MOSQUITOES

Mosquitoes are in the family Culicidae of the order Diptera and are similar in appearance to other flies. However, in many important characteristics the **anophelines** (*Anopheles* spp. only) differ from the **culicines** (all other mosquito genera occurring in the U.S., see Table 3.1). Mosquitoes pass through four distinct stages in their life cycle: egg, **larva**, **pupa** and **adult**. Prodigious numbers of mosquitoes can hatch simultaneously under the proper conditions. In rapidly developing broods, survival of the immature stages can be quite high, but estimates for many species indicate that immature survival is normally less than 5 percent. But 5 percent of millions represents a sizable number. Irrespective of population densities, if they transmit disease or preferentially feed on humans, which many **species** do, they become appropriate targets for control activities. This chapter deals with the **bionomics** of mosquitoes and reviews surveillance practices and approved control methods.

I. DEVELOPMENTAL STAGES

Immature Stages

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

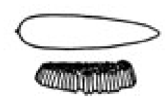

Figure 3.1. Single egg and egg raft

Permanent water and standing water species deposit their eggs directly on the water surface, and these may hatch in one to four days depending on temperature. Many floodwater and container-breeding species deposit their eggs on moist soil or other wet **substrates**. These eggs may hatch within a few days after being flooded, or the fully developed larvae may remain within the eggs for up to a year or more depending on immersion conditions. These quiescent eggs accumulate over time due to continued oviposition by blood-fed females. When temporarily flooded, they hatch, along with more recently deposited eggs. Populations can attain large numbers quickly this way.

Larvae. Larvae (wigglers or wrigglers) of all mosquitoes live in the water. Near the last abdominal segment in most species is a **siphon** or air tube that serves as a respiratory apparatus when the larva suspends vertically below the water surface (Figure 3.2). Larvae of *Anopheles*, however, breathe through a cluster of small abdominal plates, which causes them to lie flat close to the underside of the water surface when not diving (Figure 3.3). Larvae of some species are predaceous (e.g., *Toxorhynchites rutilis* and *Psorophora ciliata*) and prey on other invertebrates, including mosquito larvae. Most larvae are filter feeders, ingesting anything smaller than about 10 microns by vibrating their mouth brushes and sweeping in particulate matter and small organisms from the surrounding water. Depending on the species and environmental conditions, mosquitoes may take anywhere from three to four days up to several weeks to complete larval development. Mature 4th **instar** larvae molt to the pupal stage.

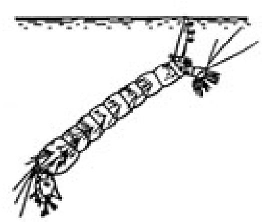

Figure 3.2. Nonanopheline larva

Figure 3.3. Larva of *Anopheles* spp.

Pupae. Unlike most other insects, mosquito pupae (Figure 3.4) can be very active and are often called “tumblers” because of their rapid, tumblinglike movement when disturbed. Mosquito pupae breathe through two respiratory “horns” when at the water’s surface, do not feed and typically transform into adults in two or more days.

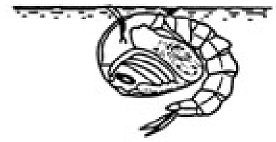

Figure 3.4. Pupa

Adult Mosquitoes

Adult mosquitoes (Figure 3.5) are terrestrial and capable of flight. With piercing-sucking mouthparts, the females feed mostly on animal blood and plant nectar. Males’ antennae have dense bristles, and their mouthparts are modified to suck nectar and plant secretions, where no piercing is required. The adults of some species remain within a few hundred feet of where they spent the larval stage, whereas others may migrate up to 50 miles or more. Eggs develop a few days after females take a blood meal. Females oviposit on the water, in crevices in the soil, or on other favored substrates or special niches that are or will subsequently be flooded, such as natural and artificial containers or tree holes, and the cycle repeats itself. Females of some floodwater species may live up to a month after they emerge, whereas those of some permanent water or standing water species can survive for several months by overwintering as mated, engorged adults. Some species, including those whose eggs require freezing temperatures, are limited to a single generation per year, whereas others have multiple generations.

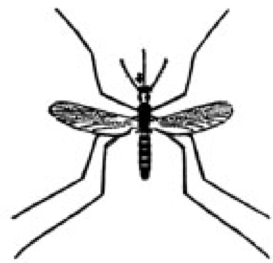

Figure 3.5
Adult mosquito

II. BIONOMICS AND HABITAT

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

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

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

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

Standing Water Mosquitoes

Permanent water group. Mosquito groups assigned to the permanent water group are *Anopheles* spp., *Culex* (*Melanconium*) spp., *Cx. salinarius*, *Cx. territans*, *Coquillettidia* spp. and *Mansonia* spp. As examples, the following permanent water habitat types and resident species of Florida are more or less typical of those found throughout the nation.

Freshwater marsh: Mosquito species often found in freshwater marshes include *An. walkeri, An. crucians, Psorophora columbiae, Cx.. nigripalpus, Cx. salinarius, Cx. tarsalis, Cx. erraticus* and *Cx. peccator.*

Lakes: Larvae may be found when many species of floating or emergent plants are present, but where vegetation occurs only in a narrow band along the lakeshore, larvae are confined to this littoral zone. Lake species include *An. crucians, An. quadrimaculatus* spp. complex*, An. walkeri, Uranotaenia sappharina*, *Ur. lowii, Cx. salinarius, Cx. nigripalpus, Cx. erraticus, Cx. peccator, Cq. perturbans, Ma. dyari* and *Ma. titillans*.

Ponds and seepage areas: There is no clear distinction between a pond and a lake except that ponds are generally smaller. Grassy woodland ponds or fluctuating ponds occupy shallow depressions and are filled by rainwater or surface run-off. They are usually of uniform depth, but the area they cover will vary, depending on rainfall. Sinkhole ponds are usually quite deep and may be covered with vegetation or free of all except marginal plants. Both types of ponds may contain larvae of *An. crucians, An. quadrimaculatus* spp. complex, *Culiseta inornata, Cs. melanura, Cx. nigripalpus, Cx. quinquefasciatus, Cx. restuans, Cx. salinarius, Cx. erraticus, Cx. peccator, Cx. pilosus, Cx. territans* and *Ochlerotatus canadensis.*

The seepage areas around hillsides and ponds or streams most often breed *An. punctipennis, An. quadrimaculatus* spp. complex*, Oc. sticticus* and *Ps. ferox*.

Springs: Mosquito breeding in springs is restricted to the quiet edges where vegetation affords cover for the larvae and there is little, if any, water movement. The only species recorded from this habitat in Florida are *An. quadrimaculatus* spp. complex and *An. perplexens*.

Swamps: Swamps differ from marshes principally in having dense cover from larger trees. The most common species of mosquito larvae found here are *An. crucians, An. quadrimaculatus* spp. complex*, Cs. melanura, Oc. canadensis, Mansonia* spp. and *Cq. perturbans*.

Transient water group. Mosquito groups assigned nationally to the transient water group are *Cx. quinquefasciatus, Cx. tarsalis, Cx. restuans, Cs. inornata* and *Cs. melanura.* As examples, the following specific habitat types and resident species described in Florida are more or less typical of those found throughout the nation.

Salt or brackish water ditches: The ditches adjacent to saltwater marshes contain many species of grasses and support a large mosquito fauna, including *Oc. taeniorhynchus, Oc. sollicitans* and *An. bradleyi*.

Borrow pits and canals: These man-made bodies of open water produce more mosquitoes as they silt-in and become overgrown with vegetation. They yield *An. quadrimaculatus* spp. complex*, Cs. inornata, Ps. columbiae, Oc. canadensis, Cx. nigripa1pus, Cx. quinquefasciatus, Cx. restuans, Cx. salinarius, An. albimanus, Cq. perturbans* and *Mansonia* spp.

Freshwater drainage ditches: In pastures, at the bottom of road shoulders, in old fields and in lowland groves, freshwater ditches will often yield the following species of mosquito larvae: *Ps. columbiae, Cx. nigripalpus, Cx. pilosus, Cx. erraticus, Cx. quinquefasciatus, An. crucians, An. walkeri, Oc. atlanticus, U. sappharina, U. lowii, Ps. ciliata* and *Oc. sollicitans.*

Floodwater Mosquitoes

Floodwater group. Mosquito groups assigned nationally to this floodwater group are *Oc. sollicitans, Oc. taeniorhynchus, Oc. tormentor/atlanticus, Oc. thelcter, Oc. dorsalis, Oc. nigromaculis, Ae. vexans, Ps. ferox* and *Ps. columbiae*. As examples, the following specific habitat types and resident species described in Florida are more or less typical of those found throughout the nation.

Mangrove swamp: In the transitional zone from normal high tide to above all but the highest spring and storm tides, the heaviest mosquito breeding occurs. Plant and grass cover keep moisture conditions suitable for egg laying. Eggs are usually laid on sloping sides of potholes, ditches, sloughs, marsh edges or on the sides of small depressions, and sometimes over extensive, level, grass-covered areas. The eggs of some species require alternate flooding and drying before hatching. Species most often occurring are *Oc. taeniorhynchus, Oc. sollicitans, An. atropos* and *Cx. nigripalpus*.

Salt marsh: Salt-tolerant herbaceous plants and typical salt grasses dominate this type of habitat. Extensive areas are often covered by a single plant species such as *Distichlis spicata*, *Batis maritima* or *Salicornia perennis.* It is in association with one of these plants or with black mangrove (*Avicennia germinans*) that breeding of *Oc. taeniorhynchus* and *Oc. sollicitans* occurs.

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

Artificial container and tree-hole group. Mosquito groups assigned nationally to the artificial container and tree-hole group are *Ae. aegypti, Oc. triseriatus, Oc. sierrensis, Ae. albopictus, Cx. quinquefasciatus, Toxorhynchites* spp. and *Orthopodomyia* spp. As examples, the following specific habitat types and resident species described in Florida are more or less typical of those found throughout the nation.

Tree holes: Tree holes or rot cavities support a rather extensive and unusual mosquito fauna, with many species breeding almost exclusively in this habitat. Resident species are *An. barberi, Tx. rutilis rutilis, Tx. r. septentrionalis, Oc. triseriatus, Oc. hendersoni, Or. signifera, Or. alba, Oc. thibaulti* and *Ae. albopictus*.

Crab holes: Along the eastern coast the holes of the large land crab, *Cardisonza guanhumi,* serve as the larval habitat for *Deinocerites cancer* and *Cx. opisthopus*.

Artificial containers: Several species breed in human-created situations around human dwellings. Tin cans, fish pools, cisterns, rain barrels, gutters and old tires, etc., containing water serve as excellent larval habitat. Species most often encountered are *Ae. aegypti, Oc. triseriatus, Cx. quinquefasciatus, Cx. restuans, Cx. salinarius, Cx. nigripalpus* and *Ae. albopictus.*

That many species are found in multiple habitat types and some in very specialized habitats illustrates the complexity of the problem faced by control agencies. While habitat association with many species is quite specific, others thrive in a variety of situations. Thus, the detection of adults of these latter species in routine surveys does not provide an immediate indication of the related breeding site(s).

III. MOSQUITO SAMPLING AND SURVEILLANCE

Surveys are essential for the planning, operation and evaluation of an effective mosquito-control program, whether for the prevention of mosquito-borne diseases or to reduce mosquito populations to levels permitting normal activities without undue discomfort. Initial surveys identify the species of mosquitoes present and provide general information on locations, densities and disease potential. With this knowledge it may be possible to determine life cycles and feeding preferences; predict larval habitats, adult resting places and flight ranges; and perhaps even make preliminary recommendations for control programs.

The next step is to embark on a formal surveillance program in which routine monitoring of mosquito presence is conducted. A basic inspection program usually addresses adult and larval population density and species composition, rainfall and tide monitoring, and breeding site locations. Additional specialized surveillance may be conducted to detect arboviral presence in birds and mosquito populations, operation of **ovitraps** (e.g., for *Ae. aegypti* and *Ae. albopictus* surveillance), or sampling of floodwater mosquito eggs to locate breeding sites. This information not only provides justification for source reduction and insecticide applications, but it also serves as an ongoing indicator of the effectiveness of these activities and continually adds to the database of knowledge concerning mosquitoes in the area. Such inspections do not determine the absolute population of mosquitoes, but they can show fluctuations in relative mosquito abundance and diversity over time in the various habitats visited.

Mapping. Reasonably accurate and comprehensive maps are essential in conducting a mosquito-control operation. Maps provide information for field survey and control activities, program evaluation, and reporting and budgeting purposes. They show elevations, streets, roads and railroads, as well as ponds, lakes, streams, sewage lagoons, flooded woodlots and other breeding areas. They are used for orientation and for locating and plotting larval breeding places and adult sampling stations.

When large areas are involved, a master map may be needed for planning drainage and other field operations. The master map will indicate the treatment areas, the possible flight range of mosquitoes from breeding sites and the potential degree of penetration into populated areas. Larval and adult sampling stations can be indicated by symbols and numbers. Counts made at these stations at weekly or biweekly intervals provide information for current evaluation of the mosquito problem at any time by indicating the abundance of mosquitoes, species involved, flight range and habitat, and disease potential. This information identifies areas requiring high priority for treatment.

Narrative descriptions, sometimes necessary for exact location description, are simplified whenever possible. For example, “N.W. corner of 15th Street and Ninth Avenue” is a brief description that leaves no doubt as to the location. There may be some areas that are difficult to accurately locate (e.g., marshlands). However, maps can be subdivided into numbered or named areas for easy reference, and Global Positioning System (GPS) coordinates are very reliable. Some common methods of subdividing maps involve the use of geographical features, artificial grids or a combination of both to set boundaries on areas that are indexed for easy reference and filing. To avoid cluttering, the larger areas may be further subdivided by the use of transparent overlays, again employing geographical features or a grid. Once the area of inspection is delineated by reference to index numbers, additional location data can be conveyed clearly by the use of cards that include a rough sketch of the area or incorporated into a Geographic Information System (GIS) format.

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

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

Mosquito Egg Surveys

Egg surveys are carried out primarily to determine the exact breeding locations of mosquitoes. *Aedes*, *Ochlerotatus* and *Psorophora* mosquitoes lay their eggs on damp soil in places subject to intermittent flooding. Two types of egg surveys may be conducted for these genera: sod sampling and egg separation.

Sod sampling. Sod samples, usually containing 8 cubic inches of soil and vegetation with a thickness of about an inch, are stored for a week or more to allow the embryos time to develop within the eggs. The sod samples are then placed in glass jars and flooded with water. The larvae are identified after they hatch. Several sequential floodings and dryings might be necessary to get sufficient cumulative hatch. In larval surveys, sod sampling delineates breeding areas, especially when sampling is done during times when larvae are not present.

Figure 3.6.
Egg separation machine

Egg separation. Egg separation machines can be used for separating mosquito eggs from soil and debris by mechanical agitation, washing, screening, or sedimentation of debris and flotation of the eggs in a saturated salt solution. Sod or soil samples are cut in the field with a sharp trowel around a 6-inch-square template, placed in plastic bags and stored (sometimes for months) in a cool room. The various species and densities of *Aedes*, *Ochlerotatus* and *Psorophora* can be identified by microscopic examination of live or preserved eggs using taxonomic keys for mosquito eggs.

Oviposition trap. Collections of mosquito eggs in oviposition traps are used to detect and monitor container-breeding mosquitoes such as *Oc. triseriatus, Ae. aegypti* and *Ae. albopictus*. The oviposition trap can easily be made out of food cans (3-pound coffee cans) or pint jars painted black inside and outside. The traps are placed in shaded areas at a height no greater than 1.2 m and filled with water and a few dried leaves placed at the bottom of the container. An oviposition **substrate** made of a strip of various materials (seed germination paper, muslin, formica, balsa wood, wooden tongue depressor, etc.) is then placed vertically inside the container with the water covering about half of it. **Gravid** females use this substrate to lay eggs just above the water level. Traps are checked every 10 to 14 days to prevent them from becoming breeding sources. If larvae are found in the trap then the water should be dumped and the trap reset. The ovipositional substrate is periodically collected and returned to the laboratory in a plastic bag. Samples are kept cool and moist during transportation, taking care to avoid too much moisture, which could cause eggs to begin hatching. Eggs or the resulting 4th **instar** larvae are then identified.

Larval and Pupal Surveillance

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

Equipment. A white enameled or plastic dipper about 4 inches in diameter (1 pint or 350 ml capacity) is frequently used for collecting mosquito larvae (Figure 3.7). The handle of the dipper may be lengthened by inserting a suitable piece of wood dowel or PVC pipe. Specially designed dippers can be created so that their capacity can be directly related to the amount of water surface examined. Thus, the number of larvae per square foot or meter can be computed with reasonable accuracy.

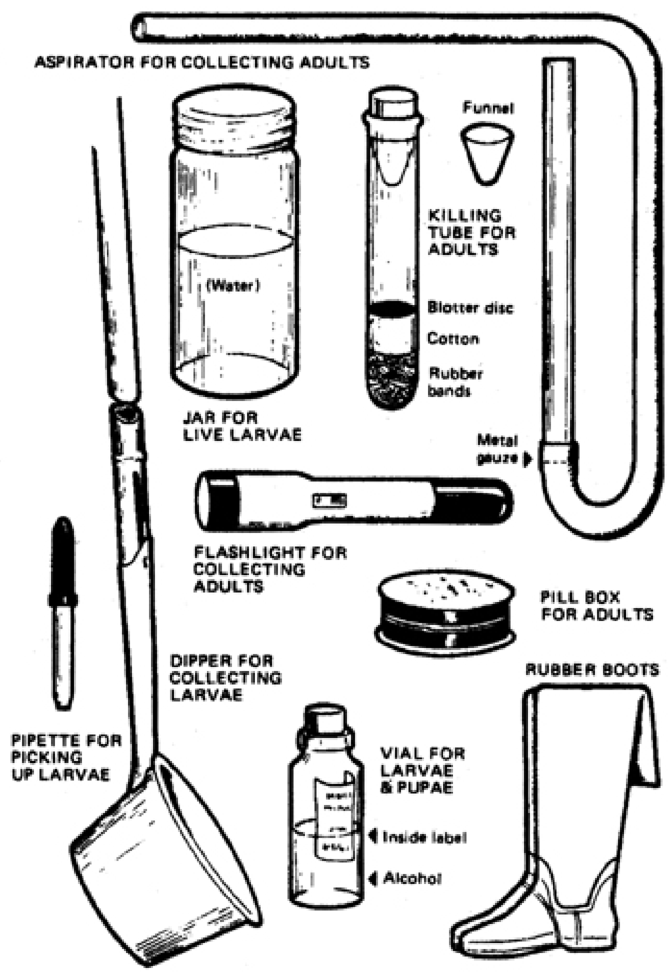

Figure 3.7. Surveillance equipment for adult and juvenile mosquitoes

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

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

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

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

Adult Surveillance

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

Landing and biting collections. The required equipment for this method of adult-mosquito survey is simple and inexpensive and consists of an ethyl-acetate-charged collecting tube or power aspirator, pill boxes, cages for live collections, field record-forms or notebook, pencil, flashlight and map (Figure 3.7). Although most districts use battery-operated mechanical aspirators, a simple mouth-suction aspirator can be made from a section of plastic (or glass) tubing 12 inches long with an inside diameter of about ⅝ inch. Cover one end of the tube with a bobbinet or fine wire screening and then insert it into a piece of rubber tubing 2 to 3 feet long. Small pill or salve boxes are convenient for holding dead mosquitoes until they can be identified. A wisp of crumpled soft tissue or lens paper will prevent subsequent damage to the specimens.

Collecting mosquitoes as they bite or land on the surveyor's body is a convenient method of sampling populations. The subject sits quietly for a designated period of time, usually five to 10 minutes, collects the mosquitoes with an aspirator and places them in the collection jar for later identification. It is customary to make landing collections near sundown as this **crepuscular** period is the most active time for most mosquitoes. Some individuals are more attractive to mosquitoes than others, so the same person or bait animal might be used throughout a survey. Make collections at about the same time of day and for the same duration, so that activity rates at different stations may be compared to show trends in mosquito abundance. In areas where mosquito-borne disease occurs, landing rates are preferable to biting rates.

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

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

Truck trap collection. Some organized mosquito-control districts use the basic truck trap, which consists of a large funnel-shaped frame covered with screen and mounted over the roof of a light truck with the entrance (larger) end forward (Figure 3.8). When driven at low speed (10 to 15 mph) for a fixed distance, mosquitoes caught in the collection bag represent a reasonably unbiased sample in terms of variables in attraction.

Figure 3.8. Basic truck trap

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

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

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

The New Jersey mosquito light trap (Figure 3.9) has been widely used in obtaining data on the density and species composition of mosquito populations. It is powered by 110 volts AC and is placed near a continuous supply of power.

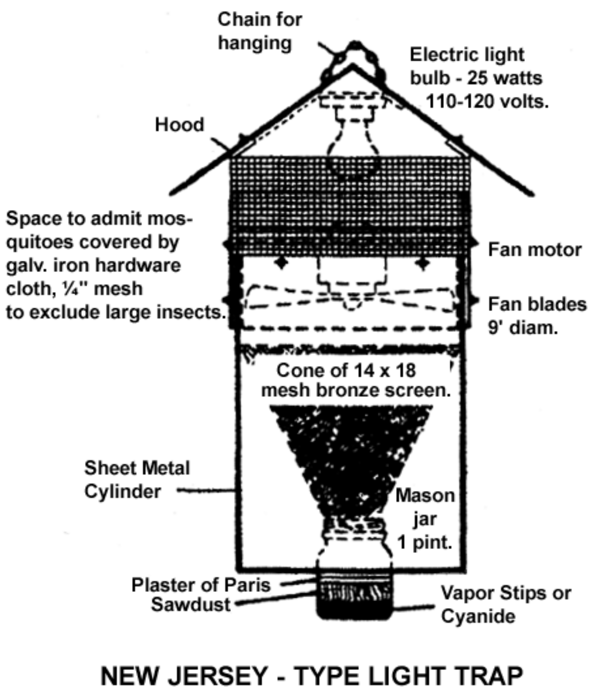

Figure 3.9

The battery-operated Centers for Disease
The battery-operated Centers for Diseases Control (CDC) Miniature Light Trap (Figure 3.10) was developed for portability to conduct live mosquito catches in remote areas where standard electric power is not available. As the mosquitoes respond to the attractants they are blown downward through a screen funnel into a killing jar or a mesh bag suspended below the trap. It collects a high percentage of mosquitoes in proportion to other insects and many more females than male specimens, a desirable feature in collecting mosquitoes for virus studies. You can also use the EVS or black can light trap developed by California State Health Department personnel.

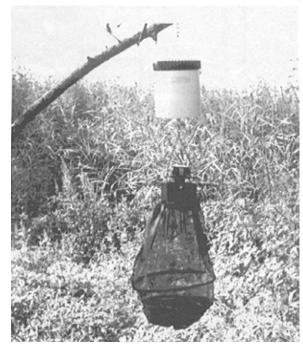

Figure 3.10.
Battery-operated
CDC Miniature Light Trap

Different species of mosquitoes have wide differences in their reactions to light. Light trap collections are often used to complement other methods of sampling mosquito populations. These traps can be converted to monitor densities of mosquitoes not attracted to light by removing the light and using only carbon dioxide as the attractant. With light as an attractant these traps have proven very useful in measuring densities of some of the culicine mosquitoes, such as *Oc. sollicitans, Ae. vexans* and *Cq. perturbans.* Some anophelines, especially *An. walkeri,* are also readily taken in light traps. The use of carbon dioxide only as an attractant collects large numbers of *Oc. canadensis, Oc. fitchii, Oc. stimulans* and *Oc. intrudens.* However, members of the *An. quadrimaculatus* and *Cx. pipiens* species complexes and *Ae. aegypti* are seldom taken in significant numbers. Light trap collections may fluctuate with the dark and bright phases of the moon, being greatest during the dark phases. The effect of moonlight can be offset to some extent by placing traps in locations shaded from the moon.

Gravid trap collection. This trap has proven to be very effective in capturing large numbers of undamaged **gravid** *Culex* mosquitoes. Gravid traps are easy to build, light-weight, portable and run on one 6-volt gel cell rechargeable battery. One gallon of attractant (infusions made from grass, rabbit pellets, manure, etc.) placed in a black tray draws gravid females to the trap to oviposit. While flying above the attractant's surface, the mosquitoes are drawn into the collection chamber by an air current created by a motorized fan. The mosquitoes are captured live and then can be used for virus-isolation studies or species density information.

Using Mosquito Survey Data

Data from the preliminary reconnaissance surveys are correlated with reported disease prevalence or complaints of pest mosquitoes. But it is only after reviewing all of this information that the health office or mosquito-control supervisor can make an intelligent decision as to the need for a control program and the type of control operations that will be most effective and economical.

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

The correlation between mosquito annoyance and numbers captured in light traps has been established in many localities. In one state, for example, it was determined that general annoyance did not ordinarily occur until the number of female mosquitoes of all species exceeded 24 per trap per night. Similar criteria can be worked out for other areas and also for various species. Meaningful action thresholds can provide justification for application decisions.

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

Arbovirus Surveillance in Vertebrate Hosts

Effectiveness of mosquito-control programs where mosquito-borne diseases are a concern clearly depend upon early detection of disease and prompt, skilled response. Enzyme-linked immunosorbent assay (ELISA) and polymerase chain reaction (PCR) methodology for testing reservoir bloods for SLE, EEE and other **arboviruses** give results fairly quickly. Surveillance methods leading to such tests include: frequent communication with other mosquito-control workers, health-care workers, and veterinarians; collecting and bleeding wild birds; and use of sentinel flocks of chickens, quail or pheasants.

Communicating with other professionals. State arbovirus surveillance committees maintain frequent contact with public-health and veterinary laboratories to collect and report information on mosquito-borne arbovirus activity. In addition, mosquito-control personnel keep in touch with local health-care personnel and veterinarians about indications of arbovirus activity in the area. If cases are suspected, that information is passed along. It is important to note that not all cases of encephalitis are mosquito-borne. Caution must be exercised in reacting to initial reports, and appropriate agencies need to work closely to get laboratory confirmation of suspected cases.

Sampling wild bird populations. Pesticide applicators may be required to collect blood from birds on a regular basis. If a wild bird is infected with a mosquito-borne virus, the serology results will be positive. However, the positive result does not indicate the time of exposure. Therefore, information from yearlings or birds that previously tested negative is much more informative. Young birds can be taken from the nest, bled and returned to the nest. Bleeding nestling birds has some advantages, but timing is critical and care must be taken not to injure the young birds. Sampling personnel must also ensure that the adult birds do not abandon the nestlings after they have been bled. An obvious advantage to bleeding nestling birds is that the age and travel history of the nestling is known, and, therefore, a positive result can be tied to a specific time frame and specific geographical location.

Vertebrate Host Collection

Use mist nets, baited traps or cannon nets to capture juvenile and adult birds alive. For special studies, birds can be shot. The appropriate state and federal permits are required before collecting birds with any of these methods. Furthermore, banding permits are required if one wishes to band birds before they are released.

Mist nets. Mist nets are perhaps the most common means of collecting wild birds. The most popular nets are about 40 feet long and 7 feet high, commonly supported by metal poles and suspended 4 to 5 feet above the ground. These nets are made of materials that are difficult to see, causing the birds to become entangled in the fibers. The mosquito-control worker can then remove the birds, draw blood samples and release them at the site. Some districts band some or all of the birds prior to release.

Baited traps. Bait traps are especially useful in trapping sparrows, grackles, doves, quail and pigeons. The bait (grain, seed or both) is scattered around the trap to attract birds. Additional bait is placed in the trap to lure the birds inside to get to the bait. Bait traps are usually equipped with large hinged openings so that the trapped birds can be removed easily. Elevated bait traps, which may be more attractive to some species of birds, are used where cats or other predators pose a threat.

Cannon nets. These devices are used to collect large numbers of blackbirds, pigeons, ducks, cowbirds and other birds that travel and feed in large flocks. They are the only realistic way to capture some species alive. The cannon net is designed so that one edge is anchored to the ground and the other is attached to rocket projectiles that carry the net over feeding birds. Because cannon nets are expensive and require several people to remove birds quickly to avoid injuring them, this is probably the least-used trap method.

Shooting. This expensive and time-consuming method is available when other methods are inadequate. The collector must purchase the appropriate hunting licenses. Furthermore, all game laws must be obeyed and collections can only be made during regular hunting seasons. In addition, since the birds (usually waterfowl) are killed, nonspecific blood reactions could interfere with antibody testing. Although this technique may yield valuable information, especially on the overwintering of viruses, it is used sparingly.

Sentinel flocks. Chickens, quail, pheasant or other birds are retained in outdoor cages in specific sampling areas and bled periodically to monitor arbovirus activity. These sentinel birds are raised in a mosquito-free environment and tested prior to placement to ensure that they have not been exposed to arboviral activity elsewhere. If the sentinel bird tests positive after being placed in an area, it is a sure sign of arbovirus activity in the area. A supply of unexposed birds should be readily available to replace those that become infected. To adequately sample large areas requires numerous sentinel flocks, so this method can be costly.

Monitoring other animals. Monitoring selected amphibians, mammals and reptiles that have been shown to circulate arboviruses or form antibodies after virus exposure is sometimes practical. When the overwintering mechanisms for the viruses, the importance of these animals as reservoirs and the bionomics of the viruses are clearly understood, they will become an important source of information.

Blood Collection

Field procedures. Quickly remove wild birds from nets and bait traps to minimize the risk of injury and place them directly into holding cages. Bleed them one at a time. Take a blood sample from the large vein in the neck (jugular) or wing, mix it with diluent in a properly labeled vial and store in an ice chest. Then release the unharmed bird. The appropriate collection data includes: date and location; species, sex, and age of the bird; state laboratory number; band number (if applicable); name of the collector; and any other relevant information.

Laboratory procedures. The vials containing blood and diluent are spun in a centrifuge until the serum has properly separated from the blood cells. The serum is then transferred to a clean, properly-labeled vial and refrigerated at 33EF to 40EF until it is ready for shipment to the testing laboratory in a watertight container packed with ice (not dry ice).

Arbovirus Surveillance in Mosquitoes

Perhaps the best early warning method available is the isolation of virus from wild mosquitoes. Because female mosquitoes must feed on an infected animal before they can pick up the virus, collect female mosquitoes that have had at least one blood meal — as indicated by an abdomen engorged with fresh or partially digested blood meals or containing eggs. There are a number of sampling methods and procedures that will help increase the ratio of engorged and gravid *Culex*, but this is more difficult with *Aedes, Anopheles, Culiseta, Coquillettidia*, *Ochlerotatus* or *Psorophora*. Aspirate *Culex* from dark closets, cabinets, or other areas of abandoned homes and vacant buildings whose open windows or doors are attractive to *Culex* mosquitoes seeking places to rest during the day. If the buildings are sampled on a regular basis, the mosquitoes collected probably will have fed on a variety of hosts. Gravid traps are also useful for collecting gravid specimens of adult *Culex* as well.

Light traps and carbon-dioxide-enhanced traps can be used effectively in wooded areas, storm drains, catch basins, manholes, tire piles, etc., but they tend to collect many mosquitoes that have not had a blood meal. Resting boxes can be used to collect some important vector species (e.g., **anophelines**), but they do not necessarily bias the collection toward gravid or engorged females, and they do not normally collect large numbers of mosquitoes.

Transporting mosquitoes. Store live mosquitoes in a cool, moist container, and identify and pool them as soon as possible. An ice chest containing a small amount of ice (not dry ice) is ideal for transporting mosquitoes, taking care that the mosquitoes do not get wet during shipment.

Holding, identifying and pooling collections. Once in the laboratory, mosquito collections may be refrigerated or frozen but should not be left outside the refrigerator for extended periods of time during identification. Mosquitoes from each collection are identified separately and a fixed number, usually 50 of the same species, placed in a properly labeled container for shipping to the laboratory in the same manner as bird bloods. Use a chill table to identify, sort and pool adult mosquito samples to keep specimens cool and preserve viruses that might be present in them.

IV. CONTROL

While it is not possible to provide a concise, generic overview of all mosquito-control programs in the U.S., there are certain components that virtually all operational programs include as they are inherent to the principles and practices of Integrated Pest Management (IPM). Traditionally an overriding concept in organized mosquito control, the IPM acronym was not used in this sense a century ago when mosquito control was in its infancy. Typical IPM programs use a combination of resource-management techniques that include source reduction, habitat modification, biocontrol, larviciding and adulticiding, all based on surveillance data as to need and timing of application. Continuing education, for both employees and the general public, is also an important component of most mosquito-control programs. This has resulted in a more-informed public and increased professionalism among mosquito-control workers where significant progress has been made in attempting to reduce pesticide use and risk.

An important consideration in the practice of mosquito control is the advisability, whenever possible, to target control operations against immature populations. These stages are usually concentrated, relatively immobile and therefore occupy minimum acreage compared with adults, which may rapidly disperse over large areas. By targeting the immatures, it is possible to minimize the area treated and often avoid treating populated areas. Conversely, targeting adult mosquitoes may require highly visible and extensive applications of **adulticides** within residential and urban areas. The adulticides registered for this use are applied at levels 100 to 10,000 times below rates that would be cause for concern about exposure risk for the general public or the environment. Nevertheless, achieving good larval control while at the same time minimizing the use of adulticides is environmentally and client friendly, and appreciated by the public.

Most states have specific regulations governing the decision to apply pesticides for mosquito control. These usually involve the collection of data that substantiate the need for the application. Thus, standardized **ultra-low-volume** (ULV) operation on a fixed schedule is not allowed in most areas. Each application must be justified by documentation of increased mosquito activity, such as trap collections, landing or biting counts, telephone complaints, etc. This documentation must be available for official inspection upon demand.

The use of pesticides for mosquito control is considered a temporary form of control. Because it is unreasonable to expect to completely eliminate the next generation by treating the current generation, the process may have to be repeated time and again. This is true for chemical treatment of both immature and adult populations of mosquitoes. The need for this type of temporary control can be reduced by implementing permanent control measures whenever and wherever possible. Permanent control measures are discussed in the next section — source reduction. They include land and water management approaches that prevent breeding. Where successful, they can be permanent in nature — perhaps requiring limited maintenance from time to time. Although this activity may escape the attention of the public, it is extremely effective in easing the management burden of protecting the public from mosquitoes.

Source Reduction

Source reduction ranges from the simple overturning of a discarded bucket or disposing of waste tires to complex water-level manipulations in marshes. The removal or reduction of mosquito breeding habitat is often the most effective and economical long-term method of mosquito control. These efforts often minimize or even eliminate the need for mosquito larviciding in the affected habitat and greatly reduce adulticiding in nearby areas.

Sanitation. Containers of all types and man-made structures such as cisterns, roof gutters and discarded tires are capable of producing prodigious numbers of mosquitoes, including species that can transmit several **pathogens**. Removal of debris and regular inspection, when conducted on a continuous basis, reduces breeding in such sites. Typically, mosquito-control-related sanitation efforts are best accomplished by homeowners and residents who through their own actions have created mosquito breeding around their homesites (**peridomestic**). Mosquito-control agencies often support educational programs that call attention to the hazards and recommend individual efforts on residential-area cleanup.

Water management. Prevention of breeding can be accomplished by removing surface waters from productive sites to reduce **oviposition**, manipulating shoreline water levels or flooding areas in which mosquitoes oviposit in the soil. These approaches have been used for decades and involve ditching, diking, daily water-management manipulation and retrofitting of catch basins and storm drains to manage the aquatic habitat. Experience has demonstrated this can be harmful to the ecology of the affected habitats if practiced without due concern for the long-term consequences of habitat manipulation. Therefore, permits are required to initiate new projects of this nature, but in many areas maintenance of existing schemes is allowed without permits.

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

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

Larvicides

The application of chemicals to kill immature mosquitoes by ground or aerial applications is typically more effective and target specific than adulticiding, yet less permanent than source reduction. Several materials in various formulations are labeled for mosquito larviciding, including some **biorational** pesticides, diptera-specific bacteria, insect growth regulators (IGR) and chitin synthesis inhibitors. Also labeled for mosquito control are conventional insecticides, several nonpetroleum oils and **monomolecular film**.

The timing of **larvicide** application is dependent on the nature of the control agent. Conventional insecticides, for example, kill **larvae** at all stages and thus can be applied when convenient. Bacterial toxins must be consumed by the larvae and are usually applied well before the 4^{th} **instar** to ensure that consumption occurs. IGRs mimic an essential hormone present in high concentration in early instar larvae but in very low concentration in late (4^{th}) instar larvae. Exposure of 4^{th} instar larvae to the IGR upsets the physiological **molting** process and kills mosquitoes in the subsequent **pupal** stage. IGRs can be formulated as slow release insecticides so that application in the 2^{nd} or 3^{rd} instar will result in an adequate exposure during the 4^{th} instar. Chitin synthesis inhibitors affect the ability of the larvae to reattach their muscles to the **exoskeleton** during the molting process and thus are effective throughout the entire larval life. Monomolecular films prevent the insect from remaining at the surface of the water by reducing surface tension. Under these conditions larvae and pupae deplete their energy reserves trying to stay at the surface and succumb to exhaustion. Nonpetroleum oils kill larvae and pupae by suffocation because the insects are not able to obtain air through the **siphon** at the oily surface.

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

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

Adulticides

The ground or aerial application of chemicals to kill adult mosquitoes is usually the least efficient mosquito-control technique and is considered the last resort. This option is reserved for managing mosquito populations that have reached the adult stage in spite of efforts to intervene in the larval stage or when such treatment has not been conducted. The tendency of poorly funded or misguided mosquito-control organizations to use only **adulticiding** and bypass the other, often more effective, options available conflicts directly with accepted practice. Nevertheless, adulticiding, when based on concurrent surveillance data, is an extremely important part of the IPM approach when undertaken with the appropriate label amount of insecticide. Adulticides are often applied as **ultra-low-volume** (ULV) sprays in which small amounts (3 fluid ounces or less per acre) of insecticide are dispersed either by truck-mounted equipment or from fixed-wing or rotary aircraft. Ground or aerially applied thermal application of adulticides is also used in some areas but to a much lesser degree.

Mosquito adulticiding with **ULV application** differs fundamentally from efforts to control many other adult insects. The fine ULV droplets (high concentration but very low dosage) must drift through the habitat and impinge on flying mosquitoes in order to provide optimal control benefits. These applications are programmed to occur between dusk and shortly after dawn, when most beneficial insects are resting. These tiny droplets are unlikely to impinge on objects larger than mosquitoes because those larger objects' physical characteristics and size cause the droplets to drift around rather than deposit on them. The very small flying mosquitoes, however, do not ward off the small droplets in this manner. Also, use of the fine ULV droplets means that there are literally millions more droplets to impinge on mosquitoes than there would be if larger droplets were used.

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

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

Barrier treatments, typically applied as high volume (low concentration) liquids with hand-held spray equipment using compounds with residual characteristics, are common in some U.S. locations and their use is growing. This technique is especially attractive to individual homeowners living near mosquito-producing habitats where residual chemicals applied to the vegetation along property borders can provide relief to the residents.

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

Adulticides labeled for mosquito control include organophosphates, natural pyrethrins and synthetic pyrethroids. As with other pesticides, the specific attributes and methods of use for adulticides are listed on the label. It is incumbent on the pesticide applicator to perform as directed by the label.

Biological Control

Biocontrol is the use of biological organisms to control pests, in this case insect pests. Biocontrol is popular in theory because of its potential to be **host**-specific with virtually no **nontarget** effects. Overall, larvivorous fish are the most extensively used biocontrol agent for mosquito control. Predaceous fish, such as *Gambusia affinis* and other top minnows (*Poeciliidae*) and killifish (*Cyprinodontidae*) that occur naturally in many aquatic habitats, can be collected (or in some cases propagated) and placed in permanent or semipermanent water bodies for larval control. Other biocontrol agents have been tested for use by mosquito control but to date have not generally been operationally feasible. These include the predaceous mosquito *Toxorhynchites*, predaceous copepods, the parasitic nematode *Romanomermis* and the fungus *Laegenidium giganteum.* Biocontrol certainly holds the possibility of becoming a more important tool and playing a larger role in mosquito control in the future when improved technology and more attractive economics may enhance its usefulness. Unfortunately, there is no basis for the often-claimed suppression of mosquito biting activity by bats or purple martins. Their predation is insufficient to impact significantly on mosquito density.

By-products of biological control agents are marketed as biorational pesticides for mosquito control. These products include dead bacterial spores that are highly toxic to mosquito larvae and a few other aquatic **dipteran** species but innocuous to nontarget organisms. While not biological agents per se, these products and the physiologically effective insect growth regulators have been instrumental in creating environmentally friendly options for control of larval mosquito populations.

Personal Protection

The public and the pesticide applicator must consciously adopt personal behavior practices that reduce the probability of receiving infective mosquito bites. For example, most, but not all, vectors are quite active during **crepuscular** periods at sunset and dawn. This is a time of day when attractiveness to mosquitoes should be minimized. Staying indoors as much as possible, especially if there is an alert situation in connection with mosquito-borne disease, is one way to avoid contact. If it is necessary to go outside, wear light-colored clothing (which is less attractive to mosquitoes), trousers and long sleeves, and apply a repellent to the exposed skin — carefully following the manufacturer's directions on the label. Remove water-holding containers from the yard, clean roof gutters and use other physical means to reduce **peridomestic** breeding near the home. Avoid known mosquito habitats, if possible, and keep personal exposure to a minimum. In the U.S. residents are fortunate that mosquito-borne disease transmission to humans is relatively rare, and infected people often do not have overt symptoms. Thousands of infections could, theoretically, occur annually without causing clinical symptoms, but in a low percentage of cases infection can lead to disease. So, prudence is the watchword. Personal protection is a means to reduce the probability of infection. Do not rely on electronic devices or claims of sonic or ultrasonic impact on mosquito behavior, as none of these has been found effective.

There are other reasons for the relatively low incidence of human involvement with mosquito-borne diseases in the U.S. But we often overlook the obvious by building homes at the margins of wetlands, thereby multiplying the probability of mosquito encounter and infection. Yet, affordable housing, proper screening, indoor plumbing, air conditioning and television all contribute to reducing human exposure to mosquitoes even in high-mosquito-density areas. Societies in tropical and subtropical climes are sometimes less fortunate in terms of the physical protection from mosquitoes that is afforded by their surroundings.

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Table 3.1. Genera and important mosquito species in the United States (**Family Culicidae)**.

Only the most important **species** in each **genus** are listed by name.

Subfamily Anophelinae (anophelines)

Genus ***Anopheles*** 17 spp.

albimanus, bradleyi, crucians, franciscanus, freeborni, hermsi, psuedopunctipennis, punctipennis, quadrimaculatus spp. complex*, walkeri*

Subfamily Culicinae (culicines)

Genus ***Aedes*** 4 spp.

aegypti, albopictus, cinereus, vexans

Genus ***Coquillettidia*** 1 spp.

perturbans

Genus ***Culex*** 29 spp. & subspecies

erraticus, nigripalpus, peccator, pipiens, pilosus, quinquefasciatus, restuans, salinarius, stigmatosoma, tarsalis

Genus ***Culiseta*** 8 spp.

incidens, inornata, melanura

Genus ***Deinocerites*** 3 spp.

cancer, mathesoni, pseudes

Genus ***Haemogogus*** 1 spp.

Genus ***Mansonia*** 2 spp.

dyari, titillans

Genus ***Ochlerotatus*** 77 spp.

abserratus, atlanticus, canadensis, cataphylla, communis, deserticola, dorsalis, excrucians, fitchii, hexadontus, increpitus, monticola, nigromaculis, punctor, sierrensis, sollicitans, spencerii, sticticus, stimulans, taeniorhynchus, triseriatus, trivittatus, varipalpus

Genus ***Orthopodomyia*** 3 spp.

signifera, alba

Genus ***Psorophora*** 15 spp.

ciliata, columbiae, cyanescens, ferox, signipennis

Genus ***Toxorhynchites*** 2 subspecies

Genus ***Uranotaenia*** 3 spp. & subspecies

sappharina

Genus ***Wyeomyia*** 4 spp.

mitchellii