LARVAE
AIR TUBE
Air tube present. Abdomen without palmate hairs.
Air tube absent. Abdomen with palmate hairs on middle segments.
PALMATE HAIR
ANOPHELES
Air tube with pecten.
PECTEN
Air tube without pecten.
Air tube with a basal pair of hair tufts. A row of tufts or straight hairs present in some species.
CULISETA
Air tube without a basal pair of hair tufts. Air tube with one to many pairs of tufts or hairs beyond base.
Air tube not pointed; without teeth.
Air tube pointed and with teeth on one side.
MANSONIA
&
COQUILLETTIDIA
Air tube with several pairs of tufts or hairs.
Air tube with only one pair of tufts or hairs on ventral side.
Head with lateral pouches. Rare species found in south Florida and Texas.
LATERAL POUCH
DEINOCERITES
Head without lateral pouches.
CULEX
Eighth abdominal segment with a plate bearing a row of teeth on posterior side. Head longer than wide; the common species with four stout spines.
URANOTAENIA
Eighth abdominal segment without a plate. Head wider than long; hairs not spine-like.
Anal segment completely ringed by the plate which is pierced on the midventral line by tufts of the ventral brush.
PLATE
PSOROPHORA
Anal segment not completely ringed by the plate, or if ringed by the plate, not pierced on the mid-ventral line by tufts of the ventral brush.
PLATE
or
AEDES
Eighth abdominal segment with comb scales. If a lateral plate is present, it does not bear hairs.
Eighth abdominal segment without comb scales, but with lateral plate bearing two spinulose hairs.
TOXORHYNCHITES
(Formerly MEGARHINUS)
Anal segment with median ventral brush. Eighth abdominal segment with two rows of comb scales.
MEDIAN VENTRAL BRUSH
ORTHOPODOMYIA
Anal segment without median ventral brush. Eighth abdominal segment with only one row of comb scales.
WYEOMYIA

# Appendix 2

## PICTORIAL KEY TO SOME COMMON MOSQUITO LARVAE OF THE UNITED STATES

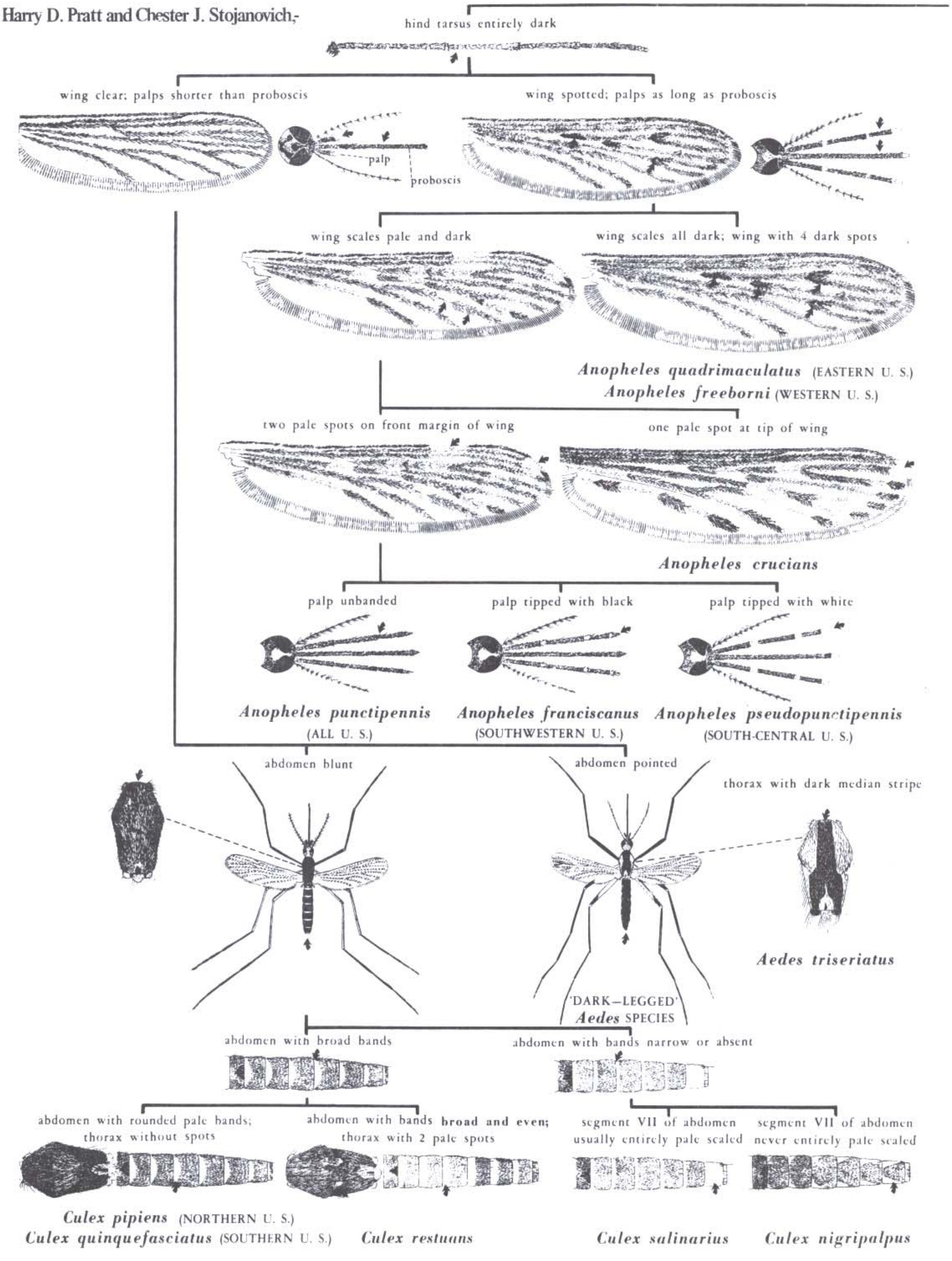
Chester J. Stojanovich and Harry D. Pratt



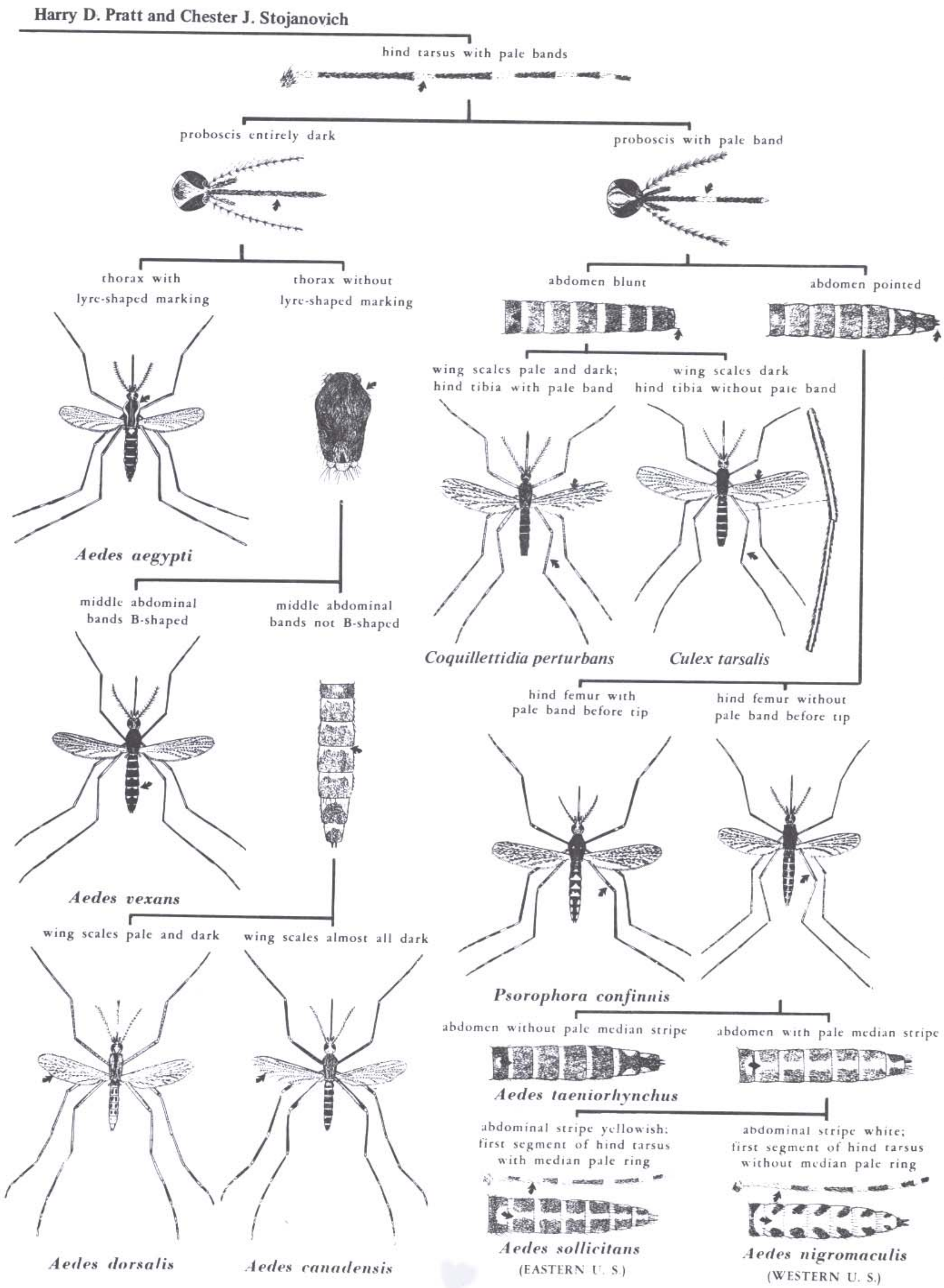
# Appendix 3

PICTORIAL KEY TO SOME COMMON FEMALE MOSQUITOES OF THE UNITED STATES

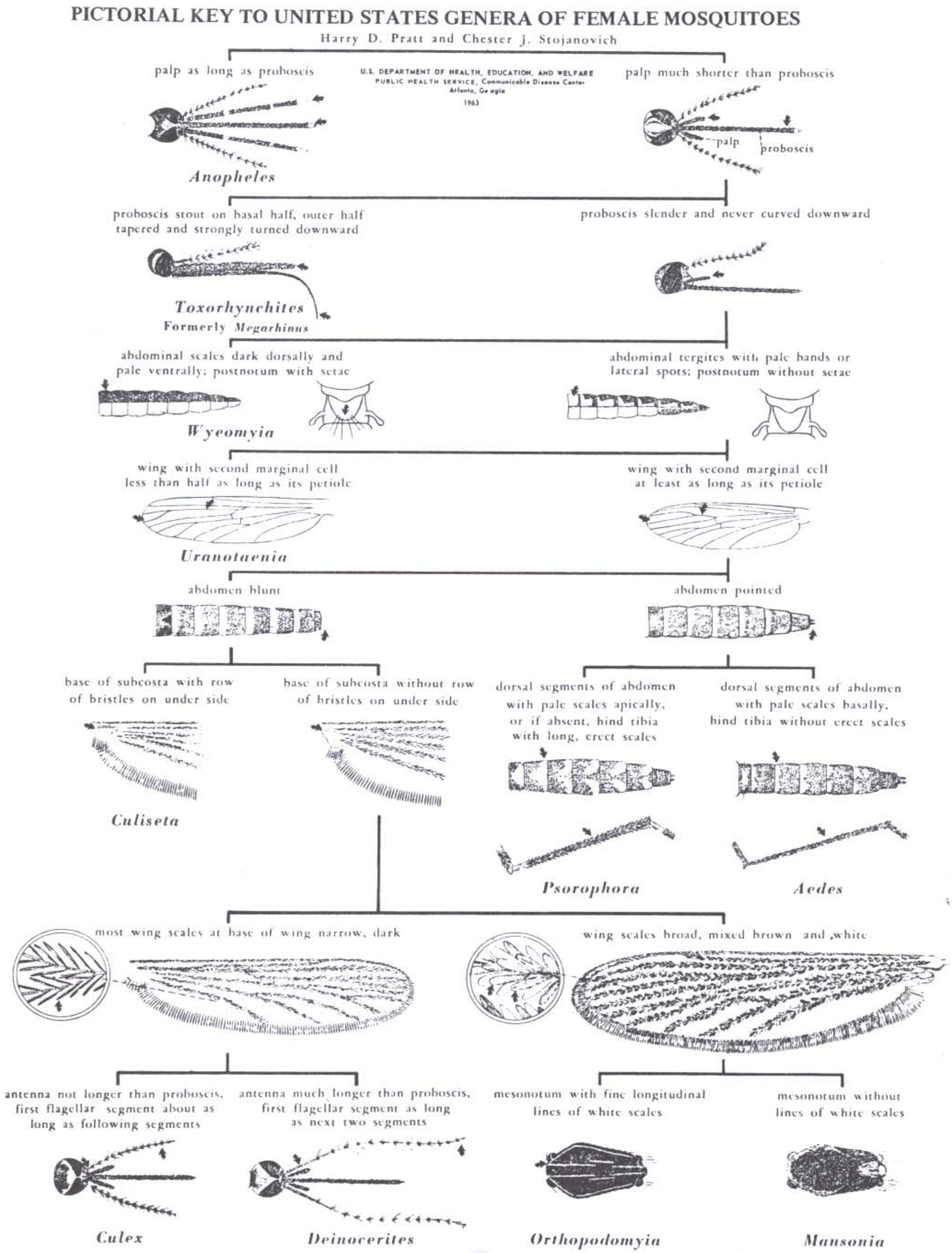
Harry D. Pratt and Chester J. Stojanovich,-



# Appendix 3 (con't)



# Appendix 4



PICTORIAL KEY TO UNITED STATES GENERA OF FEMALE MOSQUITOES
Harry D. Pratt and Chester J. Stojanovich
U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE, Communicable Disease Center
Atlanta, Georgia
1963
palp as long as proboscis
palp much shorter than proboscis
palp
proboscis
Anopheles
proboscis stout on basal half, outer half tapered and strongly turned downward
proboscis slender and never curved downward
Toxorhynchites
Formerly Megarhinus
abdominal scales dark dorsally and pale ventrally; postnotum with setae
abdominal tergites with pale bands or lateral spots; postnotum without setae
Wyeomyia
wing with second marginal cell less than half as long as its petiole
wing with second marginal cell at least as long as its petiole
Uranotaenia
abdomen blunt
abdomen pointed
base of subcosta with row of bristles on under side
base of subcosta without row of bristles on under side
dorsal segments of abdomen with pale scales apically, or if absent, hind tibia with long, erect scales
dorsal segments of abdomen with pale scales basally, hind tibia without erect scales
Culiseta
Psorophora
Aedes
most wing scales at base of wing narrow, dark
wing scales broad, mixed brown and white
antenna not longer than proboscis, first flagellar segment about as long as following segments
antenna much longer than proboscis, first flagellar segment as long as next two segments
mesonotum with fine longitudinal lines of white scales
mesonotum without lines of white scales
Culex
Deinocerites
Orthopodomyia
Mansonia

# Appendix 5

## MARYLAND DEPARTMENT OF THE ENVIRONMENT

1800 Washington Blvd. ● Baltimore Maryland 21230
(410) 537-3000 ● 1-800-633-6101 ● http://www.mde.state.md.us

| | |
|---|---|
| **REQUEST FOR PERMISSION TO USE TOXIC MATERIALS FOR AQUATIC LIFE MANAGEMENT PURPOSES** | When Completed, Mail to: *<br>Maryland Department of the Environment<br>Water Management Administration<br>Industrial Permits Division<br>1800 Washington Blvd.<br>Baltimore, MD. 21230 |
| **Toxic Materials Permit (TMP)<br>Project Number:** | *Except for requests to control Phragmites sp. with Glyphosate, which should be submitted directly to:<br>Maryland Department of Natural Resources<br>Environmental Review Unit<br>Tawes State Office Bldg., 580 Taylor Avenue, B-3<br>Annapolis, MD. 21401 |

**A. PERSON REQUESTING PERMIT**

NAME: ______________________________

ADDRESS: ______________________________

______________________________

DAYTIME PHONE: ______________________

**B. PROJECT PURPOSE**

[ ] Maintenance of surface flow conveyance
[ ] Right-of-way maintenance
[ ] Mosquito control
[ ] Wildlife management – specify:
______________________________
[ ] Aesthetic improvements
[ ] Fisheries management – specify:
______________________________
[ ] Other – specify:
______________________________

**C. TARGETED SPECIES TYPE**

[ ] Submerged aquatic vegetation - specify: ____________________
[ ] Algae
[ ] Emergent vegetation – specify:
______________________________
[ ] *Phragmites sp.* (See Section F. for General Permit conditions)
[ ] Mosquitoes
[ ] Finfish – specify:
______________________________
[ ] Other – specify:
______________________________

**D. INDIVIDUAL WHO WILL SUPERVISE APPLICATION:**

NAME: ______________________________

TITLE: ______________________________

ADDRESS: ______________________________

______________________________

**E. PROPOSED BEST MANAGEMENT PRACTICES AND IMPACT MINIMIZATION MEASURES**

[ ] Markers to delineate application area
[ ] Pond drawdown
[ ] Prevention of pond discharge following application - specify duration: ____________________
[ ] Application at slack tide
[ ] Time-of-year restrictions – specify:
______________________________
[ ] Survey of species listed by the State as endangered, threatened, or in need of conservation
[ ] Mechanical harvesting of nuisance species where feasible
[ ] Use of nontoxic dyes for algae and submerged aquatic plant control when feasible
[ ] Removal of dead fish resulting from the application
[ ] Other – specify: ____________________

**F. *PHRAGMITES SP.* CONTROL with GLYPHOSATE**

[ ] Management plan ** - (Briefly specify on the bottom of this sheet or an attachment the schedule and proposed elements of the plan, which may include controlled burns, changes in hydrology, follow-up treatments, re-vegetation with preferred species.)

[ ] Review conducted for species listed by the State as being endangered, threatened, or in need of conservation **

**The Department of Natural Resources (DNR) must approve the plan prior to issuance. The species review (shaded block) must be completed by DNR. Upon completion of their review, DNR will forward their response and the application to MDE to complete the TMP process

Form Number MDE/WMA/PER.015
Revision Date June 20, 2002
TTY Users 1-800-735-2258

1 of 2

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## MARYLAND DEPARTMENT OF THE ENVIRONMENT

1800 Washington Blvd. ● Baltimore Maryland 21230
(410) 537-3000 ● 1-800-633-6101 ● http://www.mde.state.md.us

**G. PROPOSED DATE (S) OF TREATMENT**

______________________________

______________________________

**H. NUMBER OF TREATMENTS:** ____________

**I. PROJECT AREA DESCRIPTION**

Street Address & Zip Code of Project

______________________________

______________________________

Name of water area______________________

Receiving waterway______________________

County______________________

Nearest town______________________

ADC map coordinates ______________________

(Please provide a vicinity map that accurately shows the treatment area)

Size of project area (square feet or acres)

______________________________

Depth of water______________________

**J. USE OF WATER AREA**

[ ] Public water supply
[ ] Livestock water supply
[ ] Recreational
[ ] Commercial finfish
[ ] Wildfowl management
[ ] Industrial water supply
[ ] Irrigation water
[ ] Sport fishing
[ ] Oysters, clams, crabs
[ ] Fur bearers
[ ] Other – specify:

______________________________

**K. TOXIC MATERIAL PROPOSED TO BE USED**

Trade Name: ______________________

Manufacturer: ______________________

Active Ingredient: ______________________

Formulation (pellets, liquid, emulsion): ______

______________________________

Percent Active Material: ______________________

Application Method: ______________________

Note: Activities which result in the fill or disturbance of non-tidal wetland areas and their 25-foot buffer areas through the movement of soil, changes in hydrology, or destruction of vegetation may require a Nontidal Wetlands and Waterways Permit from the Department of the Environment (COMAR 26.23). Disturbances in tidal wetland areas may require a Tidal Wetlands License from the Department of the Environment (COMAR 26.24). State agencies must insure that all actions, including permit actions, carried out by them do not jeopardize the continued existence of species which are listed by the State as endangered, threatened, or in need of conservation (DNR Statute 10-2A-04).

**MARYLAND DEPARTMENT OF NATURAL RESOURCES REVIEW**

[ ] No objection
[ ] No objection with conditions
[ ] Need additional information
[ ] Objection

Comments: ______________________________________________

______________________________________________

______________________________________________

______________________________________________

Signature: ______________________________________________

Form Number MDE/WMA/PER.015
Revision Date June 20, 2002
TTY Users 1-800-735-2258

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Recycled Paper

# ANSWERS TO SELF STUDY QUESTIONS

### Chapter 1

1. Organisms are classified by their physical similarities to others of their group, as compared to differences from other groups. Carolus Linnaeus first proposed the classification of plants and animals in a systematic manner in the mid-eighteenth century. The primary categories in the hierarchy of classification are kingdom, phylum, class, order, family, genus and species.

2. Each organism is uniquely identified by two scientific names: genus and species.

3. An adult insect has three body regions: head, thorax and abdomen.

4. The most fundamental unit of classification is species.

5. Adult insects have 3 pair of legs, for a total of 6 legs.

6. Adult mosquitoes have piercing-sucking mouth parts.

7. Metamorphosis means "change in form" and is the term that describes the physical and physiological changes that occur as an insect grows through immature stages to an adult.

8. An insect with complete metamorphosis has four life stages: egg, larva, pupa, adult.

### Chapter 2

1. The outbreak of West Nile virus disease is responsible for the recent increase in public demand for mosquito control in the United States.

2. The discovery that mosquitoes spread diseases like malaria and yellow fever led to worldwide mosquito control efforts in the 20$^{th}$ century.

### Chapter 3

1. Mosquitoes go through a complete metamorphosis from eggs to larvae (four stages) to pupae to adults.

2. Larval mosquitoes live in water, can not fly, have filtering mouth parts, no legs and look completely different from adult mosquitoes. Adult mosquitoes live on the land, have wings capable of flying long distances, have 3 pair of legs and have piercing-sucking mouth parts.

3. Larval mosquitoes generally eat algae, fungus and microorganisms, such as bacteria. A few species are predaceous and feed on small invertebrates including other mosquito larvae.

4. Most species of mosquito larvae breathe air through a siphon tube located near the last abdominal segment. *Anopheles* larvae breathe through clusters of palmate hairs located on the top of abdominal segments.

## Chapter 3 (con't)

5. Adult mosquitoes have a head, thorax and abdomen, 2 well-developed wings, 6 legs, antennae and a proboscis (mouth parts).

6. Only female mosquitoes feed on blood.

7. Adult mosquitoes are generally most active just after sunset and just before sunrise. However, there is variation between species in this activity pattern. Some species are most active during daylight (*Aedes albopictus*) and other species are most active during the middle of the night (*Culex pipiens*).

8. Standing water mosquitoes lay eggs on the surface of the water. Floodwater mosquitoes lay eggs on damp soil that is not covered by water at the time of egg-laying.

9. Standing water habitats in Maryland include freshwater marshes, brackish marshes, lakes, ponds and swamps.

10. The mosquito genera in Maryland associated with floodwater habitat for egg-laying and larval development are *Aedes, Ochlerotatus* and *Psorophora*.

11. Mosquito larvae molt four times.

12. *Aedes albopictus* is difficult to control because its favored breeding habitat (containers, such as tires, bottles, plastic toys, bird baths, etc.) is so common in urban and suburban environments. The average business or residential site in urban and suburban areas provides multiple breeding sites for this mosquito. A city such as Baltimore or a large suburban area like Bowie provides hundreds of thousands of breeding sites for tiger mosquitoes. Unlike most native mosquitoes that require significant rainfall or tidal flooding to provide flooding of marches, swamps or roadside ditches for larval development, *Aedes albopictus* larvae do quite well in very shallow water found in the folds of a plastic tarp or discarded bottle cap that are filled with water by the smallest amount of rainfall or runoff.

13. (1) *Aedes albopictus* (2) *Ochlerotatus japonicus*

14. *Ochlerotatus sollicitans*

15. *Anopheles quadrimaculatus* is the most important vector of human malaria in the eastern United States.

16. *Culisetta melanura* is the most important vector in the transmission of eastern equine encephalitis (EEE) virus from bird to bird. This species also transmits other human pathogenic virus (such as West Nile virus) from bird to bird.

17. The larvae of *Coquillettidia perturbans* have a specialized air siphon that allows them to pierce the roots and stems of aquatic plants such as cattails to breathe the oxygen within the plant stem. Because the larvae do not come to the surface to breathe, they are difficult to detect by normal dipping surveillance methods and are not affected by application of larvicidal oils.

## Chapter 4

1. Mosquito-borne diseases known to currently occur in Maryland include the following viral pathogens: California encephalitis, eastern equine encephalitis, St. Louis encephalitis and West Nile virus. Malaria was at one time common in Maryland, but has been rare during the past 60 years. Dog heartworm is the most common mosquito-borne disease in Maryland, but it is not a human health concer.

## Chapter 4 (con't)

2. Encephalitis virus transmitted by mosquitoes primarily affects the central nervous system in humans.

3. Eastern equine encephalitis virus causes the highest human mortality rate (50% to 75%) of any mosquito-borne disease in the United States.

4. West Nile virus is the mosquito-borne virus that currently causes the greatest number of human illnesses in the United States.

5. The most important genus of mosquito as a vector of West Nile virus is *Culex*.

6. West Nile virus causes the highest mortality of birds.

7. The age group of humans most susceptible to West Nile virus is over 50.

8. Young children are the most susceptible age group to eastern equine encephalitis virus.

9. *Aedes aegypti* is commonly called the yellow fever mosquito. It is found in Maryland, but is not common.

10. The two primary mosquito vectors of malaria in the United States are *Anopheles quadrimaculatus* in the eastern states and *Anopheles freeborni* in the west.

11. *Dirofilaria immitis* is commonly called heartworm and is an internal parasite that can seriously block blood flow and function of the heart of dogs.

12. Dogs are best protected against heartworm disease by regular veterinary examinations and year 'round medication to kill immature heartworms before they can mature and adversely affect dogs' health.

## Chapter 5

1. The cornerstone of mosquito control is surveillance of mosquito larvae and adults.

2. A dipper is the basic surveillance tool to assess mosquito larvae numbers.

3. False. Anopheline larvae are more solitary and widely dispersed than Culicine larvae.

4. A breeding index is commonly used to track the relative number of mosquito larvae in a community. The index is calculated by noting the number of sites where mosquito larvae are found as compared to the total number of sites inspected. For example: If a community is surveyed for mosquito breeding and mosquito larvae are found on 50 premises out of a total number of 100 yards inspected, the simple breeding index would be 50/100 = 50%.

5. A landing rate count is a simple method to assess the number of mosquitoes present (at least those mosquitoes that feed on humans). An inspector counts the number of mosquitoes landing in a specific time period (usually 1 to 5 minutes). The count may be general to record the total number of mosquitoes landing, or more experienced inspectors may identify the species of mosquitoes and the number of each that lands.

6. The most commonly used collection device for adult mosquitoes in Maryland is a CDC light trap.

## Chapter 5 (con't)

7. Dry ice is used in combination with light traps because the dry ice provides a source of carbon dioxide which is a strong attractant for many species of mosquitoes. Light traps supplemented with dry ice collect larger number of mosquitoes and a greater variety of species than traps with light attractant only.

8. True. Because tiger mosquitoes are active only during day light, the light bulb provides no attraction.

9. A New Jersey light trap has several disadvantages: (1) it is heavy; (2) it can not run on battery power so it must be used near a source of "plug in" power and so can not be used in remote areas; and (3) it collects many non-mosquito insects which results in the death of the non-targets and often results in damage to the mosquitoes, making identification difficult.

10. False. Resting boxes attract mosquitoes that rest during daylight.

11. False. Complaints from the public about mosquitoes are a valuable source of information and coupled with other surveillance techniques contribute to an accurate assessment of the adult mosquito population.

## Chapter 6

1. The more the public knows about mosquito biology, how mosquitoes affect human and animal health and the methods of mosquito control, the greater the probability that they will rid their properties of mosquito breeding sites and support community-wide control efforts.

2. (1) Remove mosquito breeding sites found around the home. (2) Keep screens on doors and windows in good repair. (3) Avoid outdoor activity when and where mosquitoes are most active. (4) Wear loose fitting, light colored, long sleeve shirts and pants, hats and gloves when outdoors and contact with mosquitoes is expected. (5) Use an insect repellent registered with the U. S. Environmental Protection Agency according to the directions on the product label.

3. Source reduction is the elimination of mosquito breeding sites by physical alteration or management of water. This commonly requires removal of artificial water-holding containers in communities, filling, deepening, draining or management of water levels of known mosquito breeding sites. Source reduction does not require the use of insecticide. Source reduction is often a long term solution of a mosquito breeding problem.

4. The mosquitofish, *Gambusia affinis*, is the biological control agent of most widespread use and greatest success for mosquito control worldwide. In Maryland, *Gambusia affinis* is not a native species and can not be used for mosquito control. Fortunately, *Gambusia holbrooki* is native to Maryland, is equally effective for mosquito control and is available for stocking in many locations.

5. Four factors considered in the selection of a pesticide for mosquito control in Maryland are: (1) does the pesticide pose a minimal risk to human health and the environment when used according to label directions; (2) is the product effective for controlling mosquitoes; (3) will use of the product minimize the potential for developing insecticide resistance in the mosquito population; and (4) is the product affordable for use.

6. A larvicide is a pesticide that kills mosquito larvae and is registered with the U. S. Environmental Protection Agency for that use.

**Chapter 6 (con’t)**

7. The four classes of insecticides used as mosquito larvicides are: (1) oils and monomolecular films of alcohol; (2) organophosphates; (3) insect growth regulators (IGR’s); and (4) bacterial toxins.

8. Bacterial toxins create ulcers in the gut, or digestive system, of mosquito larvae. These ulcers prevent food from being processed and usually cause the death of an affected larva within 24 to 48 hours.

9. A Toxic Material Permit (TMP) is required by State law for anybody in Maryland who uses a pesticide to control aquatic life (mosquito larvae, algae, fish, etc.). A TMP is also required by industry to discharge a toxic chemical into any waters of the State of Maryland including rivers, lakes, streams, ponds or groundwater. This permit is issued by the Maryland Department of the Environment.

10. ULV stands for Ultra Low Volume. ULV spraying typically applies very small amounts ( 3 fl. oz. or less per acre) of relatively concentrated insecticide. ULV technology disperses the insecticide in microscopically small droplets that remain suspended in the air column for several minutes to increase the chance of contracting flying or resting adult mosquitoes.

11. It is important to evaluate the level of mosquito control resulting from the application of pesticides to determine if the insecticide and method of application is producing a satisfactory level of control. This can be important as a monitoring method to detect insecticide resistance, detect problems with equipment calibration or performance and operator error.

12. The simplest device to apply granules for mosquito larvae control is a horn seeder.

13. Important considerations that must be followed when using ULV spraying equipment to obtain the best results include:
    1. Select an insecticide that is labeled for ULV application for adult mosquito control.
    2. Follow all label directions and safety precautions.
    3. Keep the ULV equipment well maintained and properly calibrated for the proper dose rate of insecticide and the optimum insecticide droplet size.
    4. Treatment should occur when wind speed is low, mosquito activity is high and air temperature is stable and below 85 F and above 60 F. Early morning and evening are generally the best times of day for ULV spraying.