Controlling Adult Mosquitoes with Pesticides (Part I)

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Mosquitoes are universally recognized as a substantial threat to human health, each year killing almost a million people and sickening hundreds of millions more, but how best to respond to these noxious pests is controversial. Despite over a century of dedicated research, no “silver bullet” has been found that solely counters mosquitoes, and every intervention that has been developed – from draining swamps to stocking fish or spraying oils or distributing bednets – has faced questions about cost, effectiveness, and undesired side effects. In particular, the use of pesticides to combat adult mosquitoes has prompted vigorous debate, and a recently published book on DDT is likely to rekindle arguments pro and con. This article is the first of a series that describe mosquito adulticides and the methods used to assess their benefits, costs, and risks; specifically, this Part I is focused on how and why pesticides are used against adult mosquitoes.

There are thousands of species of mosquitoes in the world, and hundreds of these bite humans, in virtually all inhabited parts of the globe. For all species, the mosquito life cycle included four distinct stages (egg, larva, pupa, adult) **[FIGURE 1: LIFE CYCLE]**, with the larval and pupal stages lived in water (eggs can be laid on water or dry areas prone to inundation). Adult mosquitoes disperse in search of food and reproduction, so they are generally distributed more widely in an area than juvenile mosquitoes. Male adult mosquitoes get their nutrition from plants, while females also bite people or other animals for blood to nourish their eggs.[i] This means that only adult female mosquitoes can transmit pathogens or cause other disease and nuisance. Therefore, the basic goal of mosquito control programs is to minimize contact between people and adult female mosquitoes, and thus to minimize the frequency of mosquito bites and their associated hazards.[ii]

All mosquito bites carry some risk of disease or discomfort, but there is a large variation in the relative risk of different bites, and this is important in deciding how to respond. The primary risk is the mosquito’s potential for serving as a vector of pathogenic (disease-causing) organisms from one infected host to another. This requires that an adult mosquito lives long enough to bite an infected animal, digest the blood meal, lay eggs, and bite again – this second or later bites being the dangerous ones in terms of disease transmission. Thus, the vector risk of individual adult mosquitoes depends not only on their sex, but also heavily on their age. It also depends on their species, with some types much more dangerous than others due to their biting habits (multiple vs. single bites per blood meal), their host preferences (how eagerly they bite humans), and/or their compatibility with the pathogens (which must enter the mosquito’s gut, develop, migrate to a salivary gland, and exit through a bite).[iii] Other disease risks associated with mosquito bites – allergic reactions to proteins injected during bites, for example, or secondary infections following scratching of bites – can be serious but are rarely life-threatening; these only require adult mosquitoes to live long enough to bite once. Finally, mosquitoes can cause significant nuisance even without clinical disease; the degree of nuisance depends on their abundance, their aggressiveness, the noise they make, the time they typically fly, and other factors which also depend on the species but not on the mosquito’s age.

There are many ways to reduce mosquito bites, and they can basically be divided into those actions which directly reduce the abundance of adult mosquitoes, those which indirectly reduce their abundance by lowering juvenile abundance, and those which prevent contact between adult mosquitoes and people. Drainage of wet areas and other habitat manipulations typically reduce the population of juvenile mosquitoes in an area, and thus indirectly prevent or minimize production of adults. **[FIGURE 2: DRAINAGE].** Biological control of immature mosquitoes is often quite effective in limiting adult mosquito production from relatively permanent water bodies **[FIGURE 3: MOSQUITOFISH]**, but predators and parasites are rarely successful tools for controlling mosquitoes produced in small or temporary habitats. Although bats and birds do eat some adult mosquitoes, biological control of adults has not been shown to be an effective control intervention. Effective traps for juvenile mosquitoes do not exist, but adult traps can be used effectively used to reduce adult populations in some circumstances. Chemical toxicants (including botanical and bacterial materials) can be used to directly reduce mosquito populations as larvae (larvicides), pupae (pupicides), or adults (adulticides). Generally, larvicides are more selective than adulticides and are applied over more limited areas, but there are exceptions to both generalities. Finally, contact with adult mosquitoes can be lessened through physical barriers (bed nets, window screens, bite-resistant clothing, air conditioners) **[Figure 4: Bed Net]**, behaviors (staying inside during periods of mosquito activity), and/or chemical repellents.

Physical barriers, behavior changes, and chemical repellents can all be used at the individual or family level to reduce mosquito biting, but if the disease risk and/or nuisance level is high enough, and there is a decision to reduce mosquito populations, this usually requires community-wide programs, as mosquitoes can easily fly across property lines.[iv] Modern community-wide mosquito control programs typically apply multiple techniques to reduce mosquito populations, with specific actions based on abundance surveys, disease risk, and historic observations, in a general strategy known as Integrated Vector Management (IVM) or Integrated Mosquito Management (IMM). IVM/IMM tools exist to reduce mosquito populations at all life stages,[v] and key operational questions are the appropriate control targets and the best mix of techniques to address them.

Many mosquito control programs preferentially target juvenile mosquitoes, in large part to minimize the extent of areas exposed to pesticides, but indirect control of adult mosquito abundance through control of juvenile populations is not always possible or appropriate. For example, targeting adult mosquitoes directly is common where larval habitat types are not amenable to physical manipulation or the introduction of biological or chemical control agents because of their configuration or distribution – tire piles, artificial containers in urban areas, tree holes, and thickly vegetated ditches can all be examples. In addition, in many areas the extent of larval habitat within mosquito flight range of inhabited areas is simply overwhelming – this is common in much of Florida and other warm, wet zones. Finally, even for programs that normally emphasize larval control, direct targeting of adult mosquitoes with interventions is critical when adult mosquitoes are present in levels which pose significant risk of disease or substantial nuisance. In other word, once mosquito adults are present in an area, and especially if a significant portion of them are infected with pathogenic organisms, then larval control tools cannot solve the immediate problem – the use of pesticides (including repellents) which specifically target adults is often the only effective area-wide means of protecting people from mosquitoes and mosquito-borne diseases. Even if adult abundance rebounds after a pesticide application, if the average age of the flying females is reduced, disease risk can be substantially lowered.[vi]

Chemical tools are critical components of almost all successful IVM/IMM programs. All chemicals, including botanical products and other biochemicals, that target mosquitoes are considered pesticides from a legal and regulatory viewpoint, even when they do not directly kill the targets. In fact, while the term "adulticide" has traditionally been applied to materials that are toxic to adult mosquitoes at the application dose, pesticides that target adult mosquitoes can also repel them (repellents), attract them to traps, excite them so they are more vulnerable to toxicants, and reduce their ability to detoxify toxicants. Toxicant adulticides are generally low-persistence, broad-spectrum insecticides, most commonly pyrethroids or organophosphates, and non-target toxicity is minimized through selective application with low doses (both small droplets and low application rates per unit area). Repellents can work on many scales, from those applied to skin or clothing, to spatial repellents such as insect coils which may protect a room, to barrier sprays applied between larval habitat and inhabited areas. Attractant baited traps have been commonly used for many years for surveillance, and are increasingly being evaluated as population reduction tools. Excitatory agents and synergists that reduce an insect's abilities to protect itself from toxicants are useful additions to other products, but do not reduce mosquito risk when used alone.

[*This is the first in a series of articles which will examine the role of pesticides in protecting public health. The second article will explore how the effectiveness of adult mosquito control tools is measured. Part III reviews the risks associated with their use and the tools used to evaluate these risks*.]

Further Reading:

American Mosquito Control Association [http://mosquito.org/mosquito-information/control.aspx]

Donald Roberts & Richard Tren, *The Excellent Powder: DDT's Political and Scientific History*, Dog Ear Publishing 2010 (452pp).

Florida Coordinating Council on Mosquito Control. Florida Mosquito Control 2009 (260pp) [http://mosquito.ifas.ufl.edu/Documents/Florida_Mosquito_Control_White_Paper.pdf]

Joint Statement on Mosquito Control in the United States from the U.S. Environmental Protection Agency (EPA) and the U.S. Centers for Disease Control and Prevention (CDC) [http://www.epa.gov/pesticides/health/mosquitoes/mosquitojoint.htm]

WHO, 2009 [http://www.who.int/malaria/world_malaria_report_2009/en/index.html

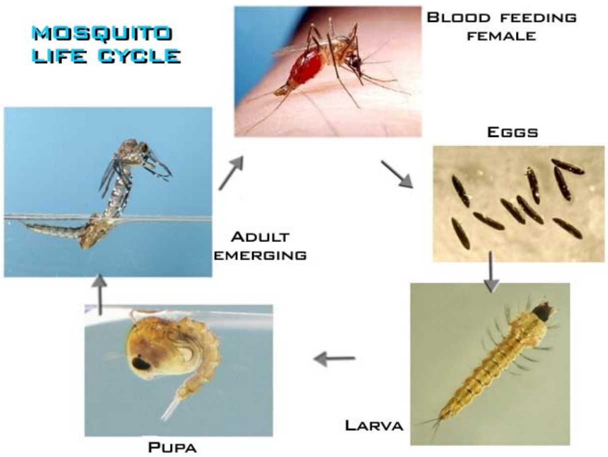

Figure 1: The Mosquito Life Cycle (source: FL Medical Entomology Lab)

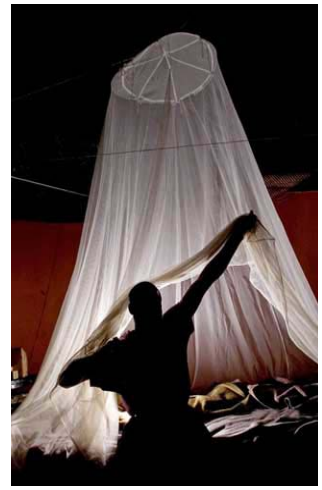

Figure 4: Chemically Treated Bed Net (Source:)

Figure 2: Digging a Drainage Ditch to Reduce Mosquitoes (source: CDC)

Figure 5: Treating larval mosquitoes with granular Bti (Source: State of PA)

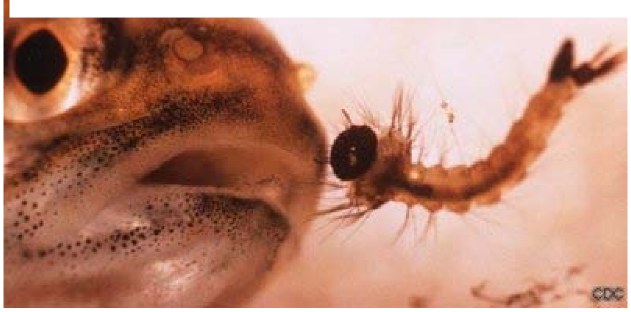

Figure 3: Mosquitofish and Larval Mosquito (Source: CDC)

[i] Some rare mosquito species can lay eggs without bloodmeals, and have no public health significance.

[ii] From a public health perspective, male mosquitoes are irrelevant. Not only do they not bite, but their abundance has little influence on the abundance of females because one male can mate with many females. Therefore, control measures never intentionally focus on reducing males. In fact, increasing the population but reducing the average fertility of male mosquitoes, by releasing large numbers of sterilized males, has shown some experimental successes in reducing the size of future generations, although this is not a routine operational mosquito control tool at this time.

[iii] These variables are typically described as the vector “competence,” which reflects mosquito-pathogen interaction, and vector “capacity,” which takes into account abundance, longevity, and biting behavior.

[iv] Community education programs encouraging household practices that reduce juvenile habitat are important components of IVM/IMM, but have not been shown to significantly reduce disease risk or nuisance without other interventions. Household “misting” systems, which spray a chemical toxicant on a timed basis, may reduce mosquito biting pressure in individual properties, but have been heavily criticized for their potential role in encouraging insecticide resistance.

[v] There are no biological or chemical interventions that focus on mosquito eggs, but some habitat management strategies can reduce the viability of eggs, especially in the genera *Aedes* and *Ochleratatus*, which depend on a dry “conditioning” period as well as a period of flooding for successful hatching.

[vi]The relationship between mosquito abundance and disease risk is complex and beyond the scope of this article. For example, reducing pathogen abundance in an area, even if mosquitoes are still present, reduces risk of pathogenic disease. On the other hand, it has been frequently observed that this may set the stage for a major resurgence of disease if the human population loses its “herd immunity” is an area and the pathogen returns. In addition, the abundance of pathogens or their mosquitoes vectors needed to maintain disease transmissions is generally unclear; even substantial reductions in mosquito populations may not break a disease transmission cycle or adequately reduce nuisance level if the initial populations are too high.