Texas A&M AgriLife Extension

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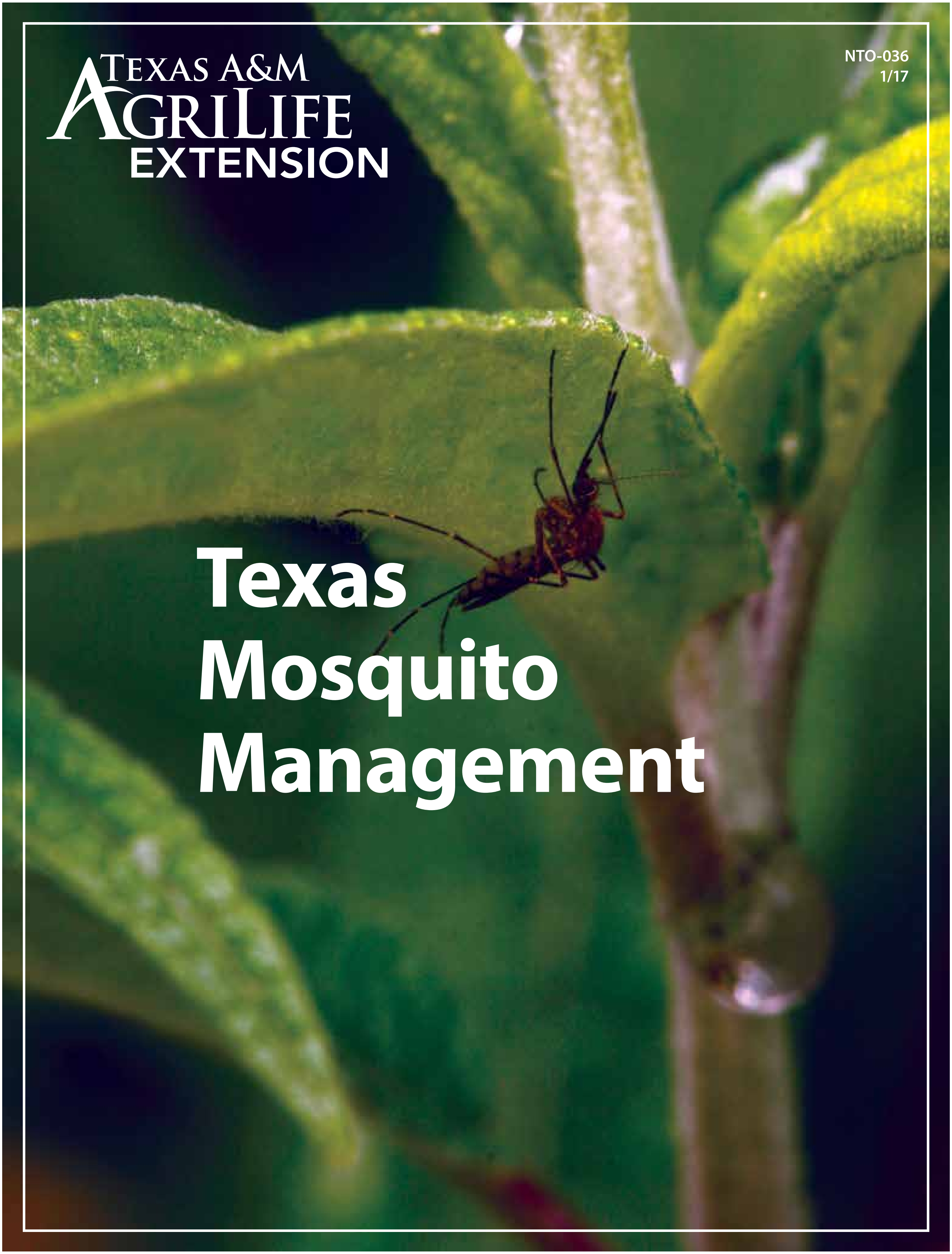

Texas Mosquito Management

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Cover photo by Mike Merchant

Contents

Introduction

This manual is designed to help public health professionals prevent mosquito outbreaks and respond quickly and effectively to the outbreaks that do occur. The best approach for protecting people from illness or death caused by mosquito-borne viruses is integrated mosquito management (IMM).

IMM evolved from the concept of integrated pest management (IPM). First proposed in the 1950s, IPM bases pest management strategies on a thorough understanding of the pest's biology as well as the multiple tactics available for control. IMM focuses on identifying the pest mosquito, knowing its biology, and using control tactics for all mosquito life stages.

The goal of IMM is to create a sustainable program that combines biological, physical, and chemical tools to minimize the cost of control, reduce mosquitoes that transmit diseases to people and animals, and protect the environment.

The tactics include conducting surveillance, reducing the number and size of mosquito larval habitats, controlling mosquitoes at different life stages—larva, pupa, and adult—and educating the public.

Mosquitoes are ideally controlled during their immature stages, before they can bite and transmit diseases. It is easier to eliminate mosquitoes when they are contained, concentrated in known sites, and accessible to control measures. When it works, this approach reduces the need for widespread pesticide spraying for adult mosquitoes.

Unfortunately, mosquito breeding sites are not always accessible, or they are too numerous to find and treat all sites. In those situations, mosquito adulticides (insecticides used to kill adult mosquitoes) may be needed to prevent intolerable populations and the spread of disease.

1 Mosquito biology

Most of the 85 species of mosquitoes found throughout Texas have little to no effect on humans. They either acquire their blood meals from other hosts, or they do not spread disease to people or livestock. The species targeted by integrated mosquito management (IMM) programs are those that cause nuisances or spread diseases.

In urban communities, IMM programs focus on surveillance and management to control the four most abundant species that transmit disease-causing organisms, or pathogens:

- **Southern house mosquito** (*Culex quinquefasciatus,* Fig. 1), the infected mosquito species collected most often in Texas
- **Western encephalitis mosquito** (*Culex tarsalis,* Fig. 2)
- **Yellow fever mosquito** (*Aedes aegypti,* Fig. 3)
- **Asian tiger mosquito** (*Ae. albopictus,* Fig. 4)

Along the coast, where marshlands and tidal water are influences, IMM programs focus more on salt marsh mosquitoes such as *Ae. sollicitans* (Fig. 5) and *Ae. taeniorhynchu*.

Figure 1. *Culex quinquefasciatus.* Image source: Mark Johnsen

Figure 2. *Cx. tarsalis.* Image source: Joseph Berger, Bugwood.org (CC BY 3.0 US)

Figure 3. *Aedes aegypti.* Image source: USDAgov (CC BY 2.0)

Figure 4. *Ae. albopictus.*

Figure 5. *Aedes sollicitans.* Image source: Sonja Swiger

Mosquito species differ in their egg-laying (oviposition) sites, flight range, and biting behavior. Because of these variations, mosquito control personnel must know which species of mosquitoes are of concern to manage them effectively.

For example, Asian tiger mosquitoes *(Ae. albopictus)* and yellow fever mosquitoes *(Ae. aegypti)* often breed in small containers (Fig. 6) in urban settings. They tend to remain close to the ground and in vegetation and are less effectively controlled with street-based, ground adulticiding efforts. These mosquitoes breed in tree holes and discarded tires.

Figure 6. Possible mosquito egg-laying site. Image source: Mike Merchant

Likewise, yellow fever mosquitoes use humans as hosts and can breed in container habitats created by people.

Controlling both species requires conducting areawide cleanup campaigns to remove larval habitats—a goal that is most effectively achieved through public education and public involvement.

In contrast, *Anopheles* mosquitoes breed in permanent bodies of water. Target them with adulticides and pesticides that kill mosquito larvae (larvicides).

An IMM approach would include draining swampy areas and ensuring that predatory fish are present to help control the larvae.

Disease cycles

As travel among continents increases, the number of mosquito-borne viruses is also on the rise. The most frequent mosquito-borne diseases in Texas are West Nile virus (WNV) and dog heartworm. To a lesser extent, mosquitoes also spread the viruses that cause St. Louis encephalitis, eastern equine encephalitis, western equine encephalitis, La Crosse encephalitis, dengue fever, and, in travelers returning from tropical countries, chikungunya and Zika viruses.

Human health threats that have not yet made their way into the Americas include Rift Valley Fever and several other tropical diseases.

West Nile virus

In 2002, an exotic mosquito-transmitted pathogen, West Nile virus, entered Texas. Although birds are the primary hosts of WNV, humans and horses can also catch the disease.

Two forms of the disease, West Nile fever (WNF) and West Nile neuroinvasive disease (WNND), are serious human illnesses. The WNV is an arthropod-borne virus (arbovirus) in the genus *Flavivirus.*

The native range of WNV includes Africa, Central Asia, and the Middle East. Since it was introduced to North America in 1999, cases of WNV in humans have been reported in the United States every year.

West Nile virus is ordinarily transmitted to humans by *Culex* mosquitoes that acquire the pathogen by biting an infected bird (Fig. 7). Most people who contract the virus exhibit no symptoms of infection. However, 20 percent develop WNF, and less than 1 percent get WNND.

Humans and horses are accidental or "dead-end" hosts for WNV, meaning that mosquitoes cannot be infected by feeding on infected humans or horses.

Laboratories often find WNV when they test "pools" of *Culex* mosquitoes for human arboviral pathogens. A mosquito pool consists of up to 50 female mosquitoes of the same species taken from a single trap (when traps catch more than 50 females, the excess mosquitoes are discarded after counting). Health officials use pooled mosquitoes to calculate infection rates when deciding whether to begin spraying adulticides.

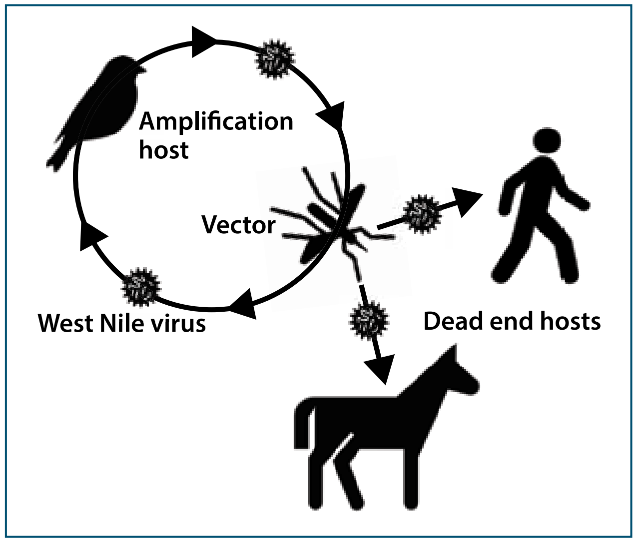


Figure 7. West Nile virus transmission by the vector, a mosquito, *Culex. quinquefasciatus,* to birds, which are amplification hosts, and accidentally to humans and horses. The vector transmits the virus from one organism to another; the virus population grows in the amplification host; and dead-end hosts are those that cannot pass on the virus to other biting mosquitoes. Icon sources: Boris Belov (virus), Ana María Lora Macias (bird), and Luis Prado (mosquito, horse)

Several *Culex* species are the principal vectors of WNV to humans in the United States. In Texas, the infected mosquito species most often collected is *Cx. quinquefasciatus;* in parts of Far West Texas, the most likely vector is *Cx. tarsalis,* the western encephalitis mosquito.

WNV infects and kills many birds, especially blue jays, crows, and raptors. Other bird species—such as mourning doves, robins, and sparrows—produce antibodies to fight off the infection and then recover.

West Nile fever causes symptoms like those of many other viral illnesses: Most people have a fever, and 20 to 50 percent develop a mild rash on their arms, back, and chest. Other symptoms include abdominal pain, depressed appetite, back pain, diarrhea, fatigue, headaches, muscle aches, nausea, and vomiting.

West Nile neuroinvasive disease is much more severe. It affects the nervous system, requires medical intervention, and can be fatal. The early symptoms may be the same as those of WNF but usually do not include a rash.

Within a few days of developing WNF symptoms, a person infected with WNND can also develop encephalitis (an acute inflammation of the brain), meningitis, weakness or paralysis of the muscles (generally on one side of the body), or a combination of these symptoms. Another symptom is chorioretinitis, an inflammation of the lining of the retina.

Zika virus

Zika is a flavivirus similar to the dengue and West Nile viruses. It was first isolated in 1947 from monkeys in the Zika forest of Uganda. Initially confined to Africa, with occasional small outbreaks in Asia, it has since slowly spread east to South and Central America. Travelers infected with the Zika virus have arrived in the United States from Latin America or other tropical areas where the virus has become established.

Zika virus is believed to be transmitted primarily by the mosquitoes *Ae. aegypti* and *Ae. albopictus.* Although humans are the primary reservoir host for the virus, another important reservoir may be wild primates.

Zika virus has can be spread through sexual transmission (male to female, or male to male), via blood transfusion, and from mother to child during pregnancy or birth. However, these methods of transmission are relatively uncommon compared to the risk of a direct bite by an infected mosquito.

On average, 20 to 25 percent of the people infected with the Zika virus develop symptoms, which last typically 2 to 7 days. The symptoms are generally mild: fever, skin, rash, red eyes and joint pain. Some patients also report headaches, vomiting, muscle pain, and general malaise.

Complications with Zika are rare but potentially serious. One of the most serious is the suspected link between Zika and Guillian-Barre syndrome, an autoimmune disease of the nervous system that causes paralysis and that can take weeks or months for recovery.

Epidemiologists have also found a strong association between Zika virus infection in pregnant women and fetal microcephaly, a condition resulting in miscarriages or abnormally small head size and underdeveloped brains in newborns. Though yet to be confirmed by research, the greatest risk for microcephaly is thought to occur when the birth mother is infected with Zika during her first or early second trimester.

The U.S. Centers for Disease Control and Prevention (CDC) advises pregnant women or those who might become pregnant to avoid visiting areas where the disease is common (endemic) and to take special care to avoid mosquito bites when in an area with endemic Zika.

St. Louis encephalitis virus

The St. Louis encephalitis virus (SLEV) is related to West Nile virus. Before WNV arrived in Texas in 2002, SLEV was the most common human mosquito-borne encephalitis in the state. Like West Nile, the St. Louis encephalitis virus circulates between birds and *Culex* mosquitoes, with humans being accidental or dead-end hosts.

Less than 1 percent of those infected with this virus develop symptoms. In the eastern United States, the fatality rate from SLEV ranges from 3 to 20 percent, with most deaths occurring in people over 60 years old. The virus does not affect horses.

Eastern equine encephalitis virus

The most severe form of encephalitis in the United States is eastern equine encephalitis (EEEV). More commonly encountered in the eastern United States, it occurs in Texas sporadically.

Like the West Nile and St. Louis viruses, the eastern equine encephalitis virus (EEEV) primarily infects birds. *Culiseta melanura,* the black-tailed mosquito, which feeds principally on birds, is the normal vector of EEEV.

However, when unusually high numbers of birds and mosquitoes are infected with EEEV, this mosquito may also bite humans and horses, spreading the virus beyond birds. When this occurs, other mosquito species may also acquire the virus and further spread the virus among human and horse populations. These other mosquito species include the eastern saltmarsh mosquito *(Ae. sollicitans),* the black saltmarsh mosquito *(Ae. taeniorhynchus)* in coastal areas, or the inland floodwater mosquito (*Ae. vexans.* Fig. 8) in inland areas.

Figure 8. Inland floodwater mosquito, *Ae. vexans.*
Image source: Mike Merchant

Although eastern equine encephalitis can affect people of any age, infants and young children are the most susceptible. More than half of the people who contract the virus die. Survivors under 5 years old often suffer neurological conditions such as convulsions, paralysis, or mental retardation. Some infected people, especially adults, recover completely.

The disease can severely affect horses, but a vaccine is available.

Western equine encephalitis virus

Western equine encephalitis virus (WEEV) is closely related to its eastern counterpart but generally occurs in the western United States. First recorded in the United States in 1930, it occasionally causes encephalitis in horses and humans.

The main vector of WEEV is *Cx. tarsalis,* a rural mosquito. Reservoir hosts include passerine birds, also called perching birds or songbirds. This group includes more than half of all bird species.

Human mortality rates from WEEV are generally less than 5 percent. Children, especially those under 1 year old, are affected more severely than adults. A vaccine is available for horses.

Dengue virus

Five closely related viruses cause dengue fever. These viruses (DENV) are transmitted from person to person by *Ae. aegypti* and *Ae. albopictus.*

Humans are the sole hosts and reservoir for DENV. For this reason, the disease occurs most often in urban areas that are densely populated.

Mosquitoes transmit the virus by feeding on an infected person. DENV incubates in the mosquito for 8 to 10 days before it becomes infective. Once infected, the mosquito can transmit the virus for the rest of its life.

As many as half of all dengue-infected people may have no or very mild symptoms. However, the disease can also be painful and debilitating, earning it the name, "breakbone fever." The most common symptoms are 2 to 7 days of high fever and two or more of the following: rash, severe headaches, joint pain, muscle pains, pain behind the eyes, and mild hemorrhaging under the skin.

A person infected by one of the five dengue viruses does not become immune to any of the other four. Survivors who are infected later with a different dengue virus are more likely to develop the more serious dengue hemorrhagic fever (DHF). Without prompt and proper treatment, DHF can lead to shock and death, especially in children.

Although both vector species are common throughout the southern United States, dengue has been mostly absent from the United States until recently. However, dengue fever is endemic to northern Mexico, and locally acquired human cases have occurred in Texas in recent years.

Considering that the vectors are present and that most Texas residents have no immunity to the virus, dengue fever is a serious disease with the potential to emerge as an important public health threat in Texas.

La Crosse encephalitis virus

The California serogroup is a group of 16 related viruses, the most important to humans being La Crosse encephalitis virus (LACV). It causes high fever in children. Although most cases cause mild or no symptoms, some can progress to severe encephalitis and, rarely, death.

LACV is distributed throughout the eastern United States; most cases occur in Illinois, Indiana, Ohio, West Virginia, and Wisconsin. It is seldom transmitted in Texas.

The principal vector of LACV is the eastern tree hole mosquito (*Ae. triseriatus,* Fig. 9). The mosquito transmits the virus to its offspring and to rodents such as chipmunks and squirrels.

Figure 9. *Ae. triseriatus,* the eastern tree hole mosquito.
Image source: Susan Ellis, Bugwood.org (CC BY 3.0 US)

Chikungunya virus

Much like dengue, the chikungunya virus (CHIKV) causes a severe fever in humans. CHIK is transmitted primarily by *Ae. aegypti* and *Ae. albopictus* mosquitoes, and humans are the primary reservoir.

Chikungunya virus spread from its native home in Africa to Asia and then Europe. It arrived in the Caribbean in 2013, and travel-associated cases arrived in the United States late that year. In the United States, CHIKV is likely to exist in the same regions where dengue virus is endemic.

The most common symptoms of CHIKV usually begin 3 to 7 days after an infected mosquito bites a person. They include fever and severe joint pain and sometimes headaches, joint swelling, muscle pain, or rash. In theory, CHIKV could spread via blood, but no reports of this happening are known.

Rift Valley fever virus

Rift Valley fever virus (RVFV) is a mosquito-borne virus that has spread throughout Madagascar, continental Africa, and the Arabian Peninsula. Although most humans exposed to RVFV develop a mild fever, about 10 percent have more severe symptoms such as encephalitis and hemorrhagic fever.

The primary vector is mosquitoes, including *Aedes* and *Culex* spp. Large outbreaks have occurred many floodwater *Aedes* mosquitoes emerge.

People can also contract the virus by breathing it from the air or by direct contact with an infected animal such as a domestic or wild cow, goat, or sheep. The virus's ability to infect both wild and domestic animals helps it spread and avoid intervention efforts, similar to the way WNV spread rapidly through the United States via wild birds as reservoirs.

RVFV control efforts must target *Aedes* spp. mosquitoes, taking into account that cows, deer, pigs, and sheep are also likely to carry the virus.

Several vaccines are being developed to help manage Rift Valley fever virus.

Dog heartworm

Dog heartworm is a serious disease caused when an infected mosquito transmits the worm *Dirofilaria immitis.* Heartworms may infect unprotected dogs of any age.

Mosquitoes pick up the worms from an infected dog's blood. The threadlike parasitic worms develop in the mosquito and move into its salivary glands. At the mosquito's next feeding, it transmits the worms to a dog, where they migrate to the heart (Fig. 10) and develop into adults.

Several species of mosquitoes spread heartworm throughout the United States, including *Aedes, Culex,* and *Culiseta*. The most common U.S. vectors are *Cx. quinquefasciatus* and *Cx. tarsalis.*

Figure 10. A dog's heart that was infected by dog heartworm, a potentially fatal filarial worm that also affects the major pulmonary arteries. Image source: Lone Star Shih Tzu and Lhasa Apso Rescue

Medication can prevent dogs from contracting heartworm. If blood tests determine that a dog is infected, drugs must be administered under veterinary supervision to kill the worms in the heart. Treatment after infection is costly and extremely stressful for the dog.

For more information

Local health departments (http://www.dshs.state.tx.us/idcu/health/zoonosis/contact/) and DSHS Regional Zoonosis Control staff (http://www.dshs.state.tx.us/regions/lhds.shtm) offer authoritative information about arboviral diseases and mosquito testing services.

2 Mosquito identification

Mosquitoes are insects in the order Diptera and the fly family Culicidae. They are related to other Dipterans such as blow flies, gnats, house flies, and midges.

Like all insects, mosquitoes have three body parts—the head, thorax (middle), and abdomen (Fig. 11). See Appendix A for a taxonomic key that can help you identify Texas mosquitoes. Biological information on mosquitoes is in Appendix B, and photos of the major species in Texas are in Appendix D.

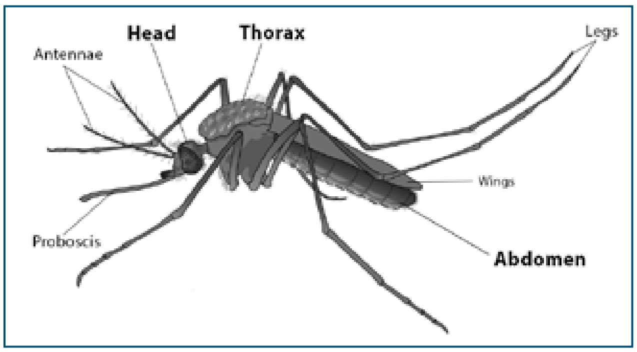


Figure 11. The general identifying characteristics of an adult female mosquito.

Identification characteristics

Head: On the head are the antennae, eyes, and piercing-sucking mouthparts (proboscises). The female proboscis pierces the skin of an animal to obtain a blood meal for egg production (Fig. 12). Mosquitoes also use their proboscises to feed on nectar and other plant sources of carbohydrates.

Figure 12. Female mosquito taking a blood meal. Image source: Mike Merchant

Thorax: The legs and wings are attached to the thorax. Like all flies but unlike most other insects, mosquitoes have only one pair of wings. Instead of the second pair of wings, mosquitoes have two tiny structures called halteres, which look like knobs on the thorax behind the wings; they apparently help the insect balance in flight.

Abdomen: The abdomen is the insect's hind region. It contains the reproductive organs and most of the digestive tract.

Males and females

You need to know the difference between male and female mosquitoes to be able to remove the males from a sample before testing. Because the males do not take a blood meal, they are not involved in the disease cycle and are not tested for disease.

To distinguish between males and females, check the antennae (Figs. 13–15). Males have feathery (plumose) antennae; females have only a few short hairs. Their mouthparts also differ: in males, the elongated appendages near the mouth (maxillary palps) are longer than the proboscis. Except for the species *Anopheles,* the maxillary palps of females are short.

Life cycles

Recognizing the behaviors and characteristics of the different mosquito species will help you develop an effective control program.

Oviposition sites: Some species lay eggs in or just above water, others lay their eggs on soil in anticipation of later flooding. Knowing the oviposition behavior of different mosquito species helps in predicting mosquito hatching and designing oviposition traps.

Behavior and biology: To treat mosquito larvae, teams need to understand the behavior and breeding site requirements of target species. Different mosquitoes have different resting and breeding site preferences. This knowledge is essential for developing control programs with larvicides and adulticides.

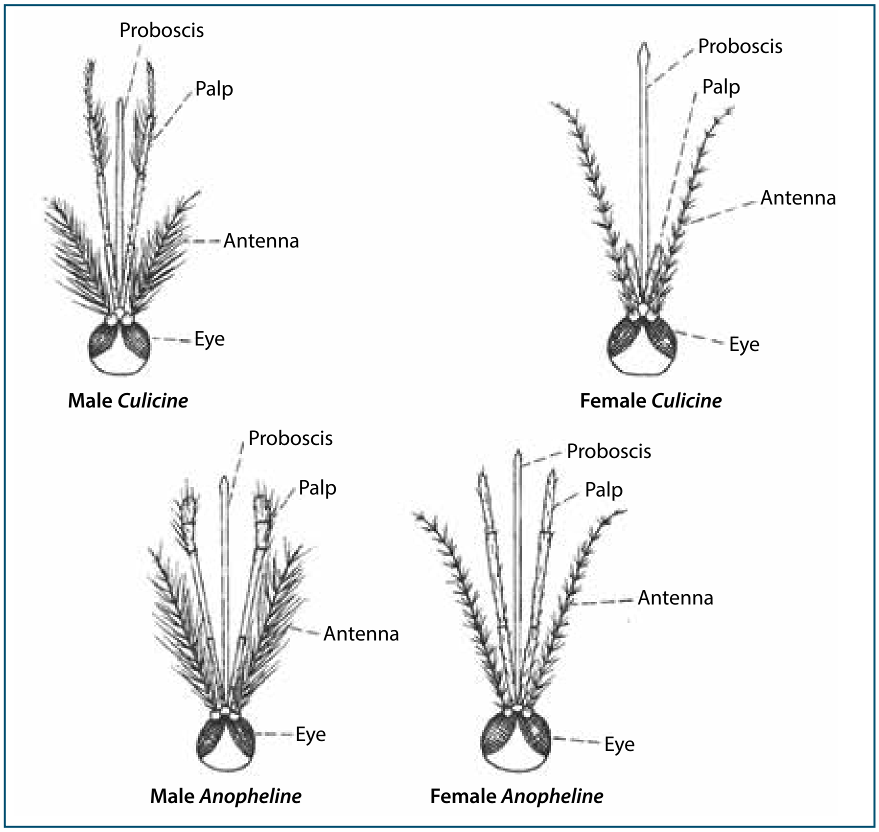


Figure 13. Varying head characteristics of male and female *Culicine* mosquitoes and male and female *Anopheline* mosquitoes. Image source: *Mosquitoes of Indiana*

Figure 14. Antennae with short hairs, *Cx. tarsalis* female. Image source: Joseph Berger, Bugwood.org (CC BY 3.0 US)

Figure 15. Feathery antennae, *Cx. tarsalis* male. Image source: Don Loarie (CC BY 2.0)

Flight patterns and peak population activity: When treating adults, you need to know such characteristics as how far the targeted species can fly and when it usually bites (Appendix B). This information can be used in public education programs and advice for the public on how to avoid mosquito bites.

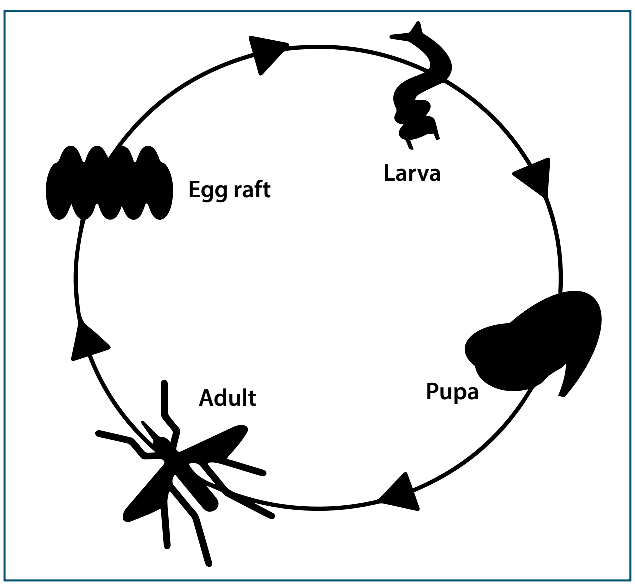


Figure 16. The mosquito life cycle, including the egg, larva, pupa, and adult. Mosquito icon source: Luis Prado

Mosquitoes undergo complete metamorphosis with four life stages—egg, larva, pupa, and adult (Fig. 16). Depending on the species and environmental conditions, they complete the life cycle in a few days to a month.

Eggs: Mosquitoes lay eggs on or just above the water surface, singly or in rafts.

Anopheles mosquitoes generally lay their eggs (Fig. 17) singly on the water surface at night. *Anopheles* eggs are shaped like cigars and are equipped with air-filled floats on the sides. Under favorable conditions, the eggs will hatch within 1 or 2 days.

Figure 17. *Anopheles* eggs.

Figure 18. *Aedes aegypti* eggs.

Some *Aedes* mosquitoes lay their eggs (Fig. 18) on moist ground around the edges of water or the inside walls of artificial containers just above the water line. After water accumulates from rain or another source, the eggs become submerged and the larvae emerge.

The eggs will die if the weather is too dry when they are first laid. Floodwater *Aedes* mosquitoes lay drought-resistant eggs on the soil of saltmarshes, pastures, and other flood-prone areas. When the areas receive water from rains or tidal currents, the eggs hatch.

Figure 19. Egg rafts of *Culex* spp. mosquitoes in a gravid trap on the water surface. Image source: Mike Merchant

Figure 20. Egg raft of *Culex quinquefasciatus.*

Psorophora and other floodwater mosquitoes lay drought-resistant eggs on the soil in irrigated fields or other flood-prone areas. When the fields and low area fill with water, the eggs hatch. These types of mosquitoes are most commonly involved in mosquito outbreaks after heavy rainfall.

Culex mosquitoes lay egg rafts (Figs. 19 and 20) on the water surface. If you see egg rafts on the water surface, you need to apply a larvicide.

Larvae: Mosquito eggs hatch into larvae, which are commonly called *wigglers.* Mosquito larvae live in the water, feed on debris and organic matter, and molt several times before becoming pupae. Mosquito larvae can be collected and used to identify the mosquito to species (Figs. 21–26).

Figure 21. *Aedes aegypti* larva. Image source: Econt (GFDL or CC-BY-SA-3.0)

Figure 22. *Aedes triseriatus* larva.

Figure 23. *Culiseta inornata* larva. Image source: Don Loarie (CC BY 2.0)

Culex and *Aedes* larvae hang from the water surface with the siphon up and head pointed down (Figs. 24 and 25). To feed, they filter small particles from the water.

Anopheles larvae (Fig. 26) lack the air tube (siphon) found on all other species. Instead of hanging downward, they lie

Figure 24. Mosquito larvae hanging with the siphons up and heads pointed down from the water surface. Image source: Mike Merchant

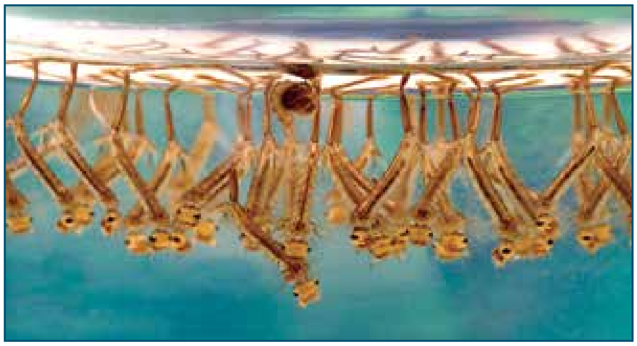


Figure 25. *Culex* sp. larvae, siphons up. Image source: James Gathany, CDC (CC BY 2.5)

Figure 26. *Anopheles stephensi* larva.

parallel to the water surface, taking in oxygen through a spiracular plate on the subterminal (8th) abdominal segment.

Mosquito larvae undergo four molts and pass through four larval stages (instars) before pupation. The larva molts when it outgrows its skin (exoskeleton). The fourth instar, the largest, is generally used for identification. For most mosquito species, the larval stage lasts 7 to 10 days but may be less under optimum conditions.

Figure 27. Mosquito pupa floating just under the water surface. Image source: © Project Manhattan / Wikimedia Commons / (CC-BY-SA-3.0)

Figure 28. *Cx. restuans* pupae with horn-like air trumpets they use as breathing tubes. Image source: Mike Merchant

Pupae: The pupal stage of a mosquito is the resting period when the larva transforms into a winged adult. An air pocket below the thorax enables the pupa to float just under the water surface (Fig. 27). Projecting from the back of the thorax are two horn-like air trumpets that serve as breathing tubes (Fig. 28–30).

Although mosquito pupae do not feed, they can be quite active, especially when disturbed. They use two rear paddles to swim with a tumbling motion to the bottom of their breeding pool—giving them the common name *tumbler.*

After pupation, the exoskeleton splits along the back, and the adult mosquito emerges. If the adult sinks underwater, it will die. Newly emerged adults must wait for their wings to dry and separate before they can fly.

Figure 29. *Anopheles stephensi* pupa.

Figure 30. *Culiseta inornata* pupa. Image source: Don Loarie (CC BY 2.0)

Adults: The adult stage is the only part of a mosquito's life cycle that is not aquatic. An adult mosquito is slender and has elongated wings and a prominent proboscis.

Male mosquitoes emerge several hours before the females and remain nearby. After the females emerge, they spend the first 3 to 5 days reaching sexual maturity and seeking a mate. During this time, female mosquitoes feed only on plant nectar or honeydew.

Females typically mate once and then fly off to find a blood meal. They usually must have a blood meal before they can lay eggs. The type of host varies by mosquito species.

Figure 31. *Toxorhynchites speciosus.* Source: Graham Wise (CC BY 2.0)

In most species, the females feed on blood and the males feed on nectar. Some mosquito species, such as *Toxorhynchites* spp. (Fig. 31) and *Wyeomyia smithii,* feed exclusively on sugar sources as adults and do not feed on blood.

Many mosquito species take blood meals at dawn and dusk. Examples are *Culex, Psorophora* (Fig. 32), and some *Aedes.* Several other species, such as *Ae. aegypti, Ae. albopictus, Ae. sollicitans,* and *Ae. taenio-*


Figure 32. *Psorophora horrida.*
Image source: Forrest Mitchell

rhynchus, are active during the day, especially in shady, humid areas.

Mosquito feeding behaviors and timing of feeding generally follow the behavior of their preferred host. *Culex* mosquitoes feed in the evenings when their hosts (such as birds) are most likely to be in their roost, nest, or den. *Ae. aegypti* and *Ae. albopictus* mosquitoes feed throughout the day when humans are more active and available. However, because these mosquitoes also seek hosts throughout the night, humans can be exposed at any time.

Species also differ in how far they will fly. *Ae. aegypti, Ae. albopictus,* and *Cx. quinquefasciatus* species fly less than a mile from the oviposition site, staying within a one- to three-block radius. Although floodwater mosquitoes typically fly 1 to 5 miles to find a host, they can fly 20 to 50 miles from the oviposition sites.

3 Integrated mosquito management (IMM)

Integrated mosquito management (IMM) is an effective, environmentally sensitive approach to mosquito management. It combines several control tactics, the latest in scientific knowledge, and the best technology available to manage mosquitoes effectively and safely.

To use the IMM approach, you must know the specific mosquito species requiring management. If you understand the mosquito's habitat, biology, and behavior, you can design control strategies that target the species where and when it is most vulnerable (Fig. 33).

IMM is also the best way to avoid harming the environment with pesticides. Use insecticides only when field data justifies their use and when integrated with nonchemical approaches.

Figure 33. A typical site for floodwater mosquito oviposition. Image source: Mike Merchant

Another benefit of IMM is that it helps larger cities meet Clean Water Act requirements for preventing stormwater pollution and the National Pollutant Discharge Elimination System (NPDES) requirements on reducing pesticides in water. Cities are increasingly being required to implement IMM programs to obtain and maintain EPA-regulated permits.

Principles

- **The starting point is to identify the pest.**

Every health department needs to have some level of expertise in mosquito identification. Before you can design an effective control program, you must know the pest's identity. Of the 85 mosquito species documented in Texas, only a few bite people, pets, or livestock and affect our well-being.

Knowing the difference between harmless or nuisance species and those that pose a genuine threat to human health will enable you to prioritize your mosquito-control activities.

- **Use thresholds to manage pests to acceptable levels.**

It is impossible to eradicate mosquitoes. Even if it were possible, the costs would be high, and the environmental impacts would likely be unacceptable.

The critical points that justify control measures are called *action thresholds* (see Chapter 9). Thresholds are usually set for a specific pest and site, and vary from community to community. The ultimate goal is to protect human health.

- **Use multiple control tactics to manage pests.**

No single method will consistently keep pests to acceptable levels. For example, you cannot manage mosquitoes using insecticides or cultural or sanitation measures alone. To be effective, IMM efforts must target mosquitoes at all life stages.

Components

The basic components of IMM are surveillance, source reduction, larval control, adulticide applications, personal protection, public education, and good record keeping.

Surveillance: Mosquito surveillance provides information on the species, abundance, and distribution of mosquitoes, as well as the presence, frequency, and distribution of pathogens in mosquito populations. The data will enable you to determine when and where to deploy public health staff and inform people about health risks.

Agencies and cities are increasingly using geographic information system (GIS) data on pathogen activity and human transmission to guide aggressive applications of mosquito insecticides.

Mosquito populations and pathogen infection rates vary widely in time and space. Likewise, the problems associated with mosquitoes are variable. Use the data from surveillance activities to inform your decisions on when to implement control programs and how to use limited resources efficiently.

Source reduction: To attack mosquitoes at the source, you must eliminate potential habitats (Fig. 34) for the larvae. Tactics include improving land drainage, shredding old tires, eliminating sources of open sewage such as leaking septic systems, and working with the public to eliminate artificial containers where mosquitoes breed.

Although it is rarely possible to remove all oviposition sites, source reduction can significantly reduce mosquito problems and mosquito-borne disease. City- and neighborhood-wide trash cleanups can minimize mosquito oviposition and breeding sites.

Figure 34. Small containers in which mosquitoes can lay eggs and where dozens or hundreds of adult mosquitoes can develop. Image sources: Mike Merchant and Michael Sanders

Larval control: For mosquito oviposition sites that cannot be easily eliminated, immature mosquitoes may need to be treated with larvicides (Fig. 35). By killing mosquitoes during their immature stages, you can prevent or minimize adult mosquito emergence and disease spread.

Also, in many areas, mosquito-breeding sites are localized and concentrated, making it more efficient to control the larvae than the adult mosquitoes.

Figure 35. Employee putting out larvicide in a larval mosquito habitat. Source: Dallas County Department of Health and Human Services

Safe, effective methods for controlling larvae include using insect growth regulators, biological insecticides, and mosquito-eating fish (Fig. 36). Methods targeting larvae generally affect the environment less than those used against adults.

Adulticides: Despite efforts to target immature mosquitoes, insecticides are often needed to kill adults. The only management tools to kill infected adult female mosquitoes are adulticides and lethal traps.

The advantages of adulticides are that they can be deployed quickly and produce immediate results. A timely, well-targeted insecticide application can rapidly reduce the risk of mosquitoes transmitting disease.

Figure 36. Mosquito fish *(Gambusia* sp.) about to eat a mosquito larva.

Disadvantages include the costs of chemicals, equipment, equipment maintenance, seasonal personnel, and public opposition to community-wide pesticide use.

Personal protection: The simplest and timeliest way to protect against mosquito-borne disease is to use proven insect repellents effectively. Public health workers and local residents can significantly reduce disease by diligently using personal repellents and wearing protective clothing (light-colored long pants and long sleeves).

Using repellents properly involves knowing how, when, and what to apply in order to prevent mosquito bites. Governmental agencies must continually encourage people to avoid harmful situations, protect themselves with repellents, and follow all of the instructions on the product label.

Public education: No mosquito control program can fully protect public health without citizen involvement. Because mosquito oviposition sites are dispersed widely, all residents must ensure that their yards do not contribute to a mosquito problem.

For IMM to be successful, it must include a sustained public education campaign that focuses on getting people to eliminate mosquito oviposition sites, wear protective clothing, use repellents, and avoid high-risk sites.

Political support for mosquito control programs is critical. If voters are to be counted on for support of mosquito-control programs, they will need to understand the mosquito problem, know what measures their local government is taking, and recognize why they are essential to protect human health.

Record keeping: Record keeping is essential for efficiency and for public accountability. Records should be maintained on site conditions, storm sewer locations, historical disease data, past mosquito control treatments, and GIS database information on mosquito breeding locations.

Surveillance data, including yearly summaries of mosquito abundance and distribution are essential for communicating about disease risk with the public.

In addition, for public and fiscal accountability, records should be kept of the types and amounts of pesticides and other materials used, and application dates, times, temperature, weather conditions, and wind speed and direction (Appendix C).

4 Surveillance

An effective IMM program monitors both vectors and viruses. Monitor mosquito abundance and viral activity to help guide your management actions and reduce disease outbreaks.

Mosquitoes

Develop a sampling plan to identify the locations and time patterns of mosquito abundance and infection. Monitoring will also help you evaluate the impact of your mosquito control program.

Set traps, and check them weekly over the summer. Collect samples from fixed trap locations throughout the year and over several years.

Birds

Gather data on bird mortality and exposure to WNV.

Dead birds: A key indicator of the severity of disease in human populations is the number of birds that the virus has killed. Those recovered by residents during arbovirus surveillance season (June to October) can help you monitor WNV activity.

Bird deaths and infection rates will peak about 1 to 2 weeks before human exposure. Unfortunately, dead-bird monitoring systems are costly, and relying on the public to report or submit dead birds can produce inconsistent data.

Sentinel birds: Sentinels are healthy live birds, such as chickens, placed in cages where mosquitoes are likely to be infected. Their blood samples are tested at specific intervals over the season. If a previously healthy bird has become infected since the previous blood test, you will know that the virus is circulating in the area.

Sentinel birds can help you monitor eastern equine encephalitis, western equine encephalitis, St. Louis encephalitis, and West Nile virus.

Because this method is costly and it takes time for the birds to produce antibodies after exposure, a more efficient way to detect viral activity is to monitor the mosquitoes.

Live birds: Another way to monitor WNV activity in bird communities is to capture free-ranging birds using mist nets or other trapping devices, which requires state and federal permits. Blood samples from the birds are screened for viruses or for the presence of antibodies, which indicates a previous exposure to an arbovirus.

However, it is very rare to capture a live infected bird—less than 1 percent of captured birds are infected. Instead, people usually rely on antibody data from captured birds.

For adult birds, the data is limiting because they may have been exposed in a previous season. But for juvenile birds that have fledged and left the nest, the presence of antibodies can be assumed to be a recent exposure to an arbovirus during the current season.

Arbovirus surveillance programs in the United States rarely use live bird captures because of the effort involved, the state and federal permits needed, and the limited value in return.

Horses

Horses are susceptible to several mosquito-borne equine encephalopathies and have been used to help monitor these pathogens.

However, because a vaccine can protect horses from these mosquito-borne threats, equine monitoring is of little use for detecting arboviruses. Also, when these tests are conducted on horses or birds that have been vaccinated, the results may indicate a false positive.

Humans

Using humans as a surveillance tool is not recommended because preventing human exposure to arboviruses is the purpose of a surveillance program. However, for the Texas cities that have not implemented arbovirus surveillance, the only option is to monitor human cases.

Local blood donation centers can provide information about positive arbovirus samples. Human case data indicate where, when, and in what populations the virus is circulating.

Cities without active surveillance programs can also use predictive models that rely on weather factors. Predictive models are statistical techniques that can be used to minimize the risk of West Nile virus spreading to people and animals.

Traps

Several types of traps are used to monitor mosquito populations and infection rates. The data can be used to determine the likelihood of human exposure to mosquito-borne diseases.

Gravid traps: The most effective type of trap to monitor *Culex* spp. mosquitoes, the primary vectors of WNV in Texas, is a gravid trap (Fig. 37).

Figure 37. A gravid trap collecting gravid *Cx. quinquefasciatus* females. Image source: Gabriel Hamer

The trap uses a tub filled with fermented, grass-infused water to simulate an organically rich egg-laying habitat. The water attracts gravid females (those swollen with eggs), and a fan sucks them into the trap. Because these mosquitoes have had at least one blood meal, they are more likely to be infected with arboviruses such as WNV.

Gravid traps are vital to a surveillance program because they attract blood-fed *Cx. quinquefasciatus* females, which are more likely to be infected with an arbovirus.

The infusion water takes 1 to 2 weeks to prepare. A common recipe is to place fresh grass clippings or hay into a large (32-gallon) plastic trash can and add 5 grams of brewer's yeast and 30 gallons of tap water.

Another option is to pour about ¼ cup of rabbit pellets containing alfalfa into a 2½ or 5-gallon plastic container, and add water to fill the bucket. Loosely secure the lid to allow gas to escape but prevent insects from accessing the water.

Leave the container in a sunny spot for at least 5 to 7 days.

Figure 38. CDC light traps, each baited with a cooler of dry ice that releases carbon dioxide to attract female mosquitoes. Image sources: Gabriel Hamer and Mike Merchant

Light traps: The CDC light trap (Fig. 38) is used worldwide to monitor biting flies. It is set up with a small cooler containing dry ice hanging above it. As the dry ice changes to gas overnight, it produces carbon dioxide, which simulates the breath of a vertebrate host and attracts host-seeking female mosquitoes.

An advantage of a light trap is that by attracting many mosquitoes, it provides standardized data on their diversity and relative abundance. Light traps are very useful for monitoring nuisance mosquitoes.

A limitation of light traps is that, unlike gravid traps, they catch young female mosquitoes that have never taken a blood meal and are therefore less likely to have an arbovirus. These captures can lead you to underestimate the risk of infection from biting female mosquitoes.

BG-Sentinel traps: The BG-Sentinel trap (Fig. 39) is used worldwide to monitor a wide variety of mosquito species, but primarily *Ae. aegypti* and *Ae. albopictus.* The trap mimics the convection currents created by a human body and provides visual cues to attract the mosquitoes.

Figure 39. BG sentinel trap. Image source: Mike Merchant

The BG-Sentinel trap is a white, collapsible, fabric container with white gauze covering its opening. An electrical fan sucks air into the trap, which draws approaching mosquitoes through the gauze and a catch pipe into a catch bag.

This type of trap is especially attractive when used with the BG-Lure, a dispenser that releases a combination of nontoxic substances found on human skin. Adding CO_2 also increases mosquito catches.

Aspirators: The best way to collect resting mosquitoes—including females containing a blood meal—is to use an aspirator (Fig. 40) or a resting trap. Prokopack traps are smaller, lighter, and less expensive than other popular traps. Another option is the CDC resting trap, which uses a fiber pot as a shelter.

Figure 40. Aspirators being used to collect adult mosquitoes from a sewer pipe. Source: Dallas County Department of Health and Human Services

Once the blood-fed females are caught, their blood can be tested to identify the type of vertebrate host on which they fed.

Other traps: Several traps are available commercially for specialized applications. For example, the CDC Wilton and Fay Prince traps can more effectively capture *Aedes* spp. mosquitoes, the vectors associated with dengue and the Zika and chikungunya viruses. Sources include BioQuip Products and the John W. Hock Company.

Figure 41. An ovitrap that attracts gravid female mosquitoes and collects eggs and larvae from *Ae. aegypti* and *Ae. albopictus.* Image source: Mark Johnsen

Ovitraps (Fig. 41) can help you monitor the relative abundance of egg-laying activity and estimate relative mosquito abundance in different types of landscapes.

Mapping/GIS

GIS and global positioning system (GPS) technologies are changing the way mosquitoes are controlled. Based on signals from more than 24 U.S. government satellites orbiting the earth, GPS receivers can report and record the mosquitoes' exact locations within a few feet.

Figure 42. Screen shot from a tablet using the low-cost application GPS Speed. When mounted in a mosquito spray truck, this app uses GPS to track spray routes and application speeds. The data can later be downloaded and saved on the computer as a permanent record of the application. Image source: Municipal Mosquito Inc.

GPS technology enables mosquito control technicians to pinpoint the locations of traps, previous insecticide applications, and observed and potential mosquito oviposition. Inexpensive apps (Fig. 42) for cell phones and tablets enable anyone with a backpack sprayer or truck-mounted ULV sprayer to record the exact times and locations where adulticides are applied.

Geographic information systems use GPS data to create detailed maps and store geographical information in powerful databases. A GIS map can store many layers of information (Fig. 43). For example, a map may have layers showing:

- Areas of a city with known mosquito oviposition sites
- Locations and characteristics of the city's storm drain system
- Lab test results from mosquitoes found at specific sites

GIS technology can also produce maps of stored data, such as the locations of known human cases of mosquito-borne illness, or mosquito-trap catches that tested positive for a pathogen. Such data can be overlaid on maps that show, for example, human population densities that would allow epidemiologists to identify areas of highest risk for human disease.

The most common GIS software used by city planning departments is ArcGIS.

The disadvantages of GIS are the cost of equipment and software and the expertise needed to

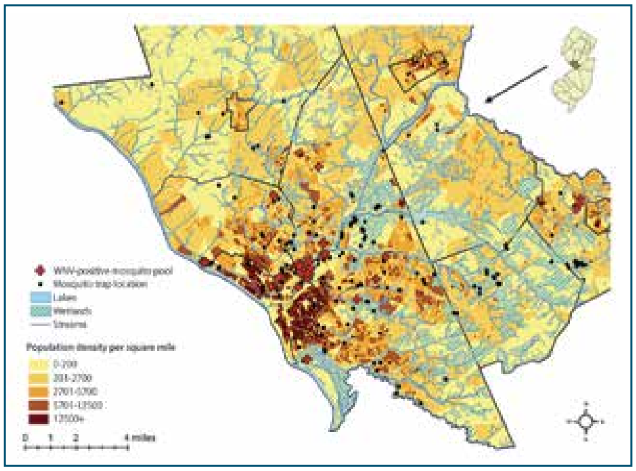


Figure 43. Vector surveillance results using GIS map from Mercer County, NJ. Layers show human population densities and the locations of waterways, mosquito traps, and traps that captured mosquitoes testing positive for West Nile virus. Image source: Matthew Kabak et. al, ArcNews Online, Winter 2009/10.

develop and run the powerful but complex software. Startup costs for such systems typically run in the tens of thousands of dollars.

Fortunately, many cities and governments employ GIS specialists who can help mosquito-control agencies build mosquito GIS databases. Also, some companies provide specialized mosquito control plugins for GIS platforms. Such plugins eliminate much of the programming needed to develop mosquito control layers for a GIS dataset. Some companies provide hand-held computer interfaces that allow technicians to enter data directly into the database from the field (Fig. 44).

Figure 44. Hand-held device for entering mosquito control information.

5 Source reduction

To reduce the sources of mosquitoes without using chemicals, eliminate standing water as much as possible. Educate the public and organize community-wide cleanup drives to dump out standing water and dispose of bottles, buckets, cans, tires, and anything else that can hold water (Fig. 45). Emphasize the need to check yards, alleyways, and commercial buildings.

Figure 45. Discarded tires are excellent sites for mosquito breeding, are difficult to treat, and can be a major nuisance and public health hazard. Image source: Mike Merchant

If you cannot eliminate an oviposition site, monitor and treat it to prevent excessive mosquito populations. In many such sites, larvicides or natural/biological measures can control the mosquitoes.

Source reduction also involves modifying habitats, such as regrading drainage ditches to help water drain quickly after a rain.

Although you can eliminate small artificial depressions that produce mosquitoes by filling them with sand or gravel, this technique is usually impossible for natural freshwater areas or large, permanent water bodies. These habitats often support *Culex* and *Anopheles* mosquitoes.

For these situations, options include:

- Maintaining steep banks on ponds and lakes
- Draining the water periodically
- Removing or minimizing emergent and floating vegetation
- Providing deep-water sanctuary for the fish that feed on mosquito larvae

Figure 46. Artificial containers that can serve as mosquito egg-laying sites: (from top left) a garbage can lid, birdbath, plastic bucket, flowerpot, plastic container, and a clogged rain gutter. Image sources: Mike Merchant and Michael Sanders

Typical oviposition sites

Artificial containers: An artificial-container breeding site is any manufactured item that can hold water for 7 or more days. These items become ideal oviposition sites when they hold stagnant water containing organic matter such as leaves or grass clippings.

Examples are birdbaths, boats, bottles, buckets, cisterns, gutters, tarps, tires, wheelbarrows, aluminum cans, bottle caps, horse troughs, kiddie pools, plastic containers, rain barrels, and septic systems (Fig 46).

The easiest way to reduce mosquito populations in artificial containers is to dump out the water and dispose of the container properly—toss it, store it so that it will not collect water, put holes in the bottom, or treat the water regularly with a larvicide.

Figure 47. A tree hole collecting water, a potential oviposition site for some mosquito species. Image source: Sonja Swiger

Figure 48. *Aedes triseriatus* larva

Figure 49. *Aedes albopictus.*

Advise residents to clean their birdbaths and livestock watering troughs weekly, more often if needed. Check and clean gutters several times a year to prevent debris from trapping water.

Tree holes: Tree holes (Fig. 47) provide excellent oviposition sites for a variety of mosquito species, most commonly the tree hole *(Ae. triseriatus*, Fig. 48) and Asian tiger *(Ae. albopictus*, Fig. 49) mosquitoes.

To treat a tree hole, apply the widely used mosquito larvicide *Bacillus thuringiensis israeliensis (Bti)*, seal the hollow with tree patch material, or fill it with expanding foam to prevent water collection and mosquito oviposition.

Water drainage systems: A water drainage system is a fabricated or naturally occurring channel—such as a culvert, storm drain (Fig. 50), or roadside ditch—that carries rainwater out of a particular area. Debris can clog these systems, allowing water to pool and become ideal mosquito-oviposition sites.

Figure 50. A storm drain, an important source of mosquito breeding, especially in dry weather. Image source: Mike Merchant

Remove the weeds and silt from them so they can drain properly. If you cannot clean an area, treat it with larvicides. Additionally, some storm drains are designed as catch basins containing sumps that capture debris to prevent pipes from clogging; these sumps hold water and are ideal habitats for *Cx. quinquefasciatus* larvae to develop.

Sites that hold water for only a few weeks after a rain are especially bothersome because they allow floodwater mosquito breeding but disappear before natural predators can develop (Fig. 51).

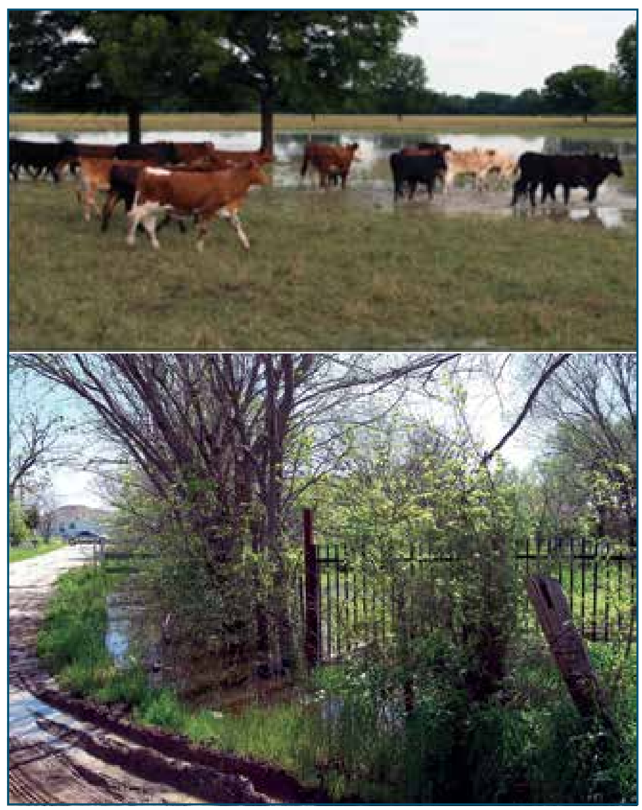


Figure 51. Floodwater mosquito habitats. Image sources: Mike Merchant and Michael Sanders

In contrast, ditches that continually hold water support the development of fish, beetle larvae, dragonfly naiads, and other organisms that prey on mosquito larvae and rarely breed mosquitoes of public health importance.

Sample water drainage systems regularly. Use a dipper to sample ditches; if you find larvae or pupae, mosquitoes are probably laying eggs there. As the numbers increase, treat the site with a larvicide.

In artificial storm drains where dippers cannot sample, use larval traps. Treatment thresholds vary according to the kind of mosquito and the risk of disease outbreak.

Areas near malfunctioning septic systems: Pollution from broken septic systems often creates major oviposition sites for the southern house mosquito *(Cx. quinquefasciatus),* the main vector of the West Nile and St. Louis encephalitis viruses in Texas. To eliminate the breeding source, drain the water and repair the system.

Ponds, lakes, and lagoons: Few mosquitoes breed in ponds, lakes, or lagoons, and predators in these sites usually inhibit mosquito larvae. The larvae that do occur in these habitats concentrate around water margins, where weeds and tall grass grow.

To reduce populations in these water bodies, mow or chemically remove the vegetation.

Marshes and swamps: Swamps harbor *Anopheles, Culiseta,* and other mosquitoes that lay eggs in permanent waters. Freshwater and salt marshes (Fig. 52) may also yield many mosquito species, including *Psorophora* (Fig. 53), *Ae. taeniorhynchus* and *Ae. sollicitans.*

Figure 52. Salt water marsh. Image source: Mark Johnsen

Marshes and swamps can be difficult to treat without airplanes, boats, helicopters, or other specialized equipment that applies larvicides effectively over large, inaccessible areas.

Figure 53. *Psorophora ferox* female. Image source: Katja Schulz (CC BY 2.0)

Floodwater sites: After a heavy rain, look for areas where floodwater collects (Fig. 54). These temporarily flooded areas can produce many mosquitoes but support few natural predators. Treat the larval sites a few days after a rain, and monitor them closely for mosquito larvae development and pupae formation.

Irrigated fields: Major mosquito problems can arise in irrigated croplands such as rice fields. Although Texas has few rice fields, they provide ideal oviposition sites for some mosquito species *(Anopheles),* and treatment can be costly.

Figure 54. An urban breeding site for floodwater mosquitoes. Image source: Mike Merchant

6 Larval control

To target the mosquitoes at their source, collect samples of mosquito larvae in wet habitats. For most situations, the standard larval sampling device is a dipper (Figs. 55 and 56).

Dippers do not work well in some container habitats such as the sumps inside catch basins, which harbor *Culex* mosquitoes.

For a catch basin that has a metal slotted lid, use a 10-foot-long conduit pipe (½ inch) with an aquarium net attached. A turkey baster is another effective tool for sampling larvae in small, hard-to-reach habitats such as tires and tree holes.

Figure 55. Mosquito control employees dipping for larvae and pupae in a possible oviposition site. Image source: Mark Johnsen

Figure 56. Mosquito larvae caught in a dipper. Image source: Mark Johnsen

Biological controls

Biological agents can help manage mosquito populations naturally in their oviposition habitats without harming the environment. They are more effective on some species of mosquitoes than on others.

The mosquito fish *(Gambusia affinis,* Fig. 57) has been used throughout the world since the 1940s. Another option is predatory aquatic insect nymphs and larvae that live in oviposition sites.

Figure 57. Mosquito fish *(Gambusia affinis).* Source: Fredlyfish4 (CC BY-SA 4.0)

Some restrictions apply for using biological agents. The larvicide technician must have basic knowledge of mosquito biology and of the agents to be applied. Although you do not need a permit in Texas to use *Gambusia* fish, it's best to contact licensing and permitting agencies for information on how to release them properly.

Appropriate agencies include the Texas Department of Agriculture (TDA), Texas Commission on Environmental Quality (TCEQ), and the Texas Parks and Wildlife Department (TPWD).

Mechanical controls

Larvasonic devices, also known as acoustic larvicides, kill larvae by emitting sounds into the water that disrupt the larvae's air bladder, killing them instantly. As the air in the bladder absorbs the energy from the sound, the membrane at the base of the larva's head ruptures. The air bubble then travels up through the body, causing significant trauma to the soft organs and then death.

Insecticides

Bacillus thuringiensis* spp. *israeliensis: One of the most widely used mosquito larvicides is the bacterium *Bacillus thuringiensis* spp. *israeliensis (Bti),* which was first isolated in 1977 from a dead mosquito larva in

Figure 58. A larvicide containing the bacterium *Bacillus thuringiensis* spp. *israeliensis (Bti).* Source: JeepersMedia (CC BY 2.0)

Israel. A protein associated with the bacterium kills mosquito larvae and black flies very effectively. When formulated as a mosquito larvicide (Fig. 58), *Bti* is non-living.

The killing power of *Bti* comes from several insecticidal proteins that persist in the killed bacterium. These proteins are lethal to several fly species but does not harm other insects, fish, or laboratory animals. For *Bti* to work, the larvae must consume it from the water as they filter feed.

Bti is more effective during the early larval stages. Higher rates must be used when treating older larvae, polluted septic water, and water bodies with dense algal growth.

For highly polluted water, consider using *Lysinibacillus (Bacillus) sphaericus,* a closely related bacterium that produces enough spores to compete with the dense organic matter.

Because mosquito pupae do not feed, *Bti* does not affect them. To kill the pupae, use another insecticide along with *Bti.*

Bti is available in various formulations, including wettable powders, liquids, capsules, granules, and briquettes. Quick-release granular formulations of *Bti* tend to break down within 48 hours of application. Briquette formulations that dissolve slowly in water typically have a longer useful life, up to 30 days. Check the product literature or ask a local insecticide distributor about the expected life of a particular *Bti* formulation.

When choosing a larvicide, consider buoyancy. Most *Bti* formulations are lightweight and very buoyant. Rain can wash them away from sites that are flushed with water. To reduce this risk, consider anchoring the briquettes or using a different larvicide.

Lysinibacillus sphaericus* (formerly and best known as *Bacillus sphaericus, Bs): Another bacterium that kills larvae is *Lysinibacillus sphaericus (Bs).* It occurs naturally throughout the world. The toxins in *Bs* damage and paralyze the gut of mosquito larvae, causing them to starve to death.

When applied according to label directions, the material should not harm people, other mammals, or other aquatic life.

Bs comes in a granular form that you must mix with water and spray from the ground or air. The active ingredient usually has a residual life of 1 to 4 weeks after application but can vary according to mosquito species, water quality, environmental conditions, and the exact granule formulation. Check the product literature or ask an insecticide distributor to determine the probable effective life of a *Bs* formulation.

Although *L. sphaericus* is generally more expensive than *Bti,* in some habitats it tends to persist longer—30 days or more. Unlike *Bti, Bs* formulations consist of living bacterial spores that can recycle in water pools via the cadavers of dead mosquitoes.

Bs is also more effective than *Bti* in dirtier water, such as cesspools, dairy ponds, and pools with heavy leaf detritus deposits or algal growth.

Spinosad: Spinosad is an insecticide based on a naturally occurring species, *Saccharopolyspora spinosa.* The genus *Saccharopolyspora* was discovered in 1975 in crushed sugar cane. The species *S. spinosa* was isolated from some soil collected inside a defunct rum distillery in the Virgin Islands.

Spinosad insecticide is a mix of two spinosoids: Spinosyn A is the major component (about 85 percent), and Spinosyn D is the minor component.

Spinosad kills many pests by contact and by ingestion. Spinosyns and spinosoids affect the insect nervous system differently from the insecticides described previously. They overexcite the nervous system, causing tremors, involuntary muscle contractions, and paralysis.

Spinosad is considered a natural product and can be used in organic agriculture in the United States. In mosquitoes, spinosad is highly effective against the larvae of all the species tested so far.

A disadvantage is that high levels of organic matter and full sunlight diminish both the effectiveness and longevity of spinosad. It also tends to be more expensive than *Bti.*

Spinosad can be used commercially in catch basins, woodland pools, fresh floodwater areas, polluted or impounded waters, and freshwater and saltwater marshes.

Insect growth regulators (IGR)

Insect growth regulators are chemicals that kill insects by interfering with their growth and development. One such product, (S)-methoprene, acts like an insect hormone and prevents normal molting, egg-laying, egg-hatching, and life cycle development. It is not very effective against the fourth instar stage of mosquito larvae.

The chemical can be used in bodies of water containing fish to prevent adult mosquitoes from emerging; it does not affect non-target species. Based on the formulation, (S)-methoprene can be used in small bodies of water such as ditches (Fig. 59), lakes, ponds, tires, catch basins, cattail marshes, flooded areas, irrigated cropland, rice fields, storm drains, and abandoned swimming pools.

(S)-methoprene comes in several forms: liquid, granular, 30-day briquettes, and 150-day briquettes. To control mosquitoes effectively, apply it at the start of mosquito season. The liquids have a residual effect of 7 to 10 days; granules 21 to 30 days; briquettes 30 to 150 days, depending on the formulation.

Oils and films

Oils: Petroleum-based oils form very fine surface films on water. The films are thought to kill mosquito larvae and pupae both by poisoning them and, at higher rates, by blocking breathing. At high rates, oils suffocate mosquito larvae and pupae by clogging their breathing tubes, which normally penetrate the water surface to obtain oxygen.

Oils may be a good option to kill mosquito pupae. They can be used with other larvicides such as *Bti*. Oils have a residual effect of up to 7 days.

Disadvantages of oils are that growing plants and windy conditions can reduce their longevity and that they can kill other aquatic insects and minnows, especially if too much is applied. To reduce this risk, the EPA has established specific precautions that are included on the product labels.

Figure 59. Ditch where an insect growth regulator may be used. Image source: Mike Merchant

Plant-based essential oils have not proved practical or affordable for use as larvicides in the field.

Monomolecular films: Also known as alcohol ethoxylated surfactants, monomolecular films kill mosquito larvae and pupae. The films disrupt the surface tension, causing the larvae and pupae to drown. They do not harm fish or other aquatic organisms.

The disadvantages of monomolecular films are that they are less effective when exposed to high winds; they tend to wick up the sides of plants; and they are more expensive than petroleum-based oils.

Apply monomolecular films using any conventional spraying methods to any mosquito habitat with standing water. Typical sites include swamps, wetlands, catch basins, flooded pastures, rice fields, roadside ditches, salt marshes, woodland pools, and abandoned swimming pools.

However, they do not last in the environment for long and are usually applied only to standing water that has few non-target organisms.

Organophosphates

Organophosphate insecticides comprise an older class of pesticides that are slowly being phased out in favor of more environmentally friendly alternatives. One such organophosphate, temephos, kills mosquito larvae. It affects the larvae's central nervous system, causing them to die before they reach the adult stage. Although temephos purchases were canceled in 2015, existing stocks may continue to be used.

Temephos is especially useful in waters that are temporary, highly polluted, high in organic content, or non-potable, such as stagnant, saline, brackish, and temporary water bodies. Examples are marshes, swamps, catch basins, intertidal zones, moist areas, shallow ponds, tidal waters, tire piles, woodland pools, and the edges of lakes.

This product helps manage resistance, which occurs when an organism becomes able to survive exposure to a toxic material that previously suppressed it. One way to help prevent resistance is to use pesticides that have different modes of action—those that work in various ways to kill pests.

Temephos is the only organophosphate insecticide approved for use on mosquito larvae. Applying it periodically can help prevent mosquitoes from developing resistance to the bacterial larvicides.

7 Adult control

Pyrethrins, pyrethroids, and mixtures containing piperonyl butoxide (PBO) are widely used to control pests in farms, gardens, homes, and other buildings. They are also in products for controlling fleas and head lice.

Studies have found no long-term health effects in humans or animals from incidental contact with pyrethrins, pyrethroids, PBO, or mineral oil from mosquito spraying (Fig. 60).

Figure 60. Mosquito fogging. Image source: © ProjectManhattan / Wikimedia Commons / (CC-BY-SA-3.0)

Adulticides

Pyrethrins: Pyrethrins are natural, broad-spectrum insecticides extracted from flowers in the *Chrysanthemum* genus. Pyrethrins and pyrethroids poison the mosquito's nervous system, causing hyperexcitation, paralysis, and then death.

Sunlight destroys pyrethrins very quickly: When used in mosquito control, most of the insecticide is broken down within 1 hour of sunlight exposure. Pyrethrins are only a small part of the liquid in adulticide mixes; most of the mix is water or light mineral oil.

When used for mosquito adulticiding, these chemicals do not harm most people. Those who are allergic to pyrethrins may feel a tight or tingly feeling under the skin, soreness around the eyelids, or a scratchy throat. Used correctly, pyrethrins do not kill fish.

Pyrethroids: Unlike pyrethrins, pyrethroids are synthetic chemicals. They also block the movement of information from the mosquito's brain to its muscles, but pyrethroids last longer in sunlight. As with pyrethrins, most of the liquid in the mix is water or light mineral oil.

The pyrethroids used in mosquito sprays do not harm most people. Rarely, individuals may feel a scratchy throat, soreness around the eyelids, or a tight or tingly feeling under the skin. Pyrethroids are potentially toxic to fish if high concentrations accidentally get into the water.

Piperonyl butoxide (PBO): Piperonyl butoxide is a chemical added to pyrethrins or pyrethroids to make them more effective. PBO inhibits the enzymes that break down the pesticides. When exposed to a pesticide mixed with PBO, a mosquito becomes less able to rid the pesticide from its body. This addition enables the insecticides to work better with less active ingredient than would be required otherwise.

PBO can also help manage mosquitoes that are resistant to insecticides. As with most pesticide formulations, PBO adulticides also contain inactive ingredients, typically petroleum distillates.

Mosquito sprays contain such a small amount of PBO that it does not harm people or pets.

Mineral oil: Mineral oil is a light, colorless, odorless mixture of alkanes from a non-vegetable (mineral) source, particularly a distillate of petroleum. Most common diluent adulticides are mixed with mineral oil.

If a person's skin becomes coated with the oil, it can cause minor problems such as a rash or burning feeling. The tiny amount of mineral oil that a person would contact from mosquito sprays would not cause any problem.

Organophosphates: Organophosphates are chemicals used to spray adult mosquitoes. These pesticides paralyze and kill mosquitoes.

Two organophosphates, malathion and naled, have been used for more than 40 years to control mosquitoes and other insect pests on farms and around houses.

If a pesticide is used for long periods to control adult mosquitoes, they can become resistant to it, making it ineffective. To prevent resistance, mosquito control programs occasionally switch to a different chemical for control. This practice is called rotating pesticides.

Rotations occasionally use organophosphates, which in some situations can be more effective than pyrethrins. Insecticide rotation does not succeed unless you use insecticides from different classes (those with different modes of action) and multiple resistances have not developed.

Organophosphates can harm people who work with them and do not follow proper safety precautions. Employees exposed to organophosphates must be tested before and after every spray season for acetylcholinesterase, an enzyme that can cause muscle paralysis. Testing helps prevent people from overexposure.

Those who contact large amounts of these chemicals can suffer dizziness, headaches, nausea, and even death.

Exposure to small amounts of these chemicals from mosquito sprays does not harm people or pets because the body rids itself of them quickly. Researchers have found no chronic health effects in people living where these chemicals are routinely used for mosquito spraying.

These websites offer more information about pesticides:

- EPA pesticide safety and regulation: http://www.epa.gov/pesticides/
- National Pesticide Information Center: http://npic.orst.edu/index.html
- National Institutes of Health: pesticides used to control West Nile virus, http://sis.nlm.nih.gov/enviro/westnilepesticides.html
- Texas A&M Agricultural and Environmental Safety: http://agrilife.org/aes/ (including study guides for pesticide applicator licensing exams).

Resistance management

Always a concern for mosquito control efforts, resistance has caused some mosquito management programs to fail. To combat resistance, all mosquito control programs should practice principles of insecticide resistance management (IRM).

IRM can prevent or delay the onset of resistance to pesticides in mosquito populations; it can also reduce pesticide resistance in mosquito populations already tolerant. The three principle management strategies of IRM can be used separately or simultaneously:

Management by moderation conserves susceptible genes in a population by applying insecticides less often, using the lowest label application rate, and leaving untreated "refugia" in treated areas.

Management by saturation strengthens the dosages to the point that it overcomes the developed resistance. The most common method is to add synergists (natural or synthetic chemicals that make insecticides more lethal) to the insecticide. Synergists make the insects less able to break down the pesticide, enabling the population to be controlled.

Management by multiple tactics uses several tactics (IMM approach) and multiple insecticides that act differently on the targeted mosquitoes. Although this strategy is not practiced regularly, it might be needed for hard-to-kill populations.

This approach would be necessary only when proper insecticide rotation has not occurred and the local mosquito population is not being controlled. Examples are mixing two insecticides from different chemical classes and applying them simultaneously or alternating them back-to-back.

Resistance monitoring

The most important component of IRM is to monitor insecticide resistance. Monitoring will help you determine whether the chemical being applied is effective as well as when tolerance begins to develop. You will be able to adjust the chemical control program to prevent resistance from fully developing or to return susceptibility to acceptable levels.

The most common insecticide monitoring programs test the chemical on a sample of the target mosquito population. They conduct a bioassay, a test that uses biological organisms to determine whether the potency or amount of an insecticide achieves the desired effect, such as death or knockdown.

Common bioassays used in mosquito control are the bottle bioassay, topical bioassay, modified vial bioassay, and the World Health Organization impregnated paper bioassay.

8 Public education

An integral part of any integrated mosquito control plan is public education (Fig. 61). One way to help people remember the primary disease-prevention methods is to emphasize the 4 Ds of mosquito management: dawn and dusk, drain, dress, and defend:

- **Dawn and dusk:** Stay indoors as much as possible at dawn, dusk, and early evening when vector mosquitoes are most active.
  However, some mosquitoes, such as the *Aedes* vectors of Zika and dengue fever, bite during the day. To reduce the chances of being bitten by them, you must use the three remaining Ds effectively.
- **Drain:** Drain all standing water. Do not allow water to stagnate in old tires, flowerpots, trash containers, swimming pools, birdbaths, pet bowls, etc. Mosquitoes need very little water to reproduce. Mosquito breeding is favored in still, undisturbed water with enough organic matter for the larvae to consume.
- **Dress:** Wear light-colored, long-sleeved shirts and long pants whenever you are outside.
- **Defend:** Use EPA-approved and CDC-recommended mosquito repellents when you are outdoors.

Figure 61. A truck publicizing the mosquito control campaign of the City of Grand Prairie, TX. Image source: Cindy Mendez

Community outreach programs

Alone, an agency or a fleet of spray trucks cannot manage mosquitoes effectively. The entire community must work together. A community outreach program consists of six steps:

1. Define the goals of your program.
2. Identify and analyze your target audiences.
3. Create the message.
4. Package the message.
5. Distribute the message.
6. Evaluate the campaign.

1. Set goals

The aims of most mosquito outreach efforts are to reduce mosquito biting rates and disease transmission, to educate residents on how to protect themselves from mosquitoes (Fig. 62), and to assure them that their local government is taking action to protect community health and the environment.

Figure 62. Proper installation and maintenance of window screens is especially important for homes without air conditioning and when windows are opened for ventilation. Image source: Mike Merchant

To meet these goals, the public needs to know:

- What the benefits and risks of adult mosquito control are
- Where mosquitoes lay eggs and how to eliminate these sites at home, school, and work
- How to report mosquito problems
- Why personal protection is vital
- What personal repellents to buy and how to use them
- How to avoid areas of high mosquito activity
- How to reduce mosquito activity around the home
- What the local government is doing to reduce mosquito-transmitted disease

2. Identify target audiences

Customize your outreach campaign for the community as a whole and for various subgroups within it. Determine the groups in your community that might benefit from an educational campaign. Work with your team to pinpoint the groups you want to reach.

Subgroups that might need targeted messages include:

- Beekeepers, gardeners, and water gardeners
- Business owners
- Do-it-yourselfers
- Elderly people
- Government decision-makers
- High- and low-income households
- Municipal employees
- Parents of young children
- People who are concerned about pesticide use
- Realtors
- School districts and principals
- Schoolchildren
- Swimming pool owners
- Walkers and runners (Fig. 63)

Other grouping criteria include demographics, occupations, geographic locations, or links to vulnerable activities, attitudes, and behavior patterns.

Although you will always need a general message for the whole community, many subgroups have special educational needs. For example, parents may want to know which repellents are safe for use on their children. People concerned about pesticides may worry that mosquito control sprays are harming birds or fish.

If you do not address these groups' needs, the public education campaign will miss some critical targets. The IMM program could also suffer a lack of cooperation or even active opposition.

Figure 63. Walkers and runners are a possible subgroup that might need a targeted message. Image source: Mike Merchant

3. Create the message

Craft persuasive messages for each group. Brainstorm with your team the messages you need to convey to each group.

For example, swimming pool owners may need to know how to test and treat their pools to prevent them from turning into mosquito oviposition sites. Ask realtors or utility company employees for help in finding and reporting poorly maintained properties. Enlist school districts to avoid floodwater mosquito problems by educating attendees of football games and other school events and by draining or treating their properties.

Messages can raise awareness about the problem, educate people about their options for solving it, and motivate people to act.

Awareness generally comes first and prepares the target audience for education or motivation. For example, people need to know that repellents can help prevent disease before they will apply one. Residents need to know that the city wants to identify abandoned swimming pools (Fig. 64) before they are likely to notice one and report it via a mosquito control hotline or website.

Education is often more detailed. For example, once people become aware that repellents can help prevent mosquito bites, they need education about the different repellents and their uses, safety factors, and application methods.

Figure 64. Abandoned swimming pools, possible mosquito breeding sites. Image sources: Mike Merchant and Michael Sanders

Motivational messages can appeal to the audience's fears, hopes, sense of responsibility, or economic or health interests.

When crafting messages, consider the barriers that the target groups must overcome before they will change their behaviors. The barriers may influence the way you tailor your message.

For example, leaking septic systems may be an important source of *Culex* mosquito production, but some homeowners may not be able to afford the necessary repairs. A local government may consider offering economic incentives for property owners to help them bring their systems up to code. The message would not only explain how disease-carrying mosquitoes breed in filthy water, but also publicize the availability of these programs for low-income residents.

Code enforcement is another municipal service that can assist in controlling mosquitoes. For example, yard debris, tires and trash in abandoned lots can harbor *Ae. aegypti* and *Ae. albopictus* mosquitoes. Also, abandoned swimming pools can breed *Culex* and other mosquitoes.

4. Package the message

Use media that will deliver your message effectively to the target audiences. Factors that will influence the delivery method include the audience's size, geographic distribution, preferred formats, and levels of awareness and education. Most public health departments must also consider the cost and staffing needed to deliver the message.

To be successful, the packaging should grab attention and be cost effective, easy to access and use, able to be repeated, appropriate for the audience, and environmentally responsible (Fig. 65). Following are examples of useful message formats.

News media and social media options include radio and TV advertisements, television and newspaper coverage, editorials, Facebook, YouTube, and Twitter. A 2012 study by the Pew Research Center found that 55 percent of Americans got their news from television, 39 percent from the Internet, 33 percent from radio, and 29 percent from newspapers. However, a more recent 2016 study showed that 62 percent of U.S. adults get at least some news via social media. This same Pew Research study showed that 44 percent of Americans got news from Facebook in 2016 compared to 30 percent in 2013. The way we get our news and information about the world is changing.

News and social media outlets are powerful tools for information dissemination. News releases about an event or an initiative can get information to many people at almost no cost.

Advertising differs from news releases in that it allows complete control of the message. Although "free" public service announcements (PSAs) can be useful, they are less common. Producing a quality ad can be expensive, and you will usually have little control over when or where the ads run.

Advertisements may be placed on bus placards, vehicle wraps, web banners, popup ads, blogs or other popular websites, and newspaper, radio, and television outlets.

Videos can be made for the Internet or broadcast, cable, or public TV. The production quality can range

Figure 65. Sign urging residents to drain standing water. Image source: Michael Sanders

Figure 66. Billboard used to educate the public in Grand Prairie, TX. Image source: Grand Prairie Vector Control

from homemade to highly professional. Low production quality does not necessarily mean low impact—as is evident almost daily by the many YouTube videos that attract many thousands of viewers.

Print materials are the most popular format for most public outreach campaigns. They are often simple and eye-catching, leading the reader to a hotline or website for more detailed information.

Formats include billboards (Fig. 66), brochures, calendars, maps, posters, fact sheets, restaurant placemats, school curricula, children's coloring books, and utility bill inserts.

Prompts are printed materials that remind people to perform an activity that they might otherwise forget. Door hangers on the front doors of pool customers' homes can remind them that proper maintenance and chlorination helps battle mosquitoes.

Presentations at community events or other public gatherings can be effective, especially when customized for a smaller target audience. Webinars provide an especially convenient way to get a message out. If you record the webinars, you could post them online for viewing later.

Figure 67. Roadside kiosk with mosquito control information in Dallas, TX.

Kiosks, booths, and pull-up banners at special events can deliver messages to both general and targeted audiences (Fig. 67).

Giveaways can remind people of a desirable behavior or an ongoing campaign. Examples are beverage holders, bumper stickers, buttons, calendars, refrigerator magnets, temporary tattoos, T-shirts, and reusable grocery bags.

Beware of sending mixed messages with giveaways, such as offering containers that might collect water if left outdoors.

Websites are powerful communication tools (Fig. 68). They can offer up-to-date information on a variety of subjects and can enable people to report problems or sign up for events and classes.

For example, the city of Grand Prairie, Texas, allows residents to sign up for its Reverse 9-1-1 program, which notifies them about local events ranging from tornados to mosquito spraying. This efficient system enables the city to call homes in neighborhoods scheduled for treatment on the day of the spray.

However, poorly designed websites can make information difficult to find. This problem becomes more likely as more information is posted on a site.

Figure 68. Web page for the City of Sugar Land mosquito control.

5. Distribute the message

When deciding how to deliver your message, consider the outlet, timing, and format. A website, for example, is a powerful format for packaging a message, but how do you entice people to visit? Without effective distribution, even the best-designed giveaway can end up in storage or be thrown away by uninterested recipients.

Local celebrities such as meteorologists, newscasters, and deejays have a ready media platform that they can use to inform residents. Respected community members can lend credibility to a message and catch the attention of many who value their opinions.

Social media such as Facebook, Twitter, and the many blogger sites can be powerful ways to spread information. Social media also have the advantage of being interactive, allowing the public to comment on and register approval of the information provided.

However, social media outlets are not an instant ticket to successful marketing. These sites also require a high level of commitment to build a network. You must also keep them relevant and up to date. And, consistently good writing skills can make the difference between effective and ineffective use of social media. For maximum effectiveness, it's best to work with people who have experience in building and maintaining these sites.

Mobile devices: The Pew Research Center found in 2012 that almost one in five Americans got their news from a mobile device, mostly (78 percent) from cell phones. More agencies are packaging their messages to be understood readily via tablets and cell phones.

Special events and community centers can be good venues for information displays or staffed booths. Local libraries often have high traffic levels and may display public service messages. Print materials and giveaways can reach both general and targeted audiences at special events such as balloon festivals, garden shows, holiday celebrations, and Earth Day and Arbor Day fairs.

The most effective way to prompt behavior changes in many people is through face-to-face communication. Speaking to someone in a booth gives you opportunities to gather information by conducting on-the-spot surveys and collecting email addresses for distribution lists.

E-mail distribution is cheap and fast, and it can deliver newsletters, photos, videos, and links to more information. A large e-mail distribution list is a valuable commodity and can take years to build. People who sign up to be on an email list may be more motivated to learn and can become the early adopters in a community.

Community groups and clubs are often eager for outside speakers to give talks on subjects of interest to their members. Because many of these groups are small, this distribution method is best for targeting a small segment of the public. For example, garden club or Master Gardener meetings are prime venues for getting information out to the local gardening community.

Local businesses can also help distribute information, especially when the business relates to some aspect of mosquito control. A pool company, for example, could distribute information to pool owners about proper pool maintenance. Tire stores and garages might be good places to raise awareness about mosquito breeding in used tires.

6. Evaluate the campaign

Most public health departments and mosquito districts must at some time justify their public education budgets. This requires setting measurable goals. A good evaluation program helps build support for ongoing funding from local government and the public. It can also pinpoint what is and is not working.

At the most basic level, success can be measured through *outputs.* Output statistics could be the number of brochures distributed, the number of attendees at a presentation, the number of people visiting a website, or the amount of time they stayed.

But outputs do not necessarily translate into impact or desired *outcomes.* Outcomes might include a lower incidence of mosquito-borne disease, increased public satisfaction with mosquito control efforts, more people using repellents, fewer mosquito complaints, or annual changes in the number of acres treated with aerial and ground-applied adulticides.

Although outcomes can be harder to measure, they are much more useful for evaluating educational programs. Data on outcomes can be gathered via internal records, mail or phone surveys, or field data such as mosquito counts and disease incident rates.

First, determine your department's most important goals, and select outputs and outcomes that will measure your progress toward those goals.

These publications offer more information on developing public outreach campaigns:

- *Fostering Sustainable Behavior: Introduction to Community-Based Social Marketing.* By Doug McKenzie-Mohr. New Society Publishers. 2011.
- *Getting In Step: A Guide for Conducting Watershed Outreach Campaigns,* third edition. U.S. Environmental Protection Agency. 2010. http://cfpub.epa.gov/npstbx/files/getnstepguide.pdf.

9 Personal protection

Although a community cannot eliminate adult mosquitoes, area residents and mosquito control personnel can reduce their exposure to mosquito bites by using repellents (Fig. 69). When choosing a repellent, they should consider:

- The amount of time they spend outdoors
- Activities that may wash off the repellent
- The types of mosquitoes in the area
- Their physical reactions to the bites of different mosquito species
- The percentage of active ingredient in the product—the higher the percentage, the longer lasting the repellent

Repellents can be ethanol, oil, or gel based. Each formulation may provide varying results even with the same percentage of active ingredient. For a list of repellents and their length of repellency, see http://cfpub.epa.gov/oppref/insect/.

Figure 69. Proper way to apply mosquito repellant. Image source: Mike Merchant

Choose an insect repellent that has been registered by the EPA. The Centers for Disease Control and Prevention recommend four active ingredients that provide longer lasting repellency: DEET, picaridin, IR3535, and oil of lemon eucalyptus (para-menthane-diol).

DEET has been registered by the EPA and available commercially since 1954. It is one of the oldest

Figure 70. Mosquito repellent label.

effective repellents for mosquitoes and other biting arthropods. Studies have shown that DEET tends to repel mosquitoes that carry both Zika and West Nile viruses. DEET is the longest lasting of repellents, protecting for 2 to 12 hours, depending on the product formulation and concentration.

The EPA has extensively tested the health effects of DEET to determine whether it harms human health. In 1998, the agency found that when people follow the label directions (Fig 70), insect repellents containing DEET are not harmful. DEET is safe for use on pregnant and breastfeeding women and on children over 2 months old. However, children should never be treated with a product containing more than 30 percent DEET.

Picaridin is a relatively new repellent, registered by the EPA in 2003. Although its repellency is poor against *Anopheles* mosquitoes, it lasts for 3 to 14 hours against the *Culex* mosquitoes that carry West Nile virus. Picaridin is non-greasy, relatively odorless, and safe for pregnant and breastfeeding women and children over 2 months old.

IR3535 can repel mosquitoes for 2 to 10 hours and is an active ingredient found in some Avon Skin So Soft repellents. Skin So Soft products without this active ingredient are not considered mosquito repellents. However, IR3535 is not as effective or as long-lasting as DEET or picaridin.

Oil of lemon eucalyptus (para-menthane-3,8-diol) is a plant-based mosquito repellent derived from eucalyptus plants that can provide protection for 2 to 6 hours, similar to that of low concentrations of DEET products. It can be very effective against *Psorophora* but has little repellency against *Ae. aegypti.*

Oil of lemon eucalyptus is the only CDC-approved natural repellent. It should not be used on children under 3 years old.

2-undecanone was registered by the EPA in 2007 but is not on the list of CDC-recommended repellents. 2-undecanone is an oil extract found naturally in various plants, specifically from tomato leaves when used as a repellent.

Because 2-undecanone is used in the cosmetic industry, its effect on humans is well understood. Research has found that its repellent properties against ticks and mosquitoes are just as strong as those of the lower concentrations of DEET.

This ingredient provides repellency for up to 4½ hours and protects against *Ae. albopictus* and *Ae. aegypti,* similar to 7 percent and 15 percent DEET. One commercial product, BioUD, contains 7.75 percent 2-undecanone and is available to consumers.

10 Virus screening

Mosquitoes and birds can be tested for viruses by university, commercial, in-house, and health department laboratories. The Texas Department of State Health Services (DSHS) Laboratory is one of the entities in Texas that tests mosquitoes for viruses.

Mosquito preparation

To ensure accurate testing, prepare the mosquitoes correctly:

1. Collect mosquitoes in the field and immediately place them in a cooler on ice. Do not freeze them.
2. Determine whether the samples will be tested in-house or by the Texas Department of State Health Services.
3. If testing in house:
   a. Discard the males and sort the females by species.
   b. Group the female vector species into 1 to 50 specimens per pool.
4. If DSHS will conduct the tests:
   a. Transfer the samples from each net to separate plastic containers, no more than 100 mosquitoes per container. You do not need to sort the mosquitoes.
   b. Ship the containers on ice packs in insulated boxes to DSHS according to the agency's shipping protocol.
   c. If you are shipping homogenized mosquito pools for polymerase chain reaction (PCR) or isolation testing, double-seal the samples in leak-proof containers and place them in an insulated box with dry ice.

Testing methods

Tests for arboviruses are usually conducted on mosquitoes, birds, horses, and humans. The following sections discuss the various options for these test subjects.

Mosquitoes

Tests that detect arboviruses in mosquitoes include real-time reverse-transcriptase polymerase chain reaction (RT-PCR) and virus isolation.

RT-PCR test: The most widely used diagnostic assay for detecting the West Nile, St. Louis, and western equine encephalitis viruses is RT-PCR. It is a sensitive test that can detect viruses in mosquito pools.

The advantages of the RT-PCR assay are that it can detect small amounts of virus, determine the amount of virus in the sample, and detect WNV only or multiple arboviruses simultaneously.

The disadvantages are that the test requires specialized equipment, is vulnerable to cross-contamination, and requires a clean working environment—typically a biosafety level 2 (BSL2) laboratory. Also, the reagents are expensive, and the results can vary among labs using different procedures to test for the pathogens.

To prepare mosquitoes for this assay:

1. Kill the mosquitoes on dry ice or in a freezer while they are in the sample carton. Do not keep them outside the freezer for extended periods or store them in a warm environment.
2. Sort the mosquitoes by species and sort out the females into pools of up to 50 individuals.
3. Combine the females of each species into a tube such as a 2.0 ml microcentrifuge tube.
4. When shipping pools for WNV testing, ask the destination lab for its preservation and shipping requirements.

Virus isolation: A traditional technique to identify viruses in mosquito pools is to culture the virus in cell lines such as monkey kidney (Vero) and baby hamster kidney (BHK) cells. The conventional testing method is to grow the virus in cell culture.

This process begins with homogenizing the mosquito pool. The supernatant is inoculated into cell culture, which is incubated and observed for 10 days for viral growth.

An advantage of using cell culture is that the test will detect any virus that is present and able to grow. It can also detect new viruses, which is how WNV was detected for the first time in 1999 in New York.

The disadvantages are that the test is less sensitive than other tests; it takes longer to obtain a result; and it requires a lab with a high biosafety level (BSL3).

Birds

Bird samples can be tested for the presence of WNV using the procedures for mosquitoes discussed previously. Samples can include blood, feathers, saliva, tissue, and cloacal swabs.

The tissues of dead birds (typically the brain, heart, kidney, or liver) can also be collected, prepared, and studied under a microscope to detect WNV antigens, which are substances in the body that stimulate it to produce antibodies.

Humans

People can be tested for the virus only under doctor's orders. The results from human testing can influence your decisions on vector surveillance and intervention.

Laws limit what human health information may be shared and with whom. Although local public health authorities generally have access to human health data in their jurisdictions, they are constrained by law as to how they may use that information.

Doctors usually order WNV testing when a patient shows symptoms of the disease. A commercial laboratory usually tests blood serum using PCR and enzyme-linked immunosorbent assay (ELISA). The Texas DSHS lab uses the microsphere immunoassay.

Laboratories and medical providers must report cases of WNV illness to public health authorities. DSHS reviews the case; if it classifies the disease as "confirmed" or "probable," the agency reports it to the CDC.

Donated blood screening: Another type of human testing that may help inform decisions is nucleic acid amplification testing (NAT). NAT is performed on all donated blood in the United States.

A donor who is healthy at the time of donation but whose blood is NAT-positive is presumed to have been infected with WNV previously. Although the donor will probably remain symptom free—80 percent of infected people do not become ill—the test indicates that the virus was transmitted in the donor's environment. This blood is not used, and the person cannot donate for a specific period.

Annual counts of Texas WNV cases and other data on birds, humans, mosquitoes, and horses are available at http://www.dshs.state.tx.us/idcu/disease/arboviral/westNile/. For national information, see the CDC website at http://www.cdc.gov/ncidod/dvbid/westnile/index.htm.

Antibody screening

Antibodies are specialized proteins that the body makes to fight infections. When birds or mammals survive an arbovirus the infection, they produce antibodies specific to that virus. These antibodies help the hosts prevent subsequent infections. Several technologies can detect arbovirus antibodies.

Plaque reduction neutralization test (PRNT): This assay measures the ability of the antibodies in serum to prevent or neutralize viral growth. It is considered a gold standard for detecting and quantifying arboviral antibodies.

However, the test requires a high biosafety level (BSL3) because it involves live arboviruses.

Rapid antigen assay: Several commercial companies have produced tests that detect virus antigens easily and quickly. When used properly, these assays are generally consistent with RT-PCR results.

Two such assays are VectorTest (previously known as VecTest) and the Rapid Analyte Measurement Platform (RAMP). These tests require minimal training and no specialized facilities, and they can produce results the same day that you collect the mosquitoes.

ELISA: The enzyme-linked immunosorbent assay (ELISA) can detect the presence of WNV and SLE antigens in mosquito pools. It takes a day to complete and requires specialized equipment (a plate washer and reader).

Harris County Mosquito Control uses ELISA to screen for West Nile virus. ELISA-positive samples are confirmed further with RAMP.

ELISA can also detect arboviral antibodies in vertebrate serum. The antibodies will produce a color change if the sample contains arboviral antibodies.

The advantages of ELISA are that it is fast and can detect West Nile and other viruses at the same time. Extensive laboratory supplies are unnecessary, making it relatively easy to develop ready-to-use lab kits and to test for antibodies on site. Increasing the sample size can make the test more sensitive.

A limitation of ELISA testing is that it can sometimes be difficult to determine a cutoff point between a positive and a negative result. The tested sample is compared with a known standard; stronger signals are "positive" and weaker signals are "negative."

Fluorescent microsphere immunoassay: Like the ELISA, this technology detects antibodies; the difference is that the fluorescent assay relies on microsphere beads to measure fluorescence in a sample.

This assay is highly sensitive and specific. Compared to other tests, it can detect multiple targets more quickly, at a lower cost, and with greater sensitivity and specificity. Luminex is one commercial company that produces the kits and instruments for this technology.

So far, no disadvantages have been found for this test.

11 Using surveillance data

It's not enough to have a good surveillance program. Once you have collected data from the program, you must know how to interpret and use that information. It will help you make important management decisions such as whether to apply adulticides.

A well-developed arbovirus surveillance program uses historical and current data to evaluate the present and future risk of West Nile virus transmission to humans.

Each community must determine the best way to use surveillance data in decision-making. A model or threshold that works in one community may not work as well in another.

WNV transmission rates and patterns can change from year to year, influenced by local vector populations, environmental conditions, and other variables. You can use predictive models and thresholds to determine whether, when, and where thresholds are likely to reach action levels, and whether to implement management actions. The models can help you minimize the risk of WNV to humans and animals.

Mosquitoes and dead birds

As more mosquitoes and birds contract viruses, the risk of transmission to people increases. This increased risk is why health departments use infections in mosquitoes and birds to judge the level of virus activity so they can take action before people are exposed. At the very least, detecting a single WNV-positive mosquito pool is enough to warrant management action.

However, finding one positive mosquito does not mean that the risk to humans is high. To estimate this risk, you'll need to identify action thresholds and gather data to determine when to increase mosquito control or to raise public awareness of a WNV threat.

Several quantitative methods can evaluate the level of mosquito abundance or infection that leads to human disease. One such method is sequential sampling, which involves collecting and analyzing multiple samples one after another until you reach specific levels of risk and precision.

Using mosquito surveillance data

Of all the methods used to detect WNV in an area, the only ones that can accurately predict human risk are mosquito and sentinel chicken testing. These tests use known numbers of hosts and test results of mosquito pools from sites of interest.

Relying on human data alone is not recommended because of the significant time lag—usually 3 to 4 weeks—between infection and diagnosis. Also, human mobility makes it difficult to know exactly where the virus may have been acquired.

Bird and horse data are suspect because not all WNV deaths are reported, and the number of susceptible animals in the area is expensive to obtain and cannot be known with certainty. Maintaining sentinel chicken flocks is also expensive.

For most cities, the preferred method of surveillance for calculating the human risk of disease transmission is to collect mosquito infection data.

Early-warning system

Some statistical models can predict when and where the risk of human exposure to West Nile virus will be greatest. These models use data such as mosquito WNV infection with or bird death from WNV to predict the risk of human exposure. For example, several U.S. states use the Dynamic Continuous-Area Space-Time (DYCAST) system, which uses dead birds to predict risk.

Statistical models incorporate weather data into a community's early-warning system because temperature and precipitation influence WNV transmission. However, these types of models and predictors are not available for diseases that that affect only mosquitoes and humans, such as chikungunya, dengue, and Zika.

Vector index

So far, the best tool for predicting human outbreaks of WNV is the vector index (VI). When calculated weekly, the VI can help you predict human disease and provide an objective measure for determining how to use mosquito control resources.

Having a predetermined VI that can predict high (outbreak) levels of human disease can eliminate much of the guesswork from the decision on whether and when to apply mosquito adulticides.

A limitation of the VI is the short notice (1 to 2 weeks) of impending increases in human disease. In large communities especially, it may not leave enough time to reduce mosquito populations significantly via larviciding and eliminating oviposition sites. Currently, the only proven method for suppressing mosquito vectors quickly once a critical VI level is reached is to apply mosquito adulticides.

For this reason, the most useful role of the VI is to help determine when to begin mosquito adulticiding. Adult control may include aerial spray campaigns and increased truck-based and foot-applied ULV spraying.

Some mosquito control programs calculate the VI based on neighborhoods, census tracts, or some other appropriate factor. But because surveillance is expensive and small samples yield uncertain results, most programs calculate VIs on a city- or county-wide basis or by combining data from multiple weeks of surveillance.

For this method to work, you must be able to protect the entire management area within 2 weeks. You may need to bring in more ground-based resources to cover the management zone or have already contracted with an aerial applicator to provide services within that timeframe.

A vector index uses three variables to calculate the risk of an infected mosquito biting a person:

- The types of vector species in an area
- The population density of each of these species
- The percentage of infection of each vector species

Mosquito surveillance programs can readily measure these variables. Taken individually, each variable offers a glimpse of the possibility of human disease in an area. Put together, the information can provide a much clearer picture.

A vector index combines the information from these three variables into a single statistic—the estimated average number of all species of infected mosquitoes collected per trap night.

Information in this section draws heavily from the CDC publication *West Nile Virus in the United States: Guidelines for Surveillance, Prevention, and Control,* June 14, 2013 (http://www.cdc.gov/westnile/resources/pdfs/wnvGuidelines.pdf), and the *Guide for Epidemiologic Analysis of West Nile Virus Mosquito Trap Data in Dallas County,* by the Epidemiology Division, Dallas County Health and Human Services, April 2013.

Estimating infection rates

The preferred method for calculating infection rates when the sample sizes vary is the maximum likelihood estimation (MLE). MLE takes the size of each pool into account and estimates the overall mosquito infection rate more accurately.

Calculating MLE with the CDC add-in: The CDC has developed a free add-in that works with Microsoft Excel to make determining the MLE relatively easy.

The CDC offers two versions of the mosquito surveillance software (Fig. 71). One is compatible with the 2003 and older versions of Microsoft Office; the other is compatible with the 2007 and newer versions. Use the later version if you have Office 2007 or later.

Figure 71. Mosquito surveillance software available as free downloads to assist in calculating the estimated maximum likelihood of mosquito infection rates.

Follow these steps to download the software:

1. Go to http://www.cdc.gov/westnile/resourcepages/mosqSurvSoft.html.
2. Click on the download link to transfer a zip file to your computer (usually in the Downloads folder).
3. Click on the file PooledInfRateV4-2007.zip to open it.
4. Double-click the zip file to show two files, the PooledInfRate plugin, and PooledInfRateManual.docx (Fig. 72). The latter file is a manual that provides step-by-step instructions on installing and using the plugin file.
5. Double-click on the add-in to install the software.

Once installed, the "Pooled Infection Rate" plug-in will be located in the "Add-In" tab of Microsoft Excel. This tab and the software will be available whenever you open Excel (Fig. 73).

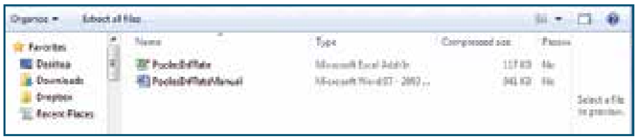


Figure 72. Screen shot of files extracted from zip file downloaded from CDC.

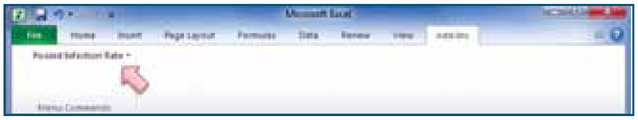


Figure 73. After installation, the Pooled Infection Rate becomes a permanent add-in to Excel.

Example: A community has two active vector species (Table 1). A local agency collects mosquitoes from seven traps, discards the males, and separates and counts the females of both species. A laboratory tests the samples, and the agency enters the data into a spreadsheet and calculates the average number of infected mosquitoes of both species collected per trap night.

Note: For this example, the number of mosquitoes in each pool varies from 0 to 50. This variation makes it difficult to estimate the overall proportion of infected mosquitoes and requires a special calculation method.

Calculating MLE for two species: To calculate the variables needed to estimate the VI, follow the steps below:

1. Enter all mosquito trap data into an Excel spreadsheet like the one in Table 1.
2. Click on the "Add-Ins" tab.
3. Click on "Pooled Infection Rate."
4. Select "One Sample." A popup window, "Pooled Infection Rate–Version 4.0," will appear (Fig 74).
5. For "Groups," select the cells containing the species names, which in this case include *Cx. quinquefasciatus* and *Cx tarsalis*. If only one species were present, you would leave "Groups" empty.

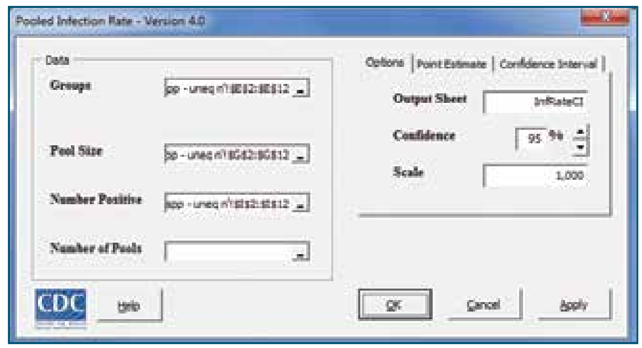


Figure 74. Popup window that displays after opening the Pooled Infection Rate add-in and selecting "One Sample."

Table 1. Sample mosquito surveillance data for two mosquito species of varying pool sizes

Week ending	Trap address	Trap No.	Pool No.	Species	No. female mosquitoes	No. in pool	Results	Coded result
6/29/2013	A	1	1	*Cx. quinquefasciatus*	10	10	Neg	0
6/29/2013	B	2	2	*Cx. quinquefasciatus*	5	5	Neg	0
6/29/2013	C	3	3	*Cx. quinquefasciatus*	4	4	Pos	1
6/29/2013	D	4	4	*Cx. quinquefasciatus*	8	8	Neg	0
6/29/2013	E	5	5	*Cx. quinquefasciatus*	16	16	Pos	1
6/29/2013	F	6	6	*Cx. quinquefasciatus*	58	50	Pos	1
6/29/2013	G	7	7	*Cx. quinquefasciatus*	2	2	Neg	0
6/29/2013	A	1	8	*Cx. tarsalis*	5	5	Pos	1
6/29/2013	B	2	9	*Cx. tarsalis*	0	0	Neg	0
6/29/2013	C	3	10	*Cx. tarsalis*	0	0	Neg	0
6/29/2013	D	4	11	*Cx. tarsalis*	1	1	Neg	0
6/29/2013	E	5	12	*Cx. tarsalis*	8	8	Neg	0
6/29/2013	F	6	13	*Cx. tarsalis*	10	10	Pos	1
6/29/2013	G	7	14	*Cx. tarsalis*	0	0	Neg	0
Total *Cx. q*					103			2
Total *Cx. t*					24			5

6. Click on "Pool Size" on the left of the "Pooled Infection Rate" box.
7. On the Excel worksheet, select all cells containing the number of female mosquitoes tested for each trap (in this example, the column labeled "No. in Pool") and all species.
8. Click in the "Number Positive" field located directly below the "Pool Size" field.
9. In the Excel worksheet, select all cells with the corresponding binary results (1 or 0) for each of the traps tested that week, both species included. Make sure to select the same number of cells under "Pool Size" as under "Number Positive."
10. Click "Output Sheet" and type in the name you want for the results page label. For this example, the entry was "Results July 29."
11. Click on the Tab "Point Estimate."
12. Select "Bias-corrected MLE" and click "OK." A new worksheet, "Results July 29," will appear with the results of the MLE calculation (Fig. 75).

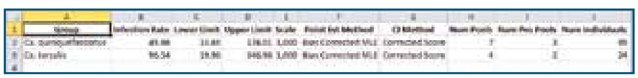


Figure 75. Output from pooled infection rate add-in.

The infection rate is the MLE estimate of the proportion of each mosquito species infected with WNV. In this example, the estimated infection rate for *Cx. quinquefasciatus* is 49.66 infected mosquitoes per thousand; for *Cx. tarsalis,* it is 96.54.

Confidence intervals refer to the statistical confidence in your estimate. In the calculation for *Cx. quinquefasciatus,* the confidence intervals are 13.65 to 174.01. This means that we can be 95 percent sure that the actual infection rate is between 13 and 174 infected mosquitoes per 1,000. The confidence interval limit for *Cx. tarsalis* is 19.96 to 346.96. We can be 95 percent sure that the actual infection rate is between 19 and 346 infected mosquitoes per 1,000.

Confidence intervals depend on the sample size and data variability. Generally, the more samples used to calculate the infection rate, the better the confidence interval.

The calculation also provides the total number of pools, number of positive pools, and number of individual mosquitoes for each species. **Note:** Scale is the infection rate expressed as numbers of infected mosquitoes per 1,000. The actual proportions of infected mosquitoes are 0.049 for *Cx. quinquefasciatus* and 0.096 for *Cx. tarsalis.*

Calculating the vector index: After estimating the proportion of mosquitoes infected, determine the vector index:

1. Using all trap data (including traps with no mosquitoes), calculate the average mosquito density per trap:
   - Divide the number of female vector species collected from all traps on the sample date by the number of traps collected on that date.
   - If there are two or more vector species, keep the calculations separate.
   - In the numerator, enter the total number of females, not just the number in the tested pools.
   - In the denominator, include the number of traps that caught no mosquitoes, but exclude any malfunctioning traps (such as those that were knocked over or that lacked an appropriate attractant such as stinky water, light, or CO_2).
   - In our example, the average number $\overline{N}$ of *Cx. quinquefasciatus* was 103 mosquitoes ÷ 7 traps = 14.71 per trap. The average number of *Cx. tarsalis* was 24 mosquitoes ÷ 7 traps = 3.43 per trap.
2. Calculate the infection rate as the proportion of all mosquitoes tested for WNV by dividing the MLE for each sample by 1,000.

   In this example:

   Infection rate $_{\text{Cx. quinquefasciatus}} = \widehat{P}_{Cxq}$ = proportion infected = MLE ÷ 1,000 = 49.66 ÷ 1,000 = 0.04966.

   Infection rate $_{\text{Cx. tarsalis}} = \widehat{P}_{Cxt}$ = proportion infected = MLE ÷ 1,000 = 96.53 ÷ 1,000 = 0.09653.
3. Calculate the vector index, VI = $\sum i$ = *species* $\overline{N}i\widehat{P}i$. Using the data for the trap catches of two competent vector mosquito species, this would be:

   $\overline{N}_{Cxq}\widehat{P}_{Cxq} + \overline{N}_{Cxt}\widehat{P}_{Cxt} = (14.71 \times 0.0496) + (3.43 \times 0.0965) = 1.06$

[1] Note: The calculator cannot accept pools with zero mosquitoes, such as pools 9, 10, and 14 in Table 1. To calculate the pooled infection rate, first delete these rows from the spreadsheet. However, to calculate the average numbers of mosquitoes per trap, you must include the data on traps with zero captures. For this reason, you may wish to make two worksheet copies of your data, one with all rows included and one with the rows for pools containing zero mosquitoes deleted.

Using the vector index: The vector index incorporates information about mosquito infection rates and the abundance of different mosquito species; however, without historical data about human infections in a given community or region, the value of the index is limited.

One way to use the VI is to plot it against mosquito abundance (Fig. 76) and human case numbers (Fig. 77).

Increases in the VI do not necessarily correlate with increases in vectors. But historically, they do appear to precede human cases of West Nile virus.

Because ecological conditions and mosquito vectors vary widely by location, the CDC cannot recommend a specific VI value as a national threshold for managing mosquito-borne diseases. The agency recommends that mosquito control authorities monitor local VI trends over time and develop their own threshold values based on local historical data on human cases.

Communities with no historical data on VI values and human infections may use a VI of 0.5 as a starting point threshold to justify adding adulticide applications to other control activities such as source reduction and larviciding. This means that the best time to begin adulticiding, such as with aerial applications or intensive ground-based sprays, to avoid a WNV outbreak is when the VI reaches 0.5.

The 0.5 VI was identified as a critical predictor of significant increases in human cases in both Dallas County and the City of Fort Collins, CO.

Applying thresholds

A mosquito-free community is not a practical goal economically or ecologically. A more realistic goal is to prevent mosquito-borne disease. One strategy is to establish a tiered system of phased-in responses to thresholds based on increasing mosquito numbers and the prevalence of disease in the mosquito population.

In its publication *West Nile Virus in the United States: Guidelines for Surveillance, Prevention, and Control,* the CDC defines four risk categories (0 to 3) and recommends activities and responses for each (Table 2):

- In low-risk (Category 1) conditions, begin seasonal public education campaigns, active larviciding, and intensified source reduction efforts.
- In high-risk (Category 2) conditions, increase adult mosquito control efforts and other preventive measures. The CDC does not specify a numerical threshold (such as mosquito abundance, the proportion of mosquitoes infected, or VI value) for Risk Category 2. However, many communities consider that the risk is high if there are any human WNV cases or WNV-positive mosquito pools, or more than average mosquito collections or WNV-positive blood donations. For many communities, this phase marks the beginning of ground- or (less often) aerial-based applications of mosquito adulticides.

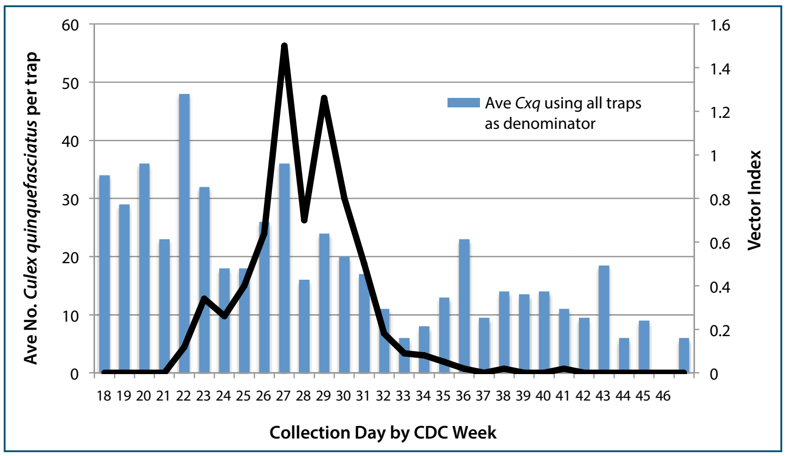


Figure 76. Weekly changes in average mosquito abundance and the vector index, Dallas, TX, 2012. Data source: W. Chung, Dallas County Health and Human Services

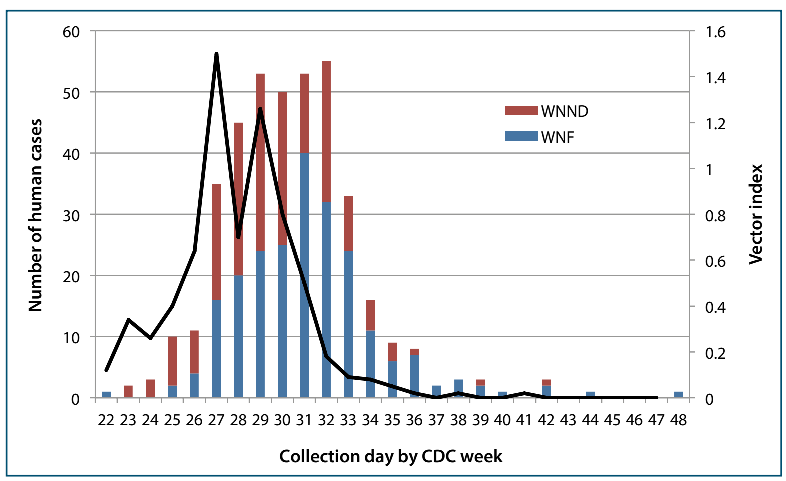


Figure 77. Weekly change in total number of human cases of West Nile fever and West Nile neuroinvasive disease and the vector index in Dallas, TX. 2012. Human case data based on date of symptom onset as obtained from medical records or patient/family interviews. Data source: W. Chung, Dallas County Health and Human Services

Table 2. Recommendations for a phased response to WNV surveillance data (Source: *West Nile Virus in the United States: Guidelines for Surveillance, Prevention, and Control, Centers for Disease Control).*

Risk category	Probability of human outbreak	Definition	Recommended activities and responses
0	None	No adult mosquito biting activity (vector species)	• Develop and review WNV response plan. • Review mosquito control program. • Maintain source reduction projects. • Secure surveillance and control resources needed to enable emergency response. • Review and update community outreach and public education programs.
1	Low	• Biting adult mosquitoes active (vector species), **or** • Epizootic activity expected based on onset of transmission in prior years, **or** • Limited or sporadic epizootic activity in birds or mosquitoes	• Response as in Category 0, plus: • Conduct integrated vector management program to monitor and reduce vector mosquito abundance. • Conduct environmental surveillance to monitor virus activity (mosquitoes, sentinel chickens, avian mortality, etc.). • Initiate community outreach and public education programs focused on personal protection and residential source reduction.
2	High	• Sustained transmission activity in mosquitoes or birds, **or** • Horse cases reported, **or** • Human case or viremic blood donor reported	• Response as in Category 1 plus: • Intensify and expand adult mosquito control in areas using ground and/or aerial applications where surveillance indicates human risk. • Intensify visible activities in the community to increase attention to WNV transmission risk and personal protection measures. • Work with collaborators to address high-risk populations. • Intensify and expand surveillance for human cases.
3	Outbreak in progress	• Conditions favor continued transmission to humans (i.e., persistent high infection rate in mosquitoes, continued avian mortality, seasonal mosquito population decreases not anticipated for weeks), **or** • Multiple confirmed human cases or viremic blood donors	• Response as in Category 2 plus: • Intensify emergency adult mosquito control program repeating applications as necessary to achieve adequate control. • Monitor the effectiveness of vector control efforts. • Emphasize the urgency of personal protection, including the use of repellents, through community leaders and the media.

12 Pesticide Use

Some mosquito pesticides are used in water to kill only mosquito larvae and pupae; others are used to kill only adult mosquitoes. The component of the product that is toxic to the mosquito is called the *active ingredient.* The active ingredients in adulticides prevent the mosquito's brain and nervous system from working properly.

Adulticides contain a tiny amount of the pesticide, sometimes less than 1 ounce per acre. They are applied from an airplane, backpack mist blower, or truck-mounted sprayer as a fog of tiny droplets. The fog drifts with the air currents.

To be killed, the mosquitoes must come into contact with the fog. Spraying is typically done when mosquitoes are most active—in the evening after sunset or in the early morning before sunrise.

The effectiveness of adulticiding depends on such variables as mosquito species, chemical flow rate, droplet size, application timing, weather conditions, and the density of homes and streets in the area. Adulticides have reduced adult mosquito populations in the United States and other countries for many years.

Safety

Before a pesticide can be used, sold, or distributed in the United States, the Environmental Protection Agency (EPA) must evaluate and register it. The agency assesses a wide variety of potential human health and environmental effects that the pesticide could cause.

Humans: If a pesticide meets the EPA requirements that it poses no unreasonable risk of harm to humans and the environment, the agency approves the pesticide for use according to label directions.

The extremely low rates that are applied make it unlikely that an EPA-approved pesticide will expose people even during or immediately after spraying. These low application rates are called ultra-low volume (ULV) rates. The pesticide is broken up into tiny droplets.

Over the years, many researchers have studied the effects of pesticide applications to control mosquitoes. They have found no harm to humans or animals.

People who live where mosquito spraying is routinely conducted have no more chemical-related health problems than those in areas that are not sprayed (Mauer et al., 2003, Karpati et al., 2004, Currier et al., 2005, Duprey et al., 2008, Chung et al. 2013). In Dallas County in 2012, there were no increases in respiratory ailments or skin rash complaints during 8 days of aerial application of pyrethroid insecticides for *Culex* mosquito control (Chung et al. 2013).

Research has also shown that in areas with high rates of human disease, ULV spraying reduces the rates of human infection immediately after the applications.

Animals: Studies have shown that the tiny amounts of pesticides applied during mosquito spraying do not harm animals. When pesticides are used properly, people and pets are exposed to much less than the smallest amount that could cause harm.

As a precautionary measure, residents may keep their pets inside during and 30 minutes after spray applications to help minimize their exposure. The pesticides used for mosquito adulticiding degrade quickly in the environment and do not accumulate.

Studies have found no ill effects in horses or other livestock from pesticide applications for mosquito control.

Bees and other beneficial insects: The pesticides used in mosquito control can be toxic to bees. To minimize the effects on bees and maximize effects on mosquitoes, apply pesticides in the evening or pre-dawn when the mosquitoes are most active and most bees are in their hives. Because most beneficial insects are inactive at night, they are generally thought to be unaffected by nighttime applications of mosquito adulticide.

People who are concerned about the effects of the pesticide on their bees should cover the hives with moistened, loosely woven fabric (such as burlap) before and 2 to 3 hours afterward. Beehive owners should contact their mosquito control districts to discuss how to prevent unintentional bee death during mosquito abatement.

Environment: The EPA has determined that mosquito-control pesticides can be applied over many types of areas. These pesticides break down quickly in sunlight and do not persist in the environment. Many studies have monitored the levels of pesticides used in mosquito control operations and have found no significant persistence or accumulation in the environment.

For example, in a study of pyrethrins and piperonyl butoxide (PBO) in California, water samples were collected after mosquito adulticide applications in the Sacramento metropolitan area. Only tiny amounts of pyrethrins and PBO were detected in samples collected up to 10 hours after application. Samples collected the day after application showed lower or no levels of both chemicals. This finding indicates that both chemicals dissipate fairly rapidly.

Licensing

The TDA licenses people to apply pesticides for public health pest control (vector control). The agency is developing regulations to clarify these licensing requirements as follows:

Storage

Pesticides must be stored and disposed of according to federal and state standards. Store them in their own separate building when possible or in a first-floor wing or corner of a building.

It would be best to erect a building just for storing pesticides. The building should be unlikely to flood, contain fireproof rooms, and stay cool and dry.

The ventilation system is vital—maintain it properly. Post signs on all the windows and doors informing people as to what is inside. Keep detergent or soap in a convenient location in case of a spill.

Store all pesticides with the label plainly visible in plastic containers large enough to hold the contents in case of a spill. Never put pesticides on the floor or overhead shelves.

In case of an emergency, federal law mandates that you give the local fire chief the name and phone number of the applicator or its representative if it stores:

- Products listed under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
- More than 55 gallons, 500 pounds, or a lesser amount of certain highly toxic or dangerous chemicals
- These chemicals for more than 72 hours within 0.25 mile of an area with three or more private dwellings

Pesticide applicator licensing under the Texas Agriculture Code Chapter 76 and associated Texas Administrative Code Chapter 7:

For general use or restricted use pesticide applications, employees of a public entity or contractors of a public entity, are required to be licensed as a commercial applicator or non-commercial political subdivision pesticide applicator (as applicable) in category 12 as defined below:

(12) health-related pest control; for the application of a pesticide of any use classification by a person who is an employee of, or an independent contractor for federal, state, county, city, mosquito or vector control district or other political subdivision to apply any pesticide for the control of pests that may be deleterious to the public health, including mosquito and other vector control. This category allows the application of pesticides to and over water for the purpose of vector control only.

A pesticide applicator license is NOT required for **general use pesticide** applications made by persons other than employees or contractors of a public entity or by those that are NOT receiving compensation for their work to their own property or to the property of others (homeowner associations, private golf courses, etc.).

Pesticide applicator licensing under the Texas Structural Pest Control Services Occupations Code Title 12 Chapter 1951 and associated Texas Administrative Code:

TDA's Structural Pest Control Service licenses and regulates pest management professionals who apply pesticides in and around structures.

A structural pesticide applicator license is required for any person who receives compensation (is in the pest control business) for making **general use or restricted use** pesticide applications. Licensing is through the Structural Pest Control Service (SPCS) of the Texas Department of Agriculture. Licensing for the purpose of controlling mosquitoes requires the "Pest" category.

If requested, you must also give the fire chief a list of the pesticides being stored and permission to inspect them on site.

For more information, see www.texasagriculture.gov.

Figure 78. Testing equipment before spraying. Image source: Michael Sanders

Equipment calibration and maintenance

To apply pesticides correctly, you must maintain the equipment properly and calibrate it yearly (Fig. 78). The calibration must match the application rates on the pesticide label, which could vary by chemical.

Correctly applying a pesticide with ultra-low volume (ULV) machinery requires that you take into consideration the vehicle speed, mix ratio, flow rate, and droplet size:

- The **application rate** is measured in pounds of active ingredient applied per acre.
- **Mix ratio** refers to the pesticide concentrate to diluent ratio.
- The **flow rate** is the fluid ounces of mix applied per minute.
- The **droplet size** is the mass median diameter (MMD), which is calculated by computer analysis (AIMES III) vs. Teflon slides or with assistance from vendors.

An Excel spreadsheet to aid in calculations for calibrations is posted at http://texasmosquito.org/Adulticiding.xls.

NPDES permits

If a pesticide will be applied to, over, or near water, contact the TCEQ for information about permits from the Texas Pesticide Pollutant Discharge and Elimination System (TPDES).

The TPDES has specific parameters for determining whether a pesticide application requires a permit. **Check first.** For information on the TPDES and TCEQ, see http://agrilife.org/aes/tceq-pesticide-permit-tpdes-information/.

Record keeping

Noncommercial applicators in Category 12a of public health pest control must keep records for 2 years on each pesticide application, including:

- Date of the pesticide application
- Time the application started
- Name of the person for whom the application was made
- Location of the application (GPS coordinates)
- Pesticide information (for each pesticide applied)
  - Product name
  - Product EPA registration number
  - Rate of product per unit
  - Total volume of dust, granules, spray mix, or other materials applied per unit
  - Name of the pest being treated
- Treatment site
- Total volume of area or number of acres treated
- Wind direction and velocity
- Air temperature
- FAA “N” number for aerial applications
- Name and pesticide applicator license number of the person responsible for the application and, if supervising an unlicensed person, the name of the unlicensed person who applied the pesticide
- Method or type of equipment used to make the application
- Type of documentation used to train the unlicensed applicator

An applicator who applies a single load of pesticide to several nearby sites may enter a single beginning time for all the applications, specifying the sequence. The applicator must keep current records of each application at the principal place of business and make them available for TDA inspection upon immediate request.

For the TDA Pesticide Applicator Record Form, see Appendix C. For more information, see www.texasagriculture.gov.

13 Starting an IMM program

When establishing a mosquito management program, you will need to make decisions on funding sources, expenses, and contractual services.

Funding sources

Most mosquito control programs are funded through local taxes. One option is to establish a mosquito district supported by such sources as sales taxes, a dedicated mileage charge, or a fixed charge collected on each household's utility bill (water or electricity).

Community-wide mosquito control operations must have a stable source of funding even when human disease cases are rare. To properly manage and expand a mosquito abatement program, choose a funding source that generates enough revenue and remains consistent from year to year. Some considerations:

- Sales tax revenue correlates directly to the economic well-being of a district and may vary.
- Rural and less densely populated districts may be unable to generate enough funds at the existing sales tax rate.
- A district with a small land base or a high percentage of tax-exempt property may be unable to generate enough funds through an existing ad valorem tax rate.
- Although a district may have several options for generating revenue, the public must accept and approve any option chosen.

State agencies generally provide funding for public health emergencies or declared disasters such as post-hurricane, post-flooding, or epidemic response. Under some circumstances, the agencies may allocate resources in response to requests from local governments. The funding process was established by the Texas Department of Emergency Management.

Federal funds may be available for emergencies such as those described for state funds. Certain criteria must be met to access these funds; and cost sharing among federal, state, and local governments is to be expected.

You may be able to reduce costs by:

- Working with other governmental entities in your district
- Contracting for services with an existing abatement district instead of providing all services in-house
- Establishing a regional mosquito abatement program by grouping two or more jurisdictions
- Contracting with a private entity for mosquito abatement services

A crucial element in garnering continued public support for a mosquito abatement program is accountability. Whether you conduct your program in-house or contract it to a private company, you must ensure that you are using public funds efficiently and effectively.

Be able to track all expenses of the program. Review and assess your operating and capital expenses often. These records will help you not only maintain current funding levels, but also obtain more funding to expand the program in the future program.

Expenses

Personnel cost (salaries and benefits): The largest expense category of any abatement program—up to 50 percent of a typical budget—is personnel (Fig. 79). You will need professional staff to administer, implement, and oversee the operations.

A developing district could cut costs by requiring personnel to take on multiple responsibilities. For example, it could incorporate surveillance into other activities such as residential inspections. However, understaffing can restrict a program's effectiveness.

Figure 79. Mosquito collecting samples of larvae from a culvert.

Chemicals: The second largest expense category is chemicals, which can total about 25 percent of a typical budget. Although you can reduce chemical expenses, be extremely careful to avoid reducing the program's effectiveness.

Operation and equipment supplies: About 15 percent of a typical budget covers fuel, insurance, utilities, vehicles, operational and equipment supplies, and facility/vehicle repairs and maintenance.

Contractual services: Contracting for aerial application (Fig. 80) and other services can be expensive, and many communities may not need aerial spraying.

Figure 80. Aerial pesticide application.

Educational activities: Consider educational and community outreach activities as operating expenses. Districts with limited resources may be able to reduce costs by using:

- Educational materials from other agencies
- Web-based information such as brochures/ fact sheets or utility bill inserts
- Media outlets during seasonal outbreaks and emergency response
- Public service announcements to educate the community

Capital expenses: Constituting about 10 percent of a typical budget, capital expenses can vary greatly and depend on funding availability. Although the initial investment may be minimal, it could increase as the district expands its services. Capital investments can drastically affect the scope and effectiveness of your program.

Contractor selection

Some county and city governments contract with private entities for mosquito abatement. Professional pest control companies offer several advantages over in-house services:

- The personnel often have a broader range of experience, more classroom and field training, and greater familiarity with the range of treatment techniques available to control mosquitoes and other public health vectors safely and effectively.
- The city or county eliminates or reduces the need to train personnel and maintain pesticide applicator licenses for employees.
- It may also reduce some of the district's liability for damages relating to storage, handling, and disposal of pesticides.

Employ only TDA-certified and -licensed contractors. Appoint someone from the city or county to oversee the firm's activities and make sure that it meets all contractual obligations.

As with an in-house program, the expenses are likely to vary from year to year.

Developing specifications for contract services: Make sure that the bid specifications are stringent and thorough. Well-designed and explicit bid specifications can help eliminate the problem of low bids by firms that cannot or will not provide the quality of work that a district should expect.

Contract officers should ask the TDA if it has regularly received complaints about a prospective contractor. The agency can also verify the certification and licensing of businesses and their personnel.

Bid specifications should require that the IMM contractors:

- Conduct a thorough, on-site inspection of the district before submitting bids to understand the scope of the abatement area and to realistically estimate the resources and personnel needed.
- Follow the abatement or IMM guidelines for using the most effective materials needed to provide satisfactory control.
- Work with the city or county to ensure that all permits needed for pesticide applications, such as the Texas Pollutant Discharge Elimination System permit, are submitted correctly.
- Regularly use the appropriate surveillance, procedures, and monitoring to locate pest infestations/disease activity and to assess the need for corrective treatment.
- Conduct insecticide resistance surveillance and management activities regularly to help in choosing appropriate mosquito adulticides.
- Provide the mosquito district with copies of labels and material safety data sheets (MSDS) for each product used, recognizing that the district reserves the right to approve or disapprove the use of any pesticide, device, or control measure.

The forms and processes for contracting with a firm for mosquito abatement services will vary according to the specific jurisdiction.

Appendix A

Taxonomic key to the 27 most important mosquitoes in Texas

Aedes aegypti
Ae. albopictus
Ae. sollicitans
Ae. taeniorhynchus
Ae. triseriatus
Ae. vexans

Anopheles pseudopunctipennis
Anopheles quadrimaculatus

Coquillettidia perturbans

Culex erraticus
Cx. quinquefasciatus
Cx. restuans
Cx. salinarius
Cx. tarsalis

Cs. inornata
Culiseta melanura

Deinocerites mathesoni

Haemagogus equinus

Mansonia titillans

Orthopodomyia signifera

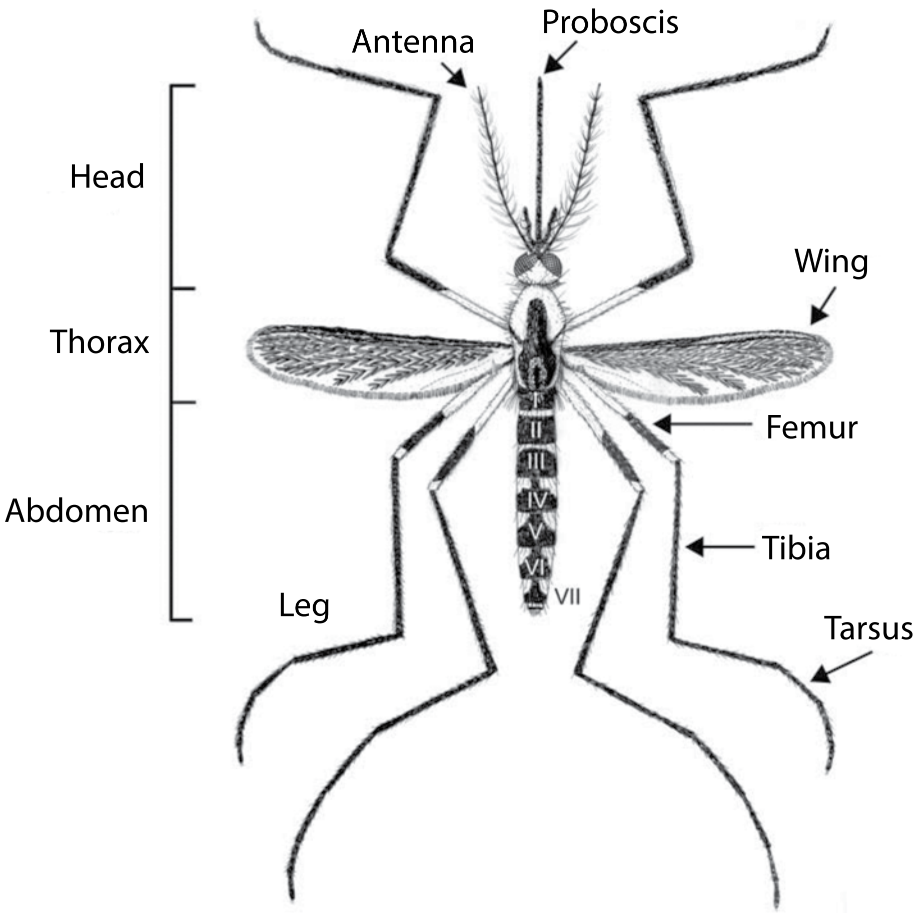
Psorophora ciliata
P. columbiae
P. cyanescens
P. ferox

Toxorhynchites rutilus septentrionalis

Uranotaenia sapphirina

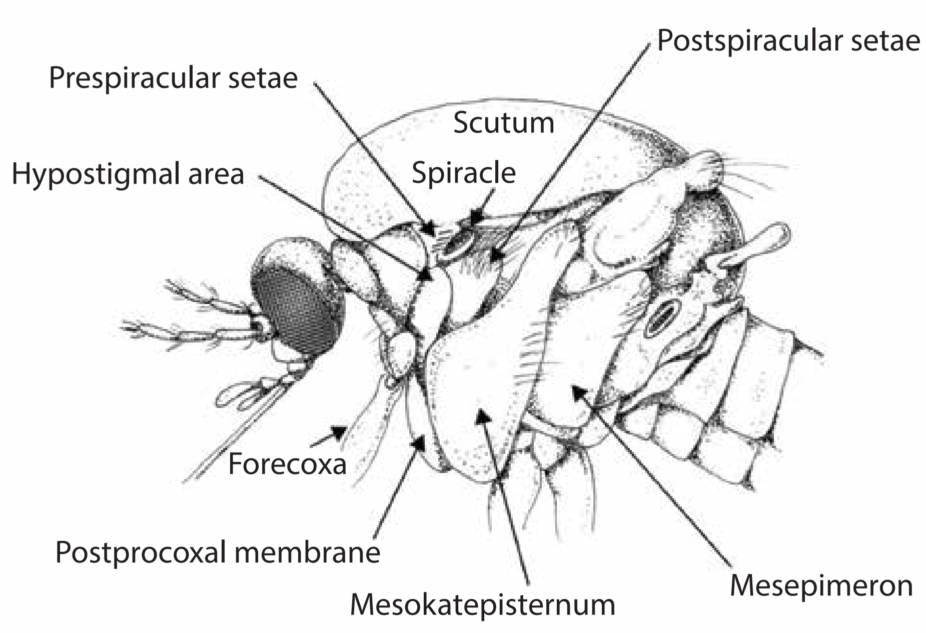
General morphology

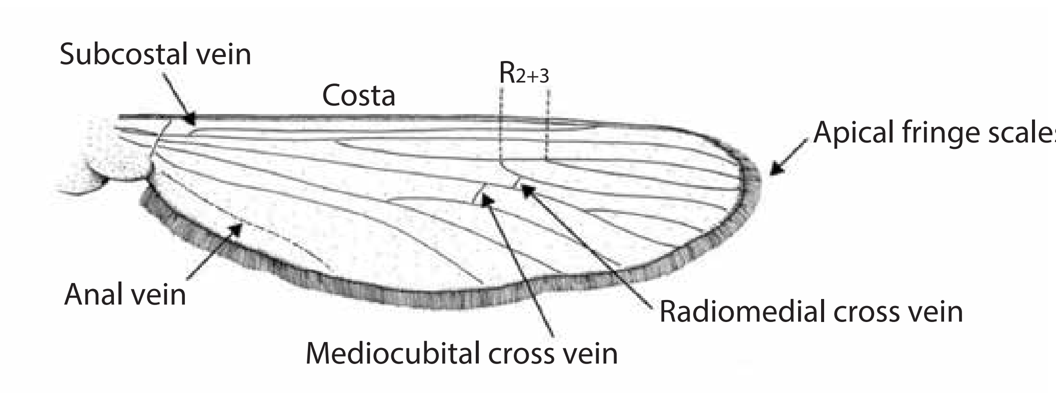
Adult morphology

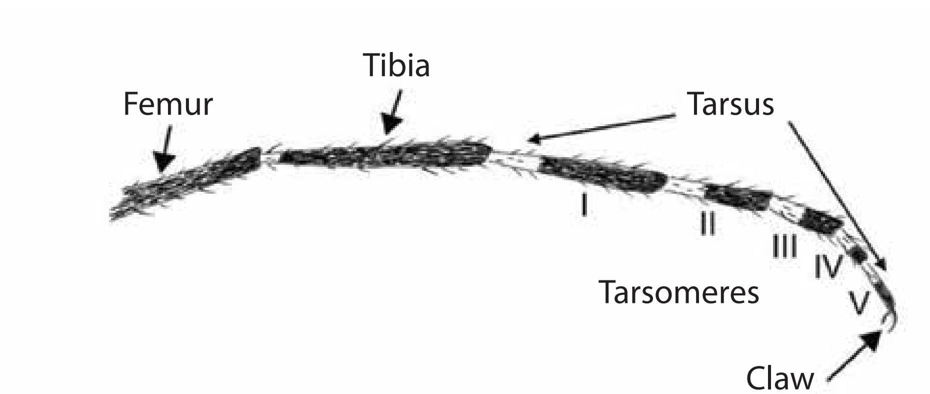


Source: Unless noted otherwise, mosquito figures are by Gale Ridge, courtesy of *Identification Guide to the Mosquitoes of Connecticut,* Connecticut Agricultural Experiment Station, 2005.

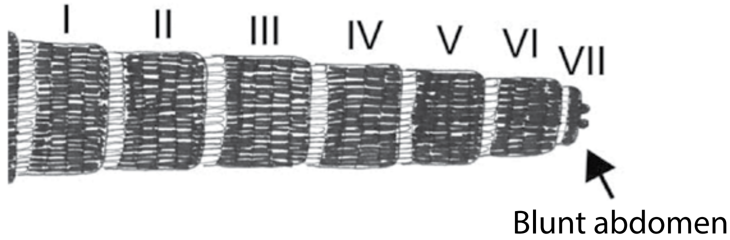
General morphology

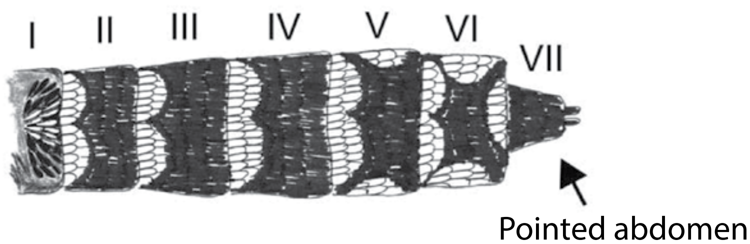


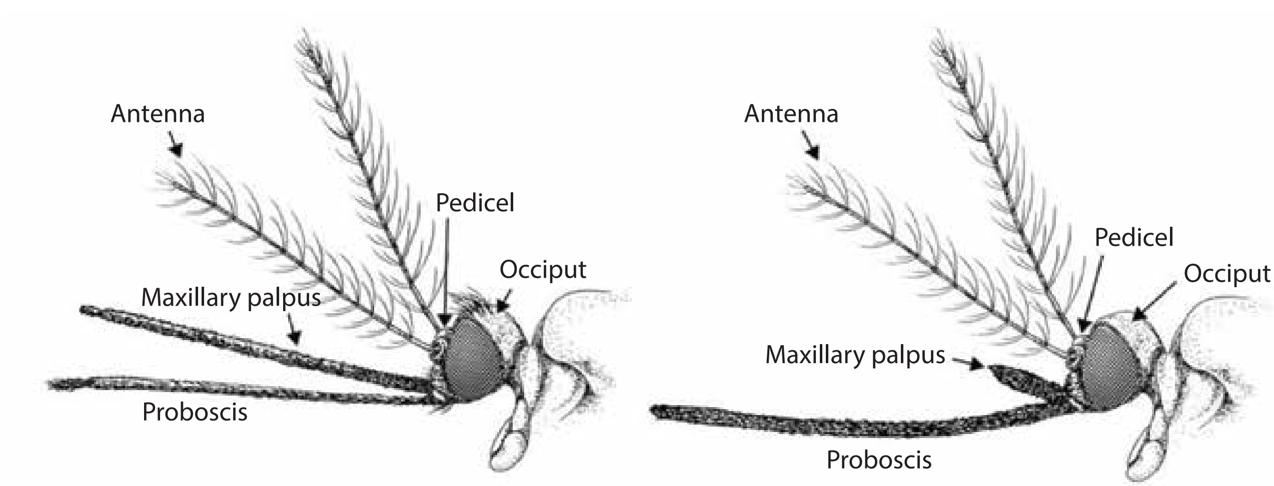




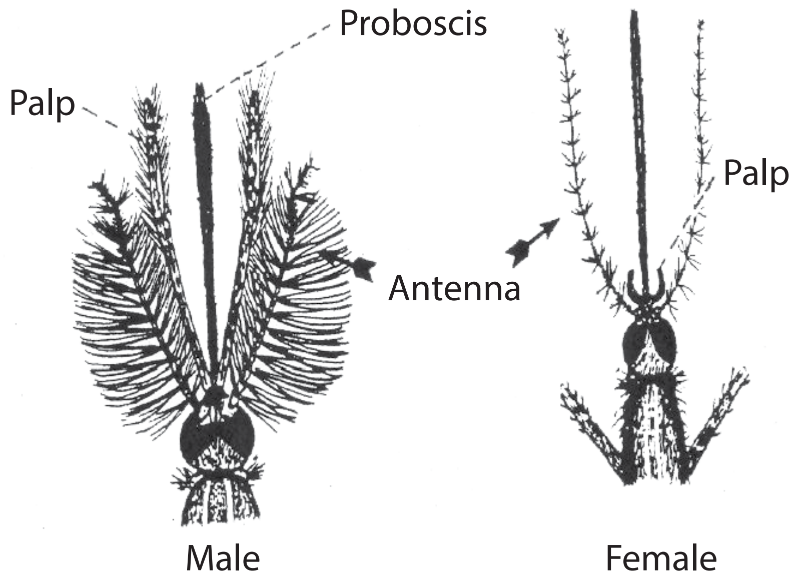
Defining characteristics



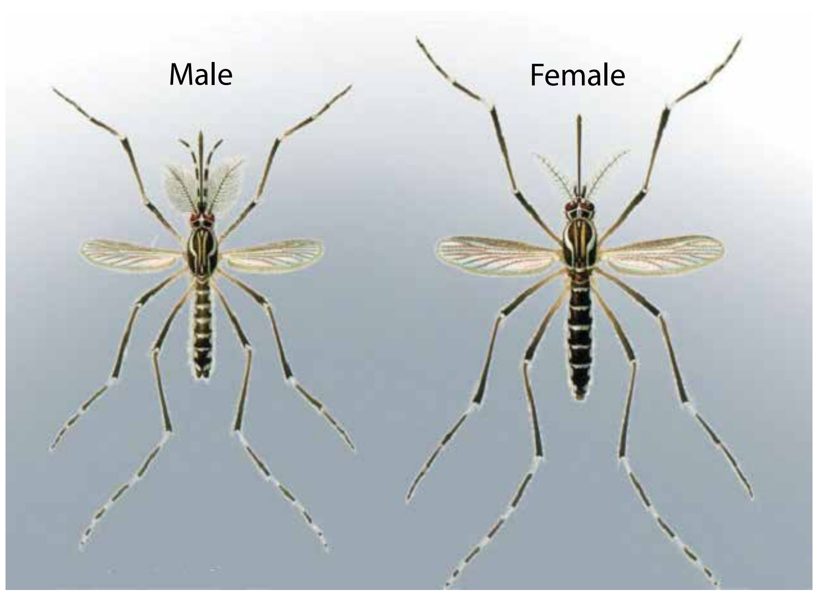




Determining sex



Source: http://armymedical.tpub.com/MD0170/MD01700117.htm



Source: http://www.sritweets.com/dont-male-mosquitoes-suck-blood-male-mosquitoes-depend-plants-food/

Texas mosquitoes: Key to genera of adult females

1. Proboscis long and strongly recurved (Fig. A1).. ***Toxorhynchites***
1. Proboscis is straight or slightly curved (Fig. A2).. Go to 2

Figure A1

Figure A2

2. Maxillary palpus nearly as long as proboscis, rounded scutellum (Fig. A3) .... ***Anopheles***
2. Maxillary palpus much shorter than proboscis (Fig. A4).. Go to 3

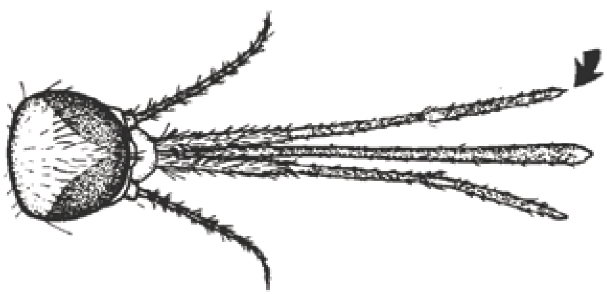


Figure A3

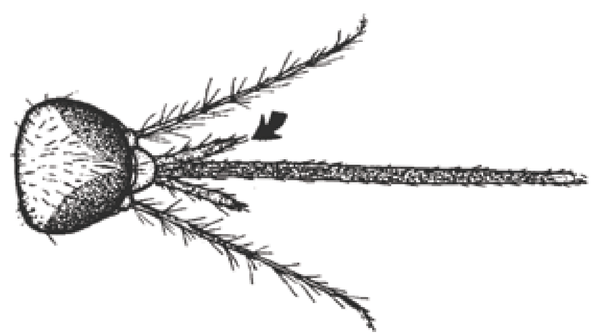


Figure A4

3. Second marginal cell (R_2) as long, or shorter than vein R_{2+3} (Fig. A5) .... ***Uranotaenia***
3. Second marginal cell (R_2) as long, or longer than vein R_{2+3} (Fig. A6)........................Go to 4

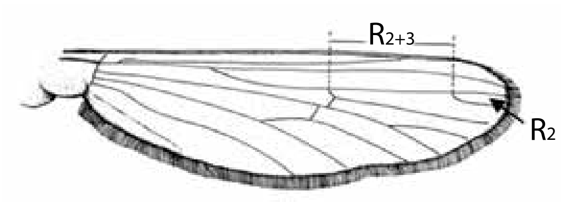


Figure A5

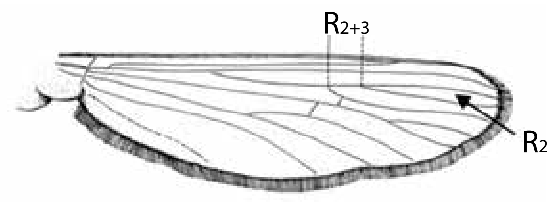


Figure A6

4. Scutum lacks visible setae on disc, scales smooth and often with metallic color, antepronotal lobes enlarged (Fig. A7) .... ***Haemagogus***
4. Scutum with at least prescutellar setae well developed, antepronotal lobes small (Fig. A8) ....Go to 5

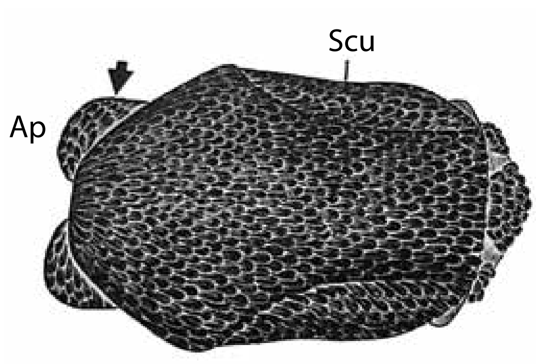


Figure A7

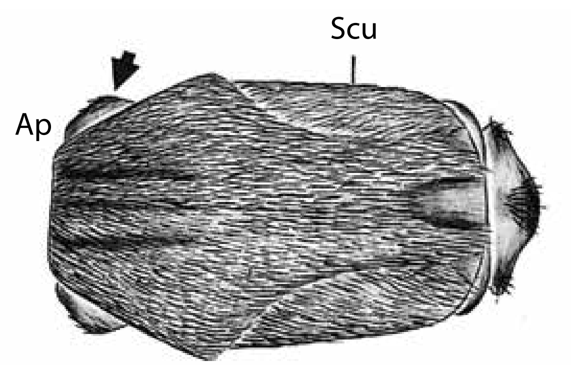


Figure A8

5. Postspiracular setae present (Fig. A9) ....Go to 6
5. Postspiracular setae absent (Fig. A10) ....Go to 9

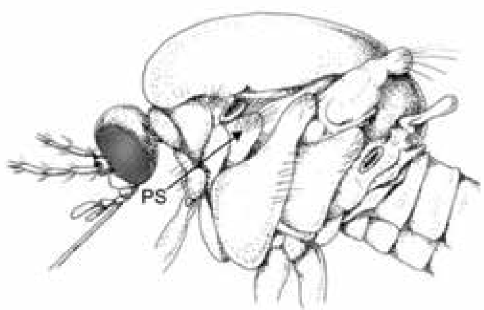


Figure A9

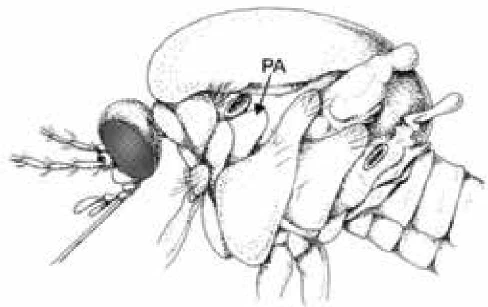


Figure A10

6. Apex of abdomen bluntly rounded from dorsal view (Fig. A11) ....Go to 7
6. Apex of abdomen tapering to a point form dorsal view (Fig. A12)..........................Go to 8

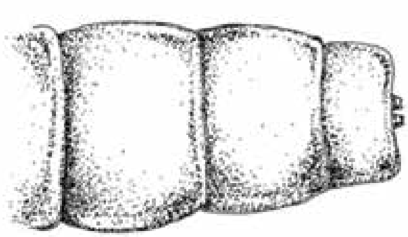


Figure A11

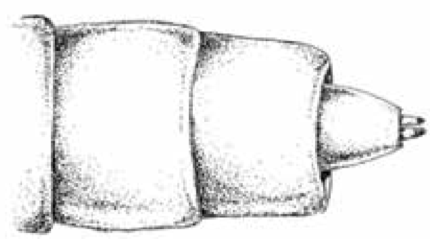


Figure A12

7. Femora with conspicuous preapical pale-scaled band (Fig. A13); wing dark-scaled with most scales on dorsal surface very broad (Fig. A14) ....***Coquillettidia***
7. Femora marked with dark and pale-scales but lacks preapical band; wing scales brown and white with most scales broad on dorsal surface .... ***Mansonia***

Figure A13

Figure A14

8. Dorsal segments of abdomen with pale scales apically (Fig. A15), or if absent, hind tibia with long, erect scales ....***Psorophora***
8. Dorsal segments of abdomen with pale scales basally (Fig. A16), hind tibia without erect scales ....***Aedes***

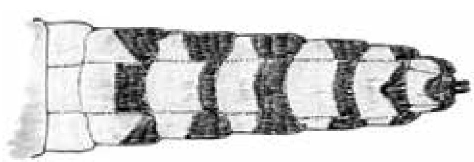


Figure A15

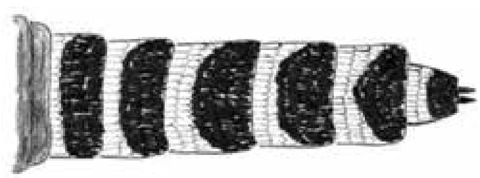


Figure A16

9. Base of subcosta wing vein with row of setae on the ventral side (Fig. A17) ..... ***Culiseta***
9. Base of subcosta wing vein without row of setae on the ventral side (Fig. A18) 10

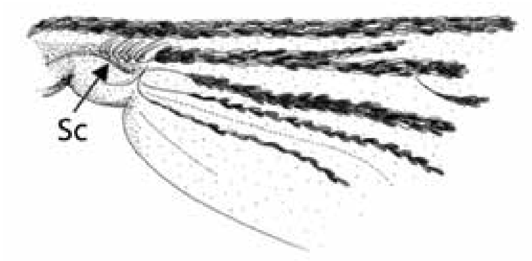


Figure A17

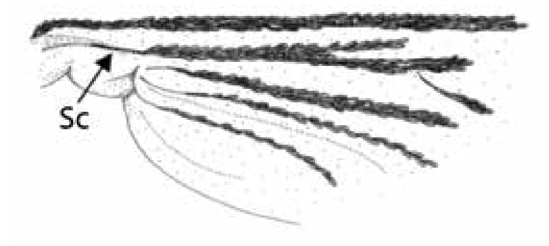


Figure A18

10. Most wing scales at base of wings are narrow and dark (Fig. A19) ....Go to 11
10. Wing scales broad, mixed brown and white, mesonotum with fine longitudinal lines of white scales (Fig. A20)... ***Orthopodomyia***

Figure A19

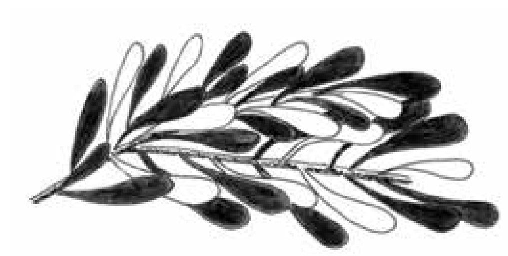


Figure A20

11. Antenna not longer than proboscis, first flagellar segment about as long as following segments (Fig. A21)..***Culex***
11. Antenna much longer than proboscis, first flagellar segment as long as next two segments (Fig. A22) ....***Deinocerites***

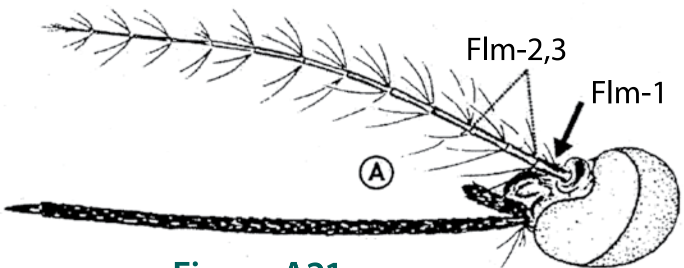


Figure A21

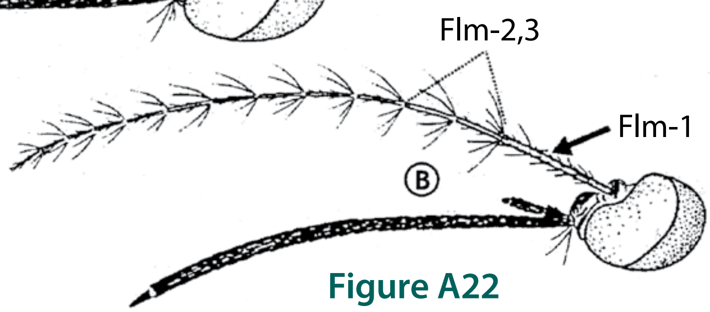


Figure A22

Appendix B

Mosquito biological data

Mosquito species	Disease agent[1]	Larval habitat(s)[2]	Biting time[3]	Flight range[4]
Aedes aegypti	DEN, YF, CHIK, Zika, (WN)	AC	C, D	<0.5 mi
Ae. albopictus	DEN, YF, (LAC), (WN), (CHIK) (Zika)	AC, TH	D	<0.5 mi
Ae. sollicitans	EEE	SM	C	5–10 mi
Ae. taeniorhynchus	VEE, (CAL)	SM	C, N	5–10 mi
Ae. triseriatus	LAC	TH, AC	D	0.5-1 mi
Ae. trivittatus	CAL	GP, WP, FW	C, N	0.5–1 mi
Ae. vexans	CAL, EEE, DH	FW, GP, IP	C, N	1–5 mi
Anopheles crucians	(EEE), (VEE), (M)	SM, FS, LM	C	1–2 mi
A. quadrimaculatus	M	FW, GP, LM	C	0.5-1 mi
Coquillettidia perturbans	EEE, (VEE)	FS, GP, LM	C, N	1–2 mi
Culex quinquefasciatus	WN, SLE, (WEE), (VEE)	SCB, GRP, AC	C, N	0.5-1.0 mi
Cx. restuans	(EEE), (WEE), (WN)	WP, GRP, DD	C, N	1–2 mi
Cx. salinarius	(EEE), (WN)	GP, LM, FS	C, N	1–5 mi
Cx. tarsalis	WEE, WN, SLE	IP, RF, GRP	C, N	1–2 mi
Culiseta inornata	(WEE), (CAL)	GRP, DD	C, N	1–2 mi
Cs. melanura	EEE	FS, WP	C, N	0.5–1 mi
Psorophora columbiae	VEE	IP, RF, GRP	C, N	1–5 mi

[1] Parentheses indicate secondary vector or suspected vectors; otherwise, primary vectors
CAL = California group encephalitis; CHIK = chikungunya; DEN = dengue fever;
EEE = eastern equine encephalitis; LAC = La Crosse encephalitis; M = malaria; SLE = St. Louis encephalitis;
VEE = Venezuelan equine encephalitis; WEE = western equine encephalitis; WN = West Nile; YF = yellow fever
[2] AC = artificial containers; DD = drainage ditches; FS = freshwater swamps; FW = flood water;
GP = grassland pools; GRP = ground pools; IP = irrigated pastures; LM = lake margins; RF = rice fields;
SCB = sewer catch basins; SM = salt marshes; TH = tree holes; WP = woodland pools
[3] C = crepuscular (dusk and dawn); D = day; N = night

Appendix C

Pesticide applicator record-keeping requirements

http://www.texasagriculture.gov/Portals/0/forms/PEST/Applicator/applicatorrecq527.pdf

TDA Q527
7/15

Texas Department of Agriculture
Pesticide Applicator Record

COMMISSIONER SID MILLER

Business/Applicator Name ______________________ **Address** ______________________

Application Date	Time Started	Name of the person for whom the application was made	Location of Land Treated	Site Treated	Wind Direction	Wind Velocity	Air Temp

Product Trade Name	EPA Registration Number	Target Pest	Rate of Product Per Unit	Method or Type of Equipment Used To Make Application	FAA "N" Number for Aerial Application Equipment:

Is Application Applied in Regulated County: □ Yes □ No	Regulated Herbicide Permit Number:

Licensed Applicator's Name and License Number	Non-licensed Applicator's Name Working Under Licensee	Total Acres or Volume of Area Treated	Total Volume of Spray Mix, Dust, Granules or Other Materials Applied Per Unit

Documentation used to verify training of non-licensed applicator (Mark Applicable Box)
□ Direct Supervisor Affidavit □WPS Handler Card □Signed & Dated Label

Application Date	Time Started	Name of the person for whom the application was made	Location of Land Treated	Site Treated	Wind Direction	Wind Velocity	Air Temp

Product Trade Name	EPA Registration Number	Target Pest	Rate of Product Per Unit	Method or Type of Equipment Used To Make Application	FAA "N" Number for Aerial Application Equipment:

Is Application Applied in Regulated County: □ Yes □No	Regulated Herbicide Permit Number:

Licensed Applicator's Name and License Number	Non-licensed Applicator's Name Working Under Licensee	Total Acres or Volume of Area Treated	Total Volume of Spray Mix, Dust, Granules or Other Materials Applied Per Unit

Documentation used to verify training of non-licensed applicator (Mark Applicable Box)
□ Direct Supervisor Affidavit □WPS Handler Card □Signed & Dated Label

Glossary

active ingredient: the material in a pesticide that destroys, prevents, repels, or mitigates a pest, or is a plant defoliant, desiccant, regulator, or nitrogen stabilizer

adulticide: an insecticide used to kill adult mosquitoes

arbovirus: a virus that can be transmitted by arthropods to a person or another animal. Examples: West Nile virus, yellow fever, dengue fever, and western equine encephalitis

Centers for Disease Control and Prevention: a federal agency that is part of the Department of Health and Human Services; its purpose is to develop and apply principles of disease prevention and control, protect environmental health, and promote education to improve the health of U.S. residents

chikungunya: an arthropod-borne virus of the genus *Alphavirus* that is transmitted to humans by virus-carrying *Aedes* mosquitoes

cytopathic effects: degenerative changes in cells that occur when certain viruses multiply; in tissue culture, the effect may lead to the formation of plaque when the spread of a virus is restricted by an overlay of agar

dengue virus: a mosquito-borne virus of the genus *Flavivirus;* four serotypes can cause dengue fever

eastern equine encephalitis: the severest form of encephalitis caused by arboviruses in the United States. The primary host is birds. Humans and horses are dead-end hosts; the disease can severely affect horses.

equine encephalitis: a mosquito-borne alphavirus that causes eastern equine encephalomyelitis, western equine encephalomyelitis, and Venezuelan equine encephalomyelitis; all of these can cause acute encephalitis with high fever in horses, donkeys, and mules

enzootic activity: the maintenance of disease in an animal population of a defined geographic area at a level less than epizootic (epidemic) level

gonotrophic cycle: in a female mosquito, the reproductive cycle of blood-feeding, blood meal digestion, egg development and maturation, and oviposition

gravid females: female mosquitoes that are full of or swollen with eggs

haltere: one of a pair of short projections in dipterous insects that are modified hind wings and may be used to maintain balance during flight

inactive ingredient: a substance other than an active ingredient that is intentionally included in a pesticide product

infusion water: water containing fermented grass to simulate an oviposition habitat

integrated vector management: a decision-making process to control vectors at the lowest cost and greatest effectiveness, sustainability, and ecological soundness

integrated mosquito management (IMM): an effective and environmentally sensitive approach to mosquito management that optimizes results by combining several components, including surveillance, source reduction, larviciding, adulticiding, public education, and personal protection (SSLAPP)

La Crosse virus: the most important human pathogen in the California serogroup; it causes high fever in children. Although most infected people develop mild or no symptoms, some can progress to severe encephalitis and, rarely, death. It is transmitted to the mosquito offspring and rodents such as chipmunks and squirrels.

larva: the newly hatched, earliest stage of an insect that undergoes metamorphosis and differs markedly in form and appearance from the adult

larvicide: an insecticide that is used to kill mosquito larvae

maxillary palps (palpi): elongated, segmented appendages near the mouth of invertebrate organisms; they are used for sensation, locomotion, and feeding

mesonotum: the dorsal (back) part of the mesothorax of insects

molt: to periodically shed part or all of the outer cuticle, which is then replaced by a new growth

mosquito pool: a sample of no more than 50 female mosquitoes of one species from a single location and trap; it is used to calculate infection rates and develop a vector index. If more than 100 mosquitoes are collected from a single trap, more than one pool may be obtained from the location. Pools are generally collected for testing for West Nile virus or similar diseases.

nulliparous: the condition of a female mosquito that has not yet undergone a complete gonotrophic cycle; nulliparous females are less likely than parous females to have been infected with a virus or other diseases

oviposition: the process of laying eggs

oviposition habitat: a site where gravid females deposit eggs

parous: the condition of a female mosquito that has completed one or more reproductive cycles; because it has taken multiple blood meals, it is more likely than a nulliparous female to have been infected with parasites

proboscis: the slender tubular feeding and sucking mouthpart of a mosquito

pupa: the non-feeding stage between the larva and adult in the metamorphosis of some insects; during this period, the larva typically undergoes complete transformation within a protective cocoon or hardened case

reservoir: any animal host (vector or vertebrate) that can maintain a pathogen for an extended period. A reservoir host must support parasite development; be able to remain infective for long periods, usually without developing acute disease; and serve as an ongoing source for spread of infection.

Rift Valley fever virus (RVFV): a mosquito-borne virus in the family *Bunyaviridae* that affects livestock and humans. Although RVFV causes a mild fever in most people, 10 percent have more severe symptoms including encephalitis and hemorrhagic fever. It has spread throughout Africa, Madagascar, and the Arabian Peninsula. The virus is not in the United States, but the vectoring mosquitoes are.

RT-PCR (reverse transcription-polymerase chain reaction): a test that uses RNA to detect viral infections in mosquitoes

St. Louis encephalitis virus (SLEV): related to West Nile virus, SLEV was the most commonly occurring human arboviral encephalitis in Texas before 2002. It circulates among birds and *Culex* mosquitoes. Humans are a dead-end or accidental host. The virus does not affect horses.

serology: the study of blood serum to learn the characteristics of a disease or organism

spatial patterns: the occurrence of the same phenomenon in different areas of the world; the geographical distributions of the same phenomena in different climatic conditions

temporal patterns: the distribution of occurrences in time when established criteria are met

vector index: the estimated average number of all species of infected mosquitoes collected per trap night; a vector index can help predict outbreaks of virusus in humans

viremic: a condition in which enough virus particles circulate and reproduce in the bloodstream to enable the host to infect a vector

western equine encephalitis (WEEV): a virus closely related to eastern equine encephalitis virus but occurring more often in the western United States. Vectored by *Cx. tarsalis,* the virus causes encephalitis in horses and humans. Songbirds serve as reservoir hosts.

West Nile virus (WNV): a mosquito-borne zoonotic arbovirus belonging to the genus *Flavivirus*

Zika virus: a mosquito-borne zoonotic arbovirus in the genus *Flavivirus* that was originally identified in the Zika forest of Uganda, Africa. Zika has been linked to microcephaly, a serious disease that stops fetal brains from developing.

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http://www.cmmcp.org/larvfs.pdf

Index

Common mosquitoes in Texas

Aedes aegypti. Image source: USDAgov (CC BY 2.0)

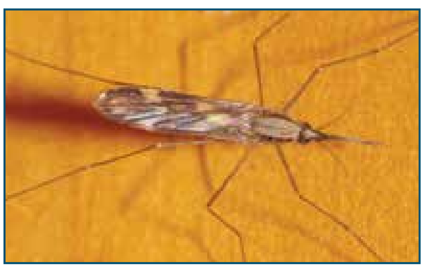
Aedes aegypti after a blood meal. Image source: USDAgov (CC BY 2.0)

Ae. albopictus.

Ae. sollicitans. Image source: Sonja Swiger

Ae. triseriatus. Image source: Susan Ellis, Bugwood.org (CC BY 3.0 US)

Ae. vexans. Image source: Mike Merchant



Anopheles punctipennis. Image source: Fyn Kynd Photography (CC BY 2.0)

Culex quinquefasciatus.

Cx. tarsalis. Image source: Joseph Berger, Bugwood.org (CC BY 3.0 US)

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