## IV. DESCRIPTION OF MOSQUITO SPECIES AND ABATEMENT HABITATS

### A. Mosquito Species

#### 1. General Biology

Mosquitoes belong to the family Culicidae of the Order Diptera (true flies), insects with one pair of clear wings. There are 167 North American species in 13 different genera (Darsie and Ward 1981). Of these, 46 in 9 different genera have been found in Massachusetts (Table 12). About one-half of these (from 5 different genera) may at times cause significant human annoyance in certain localities; the majority belong to the genus *Aedes*. No mosquito species feeds exclusively on humans. Those species that annoy humans feed on a wide variety of other mammals and occasionally on birds as well. Some non-human-biting species such as *Cs. melanura*, *Cs. morsitans* and *Cx. restuans* can be important in the maintenance of enzootic disease cycles in wildlife. Some of these diseases, e.g., Eastern equine encephalomyelitis (EEE), occasionally spill over into human populations via transient epidemic vectors.

Mosquito life cycles can be grouped into two basic types: permanent-water and temporary-water (or flood-water). Temporary-water species generally belong to the genus *Aedes* or *Psorophora* and present the major pest problem in Massachusetts. Adult females can readily be distinguished from permanent water forms because their abdomen terminates in a sharp point formed by the extended cerci. This group overwinters as dormant eggs laid singly by females (usually ca. 75-150/female) in the band of moist soil surrounding the evaporating temporary pools in which the larval stages developed. Hatch (stimulated by increased temperature or reduced $O_2$) occurs when these depressions are flooded by tides, rains, irrigation or flooding rivers. The eggs of most temperate flood-water species must undergo a prolonged cold-conditioning period prior to hatch so there is normally only a single generation early each season (univoltine species). In a few species such as the eastern saltmarsh mosquito, *Ae. sollicitans*, eggs laid in the earlier part of the season will hatch after only 2-4 weeks of conditioning so multiple generations (multivoltine) are commonplace. The terms generation and brood are not always synonymous because not all eggs hatch when flooding occurs, so that multiple <u>broods</u> may sometimes occur from a single <u>generation</u> of overwintering eggs. In Massachusetts, reflood species like *Ae. vexans*, *Ae. sticticus*, and *Ae. trivittatus* (and perhaps late spring-hatch species like *Ae. canadensis* and *Ae. cinereus*) may have multiple generations or just multiple broods caused by delayed egg hatch. In spring, larval development of temporary-water mosquitoes may require two months or more

Table 12. Systematic Index of the Culicidae of Massachusetts

| Taxon | Taxon |
|---|---|
| Genus *AEDES* | Genus *CULEX* |
| Subgenus *Aedes* | Subgenus *Culex* |
| *cinereus* (Meigen) | *pipiens* Linnaeus |
| | *restuans* Theobald |
| Subgenus *Aedemorphus* | *salinarius* Coquillett |
| *vexans* (Meigen) | |
| | Subgenus *Neoculex* |
| Subgenus *Ochlerotatus* | *territans* Walker |
| *abserratus* (Felt & Young) | |
| *atropalpus* (Coquillett) | Genus *CULISETA* |
| *aurifer* (Coquillett) | |
| *canadensis* (Theobald) | Subgenus *Climacura* |
| *cantator* (Coquillett) | *melanura* (Coquillett) |
| *communis* (De Gerr) | |
| *decticus* Howard, Dyar & Knab | Subgenus *Culicella* |
| *diantaeus* Howard, Dyar & Knab | *morsitans* (Theobald) |
| *dorsalis* (Meigen) | *minnesotae* Barr |
| *ercrucians* (Walker) | |
| *fitchii* (felt & Young) | Subgenus *Culiseta* |
| *implicatus* Vockeroth | *impatiens* (Walker) |
| *intrudens* (Dyar) | *inornata* (Williston) |
| *provocans* (Walker) | |
| *punctor* (Kirby) | Genus *ORTHOPODOMYIA* |
| *sollicitans* (Walker) | *signifera* |
| *sticticus* (Meigen) | |
| *stimulans* (Walker) | Genus *PSOROPHORA* |
| *taeniorhynchus* (Wiedemann) | |
| *trivittatus* (Coquillett) | Subgenus *Grabhamia* |
| | *columbiae* (Dyar & Knab) |
| Subgenus Protomacleaya | |
| *hendersoni* Cockerall | Subgenus *Janthinosoma* |
| *triserlatus* (Say) | *ferox* (von Humboldt) |
| Genus *ANOPHELES* | Subgenus *Psorophora* |
| | *ciliata* (Fabricius) |
| Subgenus *Anopheles* | |
| *barberi* Coquillett | Genus *URANOTAENIA* |
| *crucians* Weidemann | Subgenus *Uranotaenia* |
| *earlei* Vargas | *sapphirina* (Osten Sacken) |
| *punctipennis* (Say) | |
| *quadrimaculatus* (Say) | Genus *WYEOMYIA* |
| *walkeri* Theobald | |
| | Subgenus *Wyeomyia* |
| Genus *COQUILLETTIDIA* | *smithii* (Coquillett) |
| Subgenus *Coquillettidea* | |
| *perturbans* | |

while in summer it may be as brief as 4-6 days. Permanent-water mosquitoes deposit their eggs (generally a multi-egg raft of ca. 100-250 eggs except in the *Anopheles*) on the surface of permanent or semi-permanent (i.e. persists for several weeks) water and hatch occurs within 1-3 days. Populations are asynchronous compared to flood-water species (with several overlapping generations), and larval development tends to be longer. Some permanent water species (e.g., *Cq. perturbans*, *Cs. melanura* and *Cs. morsitans*) overwinter in a diapausing larval stage, but most overwinter as hibernating adult females that are fertilized, nulliparous (never having produced eggs), and non-blood-fed.

Mosquitoes metamorphose into the winged adult stage within the nonfeeding pupal stage. The pupa is active and aquatic (called tumblers) and is resistant to most chemical control measures (suffocating surface films are an exception). It normally lasts only 2-4 days. Males generally pupate and emerge about 1 day ahead of females of the same cohort.

Mating most commonly occurs in twilight swarms within 2-3 days after females emerge. Most, but not all, females mate before they take blood. Both sexes feed frequently on plant nectar; females take blood in order to obtain protein for egg development. A few species are autogenous, meaning they do not need a blood meal to produce eggs. One Massachusetts species, the pitcher plant mosquito (*Wy. smithii*), never takes blood. Most females begin seeking hosts 2-4 days after emergence but some species (e.g., *Cs. morsitans*) may delay feeding for 2 weeks or more. Thus, the time period between adult emergence and the first egg laying (first gonotrophic cycle) is usually 7-10 days. Subsequent host-feeding to egg-laying cycles in most temperate species require 4-6 days.

Species that transmit disease (vectors) must feed at least twice, once to acquire the infection, and once to transmit it, unless the infection is acquired transovarially (into the egg while in the ovary) from their mother. This means that females must normally survive for 12-14 days in order to be a vector. If the extrinsic incubation period of the pathogen/parasite in the mosquito is longer than the gonotrophic cycle, as is often the case, the survival time required for transmission is even longer.

Most females do not survive beyond the first oviposition but a few individuals in all mosquito populations live a long time (i.e., several weeks). Exceptionally, overwintering adults live 5-7 months. Males generally survive for shorter periods than females and never overwinter.

2. Saltmarsh mosquitoes

The leading pest mosquito problem in coastal communities in Massachusetts is caused by two brackish water species, *Ae*. *sollicitans* and *Ae*. *cantator*. The latter species is abundant only in the early part of the season (mid-May to mid-June); *Ae*. *sollicitans* is the major target of most saltmarsh mosquito control efforts. Both species develop in pans in the high salt marsh (dominated by *Spartina* grasses) which are normally only flooded by moon tides. Heavy rains or high tides caused by unusual winds can also cause intermittent flooding in the high marsh. *Ae. cantator* tends to occur more in the extreme upland edge of the high marsh. This area is often quite fresh and may include plants such as cattails. Unmaintained mosquito ditching can become an important breeding area, as *Spartina alterniflora* prevents the ditches from draining and shallow water is held between moon tides.

*Aedes taeniorhynchus* is a third species that occurs in salt marshes, often in conjunction with *Ae. sollicitans*. Complicating the control picture further is *Cx. salinarius* which sometimes breeds in after heavy, late-summer rains. As a result, salt marshes generally require monitoring at least twice a month (once after the full-moon high tide and once after the new-moon high tide) as well as after any major rain event. With regard to saltmarsh mosquito control, one should always assume that there are huge numbers of eggs available to hatch after any flooding; any other assumption will result in broods being missed and adult mosquitoes swarming in numbers not easily understood by one who has not experienced them.

Uncontrolled populations of salt marsh *Aedes* often reach extremely high biting densities (i.e., 100+ females landing/minute). Adults may not be particularly long lived, but because moon tides occur so regularly and often, multivoltine *Ae*. *sollicitans* can be a problem throughout the summer season. Because the economies of coastal areas affected by this mosquito often depend heavily on summer tourism, the impact of saltmarsh mosquitoes is greatly magnified. This is reflected in the percent effort coastal projects spend on saltmarsh *Aedes* control (Table 9).

Salt marshes and the estuaries they feed are the principal nursery grounds for a variety of marine and brackish water organisms, including several commercial forms. Disrupting these vital wetlands to control saltmarsh mosquitoes can cause unintended, long-term problems.

3. Freshwater mosquitoes. The most severe and predictable late-spring to early-summer mosquito annoyance in all inland (and many coastal) areas is caused by several species of *Aedes* collectively referred to as spring-hatch or snow-pool mosquitoes, the most common of which is *Ae. canadensis*. These mosquitoes tend to

develop in similar aquatic situations (i.e., temporarily flooded woodland depressions including the flooded borders of permanent swamps and bogs) and have similar life cycles. They overwinter as dormant eggs and have a single, spring generation each year (univoltine). Adult mosquitoes are most active from late spring to mid summer; the females taking blood meals and depositing their eggs in the moist soil and leaf litter around the edges of the evaporating woodland pools in which they developed as larvae. They are part of a larger grouping of mosquitoes called temporary-water or flood-water species which all have eggs that hatch synchronously when flooded by rain, tide, snow melt or rising rivers. In this case, snow melt and spring rain fill the woodland depressions that are stocked with eggs, usually causing hatch sometime in early March. Mild conditions in late February and early March followed by severe cold, or spring precipitation, can reduce larval populations by freezing or flooding. As a result, considerable year-to-year population variation occurs.

Spring-hatch *Aedes* can be subdivided into two major groups, dark-legged and banded-legged, based partly on the physical appearance of biting females and partly on some minor differences in their life cycles. The dark-legged group hatch and emerge about 1-3 weeks ahead of the banded-legged group and seem to survive as adults for a shorter period of time. Some members of this group (e.g., *Ae. punctor*) become more abundant at more northern latitudes (coniferous forest zone) and at higher elevations (e.g., near the top of the Holyoke Range). When people enter the densely shaded daytime resting places of these mosquitoes, females attack more aggressively than do members of the banded-legged group such as *Ae. stimulans* and *Ae. canadensis*. Dark-legged *Aedes* appear to be the principal vectors of California group encephalitis viruses. These viruses overwinter inside the eggs of their mosquito vector (Calisher & Thompson 1983).

The banded-legged group often develop in the same pools and rest in the same wooded, daytime resting habitats as some species in the dark-legged group. However, they tend to disperse further from the larval habitat and, during the early evening biting peak of both groups, banded-legged females feed more readily in open and semi-wooded habitats than to dark-legged females. Some banded-legged females survive into August, and this group seems to be the principal vector of dog heartworm in Western Massachusetts.

Although the general larval habitat of both groups is similar, considerable variation in habitat occurs and some species are more restricted than others. For example, certain dark-legged *Aedes* are mainly found in association with cranberry (*Ae. aurifer*) or sphagnum (*Ae. decticus*) bogs. Spring woodland pools vary from small, shallow depressions formed by fallen trees to large, deep ravines in mountain bedrock and natural swales in forested flood plains.  Permanent woodland or grassy swamps and bogs are also a common source of some members of the spring *Aedes* group.

a. *Aedes canadensis*. *Aedes canadensis* is perhaps the dominant spring-breeding mosquito in the Northeast.  It's primary habitat is woodland vernal pools; pools that having standing water from snow-melt until early summer.  Larvae can be collected even before the last frosts but development is slow during the cool spring months and adults usually do not emerge until near the end of May or in early June.  Although *Ae. canadensis* is an active biter, it does not generally fly far from the woods in which it breeds.  As residential areas have cut their way into the woods of Massachusetts, however, *Ae. canadensis* has become an increasing problem.

*Aedes canadensis* control is difficult because the pools in which it breeds are isolated from each other.  A small woodlot can contain many pools, some of which may require field workers to cut through poison ivy, multiflora rose, and bull brier just to reach.  Ground application of larvicide under such circumstances is tedious and, regardless of intent, often less than complete.

*Aedes canadensis* is predominantly univoltine, but a second brood (either delayed hatch of over-wintering eggs or early hatch of spring-laid eggs) can develop in early fall if rainfall is sufficient to partially fill the woodland pools.  In such cases, treatment is nearly impossible, as a summer's growth of the above-mentioned plants, coupled with a dense canopy of leaves from the many shrubs that line the pools make getting to the pool, and placing the correct amount of pesticide in the pool, extremely difficult.

b. *Aedes vexans*. *Aedes vexans* is the most ubiquitous floodwater mosquito in North America and is the predominant summer reflood mosquito in Massachusetts.  *Aedes vexans* is found in lake and river flood plains, shrub swamps, flooded meadows, and shallow grassy depressions associated with open habitats such as roadside ditches, pastures, golf courses and athletic fields.  It will also breed in woodland pools and shallow cattail marshes, such as those that develop in some retention ponds.  The first *Ae. vexans* are normally not on the wing before mid-June.  Populations of *Ae. vexans* are unpredictable because they depend entirely on the frequency and spacing of major rains.  Rainfall of 1 inch many produce some *Ae. vexans* but it usually requires 3" of rain within a short period of time (several days) to produce a large brood.

Larval broods of *Ae. vexans* have been observed as late as mid-September in Amherst.  It is not always clear whether such late season broods result from the delayed and staggered hatching of eggs that are a year or more old or from the hatching of non-diapausing eggs laid earlier the same season.  Brust and Costello (1967) and

Horsfall *et al* (1973) have shown that many species such as *Ae. vexans* lay some eggs that will hatch without cold conditioning. Sequential hatching of eggs is also well documented in five reflood *Aedes* species (i.e., *canadensis, cinereus, sticticus, trivittatus,* and *vexans*). Larval development is rapid, 4-6 days, and the pupal stage lasts for about 2 days. Hence, the window for effective larval/pupal control is narrow. Moreover, a large number of scattered pools all need to be treated within the same brief time span following major rains. Control efforts suffer from the same difficulties as described for *Ae. canadensis*, as *Ae. vexans* will often breed in mid-summer in the same pools used by *Ae. canadensis* in the spring.

c. Additional *Aedes* species

Lesser, but at times significant, populations of *Ae. triseriatus*, *Ae. trivittatus* and *Ae. sticticus* do occur in Massachusetts. Larvae of the latter two species are associated with ground pools in wooded or semi-wooded flood plains. Extremely heavy general rains sufficient to cause river flooding commonly proceed large populations of *Ae. trivittatus* and *Ae. sticticus*.

*Aedes triseriatus* is a treehole mosquito, breeding in the wild in holes left in trees when a branch breaks off and/or insect damage causes a part of the tree to rot out. Within the shaded forest it is a ready biter but it does not venture far from it's breeding areas. Because it's larval habitat is widely dispersed (and often well above the height that a person could reasonably be expected to reach), larval control is not possible. Fortunately, because it stays within the woods, control targeting *Ae. triseriatus* is rarely necessary.

*Aedes triseriatus* overwinter as eggs in the larval habitat; hatching occurs in early spring and development to the adult stage takes about 3 months. The first biting adults appear in late June in Massachusetts. Larval populations are often crowded and asynchronous so some emergence continues until early August. A second generation of larvae has been observed, especially in tires, where water is usually warmer and development is faster. However, it is doubtful that many adults from this generation are successful at this latitude. This mammal-feeding, diurnal species does not normally disperse far from its sylvan larval habitats. Biting adults are particularly active in the late afternoon, pre-twilight period (i.e., 4-7 PM).

If *Ae. triseriatus* stayed in the trees, it would be a minor pest, but it has become well adapted to breeding in tires, particularly where they are shaded. As a result, *Ae. triseriatus* can be a locally important pest wherever rimless tires are stored. Tire removal, and the prevention of illegal tire dumping along wooded roads, is an important part of mosquito control.

*Aedes atropalpus* is another natural container breeder, but it is associated with rock pools, especially those in exposed riverbeds. The northern form is autogenous for the first egg batch so it is a less bothersome daytime pest species than its southern sibling, *Ae. epactius*. This species has also become adapted to tires in the Midwest.

A new Asian container breeder, *Ae. albopictus*, has recently been introduced into the Southern United States (Texas), apparently via imported used truck tires (Moore 1986). This diurnal urban pest throughout Asia has already spread as far north as Indiana and is likely to appear in Massachusetts at some point (Nawrocki & Hawley 1987) Locations where used truck tires are brought in and stored for recapping are the most likely points of introduction. This species has mainly been found in tares in the United States to date. It is an efficient laboratory vector of many Western Hemisphere arboviruses (Shorter 1986).

d. *Culex* species. *Culex* mosquitoes have an ambiguous place in mosquito control in Massachusetts. On the one hand, they are commonly encountered as larvae in storm drains, cisterns, drainage basins and other contain-type situations but, on the other hand, the extent to which they cause biting problems for people and are involved in the transmission of disease, for example encephalitis between birds, is unknown. Species such as *Cx. territans* and *Cx. restuans* are certainly not pests of humans, but *Cx. restuans* may be involved in transmission of EEE between birds (it is common to pick up EEE in *Culex* pools in areas where it is present in *Cs. melanura* pools–the problem being that *Culex* pools are rarely sorted to species before testing).

*Culex* mosquitoes are multivoltine, having several generations per year. There can be considerable overlap among the generations. Adult females overwinter and are among some of the first mosquitoes to be seen in the spring. *Culex* mosquitoes do not bite during the day and are more active later at night than are most *Aedes* species.

The house mosquito, *Cx. pipiens*, breeds prolifically from mid to late summer in urban storm sewers, ornamental/wading/swimming pools, bird baths, plugged rain gutters, tires, car bodies, empty barrels, and other similar manmade containers. This species tolerates pollution, so the highest densities often occur in eutrophic water enriched by animal waste (e.g., sewage oxidation ponds). Multiple, overlapping generations (each requiring 8-10 days) occur in the same habitat. Mated but non-blood-fed females produced late in the season overwinter in underground sewers, basements, and other protected places.

The southern form, *Cx. pipiens quinquefasciatus*, feeds readily on both mammals and birds (Edman 1974), but the northern form, *Cx. pipiens pipiens*, which occurs in Massachusetts, is mainly associated with avian hosts. In large urban centers in the North, a less common autogenous form (*Cx. pipiens molestus*) exists. It readily attacks humans after the initial blood-free gonotrophic cycle is completed. This form has been documented in Boston, where it is associated with underground sewers and subway tunnels (Spielman 1973). *Cx. restuans* is often found in some of the same container habitats as *Cx. pipiens*.

*Culex salinarius* differs from the above-mentioned *Culex* species in that it is an active human biter and can occur in significant numbers. It's breeding habits are poorly understood as it is generally classed as a permanent-pool breeder but dense larval populations have been found in rain-fed pools in salt marshes in Rhode Island (salinities close to 0 ppm) and large adult populations existed in the coastal residential area of Bonnet Shores, RI in 1986 (Christie, personal communication).

The extent to which *Culex* species require control can be debated. Species such as *Cx. territans* almost certainly play no role whatsoever in either pest or disease problems. However, the ability to identify mosquito larvae to species is often not well developed and field identification can be difficult (though separating A*edes* from *Culex* requires little more than direct observation). Under such circumstances, treatment of any larval population is the general rule. Defining the role of *Culex* species in the magnification of EEE within the bird population would aid in determining the extent to which larval control of *Culex* should take place.

e. *Culiseta* species

*Culiseta melanura* occupies an interesting position in Massachusetts mosquito control in that it is the only known vector species in Massachusetts that is not also a significant pest. Therefore, controlling *Cs. melanura* in the larval stage, especially prior to documentation of EEE in adult *Cs. melanura* populations, is controversial in that the MCPs, as established, are not expected to target vector mosquitoes as a part of their routine work. The decision as to whether or not to attempt larval control would be made easier if *Cs. melanura* bred in habitats occupied by other pest species such as *Ae. vexans* or *Ae. canadensis*. Unfortunately, *Cs. melanura* breeds in a very specific habitat, the holes that develop around the roots of trees with cedar/maple swamps and is not routinely affected by treatment work for other species. In fact, because the holes are not interconnected and are often have only small openings, they are extremely difficult to treat even when the decision has been made to attempt larval *Cs. melanura* control.

Other *Culiseta* species exist in the state but have not been identified as vectors of disease or pests of humans.

f. *Coquillettidea* (formerly *Mansonia*) *perturbans*. Among a group of insects already disliked by humans, *Cq. perturbans* stands out as being particularly disliked by mosquito-control personnel. First, it is a large, aggressive biter that sparks complaint calls like few other mosquitoes and, second, because the larva lives attached to the stems of cattail, it is exceedingly difficult to monitor and control

In Massachusetts, *Cq. perturbans* has one generation per year. It overwinters in the larval stage (3rd instar) and adults begin to emerge in mid to late June, peaking in mid-July. Breeding occurs principally in cattail/water-willow ponds. These ponds are often caused by road, railroad, pipeline, power line, and parking lot construction next to natural wetland or seepage areas. Adults feed primarily during evening twilight periods on larger mammals situated in open pastures or in transitional habitats (Edman 1971). Birds are also attacked when they are available in the foraging habitat of this mosquito.

*Coquillettidia perturbans* presents unique control problems because larvae and pupae remain attached to the base of emergent plants at the bottom of deep ponds. Oxygen is obtained directly from the plant cells in which the modified air tube is imbedded. At this time there is no known effective larval control for *Cq. perturbans*, making adulticiding the only real choice for control in residential areas located near cattail marsh. For this reason, the present pollution-control fade of cattail ponds must be carefully monitored by mosquito-control programs. Wherever possible, manmade cattail drainage basins should be avoided or should be so constructed that, for a period of several weeks in late summer, no standing water is present in the basin. This will break the aquatic part of the life cycle.

*Coquillettidea perturbans* is a vector of EEE, compounding the problem of it's control by increasing the stakes in any decision not to control it.

g. Other freshwater species. Mosquitoes of the genera *Anopheles* and *Psorophora* can also be pests in Massachusetts. *Anopheles* mosquitoes differ from the other genera of mosquitoes in that, as larvae, they lie, upside down, on the under-surface of the water. They commonly inhabit more permanent waters and can sometimes be found along the edges of slow-moving streams. They are also fairly common later in the summer in puddles in dirt roads and other pools, often being found together with *Ae. vexans* and/or *Culex* species. *Anopheles* mosquitoes do not occur in the kinds of swarming numbers that *Aedes* mosquitoes do, but they enter houses more readily. They overwinter as adults and are some of the first mosquitoes to bite in the spring. Individual females are not uncommon in-house biters on the occasional warm day in spring.

*Psorophora ferox*, is a large, aggressive mosquito that breeds in the flood plains of overflowing summer rivers and streams. It is not common in the northeast but, where it is present, it is an unforgettable insect, both because of  it's size and the painful bite.

B. Habitats in which mosquito control takes place.

An understanding of where mosquitoes breed and feed is essential to understanding mosquito control. Perhaps one of the most frustrating things to the mosquito-control professional is the misunderstanding within the general public as to where mosquito breeding occurs and where mosquito control should take place. To anyone who works in coastal mosquito control, the new homeowner, experiencing her first summer brood of saltmarsh mosquitoes, is a familiar, and somewhat sorry, sight. Calls concerning, "...that pond of my neighbor's" are far more common than, "I have some vernal pools in the wood lot behind me."

The following discussion will start with breeding areas (coastal and inland wetlands and, to some degree, surface water bodies) and progress to adult habitats (surface water bodies, recharge areas, upland areas and agricultural areas). Finally, sensitive environments will be discussed from both a breeding perspective and with regard to adult mosquito control.

1. Coastal Wetlands

a. Marine. The marine habitat for mosquito breeding is restricted to salt marshes, generally between the level of mean high water and high high tide. Below mean high water tidal flushing is too frequent and too strong for mosquitoes to successfully breed and above high high tide the water longer has sufficient salinity to breed saltmarsh mosquitoes. The plant species most frequently associated with mosquito breeding are the short-form *Spartina alterniflora*, *Spartina patens*, and *Juncus gerardii*. Tall-form *Spartina alterniflora* generally defines the lower breeding edge (except in blocked ditching where the tall form edges the ditch) and *Iva fructesens* generally defines the upland edge.

*Aedes cantator* is the most common species when salinities are low (0 to 10 ppt) as occurs in the spring and after heavy summer rains. *Aedes sollicitans* dominates the mid-summer months when salinities are high (10 ppt and up). However, there is considerable overlap between the two species and it is not difficult to collect both in the same dip of water. *Aedes taeniorhynchus* is less common than above two species. *Culex salinarius* seems to be restricted to rain-fed pools at the upland edge.

b. Brackish. Both *Phragmites communis* (tall reed) and *Typha* species (cattail) obscure the boundary between fresh and salt water. Salinities in the range of 1 to 5 ppt occur and *Ae. cantator* dominates this type of habitat. Cattail tends to indicate a fairly constant source of freshwater, such as a stream or spring, while

*Phragmites* tends to indicate pooling of water for temporary periods at a level just high enough to avoid salt-water influence except under storm conditions.

2. Inland Wetlands.

Freshwater wetlands vary tremendously in size and hydrology, from small damp spots in isolated wood lots, to broad wooded swamps to sheet flow of spring water down the sides of hills. Mosquito breeding tends to be maximized in areas of temporary, standing water but the number of species that breed in freshwater makes generalizations difficult at best.

Red-maple swamps are a significant source of *Ae. absserratus* and *Ae. canadensis*. Flood plains, flooded meadows and shrub swamps produce *Ae. excrucians* and *Ae. vexans*.

Vernal ponds have received particular attention both because they breed mosquitoes and because they are an important breeding site for amphibians and other semi-aquatic animals. These ponds are rarely more than one-to-two-hundred square feet in surface area, and remain flooded from snow melt until drydown in mid to late June. They breeds *Ae. absserratus, Ae. excrucians, Ae. canadensis, Ae. cinereus* and, if dry down is late or the pool is reflooded by rain, *Ae. vexans* and *Anopheles* species. If such a pool is located in a flood plain, it can breed *Ps. ferox* as well.

Larger, deeper swamps cause considerable difficulty because, although the number of mosquito larvae per square foot may be low than in the vernal ponds, the size of the swamp more than makes up for the difference. Further, access to the central areas of the swamp is extremely limited, making aerial application the only practical control technique. *Aedes absserratus* and *Aedes* canadensis are two primary pest mosquitoes that emerge from these swamps. As the swamps dry down, innumerable pockets of water are left among the tree roots and *Cs. melanura* becomes increasingly easy to find as the swamps dry.

Flood-plain marshes, wet meadows and swamps produce *Ae. excrucians* in the spring and *Ae. vexans* in the summer. Flood plains are ideally suited for *Ae. vexans* as peak flooding is delayed for a day or more after rainfall and areas remain flooded longer than in other areas. This creates ideal conditions for breeding. In the summer East Middlesex MCP has recorded up to 5,000 *Aedes vexans* per night at collection sites in close proximity to river flood plains.

Shrub swamps are much less common than forested swamps so are less a target for mosquito control on that basis. *Aedes excrucians* seems to be the pest mosquito most likely to be found in such sites, and *Cu. restuans* is also common.

The mosquito problem associated with marshes depends on water depth and the presence of cattail. A marsh more than a foot deep with an extensive stand of cattail will breed *Cq. perturbans* and be a constant source of difficulty to control personnel. If water levels are lower, and cattail is replaced by emergent grasses and rushes, then *Ae. canadensis* and *Ae. vexans* may be present. Again, *Culex* and *Anopheles* species are fairly common in this type of marsh.

A less-common type of wetland is the sloping, forested wetland caused by water seepage and typically having a ground cover of skunk cabbage. Mosquito breeding is not high in such places, the slope preventing significant pooling, but manmade disturbances, such as cutting a dirt trail across the face of the slope, can pool water and provide breeding habitat.

3. Surface Water Bodies. As opposed to the wetlands described above, in which surface water often disappears for at least part of the year, surface water bodies generally have standing or moving water year-round and have an extensive, open water surface.

a. Lakes and ponds. Few mosquitoes breed in the open water of lakes and ponds. Breeding does occur in the wetlands, particularly cattail, that border the lake or pond. In East Middlesex MCP, flood plains and cattail marshes located on the edges of lakes and ponds produce massive populations of *Ae. Excrucians, Ae. vexans,* and *Cq. perturbans* (Henley, personal communication). Small ponds which become covered with floating plants such as duckweed can breed *Culex territans* and *Anopheles* mosquitoes. Small, manmade ponds lacking fish populations can also breed mosquitoes, especially where emergent vegetation exists.

Although not significant breeding sites, lakes and ponds are areas where adult mosquitoes congregate. Several reasons probably play a role, from the availability of water to drink, to the fact that mammals and birds tend to come to water to drink also and, that there are often wetlands immediately adjacent to more open bodies of water.

One important point to make is that there are numerous types of gnats and midges that, to the untrained observer, look much like mosquitoes. These insects breed in the sand or mud edging ponds and lakes and can give the appearance of huge numbers of mosquitoes as the adults swarm among the vegetation. Early-season complaint calls are often based on observations of these, no-biting, insects.

The fauna of all open bodies of water, including rivers and streams discussed below, are particularly susceptible to broad-spectrum pesticides such as malathion and the pyrethroids group. Larval control is rarely an issue, but adulticiding near open water always carries some risk of non-target kills.

b. Rivers and streams. The current in the open water of rivers and streams makes mosquito breeding impossible in all but the slowest moving sections. Even here the predator complex in most cases is too well developed for mosquitoes to survive in any numbers. Again, however, the wetlands bordering the river are significant breeding sites. Some breeding also can take place in intermittent streams, once they have stopped flowing and before they dry down completely.

4. Recharge Areas. Recharge areas are those in which surface water percolates down to recharge aquifers or drains into reservoirs. The obvious concern in such cases is that pesticides used in such areas may move along with the water, causing contamination of the aquifer or reservoir. The primary pesticides for mosquito control, resmethrin and Bti, break down quickly and do not pose a water-quality risk to reservoirs. Of course, adulticiding over wetlands can kill wetland species directly, though ULV rates are low enough that such kills are infrequent.

a. Wetland. Because wetlands are wet due to the impermiability of the substrate, their addition to recharge areas is often less than that of surrounded, drier areas. Pesticides applied to wetlands, therefore, are not likely to cause contamination by percolation. However, because wetlands do store water which can then move out of the wetland as runoff, pesticides applied to such areas may move off-site, including into reservoirs.

b. Upland. Upland recharge areas rarely have significant mosquito breeding, because the water percolates downward quickly. The primary concern in such areas would be heavy rainfall immediately after a treatment for adult mosquitoes. In such cases there could be overland flow of runoff contaminated by pesticide washed from leaf surfaces.

5. Upland Areas. This is a catch-all category for all lands not defined as wetlands. Obviously, the majority of human developments are located on uplands and the majority of adulticiding takes place within upland areas. Perhaps unconsciously, pesticides used for adult mosquito control are designed to be relatively benign to the plants and vertebrate animals of Massachusetts. No material that caused robins or squirrels to drop in their tracks, or which killed maple trees, would ever be permitted for use in Massachusetts. This makes ULV sprays in such areas appear reasonably benign. However, simply because the larger species do not exhibit acute effects, does not mean that no effects occur. One clear question that cannot be answered is what long-term effects do regular

adulticide treatments have on the less-visible fauna of the typical suburban woodlot-meadow habitat in Massachusetts.

6. Agricultural Areas. The muddy hoof-prints of the milk cows around the water hole may well breed *Ae. vexans*, but the proper control in such cases must take into account the fact that food for human consumption is the primary purpose of the land in question. The Bti and IGR larvicides currently available are unlikely to cause problems in meat, dairy or crop production, but adulticides are a different story. Pesticide residues are limited even on non-organically grown produce and a late-summer application has the potential to cause problems for growers. Of particular concern are the backyard gardens of homeowners which cannot help but receive the drift from pesticide applications.

Agricultural enterprises of particular concern are apiaries and organic farms. Bees are susceptible to pesticides but the exposure to bees caused by mosquito control applications of resmethrin at night is minimal since the bees have already returned to their hives.

During the EEE vector control aerial applications of malathion, beekeepers were advised to cover their hives. The applications were scheduled for 2.5 hour windows after dawn and before dusk. The criteria used in determining the period of the spray window included daylight periods when mosquito activity would be optimal and bee activity would be minimal.

The owners of properly run organic farms have gone to great lengths to become certified as pesticide free. In most cases the farms are small and the business, at least in the first years, marginal. The problem with organic farms, under normal circumstances, is knowing they exist, not avoiding them once known. Massachusetts MCPs have systems in place so that organic farmers can heave their land excluded from pesticide applications. Problems can develop when the question of drift from nuisance spraying occurs, or when there is a public-health threat.

7. Sensitive environments and populations. Certain environments and populations have special considerations which require a more cautious approach to mosquito control. Some of these have been discussed above but there are others worthy of mention.

a. Urban. The urban environment requires special care due to the increased population density and the difficulty in ensuring that people know the benefits and the dangers associated with mosquito control.

b. Recreation. People who enjoy outdoor recreation areas often have a higher tolerance for mosquitoes and a lower tolerance for spray vehicles than does the population at large. On the other hand, resort communities may demand higher than normal levels of mosquito control in order to make their site more enjoyable to the public. In any event, areas in which summer recreation takes place tend to polarize the debate over control and provide increased political headaches for MCPs, even where mosquito control itself is relatively straightforward.

c. Sensitive individuals. There are several groups of people who are sensitive to pesticide applications. Some individuals with emphysema or asthma can be adversely affected by airborne pesticide applications and such individuals sometimes request that their property be excluded from spraying.

Individuals with Multiple Chemical Sensitivity (MCS) have contacted MCPs and requested exclusion from spraying. No project has reported difficulty working with these individuals to create acceptable no-treatment zones. The causes, systems, diagnosis, and treatment of MCS all remain in a great state of flux, so MCPs are well advised to work carefully with MCS individuals and pay attention to the changing medical knowledge concerning MCS.

d. Public and Private Wildlife Refuges and Conservation Areas. These areas are often excluded from mosquito control at the request of the property owner because mosquito control runs counter to the goal of preserving the area in as natural a state as possible. Exclusion is not always absolute, however, as sometimes environmentally friendly pesticides like Bti can be used or water management may be practiced where pesticide applications are not permitted. The best way to approach such areas is to contact property owners and discuss with them possible mosquito-control alternatives.

e. ACEC and areas with rare or endangered species. Whenever rare or endangered species are present, pesticide applications and/or wetland alterations need to be approved by the appropriate agencies (see discussion under Rare and Endangered Species under impacts of physical control below). In many cases they will be rejected out of hand.

f. Water supplies. As stated above under surface water bodies and recharge areas, open water and water that is destined for drinking supplies, whether through percolation into the groundwater or by flow into reservoirs, must be very carefully protected. Fortunately, it is rare indeed that water supplies are held in such a way as to breed mosquitoes. For water supplies in general, therefore, mosquito control must consist of influencing the design of such systems to avoid creating habitats that would produce mosquitoes.

C. Mosquitoes as Disease Vectors

Most of the 9 organized mosquito control projects in Massachusetts justify their activities (and claim benefits) in part on the disease threat to human and animal populations posed by vector mosquitoes. Control programs in Berkshire County and Cape Cod (Fig. 1) lie outside of the area historically affected by outbreaks of Eastern equine encephalomyelitis (EEE) and therefore do not justify or plan their programs to address this disease problem. Dog heartworm is recognized throughout the Commonwealth (Arnott & Edman 1978). California group viruses have also been found in mosquitoes. To date human illness attributable to these agents has not been identified in Massachusetts..

A major practical difficulty in addressing the vector mosquito problem in Massachusetts stems from the fact that the specific species responsible for transmission of disease agents to humans and domestic animals are often unknown. The enzootic vector of EEE among birds is clearly *Cs. melanura*, but the vector(s) to horses and humans is unknown. The cattail mosquito, *Cq*. p*erturbans*, and the most common reflood species, *Ae. vexans*, are prime suspects. Other mammal-feeding *Aedes* such as *Ae. canadensis* also may be involved and perhaps even *Cs. melanura* feeds sufficiently on mammals under unusual circumstances to cause some transmission to these dead-end hosts (Nasci & Edman 1981a).

Based on isolations in other states (Calisher & Thompson 1983) and a few in Massachusetts (Walker 1984), it seems likely that the important California group viruses in the Northeast, i.e. LaCrosse and Jamestown Canyon, are transmitted by the treehole mosquito, *Ae. triseriatus*, and spring, woodland *Aedes*, respectively. Dog heartworm also may be spread primarily by spring *Aedes* but reflood *Aedes* (e.g., *Ae. sticticus* and *Ae. trivittatus*), *Cq perturbans*, *Cx. salinarius* and *Anopheles* spp. also may be involved in transmission of this parasite (Arnott & Edman 1978).

1. Eastern Equine Encephalitis

MCP's in Southeastern Massachusetts, i.e., Norfolk, Bristol and Plymouth Counties, face the greatest threat from this disease. During major epidemic years, virus activity extends northward from this enzootic focus into southern New Hampshire and westward into Rhode Island, Connecticut and Central Massachusetts. All projects except Berkshire County give considerable continuing attention to this potential problem. Upon occasion, projects may submit mosquitoes to the SLI for EEE virus analysis.

The enzootic foci of EEE are red maple/white cedar swamps. The largest adult populations of the enzootic vector, *Cs. melanura*, occurs in or near the localized swamps where this species develops. Most human and horse cases also occur in the immediate vicinity of these same swamp habitats. Still, at times this mosquito may disperse several miles from its larval habitat (Morris et al. 1980. Nasci 1980. Nasci & Edman 1984) and human/horse cases occasionally occur in upland areas. This mosquito is unusual in that it overwinters in the larval stage (4th or 3rd instar). Adults from this generation emerge in late spring (i.e., mid to late May). Two to three summer generations occur about one month apart, e.g., in late June, July and August, depending on water levels and temperature (Nasci 1980). EEE virus is generally not isolated from this mosquito until late summer. During epidemic years it tends to be isolated earlier, i.e., beginning in early July, but apparently never from the overwintering generation. The location of the virus from November to July remains a mystery. *Culiseta melanura* feeds only after dark and the vast majority of blood meals are obtained from passerine birds (Nasci & Edman 1981a). This sylvan mosquito feeds equally at ground level and at higher elevations in the tree canopy. Activity is concentrated just after dark and just before sunrise (Nasci & Edman 1981b). The morning flight activity peak does not seem to involve blood-feeding but rather the return to suitable daytime resting sites.

The isolation of EEE virus from the cattail mosquito *Cq*. *perturbans* during disease outbreaks (Crans, personal communication) has focused suspicion on this species at the most likely epidemic vector to horses and humans. *Ae*. *vexans* and *Ae*. *canadensis* are two other prime suspects for EEE virus transmission to humans and horses in Massachusetts. Like *Cq*. *perturbans*, they are major pests. Their biologies will be described along with the other pest species.

A new EEE threat may be developing in New England as *Ae. sollicitans*, long a known vector in New Jersey (Crans et al. 1991), was, for the first time, found to be EEE-positive in Connecticut in 1996 (Andreadis 1996). Crans (1991) gave a suggested cycle for EEE transmission to *Aedes sollicitans* in which *Cs. melanura* infected night-roosting glossy ibis, which were then fed upon by *Ae. sollicitans* while feeding in the salt marsh. Though the link between glossy ibis and *Ae. sollicitans* is tentative, there can be no question that *Ae. sollicitans* is a potent vector in New Jersey and could be an important vector in Massachusetts as well.

2. California encephalitis vectors

Jamestown Canyon virus has been isolated from both dark-legged and banded-legged spring *Aedes* in Massachusetts and neighboring New York State (Walker 1984, Calisher & Thompson 1983). LaCrosse virus is associated with the tree-hole species *Ae*. *triseriatus* in Eastern New York State, but it has not yet been found in Massachusetts. All suspect human cases of arboviral disease which are found not to be EEE are sent by the SLI to the CDC for a full arbovirus analysis. No California Group virus infections have been identified.

3. Dog heartworm

A wide variety of mosquito species are capable of vectoring this debilitating nematode parasite of canines. Coin lesions in human lungs can occur from accidental infection with this parasite (Adkins & Dao 1984, Deren & Feinberg 1984). Felines are more susceptible to infection than was previously thought because they apparently do not produce microfilaria (Fukushima et al. 1984). Natural infections have been found in three different species of spring *Aedes* in Massachusetts but other potential vectors cannot be discounted (Arnott & Edman 1978). The treehole mosquito, *Ae. triseriatus*, and three permanent water species, *Cx. salinarius*, *An. punctipennis* and *An. quadrimaculatus*, are all possible late season vectors.

King and Munro (1989) reported on a questionnaire sent to Plymouth County veterinarians concerning dog heartworm. Infect rates were reported as generally less than 5% but one veterinarian reported rates above 20%. With between 25,000 and 30,000 dogs in the reporting area, the estimated cost of yearly preventative treatments was $750,000.