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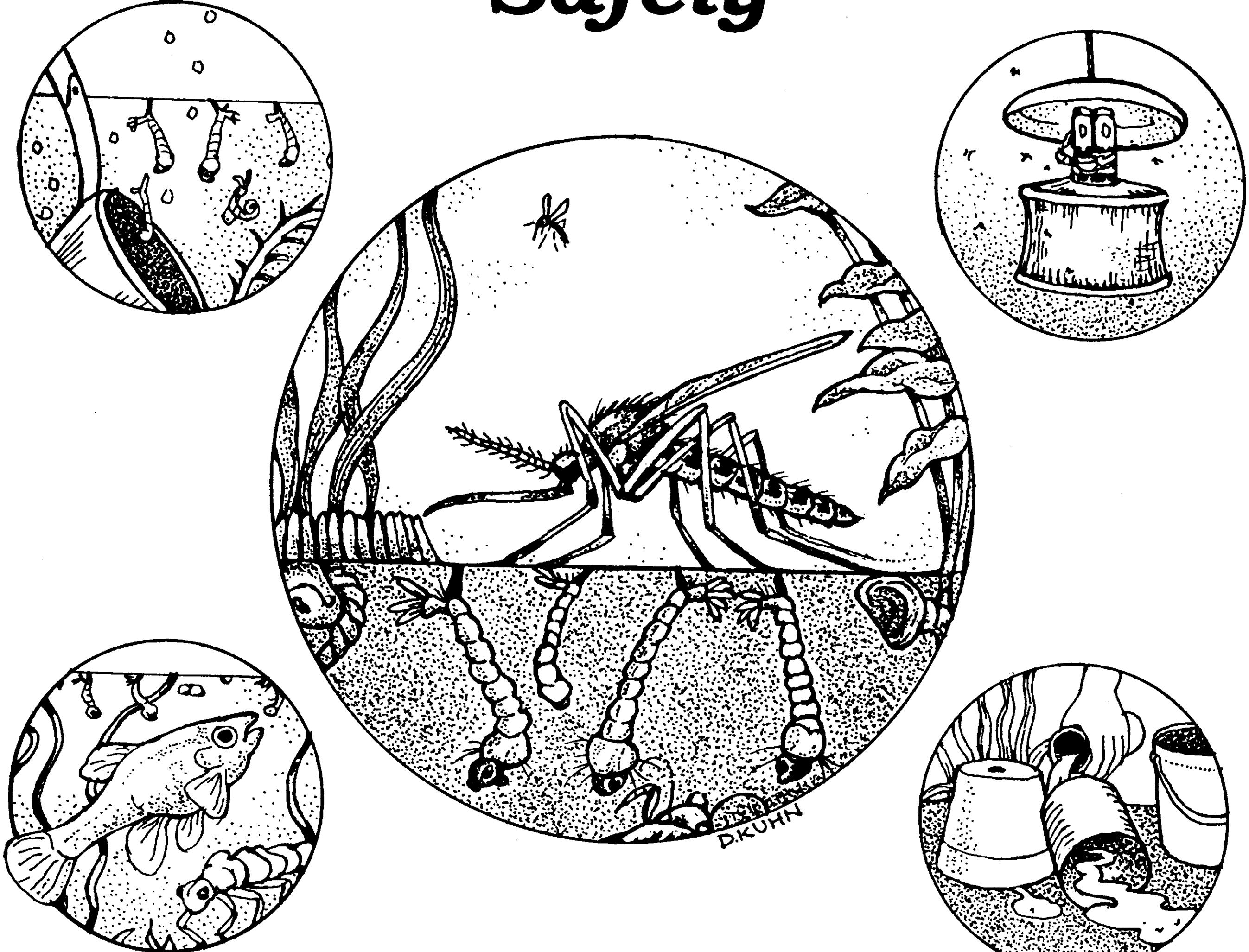
Stopping Mosquitoes Safely



An Invitation to Join

B · I · R · C

The Bio-Integral Resource Center

BIRC, A NON-PROFIT CORPORATION, WAS FORMED IN 1979 to provide practical information on the least-toxic methods for managing pests. The interdisciplinary BIRC staff and an international network of advisors and research associates have designed highly effective alternative solutions to a wide variety of pest problems throughout the world. This work has been based on the principles of 'Integrated Pest Management' or 'IPM'.

IPM IS A DECISION-MAKING PROCESS that considers the whole ecosystem in determining the best methods for managing pests. The objective of an IPM Program is to suppress the pest population below the level that causes economic, aesthetic, or medical injury. IPM strategies are designed to be the least disruptive of natural pest controls, human health, and the general environment. Horticultural, physical, mechanical, biological, least-toxic chemical, and educational tactics are integrated to solve pest problems with a minimal reliance on pesticides.

THE IPM APPROACH HAS GAINED FAVOR with government and business because it is cost-effective. Community groups and pest management professionals are enthusiastic about IPM programs because the use of toxic materials is reduced while better pest control is achieved.

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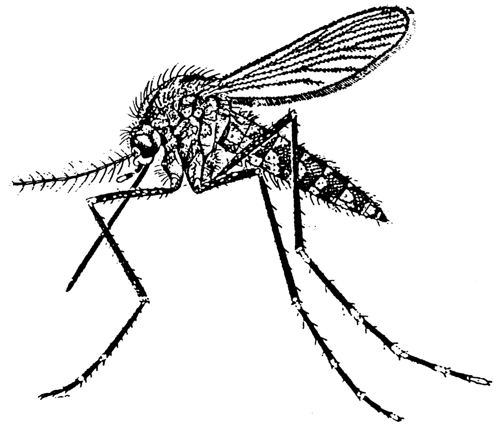
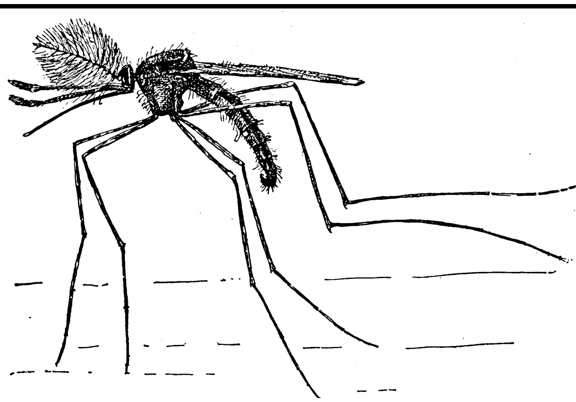
Sprays for Adult Mosquitoes— A Failed Technology?



By William Quarles

Before World War II, mosquito control in the U.S. relied solely on source reduction and larval control programs. Due to rigorous application of these methods, malaria had been reduced to 60,000 cases a year by the early 1940s, despite the fact that sprays for adult mosquitoes (adulticides) were not available. After the war, DDT was sprayed inside more than a million homes a year to control the *Anopheles* mosquitoes that carry malaria. Addition of DDT to the mosquito control program brought the number of cases down to about 10,000 a year. At this point, it looked like targetted sprays of DDT as part of a rigorous public health program could be useful in reducing malaria (Mulrennan 1995; USDHEW 1969).

However, the World Health Organization (WHO) then began a massive campaign to eliminate malaria in the rest of the world. Perhaps because money and resources were not available, less effort was expended on larval control, exclusion, and source reduction in other countries. Because WHO relied so heavily on chemical control, mosquitoes became resistant to DDT. Each year, there are still 500 million cases of malaria and millions of cases of dengue. (Metcalf 1986; Service 1995; WHO 1995; WHO 2000). Sprays to kill adult mosquitoes failed to stop malaria and dengue. In this instance, it is certainly a failed technology.



A male *Anopheles* sp. mosquito

Stopping Disease

But problems with resistance aside, has this approach alone ever been successful in stopping mosquito-borne disease epidemics? In the 1960s adulticides were used during an epidemic of St. Louis encephalitis in Texas to knock down populations of infected mosquitoes (Howard and Oliver 1997; Kilpatrick and Adams 1967). Undoubtedly, the sprays had some effect, but there is no way of measuring in retrospect just how useful they were. And there are other ways to stop disease transmission. In Florida, in the 1990s "a public information campaign aimed at the people living in the areas where human encephalitis cases were occurring was very effective in reducing the number of cases" (Mulrennan 1995; Meehan et al. 1991).

Aerial sprays of adulticides were used as a reaction to outbreaks of eastern equine encephalitis (EEE) in Massachussetts in 1972 and 1974. Later analysis showed that these sprays produced equivocal results. Sprays were used despite the absence of human cases, and there was no way to judge effectiveness, because no areas were left untreated (Grady et al. 1978). Despite doubtful success, aerial applications of malathion continue to be the knee jerk reaction to EEE in Massachusetts (Edman et al. 1993).

Putting too much faith in mosquito adulticides may have contributed to the West Nile virus outbreaks in New York in 1999. New York City and New York State had become lax in rigorous source reduction and larval methods and were relying more on adulticides. For example, in Central New York, two swamps, Toad Harbor and Cicero, are primary sources of mosquitoes carrying eastern equine encephalitis (EEE). For years, aerial sprays of adulticides in these swamps were the only control measures taken. Applications of the organophosphate naled would initially knock back the vector of EEE, the mosquito *Culiseta melanura*. Within two weeks, the population would rebound to earlier levels. Over an 11-year treatment period, these sprays led to a 15-fold increase in populations of *Cs. melanura*. Isolations of EEE also increased (Howard and Oliver 1997).

West Nile Virus Public Reaction

The West Nile fever outbreak in New York City in 1999 and 2000 was partly due to failure of the mosquito control program, and partly due an unusual pattern of weather and wildlife populations (Epstein 2000). Although the public health response to West Nile virus was generally rational, in retrospect perhaps fogging with mosquito adulticides was not a good idea. According to a report released by the New York State Health Department on June 14, 2001, more New York residents got sick from pesticide sprays than from exposure to the virus, at least in the year 2000. More than 200 people reported to the public health department that they had adverse reactions to sprays of the pyrethroid sumithrin (Anvil). In addition, another 22 cases of pesticide poisoning were reported to physicians. Only 14 people got sick from the virus.

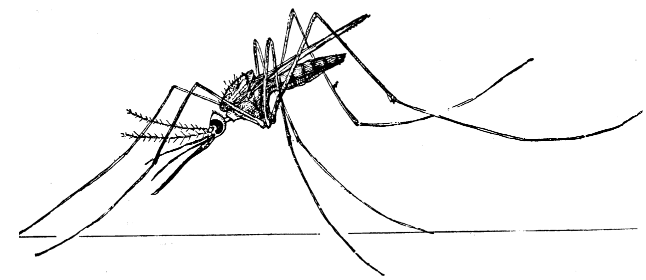
The pest control companies also had problems. Mobilizing for repeated fogging in New York City was a massive effort. The pest control companies were forced to rely on newly hired and poorly trained technicians who made mistakes in application that put the public at risk. These mistakes led to fines of more than a million dollars. New York officials have now promised to use mosquito adulticides only when there is "an imminent risk to human health" (Feldman 2001).

When Should Adulticides be Used?

Pesticides to kill adult mosquitoes (adulticides) around the home should only be used as a last resort. In a home situation, screens can be used to exclude *Culex* spp. and *Anopheles* spp. mosquitoes that bite inside houses. Outside, mosquito repellents can give adequate protection against salt marsh mosquitoes that bite outdoors. For home barbeques and backyard gatherings, large fans can be set up to protect guests. Mosquitoes are generally weak fliers and cannot fly in a strong wind. If mosquito adulticides are used at all, they should be to spray screens to increase efficacy of exclusion (see Quarles 1996ab).

Because repeated sprays can lead to insecticide resistance, and because larval mosquito programs often provide satisfactory control, many mosquito abatement districts now use adulticides only in emergency situations. The ultra low volume (ULV) technique is used. A concentrated solution of resmethrin (Scourge), malathion, naled or other pesticide is applied without dilution. Very fine droplets of the concentrate in the 5-20 micron range are produced and less than 1 ounce per acre (70 g/ha) is applied. Sprays are ideally timed for when mosquitoes are flying and active.

The low application rates are good news, but the fine mist is perfect for inhaling deep into the lungs. Consequently, ULV fogs should be applied when most people are inside structures. Pesticides targeted for adult mosquitoes should not be applied during windy or hot conditions. The best condition is during a slight breeze of 3 mph or less. This air movement helps to disperse the pesticide effectively, but does not move it to unwanted areas. Generally, adulticides are applied in early mornings or late evenings to reduce impacts on butterflies, bees and other non-target insects. Applications should not be made near beehives or near flowering plants that encourage beneficials (Alameda 1999).



A female *Anopheles* sp. mosquito

Are Adulticides Really Effective?

But even when mosquito adulticides are reserved for use in emergencies, are they really effective? Spraying bed netting or window screens with permethrin seems like a good use of mosquito adulticides. There is clearly demonstrated effectiveness with somewhat modest risks for the average person. Pyrethroid treatment of mosquito bed netting has reduced malaria cases on a local level throughout the world (Li et al. 1997; Rowland 1999).

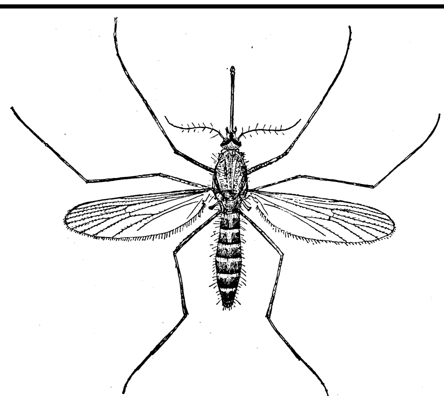
But how effective is fogging by a mosquito abatement district? Unless mosquitoes are hit by the pesticide fog, then applicators are relying on residues left on foliage and surfaces to kill landing mosquitoes. Most of the pesticide is lost to the atmosphere or the soil or to water. Residuals fall onto mosquito resting places mostly by accident.

Applications are spotty. In one instance, monitoring with caged mosquitoes in open areas showed up to 80% variation in mortalities 250 ft (76 m) away from the spray. Vegetative cover also reduces effectiveness. In the same experiment, mean mortalities measured at 300 ft (91.4 m) away from the spray in vegetated areas were depressed as much as 62% over mortalities seen in open areas (Linley and Jordan 1992). Most of the residuals are quickly inactivated and provide no long-term protection. Truly, areawide fogging should be seen as a desperate action for an emergency situation where officials must be perceived as doing something.

In the past, this kind of action was often welcomed by a mosquito-beleaguered population. In Florida in the 1960s, airplanes flew over every day about noon fogging with DDT and the general reaction was "thank God, they are doing something about these mosquitoes." Now this kind of highly visible approach is not welcomed, and a highly charged political debate usually precedes any authorization for aerial sprays of an urban area.

Population Control

Can adulticide sprays reduce mosquito populations? Although several reviews seem to show that adulticides can knock back mosquito populations (Lofgren 1970, 1972, 1974; Mount et al. 1996; Mount 1998; Jensen et al. 1999), estimates of efficacy often come from caged mosquito monitoring traps. Although these may be good measures of pesticide dispersion, they may not be representative of effects on actual landing and biting populations (Mount et al. 1970; Vaidyananthan and Edman 1997ab). Also, monitoring at 12-14 hours after fogging gives greater estimates of population suppression than counts taken at 24 hours (Lofgren et al. 1968; Bourg et al. 1978). Monitoring results like these suggest that any effect is temporary. Some mosquitoes apparently just leave the treated area, then come back.



A female house mosquito, *Culex* sp.

Even with widespread mortality, unless breeding sources are treated, adult populations just rebound. Those that survive tend to be resistant.

Since fogging with the ULV technique leaves few persistent residues, sprays must be repeated often to retain control. Eliason et al. (1975) needed 6 applications of 95% malathion applied at rates of 4.5 ounces per acre (315 g/ha) or more to control *Anopheles* sp. populations. Adulticides are used every night near the rice fields in Arkansas (Efird et al. 1992). Repeated sprays lead to resistance and decreased effectiveness.

In the case of aerial sprays, areas with dense foliage often require application rates higher than allowed by the pesticide labels for effectiveness. Also, if aerial sprays are used, the target is often missed entirely (Mount et al. 1996).

Mosquito Resistance

One sure way to know whether a pesticide is reaching the target organism is to measure insecticide resistance. If the organism shows increasing resistance to pesticides over time, the pesticide has to be reaching the target. Unfortunately, increased resistance also means less effectiveness. In Texas, *Culex quinquefasciatus*, a vector of St. Louis encephalitis, has developed resistance to resmethrin (Scourge) and to malathion (Pietrantonio et al. 2000). In Wenzhou China, populations of *Aedes sinensis* have grown resistant to deltamethrin (Wang 2000). *Anopheles sinensis* in Zhejiang, China is resistant to deltamethrin and permethrin (Wang 1999). Populations of *Culex pipiens* in Cyprus are resistant to several organophosphates and permethrin (Wirth and Georghiou 1996). *Anopheles* sp. is resistant to malathion in Arkansas (Efird et al. 1992). In Mexico, *Anopheles albimanus* is resistant to

Table 1. Toxicities of Mosquito Adulticides

Name	Class	EPA Rating	Toxicity in mg/kg	Appl. Rate/acre
Permethrin	pyrethroid	Class II	430-4000 o. rat; dermal 2000 rabbit	.003-.007lb
Resmethrin	pyrethroid	Class III	2500 o. rat	.003-.007lb
Sumithrin	pyrethroid	Class IV	10,000 o. rat	.003-.007lb
Malathion	OP	Class III	5500 o. rat; 2000 dermal	0.23lb
Naled	OP	Class I	92 o. rat; 360 dermal	0.05lb
Dichlorvos DDVP	OP	Class I	50 o. rat; dermal 90 mg/kg	degradation of naled
PBO	synergist	Class IV	7500 o. rat	--------

Sources
Tomlin 1997; Extoxnet 2000; EPA 1995, 1997, 2000

Box A. Relative Toxicities of Mosquito Adulticides

Naled or dibrom is phytotoxic and can cause injury to fruit, cotton, beans and some ornamentals. Naled is hydrolyzed quickly with a half-life of about 15 hours, but its degradation product dichlorvos is also a toxic pesticide with a half-life of about 5 days. Resmethrin degrades quickly, but permethrin leaves residues that last for at least two weeks (Tomlin 1997).

According to an EPA registration document, there is no monitoring data for naled or its equally toxic degradation product dichlorvos for either surface or ground water. The chemical is also not regulated under the Safe Drinking Water Act, so no drinking water tolerances have been published. It is very mobile in soil and presents a runoff hazard for about 2 days after application.

Naled is highly toxic to birds, moderately to highly toxic to fish, and is highly toxic to the water flea. For most applications, naled must be applied at least 175 feet (53.3 m) away from water. For mosquito control an exception is made. Application for mosquito control presents a chronic risk for marine invertebrates (EPA 1997).

Resmethrin

Resmethrin has a low acute toxicity to mammals, although there are large species differences. For instance, the oral LD_{50} in rats is >2500 mg/kg but is only 300 mg/kg in mice. It has a slight dermal toxicity, and the LD_{50} in rats is 1244 mg/kg. A 2-year feeding experiment in rats showed that it did not cause cancer, was not mutagenic and did not cause birth defects. Constant exposure caused toxic effects on liver and kidney and the No Observed Effect Level (NOEL) was 10 mg/kg day. Human exposure causes skin irritation, headache, stuffy nose, scratchy throat and dizziness. It is slightly toxic to birds and highly toxic to fish and bees. It is absorbed by aquatic sediments, and there is no information on its breakdown products in the environment. The formulation Scourge is a combination of resmethrin and the synergist PBO (Extoxnet 2000).

Permethrin

Permethrin has fairly low acute toxicity to mammals. It has an LD_{50} of about 430-4000 mg/kg in rats, and the large variation in toxicity is due to the purity and kind of the formulation. In laboratory animals, chronic exposures to large doses led to neurotoxic effects and increased incidence of lung tumors. Low oral chronic doses at 1/100 of the LD_{50} led to depression of the immune system in mice. Permethrin may be an endocrine disruptor, binding to and blocking androgen receptors. As with most pesticides, effects are greater on immature mammals than on adults. Permethrin is about 5 times more toxic to young rats than to adults (Cox 1998).

DDT, organophosphates, carbamates, and pyrethroids (Penilla et al. 1998).

The encephalitis and yellow fever vector, *Aedes aegypti*, has grown resistant to organophosphates in the Caribbean, India, Malaysia, Thailand and Vietnam. Resistance to pyrethroids has developed in Thailand (Service 1990).

Environmental Effects

All of the commonly used mosquito adulticides are toxic to bees, fish, and aquatic organisms. (See Box A and Table 1 for information on pesticide toxicity.) Registered pesticides include pyrethroids such as permethrin, resmethrin, and sumithrin, or the organophosphates such as malathion or naled. Piperonyl butoxide (PBO) used as a synergist for pyrethroids is somewhat toxic to fish (LC_{50} is 5.3 mg/l), toxic to bees, and has some toxicity to the water flea (LC_{50} is 3mg/l). These pesticides will kill beneficial insects as well as adult mosquitoes.

Permethrin is more toxic to aquatic organisms than resmethrin. Malathion is more toxic to bees and fish than naled, but naled is especially toxic to the water flea. For this reason, these materials should not be applied directly to water, and should not be allowed to drift into sensitive wetland areas (Tomlin 1997).

The "Best" Adulticide

According to the pest, local conditions, and degree of resistance, one pesticide might be more effective than another for a particular case. (See Box A for a discussion of pesticide toxicity.) For instance, naled can be more effective than malathion or resmethrin for control of biting midges, *Culicoides furens* (Linley and Jordan 1992). Nightly applications of adulticides in Arkansas has caused *Anopheles quadrimaculatus* to become resistant to malathion, but resmethrin (Scourge) is still effective (Efird et al. 1992).

From an environmental point of view, although naled degrades quickly, its overall toxicity makes it unattractive. All of these adulticides are toxic to most components of the environment including birds, bees, fish and other aquatic organisms. The resmethrin (Scourge®) used by many mosquito abatement districts may be the best of a bad situation (Alameda 1999; EPA 2000).

Conclusion

Sprays for adult mosquitoes have failed to stop mosquito borne diseases, and in fact without source reduction and larval control, may make them worse. Areawide fogging may quickly knockdown populations, but due to spotty application, some mosquitoes just evade the fog or leave the treated area. Even if many are killed, unless source reduction and larval control programs are successful, resistant populations quickly resurge to levels greater than before. Areawide sprays used as emergency measures to contain disease have not been rigorously proved effective. Areawide spraying for adult mosquitoes represents a technology that has failed, and possibly it should be abandoned altogether. If it is retained for emergencies, officials should obtain better estimates of its effectiveness.

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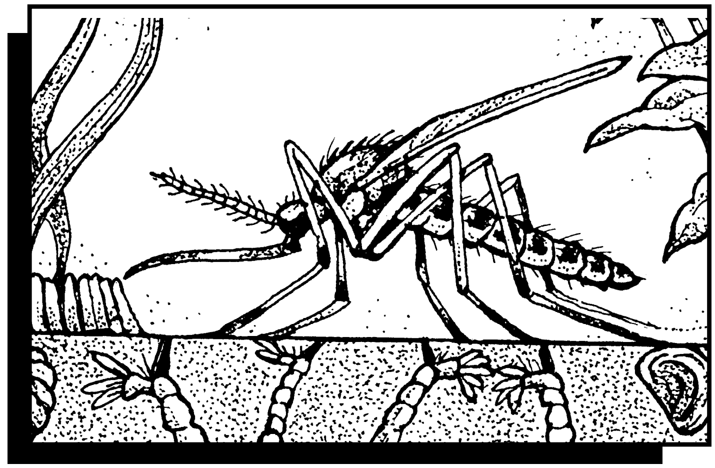
Larval Control of Mosquitoes



By William Olkowski

Mosquitoes are a nuisance, but they are also responsible for diseases that affect the health and happiness of human beings. Worldwide, mosquitoes continue to vector (carry) some of the most widespread and devastating human pathogens, including those for malaria, yellow fever, dengue, and filariasis. About 1 of 17 people now alive will die due to a mosquito vectored disease, and mosquitoes are responsible for over 3,000,000 deaths a year (Fradin 1998).

Because mosquito treatments often expose large areas to toxic materials, these pests also sometimes cause conflicts between public health professionals who are applying pesticides and members of the public who do not wish to be exposed. Mosquito adulticides are the main problem, and though the situation has improved greatly since 1985, the mosquito spray fenthion has recently killed large numbers of birds in Florida (ENN 2001).

In the United States the primary reasons for controlling mosquitoes are to lessen the annoyance caused by their bites and to reduce the transmission of human and equine viral encephalitis, West Nile virus, and dog heartworm. By annoyance we mean the itching, restlessness, loss of sleep and nervous irritation people, pets, and domestic animals suffer as a result of mosquito attacks. Sometimes this annoyance can be documented as economic loss, such as decreased recreation income, milk and beef production. Mosquitoes also are reported to have caused the death of domestic animals due to blood loss and anaphylactic shock from reactions to mass injections of saliva, but these are rare. Though they are rarely appreciated, mosquitoes also have a good side, and are a major food source for many wildlife species (Harwood and James 1979; Furman and Catts 1982; Smith 1973; Busvine 1980, Goddard 2000).

Traditional Mosquito Control

Mosquito control agencies in the United States and Canada spend in excess of $80 million annually to reduce mosquito annoyance. In addition, the money spent by the public for aerosol insecticides, repellents, window screens, and other controls easily exceeds this figure (Olkowski et al. 1991).

Unfortunately, much of the money and effort expended by individuals and communities to control mosquito problems is ineffective and serves only to put toxic materials into the air that people and their pets breathe. In addition, these mosquito control efforts often result in new pest problems, such as pest outbreaks on shade and forest trees. These secondary problems result when mosquito control activities kill off the natural enemies of pest insects that otherwise would be under adequate control (Olkowski et al. 1991).

The wasted money and effort, and annoying or potentially dangerous side effects, result because much mosquito control effort is still directed against the adult mosquito, instead of going to the source—water—where the larval stages are found. The misdirected and often dangerous practice of routine fogging or space-spraying for mosquito control continues in spite of decades of experience with successful alternatives. Routine aerial fogging still occurs, even though source reduction techniques have been taught for decades as the most desirable management approach (Mount et al. 1996).

However, using insecticides to reduce adult mosquito populations (adulticides) can be an acceptable emergency procedure where larval programs have failed, and serious diseases are being transmitted. When such emergencies occur, it is imperative that spraying of adulticides be followed with source reduction and application of larvicides such as *Bacillus thuringiensis israelensis* (BTI). This is the only way to prevent buildup of mosquito resistance to the adulticides, rendering them useless when needed for an emergency (Olkowski et al. 1991; Service 1980).

A Better Way

As is common in many pest control situations, safe and effective management of the pest requires more attention, time, and effort than the traditional spray-hope-and-curse approach. And, because mosquitoes form the basis of many important wildlife food chains, even good mosquito control programs can cause political problems in local communities (see Box A). Good mosquito control practices, like other services, may

Box A. Mosquito Control-Often a Political Headache

Acrimonius debates sometimes rage regarding the control of mosquitoes in parks and other, less urbanized areas. Fishermen and naturalists understand that mosquitoes form an important part of the diet of fish and other wildlife. When you eliminate the mosquitoes from a marsh or creek, you are affecting an important component of the aquatic food chain. If you use persistent or accumulating poisons, you can end up killing not only fish, but birds as well, as experience with DDT showed long ago.

Even proper mosquito management can become a political football, as the National Parks Service has learned to its dismay more than once. What about a creek area where many residents depend on fish for nutrition and others want mosquito-free streamside golfing? Or the preservation of a natural marsh habitat, which happens to be a breeding ground for mosquitoes that then annoy people visiting nearby beaches and summer homes?

In some of these cases, one is reminded of the story about a king who was so enamored of the feel of leather under his bare feet that he ordered the entire kingdom covered with leather. Luckily, a wise person pointed out that the king might achieve the same effect by tying leather to his own feet. Surely, screened porches and windows on summer homes, and repellents applied to individuals enjoying recreation in mosquito-prone natural settings are better solutions than wiping out entire wildlife food chains.

also require greater expenditures, particularly during transition periods when sound Integrated Pest Management procedures are being implemented.

This article is not an exhaustive essay on the technical aspects of safe and effective mosquito management for communities. Much has been written elsewhere about the subject, as indicated in the References. Here, we will focus on what you as an individual can do around your home, and how you can intelligently judge the appropriateness of the treatment activities carried out by public agencies in your area. In basic respects they are much the same.

First, you must learn something about mosquito biology. Then, you need to know where to look for breeding sources. (See Box B for Mosquito Biology and Table 1 for common mosquito breeding areas.) Finally, you need to sort through the safe tactics available to find those most appropriate to the situation at hand.

On the community level, critical operations are surveying for larval breeding areas and monitoring of larval and adult mosquitoes. Judgments will have to be made about injury levels (that is, the level of mosquito abundance that is no longer tolerable). Managers must stay knowledgeable regarding the latest developments in the field of least-toxic controls. There is always a need for citizens to inform themselves and keep watch on how local control programs are proceeding (Olkowski et al. 1991).

How to Begin?

Are mosquitoes bothering you at home? Start a systematic survey of your premises for standing water in which mosquitoes could develop. Believe it or not, chances are very good that the pests are being produced within a few yards of where you are bitten. Do not overlook such minute sources as water in vases, treeholes, storm sewer catch basins, poorly draining roadside ditches, potted plants, and stray tin cans that may have caught rain or irrigation water, or hard-to-examine areas such as clogged gutters and downspouts (USDHEW 1969). Gradually working outward from the house, check the periphery and nearby neglected areas such as vacant lots. Look for old tires and similar miscellany behind garages, gas stations, and other areas. Old tires should be recycled or cut in half. It is very difficult to completely drain an intact tire that has water in it. Legislation is needed to help alleviate tires as breeding sources, particularly now that the Asian tiger mosquito, *Aedes albopictus*, which vectors the dengue viruses, has become established (Moore 1999).

Culex pipiens that vectors West Nile virus breeds in stagnant water and water sources found near houses (see Quarles 2000; Monath 1989). Most small sources of mosquitoes you encounter around the house or neigborhood can usually be handled by simply emptying the container, removing it, or turning it upside down so that it no longer collects water. Those that cannot simply be drained or filled will have to be treated with one of the methods discussed in the more detailed section on Habitat Management, below. Recycling programs that remove cans, tires, and similar debris can reduce mosquito sources (Kettle 1984; USDHEW 1969).

Field surveys are also the foundation of any effective community-scale mosquito control program. Surveys make it possible to determine which species are biting and, based on identification of the species, where and when they are breeding. This information is necessary in order to apply control measures efficiently and precisely to just those sites where mosquitoes are present and causing a nuisance (Service 1993).

Community Surveys and Monitoring

Community field surveys are of two types: preliminary surveys provide an overview of the situation and establish sampling sites; ongoing surveys are made at weekly or biweekly intervals in order to monitor mosquito population growth and species composition over the season.

Box B. Mosquito Biology

Mosquitoes belong to the family Culicidae of the order Diptera—the true flies. Although mosquitoes are distinctive looking, there are other flies which may be mistaken for them. For instance, crane flies, beneficial aphid-eating gall midges, fungus gnats and biting midges can be mistaken for mosquitoes (Olkowski et al. 1991).

Worldwide, the mosquitoes, or culicids, are a large family with over 3,000 species. The U.S. has about 160 species belonging to 13 genera, the most important of which are *Culex*, *Aedes*, *Culiseta*, *Psorophora*, and *Anopheles*. (See Table 2 for a description of common mosquito species.) Each genus differs from the others primarily by the type of habitat in which it develops. All mosquitoes, however, develop in water, preferably still or very slowly moving water.

Adult mosquitoes are small, long-legged insects with a single pair of membranous wings (a characteristic of all true flies). They can be distinguished from all other flies by the presence of a long piercing mouthpart (the proboscis), and scales on the margins and veins of the wings. Morphologically, males differ from females in having feathery antennae and long feathery palps (mouth parts) (Busvine 1980; Service 1980).

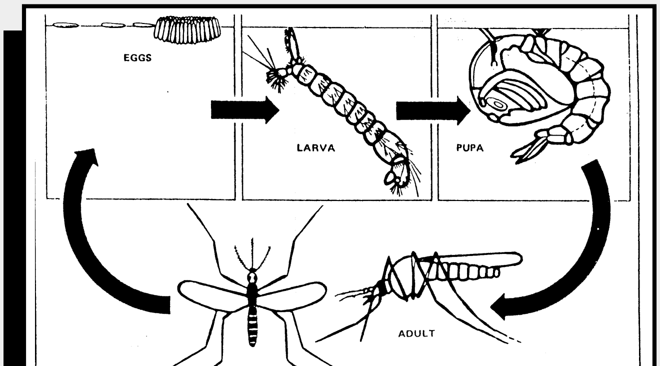
Mosquitoes develop through four distinct stages: egg, larva (or "wriggler"), pupa (or "tumbler"), and adult. Only adult females feed on human and animal blood, the protein which they require to mature their eggs. Moreover, not all mosquitoes will feed on people. Some species feed almost exclusively on birds, others on amphibians. Both males and females feed on plant nectar as a source of energy (Service 1980; Furman and Catts 1982).

Mosquito eggs fall into three general groups:

- those laid singly on the water surface (Anopheles), each egg having a series of "floats" along its perimeter;
- those laid in groups to form rafts which float on water surfaces (*Culex* and *Culiseta*);
- those laid singly out of the water in the mud (*Aedes* and *Psorophora*).

The egg-laying (ovipositing) adult females of the first two groups tend to utilize permanent water sources that are generally present throughout the season. The females lay their eggs directly on the surface, sitting on the water and using surface tension for support (Goddard 2000; Kettle 1984).

Aedes and *Psorophora* females, on the other hand, are most likely to lay their eggs in or on soil surfaces at the edges of more temporary water sites. When later flooding occurs and the eggs are inundated, they hatch. The pasture mosquito in the West, A. *nigramaculis*, and the salt marsh mosquito, *A. sollicitans*, on the East Coast use this egg-laying method (Darsie and Ward 1981; Glasgow 1938; Richards 1938).



The mosquito life cycle

The larvae of all mosquitoes are aquatic; they have adapted to a wide variety of habitats, including permanent ponds, marshes, woodland pools, tree holes, and artificial containers. A list of such common mosquito sources around the home is found in Table 1. These breeding sites all resemble each other in that they are quiet pools of water offering shelter from wind and wave to the ovipositing female. Thus, neither a fast-flowing stream nor the open water of a river, lake, or sea is generally suitable for mosquito breeding (Kettle 1984).

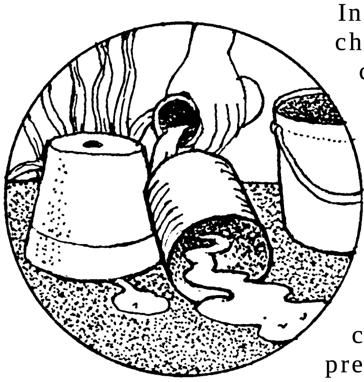
Larvae generally feed on micro-organisms and particles of organic matter. Food is swept into the mouth by a pair of feeding brushes. Mosquito larvae do not have gills for breathing. Most breathe directly from the surface of the water via a siphon tube located on the tip of the abdomen. (There are a number of exceptions to this; for example, there are species in one genus which obtain air through the underwater portions of plants.)

The larval stage requires a minimum of 3 to 10 days for completion and is marked by four separate developmental periods, or "instars." After the fourth stage the pupa appears and thereafter the adult emerges to mate, feed, and lay eggs. Larvae move principally by jerks of their body. This behavior accounts for their often being referred to as wrigglers (Busvine 1980).

Table 1. Mosquito Sources Around the Home

Bird baths	Puddles from evaporative cooler drains
Boats that have not been drained	Rain barrels
Catch basins at road corners	Saucers under potted plants
Cisterns	Septic tanks
Clogged roof gutters	Standing water in tire ruts
Drain outlets from air conditioners	Street gutters
Dripping outdoor faucets	Sumps
Leaf-filled drains	Tin cans, jars and other containers
Leaky pipe joints	Tree holes
Old tires	Vaults in utility meters
Ornamental ponds	Watering cans, buckets
Over-irrigated lawns and fields	Watering troughs
Plastic wading pools	Wells
Poorly constructed cesspools	Wheelbarrows or tilt-up carts

Both preliminary and ongoing surveys generally include sampling for both immatures and adults. Often areas can be treated appropriately at the same time they are monitored and discovered to have mosquito larvae (see Habitat Management below). In the same way that you check in ever-widening circles around your own residence, community surveys should be carried out in concentric circles around inhabited areas, moving further and further from populated areas as resources permit. The seasonal changes in the direction of prevailing winds also needs to be factored into these plans. Use of maps to record areas found to be mosquito sources can be very helpful in subsequent seasons (Service 1993).



Looking for Breeding Sites

Larval surveys make it possible to locate mosquitoes before they emerge as adults. This has the obvious advantage of making it possible to prevent biting by eliminating the pest before it reaches the adult (or biting) stage. In addition, the larvicides (insecticides used for larval insects) now available mean that treatment of mosquitoes in this stage will have the least possible effect upon humans, their domestic animals, and the larger environment (Service 1995; Service 1993).

Larval samples are taken most commonly from suspected aquatic development sites with a long-handled dipper. This takes some experience in order to avoid the evasive actions of larvae, which are sensitive to vibrations, shadows, and ripples, diving to escape being "dipped." The number and instar (developmental stage) of larvae and the number of pupae are recorded. Also noted are the number and kinds of natural enemies. The need for larval treatment should be based on this information (Service 1993; Service 1980). Mosquito sampling equipment can be purchased from companies such as BioQuip (see Resources).

Which Ones are Biting?

Surveys of adult mosquitoes establish which species are biting, where they occur, and when during the day or night they are most troublesome. Also, they can provide clues as to the probable development sites that should be located and treated to prevent intolerable biting levels.

"Biting counts" are a simple way of monitoring adult mosquito activity. They indicate whether treatment activites have been successful and for how long. Such collections require nighttime work and are most valuable in determining injury levels (Service 1993; Service 1980).

Biting counts are made by exposing some part of the body (usually a forearm or lower leg) for a given time (usually 2 to 15 minutes) and collecting female mosquitoes as they land to feed (it is only the female mosquito which bites). An aspirator is used to collect these adults, which are later identified and counted. Unless each mosquito is allowed to feed, such measurements are more properly called "landing counts." As an aspirator tube is filled with adults, it is replaced with a new one. Thereafter, the mosquitoes can be killed by placing the vials in a freezer (Service 1993; Kettle 1984; Busvine 1980).

Light traps, animal bait traps, resting stations, and CO_2 traps are commonly used to monitor adults but are considerably more elaborate, inconvenient, and expensive than biting or landing counts. As activity measurements, they are also more indirect than landing counts since they introduce extraneous variables into the monitoring process. Some of these systems have the advantage that pathogens can be identified and mosquito distribution can be determined for mapping (UC 1980; Service 1993; UC Davis 2001).

Since it is people who complain about being bitten or annoyed by mosquito activity, direct measurements

Table 2. Kinds of Pest Mosquitoes

Scientific Name	Common Name	Breeds In	Flight Distance	Diseases or Other
Aedes aegypti	yellow fever mosquito	containers	1-5 miles	yellow fever, dengue, encephalitis, canine heartworm
Aedes albopictus	Asian tiger mosquito	tires	1-5 miles	dengue
Aedes dorsalis	salt marsh mosquito	salt marshes	1-5 miles	bites outside
Aedes nigromaculis	-------	muddy pastures	2-5 miles	bites outside
Aedes sierrensis	tree hole mosquito	tree holes, tires, containers	1/2 mile	canine heartworm
Aedes sollicitans	--------	brackish marshes	5-20 miles	------
Aedes squamiger	winter salt marsh mosquito	salt marsh	5-20 miles	aggressive biter, high numbers
Aedes taeniorhynchus	salt marsh	salt marsh	5-20 miles	aggressive biter
Aedes triseriatus	--------	tree holes	1/2 mile	aggressive biter
Aedes vexans	--------	temporary pools	5-20 miles	aggressive biter
Aedes washinoi	woodland pond	mud holes	-----	aggressive biter
Anopheles freeborni	malaria mosquito	fresh water	1-2 miles	malaria
Anopheles quadrima culatus	malaria mosquito	fresh water	1-2 miles	malaria
Culex pipiens	house mosquito, bites inside houses	foul water, containers	1 mile	west nile, St. Louis encephalitis, canine heartworm
Culex tarsalis	encephalitis mosquito	stagnant water	2-10 miles	west nile, equine encephalitis
Culiseta incidens	fish pond mosquito	creeks, containers	1/2 mile	large, bites at sunset
Culiseta inornata	winter marsh mosquito	rain filled ponds	1/2 mile	large, bites at sunset

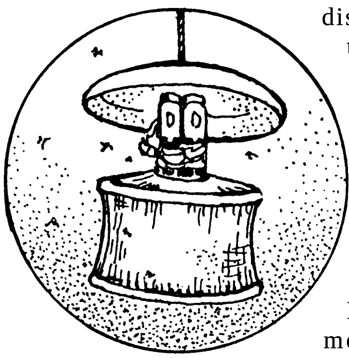
Sources
Service 1980; Alameda 1999; Olkowski et al. 1991

of biting frequency can better be correlated with complaints called into the mosquito control agencies from different areas. This can help to pinpoint where improvement is needed or where the program has been particularly successful.

One innovative mosquito control program made use of senior citizen volunteers to collect biting counts. Different people agreed to make counts at prescribed times during the night with phone calls to a central office where the data were collected and analyzed. By using volunteers, the overall cost of the program was reduced and more complete and effective mosquito control was the result. Monitoring may easily be the most costly as well as the most important component of a safe and successful mosquito control program (Olkowski et al. 1991).

Timing

The frequency and timing of surveys or regular inspections should be determined by when complaints about mosquito problems arise. The number of complaints is a function of the problem mosquito species, human population density and distribution, tolerance level of the people, and the type of management strategies and tactics practiced. (See Table 2 for a description of the common pest mosquito species).



For example, in the mid-Atlantic states, monitoring should start in March for the salt-marsh mosquito, *Aedes sollicitans*, and continue at least at 10-day intervals until the middle of May. This species is usually the major pestiferous mosquito on the East Coast where salt marshes are common. It has the capability of traveling many miles from its coastal marsh development sites. Further south, the major salt marsh mosquito is *A. taeniorhynchus* (Darsie and Ward 1981; Means 1979).

Part of the monitoring process involves identification of the species of larvae and adults. Once the adult pestiferous mosquitoes are identified, the likely water sources in the vicinity can be located, mapped and sampled. If the larvae from such samples are of the same species as the adults found in the biting counts, then the most probable source(s) of the biting adult population(s) has been found.

Without correct identification of species, and the correlation between adult biting activity and most probable larval sources, mistakes will be made during treatment. Species determinations will also indicate possible vectors (those mosquito species that might be carrying organisms causing disease in humans or animals) (Olkowski et al. 1991).

Establishing Action Levels

It is not realistic to assume that all mosquitoes can or should be eliminated. The cost of environmental degradation in terms of wildlife loss would be too great. Because mosquitoes are important prey in many bird, bat, reptile, amphibian, fish, and other food chains, these animals would be adversely affected when their food supplies were reduced. The use of broad spectrum insecticides also reduces these and other populations directly by introducing toxicants which kill by indirect action. However, it is difficult for most communities to agree on how many mosquitoes are too many. In other words, at what point should treatment action be initiated? This is called the "action level" (Olkowski et al. 1991).

The action level is reached before the so-called injury level, or level at which intolerable pest numbers are present. That is because there must be time to do something before numbers become intolerable. This is particularly true in least-toxic mosquito management, since it is the immatures that must be treated. Once they have developed into adult mosquitoes, it is usually too late to use environmentally benign methods of managing the situation (Service 1980).

Injury levels for a few nuisance and vector mosquito species are mentioned in the literature, but a great need still exists to establish levels for other nuisance species in various situations. Larger numbers of mosquitoes are usually tolerated in rural areas. Mosquitoes there breed over wider areas, and management is more difficult and expensive. Urban areas have less tolerance because of the political process. Action levels are set low because pest control professionals in urban areas would lose their jobs unless adequate mosquito control was provided (Olkowski et al. 1991).

In order to establish an action level in an area where this has never been done before, one must start with some arbitrary number. If possible, this should be based on the estimated or recorded number of complaints received in previous, similarly wet, years. If good records are kept for the current year, this initial "working" action level can be used as a baseline, and revised in subsequent years as more information is collected. With several years of good recordkeeping (including records of complaints, details on treatment actions and precise areas treated, and results) a useful and reliable action level for the local environment can be developed (Alameda 1999).

Treatment Tactics

The precise tactics for mosquito treatment and prevention must be fitted to each source of mosquitoes, balancing effectiveness, costs, and environmental damage. Professional managers trained in mosquito identification, biology, ecology, and management are usually required for most regions because of the complexity of the biological and sociological situation that exists where mosquitoes are chronic problems.

Habitat Management

Elimination of all standing water is the key to prevention of mosquitoes that develop around the home. Since even the smallest collection of water— in an unused watering can or old saucer left from feeding a pet—can be the source of a surprisingly large number of mosquitoes, not even the tiniest collection of water should be tolerated unless stocked with fish.

Keeping roof drains and gutters clean is critical, as these are common breeding sources. Proper grading of landscape areas is important to avoid standing pools of water. Drainage of water, in large or small areas, can be accomplished by gravity ditches, subsurface drainage tiles, or sump pumps, or by filling the low areas with imported soil. Storm sewer catch basins, unfortunately, cannot be easily drained, so they need to be placed on regular monitoring and treatment programs (UC 1980; USDHEW 1969).

Natural Pools, Swamps, and Marshes

Woodland and grassland pools, flood plains, marshes, and swamps are other sources of mosquitoes which require different approaches depending upon how extensive these areas are. Woodland pools are shallow pools of water that last for weeks or longer after rains. They can produce enormous numbers of mosquitoes, sometimes in relatively close proximity to large population centers (USDHEW 1969).

In areas where spring and summer rains fill woodland pools and other water accumulation surrounding homes, inspection and drainage should be carried out in concentric circles as described earlier, to the extent that resources permit. Only those pools found to contain live mosquito larvae should be drained or filled.

However, draining certain bodies of water can be highly disruptive of natural areas, food chains, and ecosystems. Considerable judgment is required to decide if drainage is appropriate or whether some other, less permanent, procedure would be less environmentally damaging (Merritt and Cummins 1978; Pennak 1978).

With the development of such selective and benign microbial products as BTI (*Bacillus thuringiensis israelensis*, see Biological Controls, below), the choice has become easier, because this material can be used for spot-treatment applications with minimal damage to non-target wildlife. Thus, where woodland pools are producing intolerable biting populations, all such sources need to be located and inspected at appropriate times each year and treated with BTI (Chapman 1974; Levy et al. 1984).

Coastal marsh areas should have drainage ditches created within them so that high tides can adequately flush the marsh. These ditches can link up artificially created pools into which mosquito-eating native fish can retreat during periods of very low tide. When water levels rise once again, the fish can fan out over the marsh, eating the mosquito larvae wherever they are to be found (Glasgow 1938; Richards 1938).

There is an extensive literature on the use of these techniques to manage certain types of marshes. These techniques have worked well on both the East and West Coast. Where there is sufficient motivation to treat these areas in an environmentally sound manner, and citizens are sufficiently enlightened and willing to support progressive mosquito control, there is little reason why coastal marshes cannot be managed in a manner that minimizes the use of toxic materials (Carlson et al. 1999; Wolfe 1996).

How to Handle Tree Cavities

Certain species of mosquito will breed in cavities in trees. A common way of treating this problem is to drill a slanted drainage hole from the outside of the trunk to the bottom of the cavity inside. Sometimes a metal pipe is inserted in this hole to make certain that drainage continues. Some very fine old specimen trees have survived this treatment, for example on the Andrew Jackson estate in Tennessee.

However, recent research on the ways trees protect themselves from disease organisms indicates that in general this approach is not a good idea. Drilling such a hole can open up the tree to fungal and other invaders by breaking the seal the tree has created around such cavities.

Where tree-hole mosquitoes are a problem, a better approach to the drainage of such cavities is the insertion of a wicking material that leads from the bottom of the hole over the lowest edge and down the tree trunk to a level below the base of the cavity. The cavity can then be filled with a loose, porous material that drains easily, such as sand or fiberglass (insulation material). There is, however, no research available evaluating this technique. Another possibility is dropping a BTI Mosquito Dunk or a methoprene Altosid Dunk in the tree cavity (see below). These will give short-term protection without harming the environment (see Resources).

Physical Controls

The most important approach to protecting yourself from mosquitoes in the house is also the most obvious one: the use of screens on windows and doors and around porches where evening activities take place in hot weather. It goes without saying that the screens should be maintained free from large holes and tears. But as usual, saying is easier than doing, especially if it requires some ladder work.

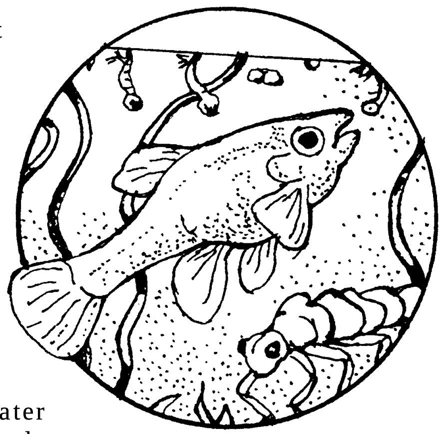
If a mosquito or two bothers you at night, it probably gained entrance through a door when someone entered the house. If this occurs regularly, a hole in a screen or a crack around the edge should be suspected. As with fly management, screens should be inspected each season for small holes or tears. These can be mended with clear caulk. Screens should fit tightly around any opening. Gaps can be bridged with soft, removable caulk around windows, and with weatherstripping around doors (Olkowski et al. 1991).

Mosquito netting around sleeping bags is an excellent way to enjoy sleeping out under the stars without having to fight mosquito attacks. These nets can be purchased, or constructed on a sewing machine. The nylon netting or window curtain material can be purchased in surplus stores or through mail order supply houses such as BioQuip (see Resources). A simple wire frame can be designed to hold the screen above the head area, and Velcro tape can be used to attach the screen to the sleeping bag.

Head nets like those worn by beekeepers can be very important pieces of outdoor equipment if you visit areas with large numbers of mosquitoes (see Resources). It is possible to go into such areas if you wear a long-sleeved shirt, long pants fastened at the ankles to prevent bites on the legs, and a head net to prevent bites around the neck and face. Although it may be uncomfortable in hot weather, a sweatshirt is a good idea, because the thickness of the material alone can prevent bites. There are also net shirts on the market which are soaked in repellent and worn over relatively light clothing or swim suits. These nets will also protect against many other biting flies. In some areas this kind of equipment is essential, since the mosquito populations are so large (Olkowski et al. 1991).

Biological Controls

Small backyard ponds should be stocked with "mosquito" fish or goldfish. Goldfish will live longer and are generally hardier and easier to find at pet stores. The fish may have to be protected from cats and raccoons by an overhang around the edge of the pool or an escape area where they cannot be caught. A one-foot section of 4- or 6-inch diameter (10-15 cm) clay drainage pipe, placed on the bottom of the pool, creates an excellent refuge from predators.



Consider stocking exotic or native mosquito-eating fish in any small body of water that has been made by humans and has no natural drainage. However, natural bodies of water should not be stocked with exotic species of mosquito-eating fish, because they will kill native fish, either directly, or indirectly by altering the habitat and competing with them for food. They may also be killed by native fish and thus would be ineffective. Stock natural lakes with native species only (Chapman 1974; Chapman 1985).

Many native fish are good mosquito predators. Efforts should be made to enhance their capabilities for predation. Unfortunately, the same conditions that make some bodies of water mosquito sources, that is, unintentional pollution and habitat alterations resulting from human action, can reduce the ability of those areas to support native fish.

For example, where shallow streams and ponds are allowed to accumulate excess fertilizer that enhances excessive plant growth, predation by native fish species can be hindered and excessive mosquito populations can ensue. The proper management tactic in such a situation is to reduce the fertilizer input and clean out the excessive vegetation so that native fish predation can be restored and maximized. Usually, artificial ponds can be drained and cleaned (Olkowski et al. 1991).

In certain sites, such as log ponds, sewage treatment ponds, and dairy waste lagoons, native fish species are not able to survive because of lowered oxygen content and other modifications of the environment. These areas may be good candidates for the mosquito fish, *Gambusia affinis*. This species has been used throughout the U.S. as an introduced species for mosquito control (Boklund 1997; Christensen and Washino 1977).

Many mosquito agencies already produce this species for use in man-made habitats such as backyard fish ponds, sewage treatment ponds, and rice fields. Mosquito fish are more effective for mosquitoes that breed in permanent or semi-permanent bodies of water than for floodwater species (Service 1995). Citizens should contact their local mosquito abatement agency to see if fish are available.

There are other fish species that may be useful in these habitats. For example, some *Tilapia* species can be used in sewage treatment ponds because they will eat mosquitoes and other pestiferous and closely related species of flies. Other countries favor the use of different species of fish, particularly the guppy, *Poecilia veticulata*.

BTI and *B. sphaericus*

The commercial development of *Bacillus thuringiensis israelensis* (BTI), marketed as Tecknar®, Bactimos®, and Vectobac® (see Resources), offers the possibility of a least-toxic suppression agent that is also highly selective. This pathogen, like other strains of BT, acts initially and perhaps primarily as a stomach poison, damaging cells of the midgut epithelium of infected mosquito larvae. BTI works best on early stage larvae that are actively feeding (Alameda 1999; Federici 1995).

In comparison with other bacterial toxins and even many synthetic insecticides, BTI has an extremely rapid lethal action on mosquito larvae. Studies show that a moderate-to-high concentration kills about 50% of a test population of some *Culex* mosquito species in 15 minutes and the rest of the population in about an hour. Furthermore, only a five-minute exposure to the toxin is necessary for death to occur later. *Culiseta* and *Aedes* species require longer exposure and higher doses than *Culex* to be effective. *Anopheles* appear to be the least susceptible of the mosquitoes tested (Levy et al. 1984).

Anopheles is susceptible to formulations of the related bacterium *B. sphaericus*. Formulations such as VectoLex are useful for treating larvae of *Culex* spp. and other mosquitoes found in polluted water (Mulla et al. 1997). VectoLex also gives good control of *Aedes triseriatus*, the predominant species found in waste tire dumps (Siegel and Novak 1997).

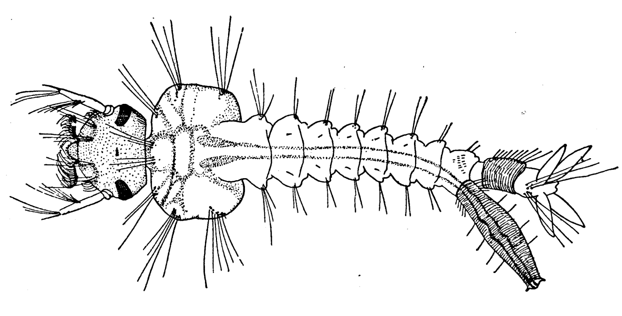
In field studies BTI has been shown to be effective against several mosquito species in widely differing water quality conditions, including irrigated pastures, storm drains, ponds, dairy lagoons, and salt marsh potholes. BTI has also been shown to be effective against many black fly (Simuliidae) species, while also being nontoxic to most other aquatic species. BTI can be applied with conventional application equipment. Although it is more costly than more toxic and less selective products, the added costs of using BTI should be weighed against the damage to non-target wildlife resulting from use of other products (Levy et al. 1984; Federici 1995).

Chemical Control

Repellents should be more widely used. Ideally they would be displayed more prominently for sale to visitors in recreation areas. They provide an excellent way for those who are particularly sensitive to mosquito bites (or other biting flies) to protect themselves. This would reduce pressure on public service providers to spray insecticides over entire ecosystems.

As much as possible, apply repellents to your clothing rather than directly to your skin. The most widely sold is "Deet," diethyltoluamide, in strengths ranging as high as 75%. Botanical repellents are also available (see Quarles 1996ab).

An old and still effective method for killing larval mosquitoes in standing water is to apply a film of oil on the surface of the water. Larvae must obtain oxygen from the air in order to breathe, and the oil clogs their breathing apparatus, thus effectively smothering them. Enough oil should be used so that a film is created across the entire open surface. While many oils, such as No. 2 fuel oil or kerosene, have been used, special oils have come on the market in recent years which are more refined and cause less damage to non-target wildlife and plants. These have been produced especially for mosquito control (Alameda 1999). One of these is GB-1111 or Golden Bear Oil (see Resources).



A *Culex* sp. larva

Another material aimed at killing larvae by disrupting their ability to breathe is a monomolecular surface film called Agnique produced by Cognis Corporation. A competing product is called Arosurf (see Resources). These products are safe and effective, and kill larvae, pupae, emerging adults, ovipositing females, resting males, and egg rafts of some species. However, larvicidal action is not immediate and the surfactant film's effects will be lessened if the surface of the water is disturbed, by wind or other activities (Alameda 1999; Olkowski et al. 1991).

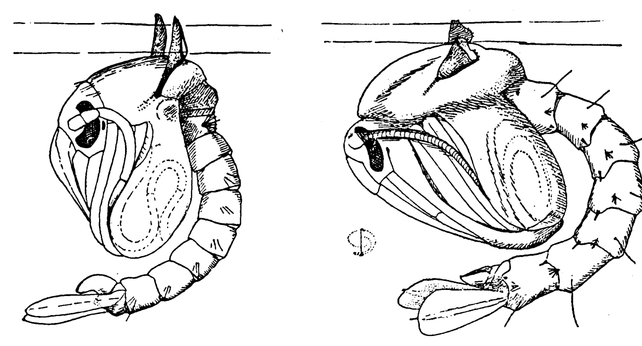
In comparison, BTI formulations—Teknar®, Bactimos® and Vectobac®—have a rapid effect on larvae, but the BTI does not persist and does not affect pupae. It is ineffective against larvae which have ceased to feed prior to pupation and against pupae (which do not feed) (Alameda 1999; Mullah 1997).

Field tests with Arosurf® and BTI in combination, however, indicate 100% control against mixed larval and pupal populations of *Culex*, *Psorophora* and *Aedes* spp. in 24 or 48 hrs. These materials are quite compatible, therefore, but either material may also find use alone in particular situations (Levy et al. 1984).

Methoprene

Other new, less toxic chemicals have entered the marketplace. An example is the insect growth regulator (IGR) methoprene, which was first introduced for mosquito control in 1974. It now marketed as Altosid by Wellmark (see Resources). This IGR offers greater selectivity and less toxicity to non-target wildlife than most other conventional insecticides. It induces damaging morphological changes in second, third and fourth instar mosquito larvae, resulting in the failure of adult mosquitoes to emerge from pupae. It is most effective on the 4th stage larvae (Alameda 1999; Mulla 1995). Use of methoprene on 4th stage larvae allows earlier stages to remain in streams to feed fish and waterfowl (Service 1995). Packaged in slow-release briquets, it is effective for at least 30 days in standing water. Altosid XR briquets supplied methoprene for 1.5 years in Minnesota (Boxmeyer et al. 1997). It can be coated on sand for easier foliage penetration, or applied as a spray solution from air or ground.

Methoprene has an acute oral LD_{50} in rats of >34,000 mg/kg, indicating a high degree of safety to mammals. This IGR is biodegradable and does not accumulate in food chains. It is far more selective in its action than the organophosphate or carbamate insecticides which are so widely used to spray for larval and adult mosquitoes. It is degraded quickly, especially in water, and has a favorable ecological profile (Tomlin 1997).

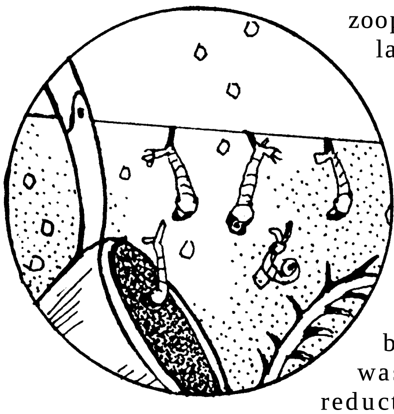


***Culex* sp. pupa** ***Anopheles* sp. pupa**

For a while methoprene was in disfavor because laboratory experiments showed that methoprene oxidation products caused deformities in frogs (La Clair et al. 1998). However, in the field "chemical analysis by several groups has failed to demonstrate the presence of methoprene (suggested to be causative because of retinoid-like activity) or its more toxic environmental degradation products in any sites at biologically relevant levels" (Burkhart et al. 2000).

Ecological Effects of Mosquito Treatments

The ecological effects of BTI and methoprene were studied for 6 years in Minnesota wetlands. Zooplankton, insects and breeding bird populations were monitored. There was no effect on zooplankton or bird populations. Insect densities other than mosquitoes were reduced by 57 to 83% in the second and third years of treatment. Bird populations were unaffected each year despite the loss of insects, possibly because breeding season was over before insect reductions became evident.



Methoprene typically led to a 76-86% reduction in emerging adult mosquitoes. BTI treatments led to a 65-72% reduction of larval populations (Niemi et al. 1999).

In general, it is less environmentally damaging to treat immature mosquito populations with relatively broadspectrum materials than to treat a much larger environment by ground-fogging or aerial application. Ground fogging is usually more selective than aerial application. Among the aerial methods, helicopter applications are more selective than airplanes. Another good generalization is that low-volume application methods are less damaging than high-volume applications. Among aerial application insecticides, some are more selective than others (Mount et al. 1996). (See the article on adulticides in this issue.)

With so many environmentally sound tools to choose from, and the extensive expertise already developed in least-toxic mosquito management, there is every reason to believe that citizen education, leading to citizen demand, will result in the reduction of toxic material application to our aquatic environments and communities in the name of mosquito control.

Conclusion

Just a few simple measures can reduce mosquito problems around the home. Screens over windows and doors should be in good repair, and all sources of standing water should be drained. Where this cannot be done, mosquito dunks or mosquito-eating fish should be added to it. Old tires should be thrown away or cut in half. Tree holes should be treated with methoprene briquets. Repellents and protective clothing should be worn outdoors in mosquito areas during mosquito-biting season.

Resources

Microbials and IGRS

Altosid (methoprene)—Wellmark Intl., 1100 E. Woodfield Road, Suite 500, Schaumberg, IL 60173; 80/248-7763; 800/426-7473

Altosid Briquets (methoprene)—Harmony Farm Supply, 3244 Gravenstein Hwy, No. B, Sebastopol, CA 95472; 707/823-9125, Fax 707/823-1734

Bactimos® (BTI)—Novo Nordisk, 77 Perry Chapel Road, Box 576, Franklinton, NC 27525; 919/494-3000; Fax 919/494-3450

Mosquito Dunks (BTI)—Summit Chemical, 7657 Canton Center Dr., Baltimore, MD 21224; 800/227-8664, Fax 410/282-7963; Harmony Farm Supply (see above)

Spherimos® (*B. sphaericus*)—Valent BioSciences, 870 Technology Way, Libertyville, IL 60048; 800/323-9597; Fax 847-968-4741

Teknar® (BTI)—Wellmark Intl. (see above)

VectoLex® (*B. sphaericus*)—Valent BioSciences (see above)

Vectobac® (BTI)—Valent BioSciences (see above)

Oils and Films

Agnique or Henkel 5996 (fatty alcohol)—Cognis Corp., 5051 Estecreek Drive, Cincinnati, OH 45232; 800/543-7370; Fax 513/482-5515.

Arosurf (fatty alcohol)—Henley Chemical, 199 Courtland Avenue, Concord, Ontario, CANADA L4K4T2; 416/661-1500.

Golden Bear 1111—Golden Bear Specialties, Oildale, CA; Witco Chemical Co., Oakland, NJ

Larval Sampling Equipment

BioQuip Products, 17803 LaSalle Ave., Gardena, CA 90248; 302/324-0620, Fax 310/324-7931.

Netting

BioQuip (Netting)—(see above)

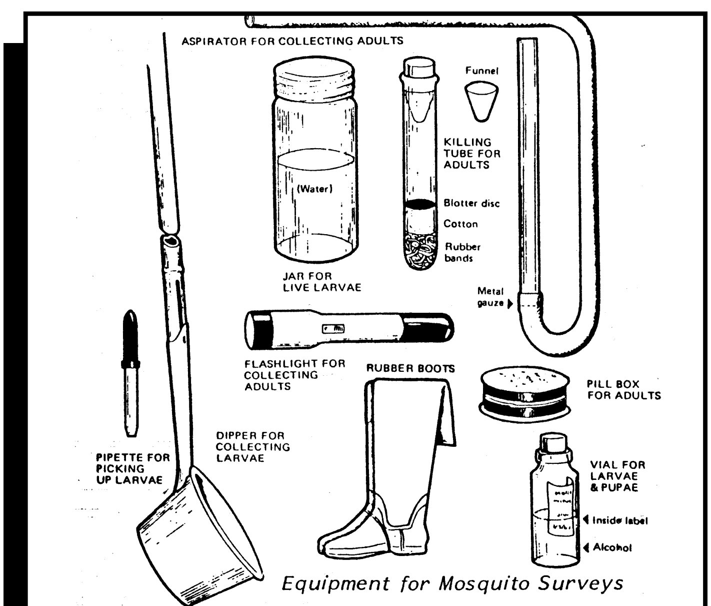
Due North Marketing (Net Suits)—1231 Hwy 17W, PO Box 2288, Sturgeon Falls, ON P0H 2G0, Canada; 705/753-2387; Fax 705/753-6113.

U-Spray (Head Nets)—4653 Hwy 78, Lilburn, GA 30047; 800/877-7290; Fax 770/985-9319.

Mosquito Traps

American BioPhysics (Magnet)—2240 S. County Trail, East Greenwich, RI 02818; 877/699-TRAP; Fax 401/884-6688.

Good mosquito abatement programs with competent larval control measures can prevent or reduce the nuisance presented by adult biting mosquitoes. A good



Equipment for Mosquito Surveys

mosquito IPM program will: quantify mosquito activity by conducting biting counts; identify species through monitoring programs; monitor for diseases with sentinel animals; establish tolerance or injury levels appropriate for adjacent land use; detect larval sources of the species feeding during biting counts; map or record larval sources for future reference and inspections; educate members of the surrounding community as to their role in reducing larval sources; eliminate larval sources by drainage, fish implants, other natural enemies; apply BTI or other least toxic materials to larval mosquito sources; return to evaluate all treatments; from evaluations, redesign treatments or develop plans for future management.

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