BIOLOGY AND MANAGEMENT OF MOSQUITOES IN RELATION TO THE OUTDOOR RECREATION INDUSTRY AND TOURISM IN MICHIGAN

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Management of mosquito populations--modern mosquito control--involves integration of a variety of methods to achieve the single end of preventing mosquito bites, and can be done in an environmentally-acceptable manner through the use of physical methods, biological controls, and appropriate and judicious application of insecticides. A knowledge of the different kinds of mosquitoes in Michigan, and their life histories and biology, is essential if they are to be managed effectively using the integrated pest management philosophy. The purpose of this article is to provide basic facts about biology and control of pest mosquitoes in Michigan.

BITING INSECTS AND OUTDOOR RECREATION

Biting flies of the insect order Diptera, especially mosquitoes (family Culicidae), black flies (family Simuliidae), and deer and horse flies (family Tabanidae) can significantly impact outdoor recreation activities during the spring and summer months in Michigan. Although quantitative data are lacking in general, yet there is undoubtedly a negative correlation between intensity of biting by these insects (i.e., their population density) and tourist activity. Here, tourist activity may be measured in terms of certain variables such as: number of booked campground nights; leaving rates or number of refund requests after arrival, from campgrounds, golf courses, or other venues; number of complaints from customers. When the biting insects are bad, one could predict reduced bookings, higher leaving rates, greater refund requests or rainchecks, and greater numbers of complaints. Another measure of biting fly problems could be unit sales of insect repellent on-site, which would be expected to be higher when biting fly densities are high and lower when the densities are lower. Regardless of how biting fly harassment of tourists and patrons is measured, there is no doubt that the annoyance of the insects can significantly impact enjoyment of the outdoors.

MOSQUITOES AND MOSQUITO-BORNE DISEASE IN MICHIGAN

Mosquitoes are true flies and like other insects have a developmental cycle involving metamorphosis from the egg to the adult stage. Mosquito eggs are laid singly or in clusters on or near water. Tiny larvae hatch from the eggs and develop in the water. The larvae feed on a variety of microorganisms and organic matter in the water, and develop through four larval stages to the pupal stage. Adult mosquitoes emerge from the pupal stage, and fly away from the water. Male mosquitoes feed on nectar and do not bite for blood; female mosquitoes of most species require a blood meal to develop their eggs, and may bite several times during their lives. Female mosquitoes not only bite people, but also other animals including birds, mammals, frogs, and snakes.

Michigan has five major classes of mosquitoes classified on the basis of the larval habitat: the spring flood-water mosquitoes, the marsh mosquitoes, the hardwood swamp mosquitoes, the summer flood-water mosquitoes, and the container mosquitoes. Overall, there are about 60 different species of mosquitoes in Michigan.

Larvae of spring flood-water mosquitoes hatch from the egg in March, in pools of water formed by melted snow in the woods. These larvae develop slowly because of low water temperatures, and emerge as adults in May, before the pools dry up. The female spring flood-water mosquitoes can be very long-lived, and may bite several times and lay eggs in the woods where they will be flooded the following year. Spring flood-water mosquitoes have only one generation per year, so even if these eggs are flooded by summer rains, they will not hatch until the following spring. The eggs are very cold hardy and drought resistant. All of these spring mosquitoes are in the genus Aedes, and they include such species as Ae. stimulans, Ae. excrucians, Ae. fitchii, Ae. provocans, Ae. intrudens, Ae. aurifer, Ae. canadensis, Ae. communis, Ae. punctor, Ae. abserratus, Ae. sticticus, and others. A few of these species may show secondary, summer hatches, such as Ae. canadensis and Ae. sticticus. The latter species also shows an affinity with flood plain areas.

Marsh mosquitoes have a different kind of egg biology than the spring Aedes. The females lay eggs either singly or in rafts on the water surface, and after a short period of embryonation, the eggs hatch and first instar larvae begin development. Species of mosquitoes dwelling as larvae in marshes include the cattail mosquito, Coquillettidia perturbans; many mosquitoes of the genus Culex, such as Cx. restuans, Cx. pipiens, Cx. salinarius, and Cx. territans; Uranotaenia sapphirina; Culiseta morsitans and Culiseta inornata mosquitoes; and Anopheles, including An. quadrimaculatus, An. earlei, An. walkeri, and An. punctipennis. Larvae of the cattail mosquito live attached to the roots of cattail plants and other aquatic plants; they obtain oxygen through the roots by tapping the aerenchymous tissue. Larvae develop slowly, and are the overwintering stage. Anopheles mosquitoes typically live in association with the surface film in the vegetated zone of marshes. Culex mosquitoes also occur in man-made bodies of water such as sewage lagoons, animal tanks, and ponds, where the water has a high organic content.

Some mosquitoes in Michigan are associated with hardwood swamps. Larvae of the mosquito Culiseta melanura may occur under the boles of trees in these swamps in a virtual subterranean setting. However, these larvae may also occur in water at the base of tree blow-downs, and in holes in bogs. Another mosquito associated with similar habitats (except bogs) is Aedes thibaulti, a spring mosquito with larval habitats similar to those of Culiseta melanura. This mosquito is associated with tupelo gum and cypress swamps in the southern US. It was recently discovered in both southwestern and southeastern Michigan in maple hardwood swamps.

Summer flood water mosquitoes include some of the most common pest mosquitoes in Michigan, including Aedes vexans and Aedes trivittatus. Larvae of these mosquitoes hatch from eggs after rainfall in the summer (usually 0.5 inch or greater) in shallow flooded areas such as meadows, roadside ditches, tire tracks, cow hoof prints, and other habitats. Reed canary grass app to be a marker for Aedes vexans larval habitats. The larvae develop very quickly (10-14 days) and several generations may occur each summer depending upon the number of heavy rainfalls which occur. In some areas of Michigan, salt marsh mosquitoes (Aedes sollicitans and Aedes dorsalis) have invaded sites with sulfur and salt mineral contamination of surface water because of industrial activities or inadequate waste water treatment. These mosquitoes have life cycles similar to summer flood-water mosquitoes.

Container mosquitoes are those that are adapted to living as larvae in natural or man-made, water-filled containers such as tree holes, pitcher plants, rock holes, and old tires. Aedes triseriatus, Aedes hendersoni, Anopheles barberi, Orthopodomyia signifera, and Orthopodomyia alba are tree hole mosquitoes. Aedes triseriatus and Aedes atropalpus also occur in tires, although Aedes atropalpus is primarily a rock hole mosquito found in the northern tier of the state. Wyeomyia smithii larvae live in the fluid of pitcher plants in bogs.

Mosquito-borne diseases occur in Michigan. At one time, malaria (carried by Anopheles mosquitoes) was common in Michigan but it has been eradicated. The last outbreak of malaria occurred in the early 1930's in Paw Paw. Dog heartworm is common in Michigan and is transmitted by a variety of Aedes mosquitoes and perhaps Anopheles as well. Prophylatic drugs are available from veterinarians to prevent dogs from contracting this disease. In some areas, up to 60% of the non-treated dogs are infected. Foxes, untreated dogs, and coyotes are reservoirs. St. Louis encephalitis, eastern equine encephalitis, and different types of the California group of encephalitis occur in Michigan. The viruses that cause these diseases are transmitted by different species of mosquitoes, and these viruses also infect various kinds of wild birds and mammals. Mosquito-borne encephalitis is not common annually, but because it may occur in epidemics in certain years, it remains a true concern for human animal health. For example, in 1975 an epidemic of St. Louis encephalitis resulted in 93 human cases and four deaths in Michigan, mainly in the southeastern part of the state. This virus is transmitted by Culex mosquitoes, and birds are the vertebrate reservoirs.

Eastern equine encephalitis has occurred in widespread outbreaks in 1942-43, 1973, 1975, 1980-83, 1991, 1993, and 1994 in southern Michigan. Horses are primarily affected. The first Michigan resident to die of eastern equine encephalitis was a 10-year old boy in 1980. In 1991, about 60 horses in 11 southern counties died of this disease, as did hundreds of pheasants on game farms. Two humans were ill from this disease in that year, experiencing coma and other serious conditions. In 1993, about 13 horses and one mule died from eastern equine encephalitis. In that year, two Michigan residents contracted this disease, and one died. In 1994, many horses and pheasants died of 333 Viral infection in southwest Michigan. The EEE viral infection in southwest Michigan. The EEE virus exists in a hardwood swamp cycle, being transmitted between passerine birds and the bird-biting mosquito Culiseta melanura. In outbreak years, the virus "spills out" of its swamp cycle owing to the presence of large populations of the cattail mosquito, Coquillettidia perturbans. The cattail mosquito will bite both birds and mammals, thus it can acquire a viral infection from a viremic bird and later transmit the virus to a horse, human, or pheasant. Michigan appears to be unique in that it is one of the few inland, noncoastal areas that has widespread endemicity for EEE virus. The history of the disease here suggests that outbreaks are becoming for frequent, but it remains rare in humans.

The most prevalent of the California serogroup of encephalitis viruses is Jamestown Canyon virus. This virus is associated with Spring Aedes mosquitoes and the vertebrate host is white-tailed deer. One human case of illness has been associated with Jamestown Canyon virus in Michigan, but cases have been documented in New York and Ontario. Other mosquito-borne agents affect wildlife. Bird malaria is probably common but little is known of its prevalence, host distribution, or impact on wild bird populations. Many mosquito-borne viruses (e.g., Highlands J, Cache Valley, Potosi, etc.) Exist in bird populations but their pathogenicity to nestlings in particular is poorly known.

MOSQUITO CONTROL

Mosquito control should involve careful consideration of the biology of the mosquitoes that are forming the nuisance problem or disease threat. In all cases, larval mosquito control should be considered as the first option for management. This process involves location and identification of larval habitats, followed by their modification or treatment in such a way that the integrity of the habitat is preserved but the mosquito larvae are reduced in numbers. By dealing with larval mosquitoes, the adults may never become a problem. Adult mosquito control invariably involves the use of insecticides. Mosquito control is best accomplished on an organized, regional, basis.

Although the common view is that mosquitoes come from permanent bodies of water (which is true for certain species of mosquitoes), most of the nuisance mosquitoes in Michigan belong to the spring mosquito group and to the summer flood-water mosquito group. The adults emerge from temporary, flood-water habitats such as woodland snow melt pools, blocked roadside ditches, puddles, flooded tire tracks, and flooded meadows. Other important habitats for mosquitoes include artificial containers such as discarded tires and trash which have filled with rainwater. These larval habitats can be permanently eliminated through environmental sanitation and civil engineering, and should be the first thing a public agency considers for mosquito control. Because of the temporary nature and small size of mosquito flood-water habitats, they often can be altered to prevent mosquito production. However, there are laws and policies regulating alterations of wetlands, and the Michigan Department of Natural Resources must be consulted before these activities take place. Indeed professionals responsible for mosquito control are in the unique position of finding a balance between preservation of our wetlands and elimination of mosquito sources, but this balance can often be achieved with careful planning and consultation with authorities. Landscape planners should consider carefully the kinds of mosquito habitats they may be creating when wetlands are integrated into landscape or neighborhood designs.

There are a variety of ways to control mosquito larvae "biologically" and three can be used effectively on a local or regional level. There is a highly effective bacterial insecticide available commercially called B.t.i. This insecticide is put in to the water where mosquito larvae are found, and the larvae eat the bacteria. Inside the bacteria is a spore which contains a proteinaceous, crystalline toxin. This toxin becomes active in the mosquito larva's stomach owing to the high pH conditions and presence of certain enzymes, and causes the cells of the stomach to break apart so the larva dies. The toxin is highly specific for mosquito larvae, and does not harm birds, mammals, fish, or other kinds of invertebrates or plants. This particular strain and formulation of B.t.i. does not replicate or persist in the environment, although it is a naturally-occurring soil bacteria. B.t.i. is registered by the US EPA in granular, sustained-release, and liquid formulations for use as a mosquito control agent, an dis currently used in Michigan for operational mosquito control by several mosquito control agencies. In Michigan, it is especially effective against spring mosquitoes when applied in their woodland pool habitats. Granular B.t.i. (Such as Vectobac-G or other commercial products) is highly effective at 2.5 to 5 lbs. Per acre. This can be applied by individuals using spreaders or backpack sprayers, or from helicopters or airplanes. Liquid B.t.i. at a rate of 0.3 liters per hectare can be used effectively as well. Control of spring mosquitoes requires thorough surveillance of the larval habitats, with well-marked maps and careful coordination so that no habitats are missed during egt application times.

Another way to control mosquitoes biologically is to spread a light mineral oil onto the water. This causes mosquito larvae and pupae to drown by breaking the surface tension and wetting the mosquitoes' air tubes. "Golden Bear' is a light mineral oil that works well in this fashion. This oil breaks down quickly through natural microbial and physical action and does not contaminate the environment; it should not be considered in the same category as crude oil or fuel oil, which should not be used for mosquito control and do contaminate the environment.\

A third way to control larval mosquitoes biologically is to prevent their normal development to the adult stage by manipulating their juvenile hormone system. Altoside (common name, methoprene) is a chemical analog of juvenile hormone (the natural insect hormone that regulates the maturity of insects) manufactured by Zoecon Corporation. It can be sprayed or introduced into the larval habitat, and the larval mosquitoes exposed to it will fail to emerge as adults. It has minimal environmental impact, and is available in sustained-release briquet formulations and pellets designed to expose larval mosquitoes long enough to have an effect.

There are other biological control methods that get attention, such as predation on larval mosquitoes by top minnows and dragonfly larvae. However, these methods are generally not effective under Michigan conditions for operational usage, and despite their attractiveness to citizens as "natural control" they cannot be solely relied upon to reduce the nuisance of mosquito biting. Development of new, appropriate biological control methods is an active area in both privately- and publicly-funded research.

Mosquito larvae can also be controlled through application of chemical insecticides. Some of these are more toxic than others, and their use is often dictated by the amount of organic matter in the water that contains the larvae. One of the most common and effective "larvicides" is Abate or temephos, which can be extremely effective against larvae in a variety of conditions. This organophosphate is of such low receptacles in the tropics which contain dangerous mosquito vectors. Another chemical larvicide is Duersban (chlorpyrifos), which is more toxic than Abate and is more often used in organically-lade waters, such as sewage lagoons. Larvicides are available in liquid and granule formulations, an dchoice of which formulation to use is important because effectiveness varies with the conditions of the larval habitat.

Adult mosquitoes can generally only effectively be reduced from nuisance levels using chemical insecticides, or "adulticides." If larval control methods have not been used or did not result in adequate control, than measures to reduce adult numbers are the only resort. Essentially, there are three ways to accomplish adulticiding. First, adult mosquitoes can be killed on the wing during their normal flight time (daytime or dusk) using ultra-low volume (ULV) equipment (a type of sprayer that is hand-held, mounted on a pickup truck, or fixed to aircraft) and an insecticide. This method is sometimes called "cold fogging," although the droplet size of ULV applications comprises a cloud that is technically not a fog. This is an excellent method for controlling mosquitoes, because it allows for use of a small amount of material (generally about 3-5 fl. Oz. Per acre) in tiny droplets in a narrow band of time and space. In Michigan, Malathion (as Cythion, an organophosphate), resmethrin (as Scourge, a synthetic pyrethroid), and permethrin (biomist, also a synthetic pyrethroid) work well as adulticides applied as ULV. None of these insecticides are very toxic when used at the labeled dosages, and each offers good activity against mosquitoes. There are other insectides currently labeled for adult mosquito control using the ULV technology as well.

A second approach to adulticiding is using thermal fogs. In this technology, an insecticide is heated along with another combustible material such as kerosene or oil, thus creating a fog which moves through the air, around vegetation, and among flying insects. For mosquito control, the best time to make a thermal fog application is in the warm air (heated by the earth during the day) has not yet mixed with cooler air above it. The insecticidal fog remains most stable and near the ground under conditions of thermal inversion. Thermal foggers can be purchased commercially in sizes small enough for backyard uses to sizes large enough for wide scale application. Currently, formulations of Malathion, resmethrin or permethrin are recommended.

Another way to control mosquitoes is to use "harborage" or barrier" spray techniques. This involves spraying a dilution of Malathion (usually 3% concentration prepared from a 57% emulsifiable concentrate) or permethrin (usually 3% concentration of a 12% concentrate) onto vegetation surrounding the area to be protected. This area could be a backyard, a cemetery, a park, golf course, etc. The insecticide provides a residual of active ingredient on plant leaf surfaces, and when mosquitoes try to fly from the harborage areas (the woods) through this zone, they die or are repelled and do not move into the open to bite. Equipment for a harborage application varies with the size of the area to be protected, but can range from a small hand pump sprayer to a motorized backpack sprayer to a large Buffalo turbine rig. A moist sprayer can be used effectively for barrier spray applications.

Many different notions exist about how adult mosquitoes can be controlled through non-chemical or so-called natural means. Aerial predators are often cited in the popular press as a means for controlling mosquitoes by predation. However, scientific studies do not support the contentions that bats, swallows, purple martins, dragonflies, or other aerial predators are effective, even though these methods might sound appealing and the animals themselves have aesthetic and intrinsic value. One has to bear in mind that predation is a natural process that is on-going, yet we have mosquitoes anyway, often in large numbers. Actually, birds and bats do not eat very many mosquitoes, despite some claims to the contrary. The idea that they eat thousands of mosquitoes per night comes from statements in the natural history literature indicating that these predators would have to eat this many (and not do eat this many) mosquitoes to maintain their existence given their high rate of metabolism. Outdoor, electronic bug zappers with ultraviolet lights do not control mosquitoes. Socalles "mosquito plants" do not effectively repel mosquitoes, and are not recommended for this purpose despite advertisements to this effect. Other devices such as those advertised to repel mosquitoes by high frequency sound do not actually repel mosquitoes.

When considering use of an insecticide for larval or adult mosquito control, it is very important to keep in mind the concept of dosage (i.e., amount used per unit are a or expelled per amount of time). The label on an insecticide container provides the information necessary to decide what dosage is necessary to be effective, and use of dosages higher than those indicated on the label is a violation of the law and is not a good pest management practice. The insecticides currently registered for adult mosquito control vary in acute toxicity, but most are not very toxic, i.e., the LD50 values of these insecticides tend to be high. The environmental and health risks of insecticides used for mosquito control can be evaluated by considering both the toxicity (which is low) and exposure (also low) elements of risk under field conditions.

Personal repellents containing the active ingredient DEET are useful and can provide temporary relief from annoying mosquitoes. The concentration of DEET varies with formulation, but generally those with 30% or less are effective. Parents should use repellents sparingly on children and babies and should apply those with low percentages of DEET (such as Skintastic! with only 7% DEET).