SETTING UP A MOSQUITO CONTROL PROGRAM

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PREFACE

Mosquito control is undergoing major changes in Mississippi. Instead of just routinely spraying malathion or a pyrethroid out of trucks several nights weekly, mosquito control personnel are now trying to get the most control with the least amount of pesticides. This involves source reduction to eliminate mosquito breeding areas, larviciding areas of standing water, and carefully timed, strategically placed insecticides aimed at the adult mosquitoes.

This booklet outlines the components of an integrated mosquito control program with emphasis on incorporating surveillance and larviciding into existing programs. General information is provided as a review of control and surveillance techniques commonly used. In addition, this booklet describes some problem mosquitoes found in Mississippi and discusses their importance as public health and pest problems.

NOTE: Much of this publication was originally compiled and illustrated by the former medical entomologist with the Mississippi State Department of Health, Mr. Ed Bowles. It has been revised several times by myself and Dr. Brigid Elchos, State Public Health Veterinarian.

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MOSQUITO CONTROL AND PUBLIC HEALTH

Mosquitoes and the diseases they carry have played an important role in our history. Epidemics of mosquito-borne diseases were once common in the United States. Outbreaks of yellow fever occurred as far north as Philadelphia during the colonial period, and epidemics took many lives in New Orleans until 1905. Dengue fever was prevalent along the Gulf Coast until 1945. Tombstones of Mississippians who died during epidemics can be seen in many old cemeteries in our state. Although these diseases have disappeared from Mississippi, their mosquito vectors have not. If these disease agents become reintroduced into Mississippi, they can be transmitted by the yellow fever mosquito (*Aedes aegypti*) and the newly introduced Asian tiger mosquito (*Aedes albopictus*).

At one time, malaria was well established in the continental United States, especially in the southern states. Eradication of malaria from the United States is attributed more to the short transmission season due to our temperate climate and the use of window screens in homes than to government mosquito control efforts. Cases of malaria are still reported in the United States among travelers and military personnel returning from abroad. Mississippi has several mosquito species, such as *Anopheles quadrimaculatus*, that can transmit the disease agent to people should malaria ever become reestablished in our state.

One mosquito-borne disease, St. Louis Encephalitis, is still a serious problem in Mississippi. The last major outbreak of this disease was in 1975 with 229 cases and 36 fatalities. The southern house mosquito, *Culex quinquefasciatus*, is believed to be the most important vector (carrier) of this disease. This mosquito can be found breeding in drainage ditches and artificial containers around houses.

With the elimination of many deadly mosquito-borne diseases from the United States, our control efforts are now mainly aimed at pest mosquitoes rather than disease vectors. However, increasing travel by U.S. citizens into countries where dengue fever and malaria are prevalent, and the immigration of people from those countries into the United States, increases the likelihood of these diseases being reintroduced. Mosquito control continues to be an important program in public health because of the presence of St. Louis Encephalitis and the potential for the reintroduction of other mosquito-borne diseases into Mississippi.

Human activities can greatly affect the ecology of mosquito populations. The movement of large segments of our population into suburban and rural areas increases human and domestic animal exposure to mosquitoes such as *Ochlerotatus triseriatus* and *O. canadensis.* The construction of man-made lakes and the use of irrigation agriculture have increased the numbers of many mosquitoes such as malaria mosquitoes (*Anopheles*) and the dark rice field mosquito (*Psorophora columbiae*). The increased use of non-degradable plastic, glass, and aluminum containers and non-recappable radial tires has increased populations of container breeding mosquitoes such as the yellow fever mosquito (*Aedes aegypti*). Expanding international trade has increased the chance of introducing new mosquito species into our areas, as has recently happened with the Asian tiger mosquito (*Aedes albopictus*).

Mosquito control strategies have changed considerably over the past few decades. Diesel oil and inorganic poisons such as Paris green (copper-aceto-arsenite) were the basic tools of early mosquito larva control efforts. Large scale ditching operations were undertaken along many coastal areas in order to eliminate breeding sites. Many of these ditches can still be seen in our marshes, particularly in Hancock and Jackson counties. Various organochlorines, organophosphates, pyrethrins and synthetic pyrethroids have been extensively used in the fight against both adult and larval mosquitoes.

However, with the growth of ecological consciousness in the early 1960s, people began to realize the environmental damage that accompanied the use of these broad spectrum chemicals, especially those that did not break down and got in the food chain. Many mosquito populations became resistant (immune) to the chemicals commonly used. We also began to realize the impact of indiscriminate ditching upon our marshes, and the nursery grounds of commercial fish, shrimp, and oysters.

In the past few years, major advances have been made in the area of biological mosquito control. This strategy involves the use of natural predators, parasites and pathogens to kill mosquito larvae. The World Health Organization, for instance, has used mosquito fish (*Gambusia affinis*) for decades to fight malaria in many parts of the world. These mosquito fish are abundant in Mississippi waters and are very effective predators of mosquito larvae. Many other biological control agents have been discovered including fungi, protozoa, bacteria, round worms, and flat worms.

Presently, only a few of these biological control agents, including the bacteria Bti (*Bacillus thuringiensis israeliensis*) and mosquito fish (*Gambusia affinis*), are commercially available.

LARVICIDING VS. ADULTICIDING

Results of a survey conducted in the spring of 1985 indicated that 148 city and county mosquito control programs were in operation within Mississippi. All but five of these programs relied exclusively upon adulticiding for mosquito control. Over 84% of these programs used only malathion. Recent surveys have indicated less use of malathion, with more and more mosquito control personnel using various formulations of Permanone (permethrin) or Scourge (resmethrin) for adult mosquito control.

Routine mosquito spraying has been going on in Mississippi for a long time. During the mosquito season, fog trucks roll up and down the urban streets one or two times per week. Continuous exposure to pesticides does not kill all mosquitoes; those that can survive the pesticide treatment are resistant to the chemical. Surviving mosquitoes can reproduce and pass this resistant trait along to the next generation. Eventually, the pesticide is no longer effective.

Adulticiding operations also continuously expose the public to pesticides. The effects of these chemicals could be particularly severe for those people who already suffer from asthma or other respiratory problems. Applicator personnel may be in danger of overexposure if proper safety precautions are not carefully practiced. Pesticide labels carry warnings about their toxicity to wildlife. However, pesticides are generally safe when used according to their label directions.

Larvicide programs are targeted at controlling the mosquito larvae before they leave the water. This strategy can be the most effective, most economical, and safest method to control mosquitoes. Programs that concentrate only on adult mosquitoes are attempting to solve a problem that has gotten out of hand. After all, it is the adult mosquito, not the larva, that passes along diseases such as encephalitis to its human victims.

Anytime we can avoid using chemical pesticides to solve our problems, we can reduce the chance of damaging our environment and, consequently, ourselves. A larvicide program allows the use biological methods to control pests without jeopardizing non-pest and beneficial organisms. If fog trucks can remain parked until really needed (relying upon them as a back-up system during severe outbreaks of mosquitoes), then not only do we reduce the chance of pesticide resistance buildup, but we lessen the amount of chemicals that the public is exposed to.

Larviciding is also more economical than adulticiding. Setting up an adulticiding program can cost as much as $30,000 for the purchase of a fogging machine and truck. Small towns may spend from $6,000-$10,000 per year for pesticide and formulation oils. Operational and maintenance costs must also be figured into the estimate. Therefore, the expense of an adulticide program is beyond the reach of most small towns and communities. A larvicide program, on the other hand, can be conducted within a town by using one or two backpack sprayers (ranging from $100 each for a sprayer that only sprays liquid to $700 each for backpacks that distribute liquid, granules, pellets, and dust) and a couple of gallons of Bti, *Bacillus thuringiensis israeliensis*, (about $25 - $30 per gallon) depending upon the size of the town and the extent of the breeding areas. Granular Bti is about $2 per pound. Alternatively, the organophosphate Abate may also be used in a larviciding program for about $2 - $3 per pound in areas without fish and other natural predators. Methoprene (Altosid) is another excellent and cost-effective larvicide which comes in various formulations. Initial material costs are higher than most Bti products or Abate, however, because of an extended residual, the cost per day is comparable to those other products. More recent labeling states that methoprene is target-specific and does not harm mammals, waterfowl, or predatory insects. Non-target studies have reported that methoprene has very little effect, if any, on 35 species of non-target organisms and can be applied to fish habitats. Agnique is a biodegradable oil emulsion sprayed as a larvicide. It acts by suffocating mosquito larvae as they float at the surface to breathe. Agnique is also safe to use in fish habitats and in the presence of biological predators.

INTEGRATED MOSQUITO CONTROL

The best mosquito control program is an integrated program that includes point source reduction of breeding areas, routine larviciding in those breeding areas that cannot be eliminated, and adulticiding only when necessary. In this present day of environmental consciousness, municipal leaders must try to use integrated methods of mosquito control and not just routine spraying with a fogging truck.

The first phase in any mosquito control program is to sponsor a spring clean-up campaign. Picking up and hauling away all rubbish piles, broken down washing machines, junk cars, bottles and cans from around houses will eliminate many domestic mosquitoes that breed right in our backyard. Activities such as cleaning out clogged street drains and culverts, cleaning up illegal dump sites, and mowing around sewage treatment lagoons will also eliminate many mosquito breeding sites. These efforts will save time and money that would otherwise have to be spent controlling mosquitoes breeding in these sites.

Wetlands are considered valuable resources. Therefore, many areas where mosquitoes breed cannot or should not be eliminated or altered. Mosquitoes breeding in permanent water areas or temporary floodwater areas can be controlled by using biological larvicides. Larvicides such as Bti will effectively control mosquito larvae when applied as needed without killing the natural predators of mosquitoes. Permanent water areas generally harbor many species of fish and insects that feed on mosquito larvae. Altering drainage ditches will often destroy these natural predators, allowing mosquitoes to breed unchecked as soon as water pools up again.

A good adulticiding operation should be a backup system, used when mosquito populations have gotten out of hand for some reason or another. Maybe local breeding habitats formed after heavy rains had been overlooked by the larviciding technician. Also, an unseasonable emergence of mosquitoes may occur during a spell of warm weather, or an encephalitis outbreak may occur. These situations may require the use of an adulticide to contain the problem. If the fog truck has been parked, being used only when necessary, then the program manager can feel confident that the chemical will be fast and effective, encountering no problems with resistance among mosquito populations.

MOSQUITO BIOLOGY AND ECOLOGY

At least fifty species of mosquitoes are found in Mississippi. They come in all varieties of size, shape, and color. The majority of these species have little impact upon our daily lives because they are rarely encountered by most people. They prefer to feed on blood sources other than humans, or they are not important vectors of diseases that affect us or our domestic animals.

Most mosquito programs are primarily concerned with controlling only three or four mosquito species. Every mosquito program in Mississippi is concerned with urban mosquitoes such as the southern house mosquito (*Culex quinquefasciatus*) and the Asian tiger mosquito (*Aedes albopictus*). The total list of problem species differs, however, from one section of the state to the other. For example, salt marsh mosquitoes (*Ochlerotatus sollicitans*) are of major importance along the Gulf Coast, while dark rice field mosquitoes (*Psorophora columbiae*) and malaria mosquitoes (*Anopheles quadrimaculatus*) are prime concerns in the Delta.

Mosquito species differ in their breeding habitats, biting behavior, flight range and in many other ways. Therefore, different strategies are needed to control different species of mosquitoes. Yearly town clean-up campaigns, for example, are very effective in reducing populations of Asian tiger mosquitoes that breed predominately in artificial containers. Malaria mosquitoes (Anopheles) usually prefer permanent bodies of water, such as swampy or marsh areas, requiring different control tactics. Therefore, it is very important for mosquito control personnel to know exactly what species of mosquito is found within their area in order to develop an effective control strategy.

DISEASE CYCLES

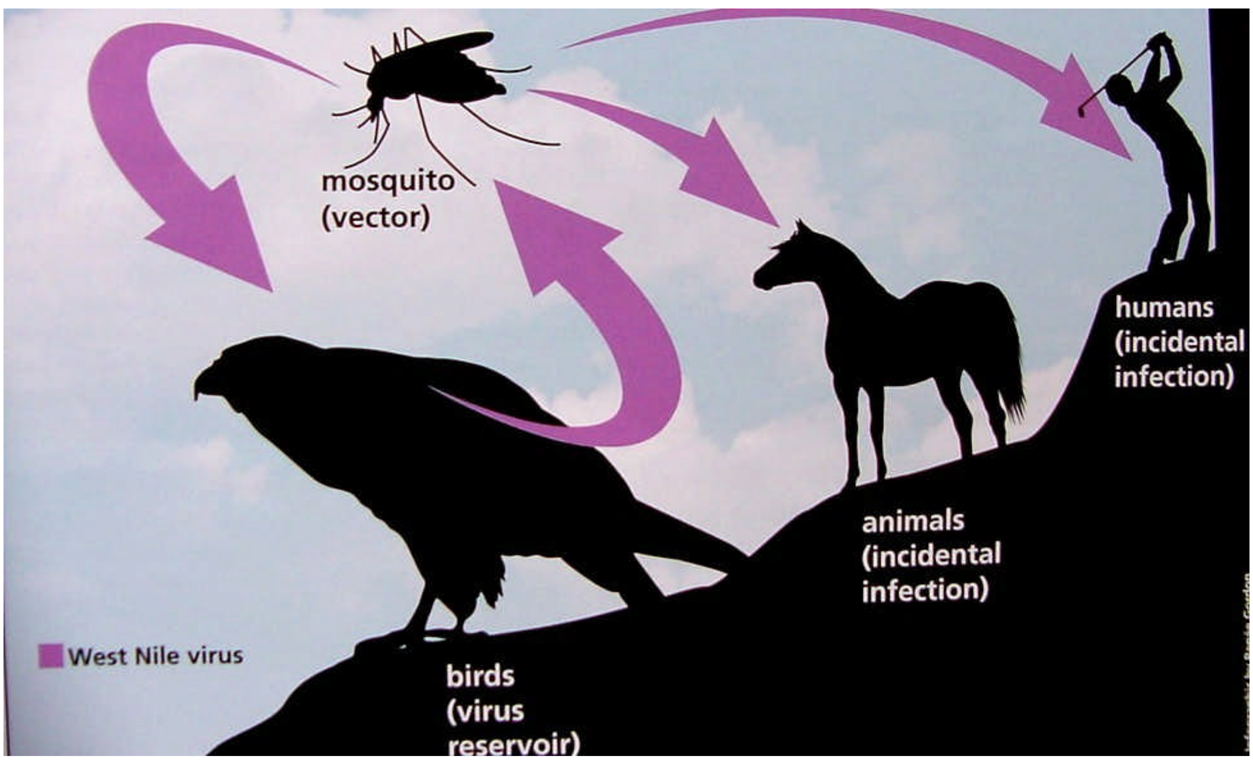
St. Louis Encephalitis

The St. Louis Encephalitis virus circulates naturally among birds and is transmitted by *Culex* mosquitoes. Humans can become infected only if bitten by an infected mosquito. Humans are actually "dead end" hosts, meaning that the virus in human blood never reaches a level high enough to infect a biting female mosquito to continue the cycle. Not all people infected with the virus develop clinical disease. However, the virus may produce abrupt fever, nausea, vomiting, and severe headache in humans within 5-7 days after being bitten. Fatality rates range from 2-20% with most deaths occurring in people 60 years of age or older. Outbreaks of St. Louis Encephalitis usually occur in mid summer to early fall. Since wild birds and domestic fowl are the reservoirs of this virus, urban areas where large bird populations and abundant *Culex* mosquitoes are found together are prime sites for a disease outbreak.

A major St. Louis Encephalitis outbreak occurred in Mississippi in 1975. Numerous people were affected and many cases resulted in death. The threat for this to happen again is a real one. We need to develop good mosquito control practices in those disease prone areas of our State and be prepared to respond promptly to the next outbreak.

West Nile Virus Encephalitis

West Nile virus (WNV) is maintained in nature in a manner similar to St. Louis Encephalitis, in a bird-mosquito cycle (see cycle above). Several *Culex* spp., including the common house mosquitoes, *Culex quinquefasciatus, Cx. pipiens*, and *Cx. salinarius*, and possibly also *Cx. restuans*, are the principal vectors to people. WNV appears to be most dangerous to the elderly or immune-compromised patient. Since WNV has been demonstrated to amplify in the Asian tiger mosquito in the lab, it is possible that this mosquito is also invloved in WNV transmission. In contrast to other mosquito-borne viruses, WNV also kills many birds in the U.S., especially crows, blue jays, and raptors. Surveillance efforts to detect the presence of WNV, therefore, can target the reporting and testing of those three types of dead birds. WNV does not cause as serious illness as some other arboviral diseases (e.g., EEE, SLE). In fact, only one out of every 150-200 people exposed to the virus will become ill, and less than 10% of clinically ill patients will die. Still, the public's perception and reaction to local reports of WNV cases cause much anxiety and fear in communities. Local officials are, then, barraged by the public to provide mosquito control to "protect" them.



West Nile Life Cycle

Eastern Equine Encephalitis

As with SLE and WNV, birds are the primary hosts and mosquitoes, particularly *Culiseta melanura*, are the vectors from bird to bird. *Culiseta melanura* rarely feeds on humans though. People usually become involved as dead end hosts when fed upon by infected salt marsh mosquitoes (*Ochlerotatus sollicitans*), inland floodwater mosquitoes (*Aedes vexans*), *Coquillettidia perturbans*, and a few other species. The disease will affect persons of any age, with young children and infants being the most susceptible. The mortality rate is over 50%, and children surviving the disease often suffer from some degree of mental retardation or paralysis. Horses are often severely affected by the disease during outbreaks. However, a horse vaccine is available.

LaCrosse Encephalitis

In contrast to most other mosquito-borne viruses that are a risk in Mississippi, LaCrosse (LAC) maintains its cycle in nature via a small mammal-mosquito cycle. Usually, the mosquito vector is the tree-hole mosquito, *Ochlerotatus triseriatus*, and the reservoir is the gray squirrel. Control efforts are obviously different for this disease, because it will focus on plugging tree holes where mosquitoes breed in small amounts of acidic rainwater. Mississippi recorded its first confirmed cases of LAC in 1967, but was not often diagnosed until eight cases were identified in 2001. LAC most often occurs in children less than 16 and can cause convulsive disorders in affected children. These facts bring extra demands on local officials by parents that control measures be implemented.

Dengue

The Dengue virus can be transmitted from person to person by the Yellow Fever mosquito (*Aedes aegypti*) and the Asian tiger mosquito (*Aedes albopictus*). Other than humans, no known bird or mammal reservoir exists for Dengue. A mosquito can become infected with the virus by feeding on a person with the disease, then the virus must go through an eight to ten day incubation period in the mosquito before it becomes infective. The mosquito will then remain infective for the rest of its life.

Symptoms include sudden onset of high fever, severe headache, backache, and joint pains. The disease is so painful that it is sometimes referred to as "breakbone fever." A skin rash may also appear. Infection may be very mild or completely without symptoms. In some areas, however, a complication called "dengue hemorrhagic fever" and "dengue shock syndrome" cause a high fatality rate, especially among children.

The disease has been raging in Mexico and Central and South America for the last 10 years. It is literally "knocking at the door" with cases frequently occurring along the U.S. - Mexican border.

Dog Heartworm

Dog heartworm is a serious canine disease in the South. Almost 100% of unprotected dogs more than five years old are infected. Mosquito vectors that feed on an infected dog take in immature worms (first stage larvae) with the dog's blood. The immature worms undergo development within the mosquito, reaching an infective state (third state larvae) in nine to 14 days after entering the mosquito. These infective larvae can be transmitted to an uninfected dog when the mosquito feeds. The worms migrate to the dog's heart and grow into adults. These adult worms produce first stage larvae that circulate within the dog's blood and are taken up by feeding mosquitoes to continue the cycle. The southern house mosquito (*Culex quinquefasciatus*) is the primary vector of dog heartworm in Mississippi, although several other mosquitoes are involved.

MOSQUITO LIFE CYCLES

Understanding life cycles of target mosquito species is a key step in developing an effective control program. Information on flight patterns and periods of peak mosquito activity helps the adulticide technician decide when and where to spray in order to kill the most mosquitoes for the money. The larvicide technician will become even more aware of the behavior and biology of the local mosquitoes. He or she will be encountering the mosquitoes first hand, visiting their breeding sites, observing their numbers and developmental stages, and gauging the response of the larvae to the larvicide used.

Mosquitoes can be divided into three major breeding groups - permanent water breeders, floodwater breeders, and artificial container/tree hole breeders. *Anopheles* and many *Culex* mosquitoes select permanent water bodies, such as swamps, ponds, lakes and ditches that do not usually dry up. Floodwater mosquitoes lay eggs on the ground in low areas subject to flooding. During heavy rains, water collecting in these low areas covers the eggs which may hatch from within minutes up to a few hours. Salt marsh mosquitoes (*Ochlerotatus sollicitans*), inland floodwater mosquitoes (*Aedes vexans*), and dark rice field mosquitoes (*Psorophora columbiae*) are included in this group. Artificial container/tree hole breeders are represented by yellow fever mosquitoes (*Aedes aegypti*), Asian tiger mosquitoes (*Aedes albopictus*), the tree hole mosquito (*Ochlerotatus triseriatus*), and the cannibalistic mosquito (*Toxorhynchites rutilus*). Several species of *Anopheles* and *Culex* may also occasionally oviposit in these areas. Some of these species lay eggs on the walls of a container above the water line. They are flooded when rains raise water levels of a container. Other species oviposit directly on the water surface. There are four stages in the mosquito life cycle: eggs, larvae, pupae, adults.

Eggs

Female *Anopheles* mosquitoes generally lay eggs on the surface of the water at night. Each batch usually contains 100-150 eggs. The *Anopheles* egg is cigar-shaped, about 1 mm long, and bears a pair of air-filled floats on the sides. Under favorable conditions, hatching occurs within one or two days.

Aedes and *Ochlerotatus* mosquitoes lay their eggs on the moist ground around the edge of the water or on the inside walls of artificial containers just above the water line. When *Aedes* eggs are first laid, they will die if they become too dry. However, after the embryo in the egg develops, the eggs can withstand dry conditions for long periods of time. This trait has allowed *Aedes* and *Ochlerotatus* mosquitoes to use temporary water bodies for breeding such as artificial containers, periodically flooded salt marshes or fields, tree holes, and storm water pools. *Aedes* mosquitoes have been carried to many parts of the world as dry eggs in tires, water cans or other suitable containers. The Asian tiger mosquito (*Aedes albopictus*) was introduced into the United States in shipments of used truck tire casings imported from Taiwan and Japan in 1985. This mosquito was probably brought into Gulfport, Mississippi in truck tire casings bought from a Texas used tire dealer. Once these tires were stacked outside and began to collect rainwater, the eggs hatched. Now the Asian tiger mosquito is all over the state.

Psorophora mosquitoes also lay dry-resistant eggs. These mosquitoes are often a major problem species in rice fields. Eggs are laid on the soil and hatch once the field is irrigated.

Culex mosquitoes lay batches of eggs that are attached together to form little floating rafts. On close inspection of a suitable breeding site, these egg rafts can often be seen floating on the surface of the water. Large numbers of egg rafts will tell the technician that a large population of larvae will be hatching out within one or two days. This information will help the larvicide technician decide what action to take to control the potential mosquito problem.

Larvae

Some larvicide agents are more effective on very young mosquito larvae, while other agents offer better control of older mosquito larvae. Bti spores must be eaten by larvae in order to work and must be used during periods of mosquito development when larvae are actively feeding. It is important to understand a little about the basic biology of larvae and pupae in order to prescribe the best control approach.

Anopheles larvae lie parallel to the water surface, supported by small, notched organs on the thorax and clusters of float hairs along the abdomen. *Culex, Aedes*, and *Ochlerotatus* larvae hang from the surface film with the heads pointed downward. Larvae feed either by slowly sweeping surface bacterial film toward the mouth, using a pair of mouth brushes, or by moving backwards and forwards through the water to produce a current just below the surface that flows toward the mouth. They generally feed upon smaller particles, rejecting the larger ones. To be effective against Anopheles larvae, a larvicide must remain on the surface of the water for a long period of time. The particles of the larvicide must be small enough to be accepted by mosquito larvae.

Mosquito larvae are air breathers and therefore must come up to the surface periodically for oxygen. *Anopheles* larvae breathe through a pair of openings called spiracles on the end of the abdomen. *Culex, Aedes,* and *Ochlerotatus* larvae have air tubes on the end of the abdomen.

Mosquito larvae undergo molts (shedding the outer skin). These skins can often be seen floating on the surface of the water. The thick head capsule "hardens" shortly after the molt, becoming non-elastic. Therefore, larvae must shed the old skin so that they can grow. During each molt, the head of a larva will swell, increasing in width by about 50%. The period between molts is called an instar. The final or fourth instar, when larvae have reached their largest size, is the stage used for species identification. A larvicide technician should be careful to include these fourth instar larvae in collections that are to be immediately identified. Otherwise, larvae must be allowed to molt into fourth instars. The larval stage will last from 7-10 days under optimum conditions for many mosquito species.

Mosquito larvae are often called "wigglers"

Pupae

Fourth instars will then molt into pupae. While resting, the pupae will float at the surface of the water. Pupae do not feed, and therefore are not affected by larvicides that must be eaten. However, pupae must come to the water's surface to breathe through their two respiratory trumpets. Generally, pupae will lie still, floating at the surface. If disturbed, they will swim forward or dive to the bottom by rapidly flexing their abdomen equipped with two paddles.

The pupal skin splits along the back and an adult mosquito emerges. This is a critical stage in mosquito survival. Should the emerging adult fall over while leaving its skin, it will become trapped on the water surface and die. The newly emerged adult mosquito must dry its wings and separate and groom its head appendages before it can fly away.

MOSQUITO BREEDING SITES

Artificial Containers

Just about anything that holds water will breed mosquitoes. Old washing machines, boats, horse troughs, steel drums, cisterns, plastic containers, glass bottles, and aluminum cans are just a few examples of artificial containers where mosquitoes are found.

Used tires make excellent mosquito breeding sites, and tire piles are a tremendous problem for towns and cities. They usually hold water and the dark, rough inner wall is an ideal egg-laying surface for species such as the yellow fever mosquito (*Aedes aegypti*) and the Asian tiger mosquito (*Aedes albopictus*). Finding ways to properly dispose of used tires is one of the most difficult problems facing mosquito control agencies today. Buried tires hold air. Unless whole tires are buried very deeply in landfills, they will work their way back to the surface. Whole tires also take up valuable landfill space. Therefore, many landfills will not accept used tires or will charge several dollars per tire to take them. As a result, many tires are being illegally dumped in wooded areas, vacant lots, gullies, and other secluded sites. Often local mosquito problems can be traced to one of those hidden tire piles. Shredding tires into small pieces before disposing of them in landfills seems to be one of the best answers to the problem. However, tire shredding equipment is expensive. Very few cities or counties can afford to purchase and operate shredders or lease the services of shredder companies. There is Mississippi law governing the storage and disposal of old automobile tires. Mayors and aldermen can direct any questions they have about cleaning up tire piles to the Mississippi Department of Environmental Quality, Solid Waste Division.

Ideally, used tires should be stored under a rain shelter. A mobile tire shredder can then be brought in to grind up stockpiles of tires on-site and then the shredded tires can be properly land-filled. Newer approvals have been granted for using tire chips on-site for sewage field lines. Alternatively, tires may be cut in half and stacked outside with the curve facing upward to prevent the collection of water. A temporary solution is to stack used tires in an open, secluded area of the landfill. Although these tires will still breed mosquitoes, the problem will be much easier to control than if tires were scattered in hidden piles throughout the town and surrounding countryside.

Measured success in controlling tire-breeding mosquitoes has been shown using granular Bti. The granules can be broadcast over tire piles with seed or fertilizer spreaders. Many granules will fall down into the tires where mosquitoes breed. Penetration in piles up to six tires deep has been obtained.

Some types of artificial containers cannot be disposed of or removed because they serve some useful purpose. In these situations, mosquito breeding must be controlled by applying Bti, methoprene, or other suitable larvicides or by preventing adult mosquitoes from entering these containers and laying their eggs. For example, cisterns used to collect rainwater should have well screened tops. Small animal watering pans should be emptied and cleaned at least weekly. Livestock watering troughs should also be drained weekly if mosquito breeding is found or larvicided with methoprene products. Bti can be applied to many types of artificial containers that are not used as sources of drinking water, such as water gardens and urns in cemeteries. *Gambusia affinis* (mosquito fish) can also be placed in water gardens, using 25-50 minnows for every 8 ft. diameter of surface area.

Tree Holes

Tree holes provide breeding sites for a variety of mosquitoes. The major species is the tree hole mosquito (*Ochlerotatus triseriatus*). Parks and hardwood stands in towns can be surveyed for tree holes and marked on habitat maps. These holes can be treated with Bti, sealed with a tree patch material, or filled with sand.

Water Drainage Systems

Water drainage systems that carry rainwater out of towns and cities are both man-made and natural. Culverts, storm drains and roadside ditches that become clogged, allowing water to pool, will become mosquito-breeding areas. Keeping these areas cleaned out, removing weeds and silt, will help prevent mosquito problems. This is particularly true for those areas that hold water for a week or two after a rain but are dry during other times. Such areas will breed floodwater mosquitoes but will not hold water long enough for large populations of natural mosquito predators to become established.

Ditches that always hold water may have populations of fish, beetle larvae, dragonfly naiads, and other organisms that feed on mosquitoes. These predators help keep mosquito populations under control. If these ditches were cleared out, eliminating natural communities of predators, a mosquito problem may develop in an otherwise non-problem site. Mosquitoes will be among the first organisms to return to the pools that from in a cleaned out ditch following a rain. In the absence of predators, the mosquitoes will develop undisturbed unless closely watched by the larviciding technician.

Ditches should be sampled with a dipper to determine the number of mosquito larvae and pupae living there. Collections should be made along the edges of pooled areas, especially around clumps of weeds and in shaded areas. The larvicide technician should also look for predaceous fish and insects living in the ditch. One or two mosquito larvae per dipper may not be a problem, especially if large numbers of predators are found. If large numbers of mosquito larvae are present, the site will need to be treated with Bti, methoprene, or Agnique to help the natural predators maintain control of the mosquito population. These larvicides will kill mosquito larvae without affecting the other organisms.

Natural permanent water drainage areas should be inspected and treated as described for permanent water ditches. Disturbing these natural areas may result in more problems than will be solved.

Major mosquito problems will often be found in ditches that are polluted with discharge from malfunctioning septic tanks. The southern house mosquito (*Culex quinquefasciatus*) prefers a breeding site polluted with sewage. These mosquitoes are very important vectors of SLE and WNV in our state. Bti should be applied to these sites more frequently (weekly) than for non-polluted sites and at recommended higher dosages (but still within label rates).

Ponds, Lakes and Lagoons

Generally, well-maintained ponds and lakes produce very few mosquito problems. Large numbers of fish and other mosquito predators are usually found in these sites. Keeping weeds mowed around banks of catfish ponds, sewage waste lagoons, and lakes will help prevent mosquito breeding. If mosquito breeding is found at these sites, it will probably be along the marshier side of the water body. The area around the dam end is usually too steep to provide suitable mosquito breeding habitats. Marshy areas can be treated with Bti or Agnique as needed. *Gambusia* mosquito fish can also be placed in larger bodies of problem water at the rate of 5,000 per surface acre. Even though the minnows cost around 10 cents each, placing them in a pond at the city park at the beginning of mosquito season may be more economical in the long run than larviciding and adulticiding all summer.

Marshes and Swamps

Swamps are permanent water habitats that produce *Anopheles, Culiseta*, and other permanent water-breeding mosquitoes. Freshwater marshes, especially those that subject to temporary flooding, will often yield species such as the inland floodwater mosquito (*Aedes vexans*). Salt marshes are breeding sites of the salt marsh mosquito (*Ochlerotatus sollicitans*). Marshes and swamps are large areas to treat and may require larvicide application by plane or boat. Smaller sites can be covered by ground. Formulations of Bti and methoprene have proven to be very successful in these areas. Agnique, which forms a film over the water and prevents larvae from breathing (without hurting other predators) is another larvicide option if vegetation is not too dense. The area that must be treated varies depending upon the flight range of the problem mosquito species. Generally, mosquitoes breeding in swamp areas do not range far. Salt marsh mosquitoes, on the other hand, have a flight range of up to twenty miles.

Floodwater Sites

A town should be surveyed following a heavy rain in order to locate sites where floodwater collects. Locations of these sites should be recorded on habitat maps. Floodwater areas are temporary water sites, and therefore usually do not contain large numbers of natural predators. Accordingly, these sites will breed several species of floodwater mosquitoes if water remains for a week or longer. Such areas should be treated a few days after a rain and closely watched for mosquito breeding.

Irrigated Fields

Rice fields are a major mosquito problem in many areas of Mississippi, especially in the Delta. The malaria mosquito (*Anopheles quadrimaculatus*) and the dark rice field mosquito (*Psorophora columbiae*) are two of the worst species in the Delta. The dark rice field mosquito can fly at least five miles, making control difficult. These floodwater and rice-inhabiting mosquitoes have their breeding cycle determined by the irrigation cycle of rice. Methods have been developed to apply Bti inexpensively to rice fields either at the point of water inflow or aerially with ultra low volume machines. Rice field mosquito control requires a cooperative effort among rice growers, and city and county agencies. Questions about effective rice field mosquito control can be directed to either the Mississippi Cooperative Extension Service at Mississippi State University (662-325- 2085) or the City of Cleveland Mosquito Control Office (662-843-1025).

MOSQUITO SURVEILLANCE

Collection, Survey, and Mapping Methods

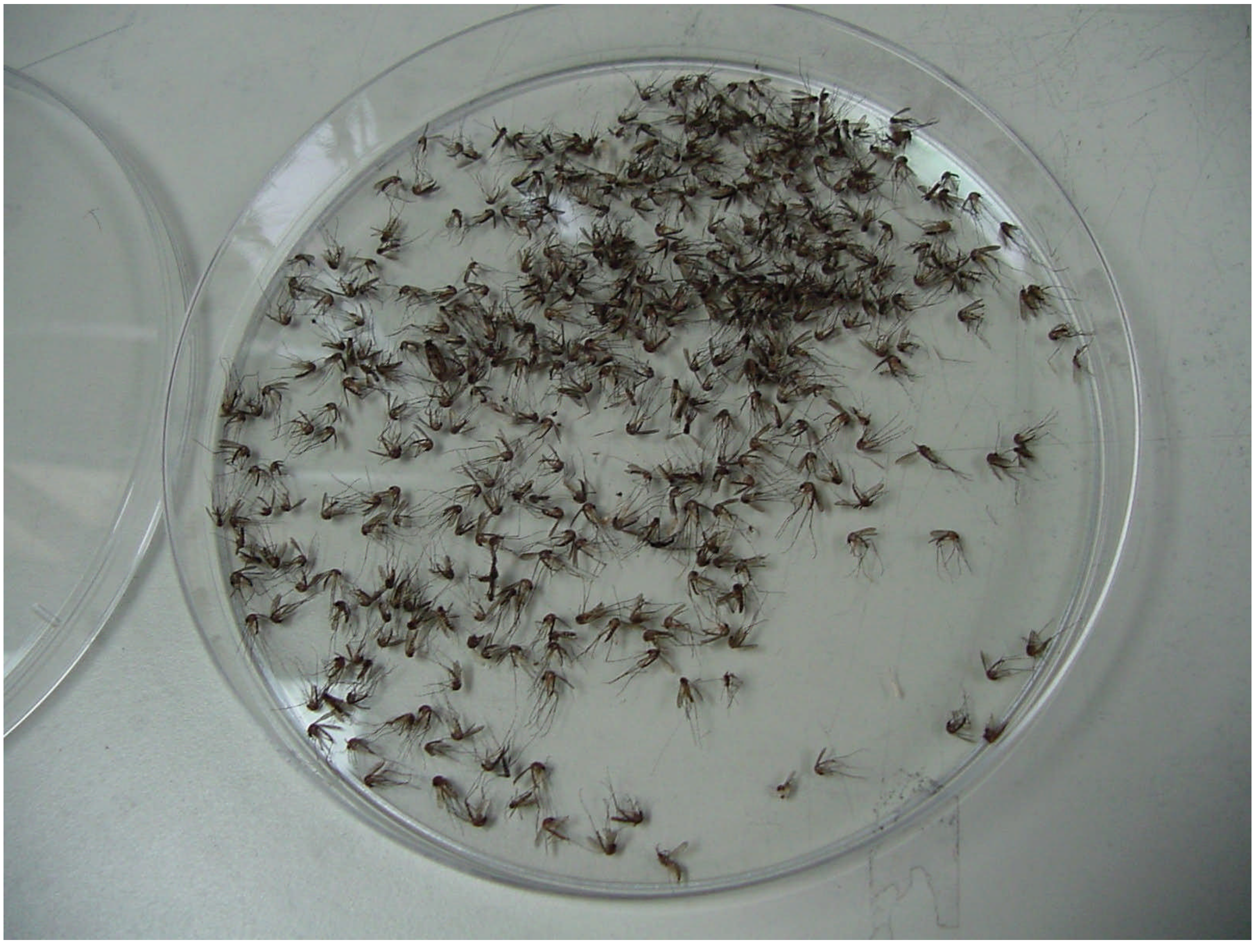
Purpose of Mosquito Surveillance

Mosquito surveillance should be a routine part of any mosquito control program. A good surveillance program will provide two types of information. 1) a list of the local mosquitoes (including distribution and population size estimates) and, 2) the effectiveness of the control strategies being used.

Routine surveillance can keep control personnel informed about locations of major breeding areas, helping to identify problem sites where control should be concentrated. Carefully interpreted survey data can provide vital information. For instance, large numbers of *Culex* egg rafts around the edge of ditches or *Aedes* eggs on oviposition strips are indicators that these breeding sites should be watched closely the next few days. Treatment should be timed to catch the heavy crop of resulting larvae during the period of their life cycle when they are active feeders. Heavy adult catches in light traps stationed near treated areas may indicate that an important breeding site has been overlooked in the survey or that mosquitoes are migrating in from other areas, depending upon the species captured.

Mosquito Surveillance Network

The State Health Department has an entomologist available to confirm field identifications. Many municipal and county mosquito control agencies do not have the facilities or personnel available to identify mosquitoes. Therefore, local mosquito control agencies can collect mosquitoes using methods described below and send samples to the Health Department. A mosquito sample can be identified and results sent back to the local mosquito control agency. Mosquito control technicians or directors can consult this manual or the entomologist to determine what control tactics should be employed to control the problem species. Eventually, however, this type of decision will become second nature to mosquito control personnel.



Mosquitoes in a petri dish

MSDH entomologist identifying mosquitoes

Establishment of fixed light traps (such as New Jersey Light Traps discussed below) can provide mosquito controllers with valuable information on adult mosquito populations. Mosquito control agencies on the Gulf Coast routinely station permanent light traps in the backyards of retired people living in mosquito prone areas throughout the city. These individuals maintain the traps, collecting the mosquitoes after each sampling, and mailing the samples to the mosquito control agency. Operational expenses can be reduced by locating light traps at fire stations, city or county barns, or other facilities where they can be easily maintained.

As an alternative, mosquito surveillance programs and even larviciding activities offer excellent summer employment opportunities for local students. Students can provide a mosquito control agency with economical, seasonally effective labor force. This program can also allow students to acquire experience in an applied aspect of biology, ecology, public health science, and municipal management. Yearly training programs in mosquito control and surveillance techniques can be provided (with appropriate advance notice) by the local mosquito control agency and the Health Department.

Mosquito Egg Surveys

Oviposition jars are useful tools for collecting information on many container breeding mosquitoes, such as the Asian tiger mosquito (*Aedes albopictus*), the yellow fever mosquito (*Aedes aegypti*), and the tree hole mosquito (*Ochlerotatus triseriatus*). Counting eggs collected from an ovitrap will give a good indication of the number of *Aedes* larvae that will hatch in an area following the next rain. Some eggs can be quickly identified to species under a microscope. Also, eggs can be hatched in the lab and mosquitoes tested for such things as pesticide resistance.

The oviposition jar should be a black plastic or glass jar, or even an aluminum can that has had the top cut out and painted black. The oviposition jar is fitted with a strip of felt covered paper or masonite hardboard clipped to the side. The jar is filled about half way up with water. Female mosquitoes are attracted to both the black jar and the water, and they will lay eggs on the rough surface of the strip just above the water line rather than the smooth surface of the jar. A hole punched in the side of the jar about two inches from the rim will prevent water from flooding the eggs during heavy rains, thereby causing many of them to hatch. The New Orleans Mosquito Control District attaches an oviposition jar to both sides of a piece of white painted board. This arrangement reduces the chance of oviposition jars being turned over, and, also, the contrast of black jars against the white boards seem to attract mosquitoes more readily.

Oviposition trap

Larval Surveys

Most of the equipment required to conduct a larval surveillance program can be purchased in a local hardware store. A white plastic or a metal dipper is excellent for collecting water from artificial containers and small water bodies that are easy to reach. Larvae can then be gathered from the dipper with a medicine dropper and placed in a small jar, containing a little water, to be preserved later. Long-handled white graduated dippers can be bought from companies that supply mosquito control equipment. These are useful for sampling ditches, margins of lakes and streams, and hard to reach areas. Kitchen strainers and fine mesh aquarium nets are also good for collecting large numbers of larvae. The contents of the net or strainer can be washed into a white enamel or plastic pan and the large larvae removed with a medicine dropper. Large meat basters are ideal devices for getting samples from tree holes or artificial containers with restricted openings. Three or four foot length sections of plastic tubing can also be used to siphon large amounts of water from tires and other similar breeding habitats. The end of the siphon can be placed in a strainer or large white pan to catch the larvae. A flat-weighted metal can with a string attached is an essential tool for collecting samples from storm drain ports protected by heavy metal gratings.

Descriptive information should be written down for each larval sample collected. Accurate descriptions of habitats sampled, including those places where no mosquitoes are found, are equally important. By having a good background on the type of local areas that breed mosquitoes, future routine surveys can be conducted efficiently, concentrating upon those areas that are known breeding sites. However, occasionally a thorough survey of all water areas should be conducted to ensure that previously unproductive areas have not become mosquito breeding sites.

Estimates of population densities of larvae can be obtained by counting the number of larvae per dip, using a standard size dipper. Three to five dips should be taken and counted at each site. The number of dips counted and number of larvae in each dip should be recorded. Information on the life stage of larvae and pupae can also be recorded. By noting numbers of larvae in each instar or size category (small, 0-5; medium, 5-15; large, 15+), number of pupae per dip, and water temperature, the investigator will be able to make an educated guess as to when mosquitoes will emerge and what control efforts should be used. Generally, larvae develop faster at higher temperatures. Large numbers of pupae indicate that a large number of adults will emerge within a few days. Since pupae do not feed, use of Bti or other products that must be eaten by mosquitoes will not control them. On the other hand, if most larvae are small, it may be eight to fourteen days before adults emerge, depending upon the species and the temperature. The investigator may decide that in this case an application of Bti is suitable. Large numbers of pupal skins floating on the surface is a sign that adult mosquitoes have recently emerged. The experienced investigator will also be able to determine the genus of many larvae based upon a few key characteristics. This knowledge will be useful in selecting the right larval control agent. For example, *Bacillus sphaericus* is highly effective on *Culex* mosquitoes but not *Anopheles* mosquitoes.

Mosquito larvae collected for identification should be handled carefully. When handled roughly, distinguishing hairs and other structures may fall off or become damaged, making identification difficult or impossible. Larvae that are to be preserved should be removed from the pan or dipper with a large tipped medicine dropper. These larvae should be placed in a small jar containing water, labeled and carried back to the office.

Adult Surveys

Adult mosquito surveillance is a very important part of any mosquito program. Adult surveillance will provide information on the effectiveness of the larvicide program. However, the presence of some adult mosquitoes does not mean that larviciding efforts are not working. No program will be successful in totally eradicating mosquitoes. The objective is to control mosquito populations, keeping their numbers at an acceptable level. Also, several species, such as the salt marsh mosquito (*Ochlerotatus sollicitans*) and the dark rice field mosquito (*Psorophora columbiae*), are capable of flying long distances and can move into an area from distant breeding sites.

Information that can be gained from a routine adult mosquito surveillance include:

1. Checklist of adult mosquito species in the local area.
2. Estimate of adult mosquito population density and distribution.
3. Indication of the presence of breeding sites that were overlooked.
4. Identification of sites where larviciding efforts need to be stepped up.
5. Source of adult female mosquitoes that can be used in SLE surveys.

The equipment needed to collect adult mosquitoes is generally more complicated and expensive than that required for collecting larvae. Adult mosquitoes are very fragile. They readily lose legs, scales and wings when handled roughly, making identification difficult or impossible. The special collection equipment described below is designed to capture adult mosquitoes with minimum damage.

Daytime Resting Stations

Adult mosquitoes, especially *Anopheles*, can be found during the daytime resting in both natural and artificial shelters. These areas include houses, barns, sheds, privies, bridges, culverts, hollow trees, overhanging cliffs, and foliage. Counts of mosquitoes utilizing daytime resting shelters can give a good indication of population density. Mosquitoes found in these shelters can be easily collected with an aspirator. In areas where no resting shelters are found, an investigator may install an artificial shelter such as a wooden box so that these sites can be routinely sampled. Many mosquitoes that do not usually bite can be collected in this way.

Light Traps

Several types of light traps are commonly used. The CDC light trap, developed by the Centers for Disease Control, is a portable model that is widely used. This light trap runs on a six volt lantern battery; a smaller version uses two "D" cell batteries. Mosquitoes are attracted to a small light at the top of the trap and are then sucked into a net at the bottom of the trap by a fan. The traps are usually set out and turned on at dusk and picked up at dawn. Timing devices can be installed on the traps so that they will only run during those hours of peak mosquito activity, conserving batteries. Only selected species of mosquitoes are attracted by light traps and catches tend to be smaller during a full moon. Mosquito catches can be increased by hanging a container of dry ice or an octenol lure near the light trap.

CDC light trap

The New Jersey light trap is a larger metal device, usually located at a permanent sampling station. This trap is often equipped with a timing device that turns it on during selected hours on certain days of the week. It works on the same general principal as the CDC light trap, except that it uses 110 AC power and mosquitoes are sucked into a paper cup inside a jar containing a killing agent such as a piece of pest strip. The paper cup prevents mosquitoes from coming into direct contact with the pest strip. Generally, New Jersey traps require little maintenance.

New Jersey Light Trap

Oviposition or Gravid Traps

Oviposition traps or gravid traps are available through some supply companies. These devices are similar to oviposition jars in that they provide a black plastic container partially filled with water as an attractant. Female mosquitoes visiting the trap to lay eggs are sucked into a net by a small fan motor like those used on many light traps. Oviposition traps are very selective for female *Culex* mosquitoes. The catch data is not comparable to light trap data. These traps are not commonly used by mosquito control agencies.

Gravid Trap

Preserving Adult Mosquitoes

Adult mosquitoes should be handled very carefully to prevent them from losing scales, legs, or wings. Collections taken from a New Jersey light trap using a pesticide strip in a killing jar are usually dead within the perforated paper cup. These mosquitoes should be gently shaken from the cup into a small tissue-lined cardboard jewelry box or equivalent container. Mosquitoes should be arranged evenly over the tissue and one layer deep. A piece of tissue should be placed on top of the mosquitoes to prevent them from being shaken about. A label containing the necessary sample information should be placed on top of the last layer of tissue and the lid secured on the box with a rubber band. Only one sample should be placed in each box. If many mosquitoes are captured in a single trap, extra boxes can be used to hold the sample and these boxes bound together with a rubber band.

Mosquitoes can be removed from net bags of light traps with an aspirator. An alternative is to remove the net bag, tie the top, and place it in an airtight container such as an ice chest with an open bottle of chloroform. Ice or frozen reusable ice packets can be used to "freeze" adult mosquitoes within an ice chest. This process takes longer than the chloroform method and some mosquitoes may revive after being removed from the cold ice chest.

Killed mosquitoes can be shaken from the net bags onto a piece of paper or into a small pan and then transferred to a small collection box. Adult mosquitoes should not be handled, if possible. When it is necessary to pick them up, use a pair of forceps, grabbing each mosquito gently by a group of legs.

Mosquitoes can be mailed by placing the collection boxes in a larger, sturdy container and filling loose spaces around the collection boxes with paper or Styrofoam peanuts. The lid should be carefully secured and the container marked "fragile". As an extra precaution, a wisp of cotton can be placed on top of the upper tissue layer of each collection box and replace the lid. This will help prevent the mosquitoes from being shaken around inside the collection boxes. These steps may seem to be a little extreme. However, it is necessary to provide the identifying entomologist with good quality samples in order that correct identifications can be made. This is especially important when adult collections are first being made from an area and a reference collection and species list is being compiled.

HABITAT MAPPING AND RECORD KEEPING

Habitat maps and records of mosquito populations and application methods used are valuable sources of information to the larvicide technician. The following describes one method of mapping and keeping records of mosquito breeding activities. However, improvements and variations of this method can be made or unique methods devised by each mosquito control person.

A habitat map should show all known water areas within a town, including artificial containers and floodwater areas. In the beginning of the larvicide program, all known water areas can be recorded upon photocopied quarter mile quadrants of a town street map or aerial photograph.

The best way to conduct a habitat survey is by foot, inspecting each site for evidence of mosquito breeding. This insures a thorough inspection and allows the inspector to become familiar with the area. Both mosquito positive and mosquito negative sites should be recorded. Positive sites should be distinguished from negative sites by placing a small star (*) next to those sites where mosquitoes were found. Water sites can be recorded by type, using a numerical code. Later, when making routine larviciding rounds, the technician can then quickly determine locations and types of water habitats in an area at a glance. He or she will know which of these sites were positive during the initial survey.

Habitat maps can be verified during the first couple of larvicide applications. Newly discovered sites should be added. Locations of ditches and storm drains, and tree lines can be checked. When the technician feels comfortable with the accuracy of the maps, photocopies can be made and the master copy kept on file. During each larviciding trip, a set of these copies can be used as field maps. Notations concerning the day's activities can be recorded on each quadrant as the larvicide technician visits each site. Maps showing each week's activities can be kept on file for future reference on mosquito breeding trends.

Some people choose to laminate each quadrant map. During routine visits to breeding sites, the technician can make notations on these maps in grease pencil. These maps should be kept in a metal clipboard with a cover in order to prevent smudging the grease pencil. Information should be transferred from the laminated maps to regular copies and filed for future reference.

Keeping records on each site can be useful. Knowing information such as previous larvicide treatments, past estimates of mosquito numbers, life stages found, and when a site was wet or dry will allow the technician to predict when a particular site will become a problem. This information can be useful in other ways. Many vector-borne diseases occur in cycles. Knowing something about breeding trends of local mosquito species over the past few years may indicate the likelihood of a disease outbreak. Any advance warning of a potential epidemic would allow mosquito control technicians to take precautions such as larviciding an area more frequently or, if necessary, fogging adult populations.

MOSQUITO CONTROL

Complaint Calls

The public can provide a valuable service by calling in mosquito problems. Complaint calls can help pinpoint large populations of mosquitoes. Spray efforts can be aimed at these "hot spots" when needed, rather than spraying the entire town. Encourage community members to notify their local mosquito control agency when mosquitoes get out-of-hand. Those complaint calls can then be plotted on a large map to provide information on probable areas to target.

If manpower allows, turn complaint calls into service requests. Gather as much information as possible over the phone, including the name, address and phone number of the caller, time of day or night the mosquitoes are biting, and areas of standing water that the resident may know about. When possible, arrange an inspection when the resident is home. This is a good opportunity to educate the homeowner on mosquito biology and control, source reduction, and personal protective measures. Plan on collecting adult mosquitoes or have the resident save a few. This will help identify the species and aid in locating the breeding source(s). Conduct a thorough inspection of the yard and adjacent yards. Talk with the resident during the inspection and collect samples as you inspect. Taking the time to help educate residents will help to reduce the number of call-back inspections. Empower the homeowner. Leave literature on mosquito control and offer sound suggestions and advice. Getting residents to change their behavior can help eliminate neighborhood mosquito problems.

Record the date, location, density, stage of development, and habitat. Save a sample for identification and create a breeding site card for locations that will need regular monitoring and treatment. Include information on adult mosquito rates encountered and the decided treatment. Keep the information in a file system for rechecks and control activities, historical information, and for legal purposes.

Biological Control

Many organisms have been or are being evaluated as potential biological control agents for mosquitoes. A few of these agents have been used to control mosquitoes for years. The World Health Organization has used the mosquito fish (*Gambusia affinis*) in many parts of the world since the 1940s. A nematode parasite (*Romanomermis culicivorax*) was at one time commercially available and has been used in many areas for mosquito control with measured success. The bacteria Bti (*Bacillus thuringiensis israeliensis*) has been on the market for several years and is one of the most successful biological control agents currently used.

Each biological control agent has certain merits and restrictions. In order to use a biological control agent successfully, the larvicide technician must have a basic knowledge of the biology of each agent used. Some biological control agents are limited by salinity, temperature, or organic pollution. Some are more effective on certain types of mosquitoes than others. These agents also differ in the ways in which they can be formulated, transported, stored, and applied. All of these factors must be considered when choosing the proper biological control agent for a specific habitat or to control a specific mosquito.

Natural Mosquito Control Organisms

As mentioned earlier, natural habitats, permanent water bodies, and even artificial containers that have held water for a long time support populations of mosquito predators. These predators include beetle larvae, certain fly larvae, aquatic bugs, dragonfly and damsel fly naiads, and fish. During routine surveillance of mosquito habitats, the larvicide technician should look for and become familiar with these organisms that feed on mosquito larvae in the wild. The occurrence of dead mosquito larvae or pupae in previously untreated sites may indicate the presence of a naturally occurring pathogen or parasite.

Use of "hard" chemical larvicides will also kill many of these natural mosquito control agents. However, the larvicide agents recommended in this manual, such as Bti or methoprene, if used according to label recommendations, do not affect these other organisms. Mosquito predators will still be around to help maintain some measure of control over mosquito populations at those sites.

HOMEOWNER / INDIVIDUAL CONTROL

Mosquito control can be divided into two areas of responsibility—individual and public. Chemical control of mosquitoes around the home may be accomplished with the use of repellents or space sprays. Repellents are substances that make a mosquito avoid biting people. Several repellents are effective against mosquitoes. All insect repellents must have the active ingredient appear on the label (e.g., DEET, permethrin, plant oils, etc.). Always advise the public to check the label before buying and using. For instance, only DEET concentrations under 10% should be used on children.

Oil of citronella is another type of mosquito repellent for space repelling. Oil of citronella is the active ingredient in many of the candles, torches, or coils which may be burned to produce a smoke which repels mosquitoes. These may be useful outdoors under windless conditions. Their effectiveness is much less than that of repellents applied to the body or clothing.

Space sprays may be used to kill mosquitoes present at the time of treatment. The major advantage of space treatment is immediate knockdown, quick application, and relatively small amounts of materials required for treatment. Space sprays are most effective indoors. Outdoors, the insecticide particles disperse rapidly and may not kill many mosquitoes. The major disadvantage of space spraying is that it will not manage insects for long periods of time.

Mosquitoes can be killed inside the house by using a flit gun or a household aerosol space spray containing synergized pyrethrum or synthetic pyrethroids (allethrin, resmethrin, etc.). Only insecticides labeled for flying insect management should be sprayed into the air. Best results are obtained if doors and windows are kept closed during spraying and for 5-10 minutes after spraying. Again, with any pesticides, always advise the public to follow directions on the label. Homeowners may use hand-held foggers or fogging attachments on tractors or lawn mowers for temporary relief from flying mosquitoes. Pyrethrins or malathion can be fogged outdoors (again, find and use only products labeled for such uses).

Homeowners can also control mosquito populations through source reduction or elimination of breeding sites. Reducing the amount of breeding areas around the home will reduce the overall numbers of mosquitoes and reduce the chances of being bitten by mosquitoes. Source reduction often involves the whole community so this will be discussed in more detail under public control.

PUBLIC CONTROL

Source Reduction

Source reduction is the elimination of mosquito breeding sites. Reducing the amount of breeding areas in a town will save the larviciding technician both time and work. A spring cleanup drive involving schools, citizen groups, and town maintenance and sanitation departments can help get rid of bottles, cans, tires, stagnant drainage ditches, and other sites that produce mosquitoes. Many types of breeding sites, however, cannot or should not be eliminated. Mosquitos in these areas will have to be controlled by applications of a suitable larvicide. Improper drainage of wetlands and indiscriminate ditching can create more mosquito problems than were there to begin with.

Larviciding

Larviciding, or killing the mosquito while in the larval stage (pupal stage included), is one of the most common methods of mosquito control used today. It is considered the best course of action for mosquito control after source reduction. When mosquitoes are in their immature stages, they are concentrated in a relatively small or fixed area (captive audience). The kill occurs before mosquitoes are out flying, causing biting nuisances, and capable of transmitting diseases to people, pets, and domestic animals. However, every body of standing water need not be larvicided. Several factors must be considered before larviciding. These include the mosquito species, larval density, stage of development, relative proximity to populate areas, size of the area, seasonality, susceptibility, equipment and larvicides selected by the program, the larvicide formulation, environmental issues, jurisdiction, rain and wind conditions, and cost.

The best pesticide is one that is extremely specific, affecting only the target pest and nothing else in the environment. It must eliminate the pest quickly before it becomes a threat and before it reproduces. It has to be easily applied, reasonably inexpensive, and non-toxic to human, domestic animals and wildlife. Finding all of these characteristics in a single pesticide has been the goal of many researches. A small group of Bacillus bacteria have been developed into a line of pesticides that are remarkably close to this idealistic model. Some man-made chemicals like methoprene and Agnique are also commercially available that will prevent the adult mosquito from forming but not harm natural organisms or the environment.

Bti (*Bacillus thuringiensis israeliensis*) is a strain of bacteria that was isolated from a dead mosquito larvae found in Israel in 1977. It proved to be a very effective killing agent of mosquito larvae and black flies. It was also lethal to several species of midges, but had no adverse effect upon other insects, fish, or laboratory animals. Bti has since been developed into wettable powder, liquid, granular, capsule, and briquette formulations that are commercially available to mosquito control personnel. It has also been formulated with growth regulators and monomolecular films.

Wettable powder is not widely used. The liquid, however, is one of the most common and versatile formulations on the market. Liquid Bti is packaged in 2.5, 5, and 30 gallon containers. It generally comes in two strengths, 600 and 1200 international toxic units. This material can be mixed with water and applied by handsprayer, truck mounted sprayer, or ultra low volume fog machine.

The hand portable sprayer provides the best way to apply Bti to many urban breeding sites. It is important to purchase a sprayer that is comfortable and easy to carry for several hours. Sprayers equipped with backpack or shoulder straps should be considered. The spray unit should hold two to four gallons and be equipped with a wand that has an adjustable nozzle.

Try not to disturb the water surface when applying Bti. A soft sweeping mist coverage is better than a strong stream. Bti spores are effective when they are on the surface where larvae generally filter feed. If the water is churned up by spraying a hard stream of material, many spores may sink rather than remain at the surface. Be sure to spray around grassy edges and shaded areas where larvae tend to concentrate.

Label application rates for liquid Bti are based on the surface area of the water being treated, not depth. Application rates of 1/2 to 2 pints per acre are generally recommended, depending on strength of the formulation used (check the label for specifics). The proper rate needed at each site depends on several factors, including predominant larval stage, larva density, water quality, type of water habitat, and amount of plants growing in the water.

Early stage larvae are more readily killed by Bti than late stages. Lower dosage rates can be used when larva are mainly early stages, but the higher recommended dosage should be applied to populations of late third and fourth stages. The higher the concentration of spores at the surface the greater the likelihood that the older larvae will pick up a few spores. Bti is less effective against the late instars: plus pupae do not feed and therefore not affected by Bti unless they fed upon it prior to pupating. Methoprene, however is very effective against the fourth stage larvae. Agnique and some other harsher oils, bonide, and golden bear are options when only pupae are present, it is too late to use Bti or methoprene, and a quick kill is required. The residual effect of most oil formulations for killing late stage instars and pupae is about 5-7 days.

Younger larvae will be feeding actively for a week or more and, therefore, have plenty of opportunity to ingest a few Bti spores, even when applied at the lower dosage rate. The higher application rate should be used when larval population density is high, regardless of predominant instar present. Mosquito larvae are very efficient filter feeders. Large numbers of larvae will quickly filter out all of the spores applied at low rates before all larvae have a chance to feed on the material.

The higher recommended rates should be used in water polluted with septic tank discharge or that has a heavy growth of algae. These waters generally have higher concentrations of suspended food particles. In this case, Bti spores are competing with food particles. Using the higher dosage rate increases the chance that larvae will pick up at least some of the spores along with all of the food particles. Lower dosage rates can be used in clear, open water conditions (ponds, pools, rice fields, floodwater) but higher dosage rates should be sprayed in heavily shaded water.

Granular Bti or liquid methoprene are generally applied to areas covered by thick vegetation, such as salt marshes and weedy ditches. It has also been used in flooded pastures, irrigated fields and tire piles. If granules are applied to large areas of open water, winds can push them against one shore. This formulation consist of spores attached to a carrier made from ground and sized corn cob particles. The carrier floats, keeping much of the material at the surface where most larvae feeding occurs. Different companies make different size corn cob particles. As a rule, smaller particles can fall through thick grass better, but may be more likely to stick to wet blades. Larger granules can be broadcast further and are less affected by wind.

Ground application of granular Bti can be made with many types of manual or mechanical seed or fertilizer spreaders that use a whirling disk. Horn seeders have not proven to be as effective. Generally, recommended application rates range from 2 to 10 pounds per acre (check the label). The actual rate required at each site is largely dependent upon the same factors discussed for application of liquid formulations. Generally, treatment should be repeated every seven days.

Bti is also formulated into briquets. The brand name is Bactimos or “mosquito dunks”. They are usually more expensive than liquid and granular formulations. Cost per acre is generally about $15-$50. However, these floating briquets will give up to thirty days of treatment under normal conditions. Briquets can be used in many habitats where mosquitoes breed. They can be anchored to tree limbs or weights with string to prevent them from floating away. Usually, one briquet will treat about 100 square feet of water surface, regardless of depth. Up to 4 briquets per 100 square feet may be required in heavily polluted water. Briquets can be applied to areas that flood during rainy periods such as woodland pools. These briquets will float when the area is flooded, releasing Bti. Effectiveness of the Bti will not be reduced by dry periods.

Using Insect Growth Regulators

Insect growth regulators (IGR) are a group of chemicals that kill insects by interfering with their normal process of growth and development. Methoprene is an IGR that affects mosquitoes. The material can be applied to any larval stage. However, results are not immediate. Larvae will not die, but will continue their growth process and pupate. Pupae that develop from exposed larvae will die and adults will not emerge. Methoprene is only effective when applied to the larval stage. Any pupae that are present in the water during application will not die and will successfully emerge as adults.

Methoprene (brand name Altosid) comes in liquid (5% and 20%), a new granular formula, 30-day briquets and extended 150-day briquet formulations. Applications of methoprene should be made at the start of the mosquito season. It can be used in a wide variety of places, such as storm drains, fountains, cesspools, waste treatment and settling ponds, abandoned swimming pools, and other man-made sites. EPA has even recently approved methoprene use in livestock watering troughs. Briquets can be tossed into the water. They will sink to the bottom and slowly release the IGR. The liquid can be mixed with sand and sprayed.

Residual effects range from 7-10 days for liquid to 30-150 days, depending on the formulation. Briquets are designed to withstand wet and dry periods to extend the residual effect through periods of heavy rainfall, flooding, etc. Mosquito control personnel must maintain current knowledge about approvals and use of larvicides, and are encouraged to attend annual training conferences offered in the state.

Adulticiding (Spray Trucks)

Only selected chemicals are approved for use in a thermofogging unit or ultra low volume (ULV) unit in Mississippi. Consult the Mississippi Department of Agriculture and Commerce, Bureau of Plant Industries (Starkville, MS, 662- 325-3390) for a current list of approved chemicals, mixing rates and application rates. Different formulations are used in thermofogging units than are used for ULVs. Be sure you purchase the correct formulation for your machines.

Truck-mounted ULV machine for adulticiding

Always read the chemical label before buying, mixing, loading, applying and storing insecticides. A few of the adulticides available are restricted use pesticides and must be purchased and applied under the direct supervision of a certified pesticide applicator. All applicators should review and carry the chemical labels and material safety data sheets (MSDS) with them while conducting control activities. Insecticide labels and MSDS contain important information concerning the application rate, personal protection measures, statements of practical treatments, environmental hazards, and storage and handling procedures. LABEL IS THE LAW!!

For the most part, adulticiding should be done after sunset. Chemicals sprayed during the day will be carried upward by thermal currents. Also during the day, mosquitoes generally are resting out of reach of pesticide in protective foliage, while bees are exposed as they gather nectar. We should try to kill mosquitoes, not bees. Spray trucks should be driven slowly; usually 10 mph. Great efforts should be made to drive the entire evening at the same speed. This assures application of the chemical at a uniform rate.

Machines must be kept in proper working order and calibrated yearly. Both flow rate and droplet size should be calibrated in ULV machines, and flow rate in thermofoggers. Personnel at the State Health Department or Mississippi Cooperative Extension Service (Ph. 662-325-2085) may be available to aid in machine calibration. When using corrosive chemicals, flush your machine after each use. Technicians should practice worker safety. Pesticide lines should be routed outside of the cab.

Adulticiding should only be done when necessary. Routine adulticiding chemical wastes expose the public to chemicals unnecessarily and promote the buildup of mosquito populations resistant to the chemicals.

Empowering Mosquito Control Personnel

Mayors, aldermen, and county supervisors should take an active role in mosquito control to ensure efficiency and limit liabilities. If a lawsuit alleges that a town's fogging truck caused a respiratory problem among residents, then the chemical in question better have been applied correctly with a properly calibrated machine. Otherwise, the municipality may be liable. Efforts should be made to certify and train mosquito control personnel by occasionally sending them to workshops and seminars on mosquito control. One such workshop is the annual Mosquito and Vector Control Workshop put on by the State Health Department and other agencies. This meeting is usually held in March of each year in Jackson. In addition, mosquito control workers should read this publication, as well as others available through the Mississippi Cooperative Extension Service concerning safe and effective mosquito control.

Mosquito Control and the Public

Providing public information and soliciting public support is vital to the success of any mosquito control effort. Communities should be made aware of the effects they have upon local mosquito populations. Efforts should be made to inform the public of the problems caused by artificial containers around their homes. They should be encouraged to clean up their neighborhoods; rid their yards of breeding sites; promote town clean-up drives and sponsor mosquito seminars for schools and local organizations; provide information on larviciding activities in their area and remind people of the potential public health threat mosquitoes represent. Invite citizens to call in complaints concerning severe mosquito problems. Mosquito control is a public effort. Without the help and support of citizens, mosquito control personnel will be fighting a losing battle.

IMPORTANT MOSQUITOES OF MISSISSIPPI

Presented here are discussions of nine important mosquitoes encountered in our state. Detailed information of life histories, behavior patterns, and breeding habitats is given for each species. No statewide mosquito surveys have been conducted in Mississippi, therefore, information on distribution and breeding habits is based on reports in the scientific literature.

Descriptions are given for each mosquito species. Important body parts are labeled on the following diagram. Each illustration shows those characteristics that can be seen by the naked eye. With a little practice, one can identify adult mosquitoes using a few key features described. Larval species are not described here because they are generally harder to identify and a microscope must be used to see many of the identifying features. Being able to identify adult mosquitoes will help the larvicide technician know what types of breeding sites to look for in a particular area. A good hand lens may be needed in the field identification of these adult mosquitoes.

THE YELLOW FEVER MOSQUITO (*Aedes aegypti*)

Description: This small mosquito is dark brown to black with silver-white markings including:

A. Silver White lyre shaped lines on upper sides of thorax
B. White bands on hind tarsi
C. Banded abdomen
D. Short palps with white tips.

Breeding Habitat: This species is found almost exclusively in shaded artificial containers around buildings, such as tires, cans, jars, flower pots and gutters. It will also breed in tree holes.

Life Cycle: Single eggs are laid on the inside surfaces of containers at or above the water line or occasionally on the water surface. The eggs can resist drying for up to several months. Flooded eggs can hatch in two or three days at high temperatures. Under good conditions, larval development is completed in 6 to 10 days. Cool weather extends the development period. The pupal period lasts about two days. The life cycle can be completed within 10 days under good conditions or extend to three or more weeks under poor conditions. Reproduction rate is slower in the winter with eggs remaining dormant for several weeks or months.

Biting Behavior: *Aedes aegypti* usually bites during the morning or late afternoon. It prefers human blood meals, biting principally around the ankles, back of the neck, and under sleeves. It readily enters houses.

Flight Range: 100 feet to 100 yards.

Important: This mosquito is a potential vector of urban yellow fever and dengue. It is also a significant pest species.

THE ASIAN TIGER MOSQUITO (*Aedes albopictus*)

Description: This mosquito is very similar in appearance to the yellow fever mosquito. It is dark brown to black with silver-white markings that include:

A. Silver stripe down the center of the thorax
B. White bands on hind tarsi
C. Banded abdomen
D. Short palps with white tips.

Breeding Habitat: Artificial containers, and especially used tires, are the prime breeding sites.

Life Cycle: Little is known about this mosquito in our area. However, its life cycle is probably similar to that of the yellow fever mosquito.

Biting Behavior: This is an aggressive biter, attacking soon after you disturb a breeding area. Often these mosquitoes land and bite immediately.

Flight Range: Less than a quarter mile.

Seasonal Occurrence: The strain of Asian tiger mosquito introduced into the United States is believed to have originated from the temperate Orient and can survive cold temperatures better than the yellow fever mosquito. They may be active most of the year.

Importance: The Asian tiger mosquito may carry the agents of yellow fever, dengue fever, and several encephalitis viruses.

THE SALT MARSH MOSQUITO (*Ochlerotatus sollicitans*)

Description: The Salt Marsh Mosquito is bronze-brown species with golden-yellow markings including:

A. Dark proboscis with a white ring near the middle
B. Abdomen with whitish yellow bands and a yellow stripe down the center
C. Yellowish-white bands on hind tarsi
D. Short palps with small white tips.

Breeding Habitat: Breeding occurs primarily in salt marshes flooded by tides and/or rain. Breeding may occur in marsh areas not covered by tides such as potholes, tire ruts, depressions or wide level areas. Small larval populations are sometimes found in freshwater.

Life Cycle: Eggs are usually laid on mud or marsh plants. Eggs that have remained dry for one to two weeks will hatch within minutes when flooded. Development to adult requires about 7 to 10 days during warm weather. Breeding occurs throughout the year with extended development time required during winter months.

Biting Behavior: These mosquitoes are fierce biters. Migratory flights consisting of large numbers of mosquitoes begins just before dark. These swarms will move from marsh areas into neighboring urban areas. During the day, mosquitoes rest on vegetation, but will readily bite when disturbed. They will even bite in full sunlight.

Flight Range: The average flight range is between 5 and 10 miles. However, they can travel 40 miles or more.

Importance: These fierce biters can often discourage coastal development and recreational activities. They are considered to be an important vector in the transmission of Eastern equine encephalitis to humans and horses.

THE BLACK SALT MARSH MOSQUITO (*Ochlerotatus taeniorhynchus*)

Description: This is a small to medium sized mosquito that is dark brown with yellowish to silver-white markings, including:

A. Dark scaled proboscis with a white ring near the middle
B. Abdomen with thin white bands and white spots on sides of last two segments
C. Hind tarsi with narrow bands
D. Short black palps.

Breeding Habitat: It breeds primarily in salt marshes flooded by tides and/or rain but will also breed in freshwater pools near salt marshes.

Life Cycle: Many broods are produced per year from late spring until cold weather in October.

Biting Behavior: These mosquitoes are fierce biters, but are less likely to bite in full sunlight.

Flight Range: Average flight range is about 4 miles with up to 18 miles being reported.

Importance: This mosquito is a severe nuisance pest and has been incriminated as a vector of dog heartworms.

THE TREE HOLE MOSQUITO (*Ochlerotatus triseriatus*)

Description: This medium-sized mosquito is brown to black with silver white markings. Other characteristics include:

A. Wide dark brown strip on thorax that becomes broader toward the abdomen
B. Abdomen is blue-black with white patches on the sides
C. Second and third pair of legs yellowish white at the base and dark on the ends
D. Proboscis black with short black palps.

Breeding Habitat: Breeding occurs in artificial containers and tree holes.

Life Cycle: About one month is required for complete development. Many broods are produced each year from spring to fall. The species will overwinter as larvae.

Biting Behavior: This species is a fierce biter both during the daytime and at night.

Flight Range: Short.

Importance: This is a pest mosquito shown to have a potential in the laboratory to carry the agents of yellow fever and eastern equine encephalitis. It is considered to be an important vector of La Cross virus in other parts of the United States.

THE INLAND FLOODWATER MOSQUITO (*Aedes vexans*)

Description: This is a medium-sized brown to golden brown mosquito with light gray or white markings including:

A. Abdomen with white bands shaped like wide "W"s on middle segments
B. Hind tarsi with narrow white rings on all segments
C. Palps short and dark with a few white scales at the tip.

Breeding Habitat: Areas include floodwaters, rain pools, and any temporary body of freshwater in both wooded and open areas.

Life Cycle: Many broods are produced per year from spring through fall when breeding areas are flooded by rains. Broods can even be produced during warm winters. Eggs are laid on the ground and hatch when flooded. Aquatic stages require 10 to 21 days to develop, depending on environmental conditions.

Biting Habits: They are vicious biters, being active mainly at dusk and after dark.

Flight Range: 5 to 10 miles on the average.

Importance: Mainly just a nuisance pest mosquito.

THE MALARIA MOSQUITO (*Anopheles quadrimaculatus*)

Description: This is a relatively large dark brown to black mosquito with:

A. Palps about as long as proboscis
B. Wings with four dark spots
C. Dark, unbanded legs.

Breeding Habitat: Clean, permanent freshwater ponds, pools, and swamps, as well as ricefields with vegetation or floating debris, are the primary breeding sites. Larvae may be found in open sunny areas or deep-shaped areas. They favor clear, quiet waters having a neutral to alkaline pH. Other habitat types include borrow bits, lime sink ponds, bayous, sloughs, slow streams, shallow lake and reservoir margins and backwater areas containing vegetation and flotsam.

Life Cycle: Males emerge first and remain near the breeding areas. Emerged females often mate on the first day either before or after the first blood meal. Egg laying begins from 2 to 3 days following the first blood meal. A female may deposit over 3,000 eggs in as many as 12 batches. At optimum temperatures of 85 to 900F development occurs in 8 to 14 days. Larvae do not complete development at temperatures below 50 to 550F. At temperatures of 65 to 700F, 30 to 35 days are needed for development of aquatic stages. Breeding may be continuous throughout the year, especially if winters are mild. Peak populations occur during July or August, declining rapidly during September and October. Fertilized females overwinter in hollow trees and protected areas around houses and barns.

Biting Behavior: Generally, adults remain inactive during the daytime, resting in cool, dark, damp areas. Almost all feeding activity occurs at night. They will readily enter houses and feed on humans. However, they feed more frequently on cows, horses, pigs, and chickens.

Flight Range: Usually, adults do not fly further than about one-half mile from their breeding area.

Importance: When malaria was prevalent in the United States, this mosquito was the most important vector east of the Rocky Mountains. However, now it is primarily a pest species.

THE SOUTHERN HOUSE MOSQUITO (*Culex quinquefasciatus*)

Description: This is a brown, medium-sized mosquito with white markings, including:

A. Abdominal segments with narrow bands
B. Dark unbanded legs that have a bronze to metallic blue green reflection
C. Dark palps that are shorter than the proboscis.

Breeding Habitat: Major breeding sites are waters heavily polluted with organic material such as ditches receiving septic tank overflow, storm-sewer catch basins, poorly drained ditches, cesspools, and polluted ground water. This mosquito will also breed in artificial containers.

Life Cycle: Eggs are laid in floating rafts of 50 to 400, hatching within a day or two in warm temperatures. The aquatic stages are completed in 8 to 10 days. During cooler weather, several weeks may be required for complete development. Generally, breeding is continuous throughout the warmer months of the year.

Biting Behavior: This species feeds on birds, domestic animals, and humans, it readily enters houses.

Flight Range: These mosquitoes migrate only short distances unless large numbers are produced.

Importance: *Culex quinquefasciatus* is the major vector of the agent of St. Louis and West Nile encephalitis and a main vector of the dog heartworm.

THE DARK RICE FIELD MOSQUITO (*Psorophora columbiae*)

Description: This is a medium to large mosquito that is dark brown to bronze with yellowish white and gray markings including:

A. Dark proboscis with wide yellow band
B. Narrow rings of white scales near the tip of each femur
C. Abdominal segments with white to pale yellow markings on the lower portion.

Breeding Habitat: It can be found in open freshwater temporary pools and ditches. It is very abundant in fallow rice fields, rice fields that have been drained and flooded, and in second cropped rice fields. It can also be found in slightly brackish areas.

Life Cycle: Many broods are produced per season (April to October). Eggs are laid on ground subject to flooding with areas of low, vegetation being preferred. Eggs that have been dry for 2 or 3 weeks will hatch within minutes upon being flooded. At a mean temperature of

790F, larval stages can be completed in 5 days. The pupal stage lasts 1 to 2 days. Areas that dry up and are reflooded every few days can produce a hatch with each flooding. This mosquito overwinters in the egg stage.

Biting Behavior: These are fierce biting mosquitoes, attacking either at day or night.

Flight Range: At least 10 miles.

Importance: This mosquito was incriminated as the vector of Venezuelan equine encephalitis cases in Texas during 1971. Western equine encephalitis and California encephalitis viruses have also been isolated from dark rice field mosquitoes.