Journal of the Minnesota Academy of Science

Volume 50 | Number 3 Article 7

1984

# Physical, Chemical, and Biological Controls: Modern and Future Approaches to Mosquito Control

Max V. Meisch
*University of Arkansas, Fayetteville*

12. U.S. Department of Health, Education, and Welfare, Public Health Service. 1976. *Epidemiology and control of vectorborne diseases.* Publication No. (CDC) 76-8245, Atlanta, GA.
13. Hess, A.D., and Hayes, R.O. 1967. Seasonal dynamics of Western encephalitis virus. *Am. J. Med. Sci.* 253(3): 333-48.
14. Issel, C.J., Trainer, D.O., and Thompson, W.H. 1972. Serologic evidence of infections of white-tailed deer in Wisconsin with three California group arboviruses (La Crosse, Trivittatus and Jamestown Canyon). *Am. J. Trop. Med. Hyg.* 21(6): 985-88.
15. Thompson, W.H. University of Wisconsin (personal communication).

# Physical, Chemical, and Biological Controls: Modern and Future Approaches to Mosquito Control *

MAX V. MEISCH**

ABSTRACT — Effective mosquito management depends on a blending of many techniques. The primary technologies available are physical, chemical, and biological; and their continued improved usage is demanded. Chemicals are more contemporary. Modern organic insecticides were first used in 1943 with the advent of DDT usage. The judicious use of pesticides remains imperative in control methodology. However, a program optimizing non-chemical applications offers the best method for long-term success. A systems approach is needed regardless of strategies used. Basing strategies on objectives differs according to objectives of disease, annoyance, or livestock protection. The strategy is predicated on knowledge of the biology of specific species involved; no one set of strategies applies to all species.

## Introduction

Perhaps the title of this presentation should be Integrated Pest Management (IPM) of mosquitoes since the three subjects, physical, chemical, and biological control, constitute the primary strategies of IPM in contemporary mosquito control. The concept of IPM came into vogue in the early 1970s. A general definition of IPM might be the combination of all known techniques to manage (not eradicate) insects, or in this instance, mosquito populations. Such blending of techniques previously was referred to as integrated control and was often confused with organic gardening or even biological control *per se.* For more details concerning IPM, Botrell (1), has provided a comprehensive report on the subject. The phrase "integrated pest management" denotes an approach to the reduction of a pest problem in which decisions are based on consideration of what is ecologically and economically in the long-term best interest of the environment and mankind. The objective of integrated pest management is to lower the mean abundance level of a pest population by any method or combination of methods that supplement the natural control agents, to provide long-term alleviation of the problem, and cause the smallest possible disruption of the ecosystem. It is based on the realization that natural pest populations cannot be eliminated. Instead, they must be managed so that they occur at tolerable levels (2). Organized mosquito control has long employed these IPM principles and has indeed served "in cognito" as a template for IPM (3).

Effective mosquito control can be essentially summarized in four categories: 1) Determination of species present within a given area. Only female mosquitoes take blood meals and all species require water for development. Beyond these facts, further generalities become increasingly difficult to make. Some mosquito species deposit eggs on moist soil, some on standing water, and others in artificial containers. Some, such as *Aedes vexans* (Meigen), which is common in Minnesota, deposit eggs on moist soil and have a flight range of more than 40 miles. Others, such as the yellow fever mosquito, *Aedes aegypti* L., deposit eggs in treeholes or artificial containers and may fly only a hundred yards from their site of development. *Aedes vexans* is both a daytime and a nighttime biter while the yellow fever mosquito is almost entirely a diurnal biter. Many *Anopheles* species rest during the day and are almost exclusively nocturnal feeders. Certain species of

*Approved by Arkansas Agricultural Experiment Station Director

**Department of Entomology, University of Arkansas, Fayetteville, AR

mosquitoes are important vectors of disease while others concern us only because they are annoying biters. The determination of species present in an area provides information on life cycles, feeding preferences, larval habitats, etc. 2) Once the species in an area are known, their breeding sources are located and mapped. 3) Once located, the breeding sites can either be eliminated or treated with a suitable larvicide. Often it is neither practical nor desirable to eliminate breeding sites. For instance, if mosquitoes and waterfowl are sharing the same breeding sites, the waterfowl areas must be maintained. Irrigated agricultural lands or certain lakes may also breed mosquitoes, and again, these areas must be maintained. It would be a foolish and economically unsound policy for mosquito management personnel to attempt to eliminate all mosquito breeding sites in Minnesota, and it is the challenge of effective mosquito control to manage populations in these often environmentally sensitive areas. 4) Finally, not all mosquitoes will be effectively managed by larva control approaches, meaning adult mosquitoes must then be reduced. The control of adult mosquitoes depends almost entirely on the judicious use of pesticides since effective biological control agents are lacking for this population.

The best available tools to implement the successful management or IPM of mosquitoes use a combination of physical, chemical, and biological controls. Many nonchemical control techniques have been known for years. With the advent of organic insecticides beginning with the use of DDT in Naples, Italy, against the human body louse in 1943-44, many such non-chemical techniques were either neglected or declined in use.

## Physical Controls

Physical controls are certainly among the most ancient of mosquito control methodologies and include such items as screens or mosquito netting to exclude biting flies. Smoke screens have been used by early man, outdoorsmen, farmers, ranchers, and even wildlife specialists. During a recent outbreak of the southern buffalo gnat, *Cnephia pecuarum* (Riley), in the White River Wildlife Management Area in eastern Arkansas, discarded tires were burned in the refuge to provide deer and other wildlife relief from attacks by the gnat.

Physical control of mosquitoes is often referred to as source reduction, which implies any method of physical alteration of a mosquito breeding site to render it unsatisfactory for the completion of the mosquito life cycle. Meek and Hayes (4) provide a considerable discussion of this subject. Source reduction takes many forms, a familiar one being drainage by ditching. Other types of source reduction include flooding of breeding areas by impoundment or maintenance of minimum water level by the use of floodgates or weirs. Shallow swales or lowland areas can be filled with soil in order to eliminate their mosquito breeding potential.

In coastal areas, the majority of saltmarsh mosquito breeding occurs above the high tide line. Man-made conditions are the result of deliberate or accidental alteration of natural drainage conditions. Highways and railroads are often built on embankments which impede drainage. Barrow pits, from which the roadbed fill is obtained, make good breeding sites if not properly engineered. (Because of the expense involved, large drainage projects are usually well engineered.)

A tremendous mosquito breeding problem occurs along the gulf and east coastal areas of the United States in the form of spoils. These result from the blockage of natural drainage patterns when canals are dug. Spoil is generally deposited as a continuous bank without regard to natural drainage conditions, creating impounded situations conducive to high levels of mosquito breeding.

A major portion of source reduction often occurs in areas that support valuable fish and wildlife fisheries. Therefore, it is incumbent upon mosquito control interests to create as little disturbance to the natural environment as possible. In many instances source reduction may serve to restore a habitat to its original condition or to enhance wildlife production.

In tidal marshes, where there is insufficient grade for drainage, level ditches are often dug to at least mean sea level, preferably below low tide level. This permits the area to be flushed by daily tides and keeps water in the ditches, which serve as a reservoir for larvivorous minnows and other predators. Where complete run-off is not possible, a deep pond may be dug and stocked with minnows for mosquito control, or ditches and ponds may be interlocked (5).

The destruction of any mosquito breeding site might be termed physical control. This would include such classic forms of control as changing birdbaths or pet watering containers every four or five days, cleaning clogged roof gutters, or eliminating old tires and containers.

## Chemical Controls

The use of pesticides still offers the most immediate method of controlling mosquitoes. Pesticides are indeed a most integral part of IPM programs, and it is imperative that they be used judiciously. Programs optimizing non-chemical approaches offer the best long-term controls, and pesticides should serve as a supplement to these control methodologies. Insecticide application may be the only practical technique to manage massive mosquito outbreaks or to reduce the threat of disease, consequently, there is a continuing need to develop new and promising insecticides that minimize environmental contamination and injury to non-target species. By their very nature, pesticides are toxic, and rigid adherence to label specifications is essential. Label recommendations are based on approximately six years of research and an investment of millions of dollars. Insecticides can be safely used if these directions are carefully followed.

Organic insecticides constitute practically all insecticides used in mosquito control today. As mentioned previously, the organic age of insecticides began in 1943 with the advent of DDT usage. DDT is a member of the organochlorine group of insecticides, a group which primarily acts against the central nervous system. Many chemicals in this group are now banned. They are "hard" persistent pestcides which accumulate in body fat of animals and are magnified in the food chain. After World War II, the use of DDT flourished. Prior to that time, chemicals had been restricted to inorganic compounds, botanical insecticides, and petroleum products. Chemicals were only a supplement to natural control and source reduction (6). DDT produced spectacular results not only in mosrquito control but against a wide variety of insects.

Shortly after World War II, organophosphorous insecticides came into being. Early compounds in this group included malathion, TEPP, and parathion, which were used in 1948. Unlike the organochlorines, this group does not accumulate in the body fat of animals and is not magnified in the food chain. The mode of action of this group is the inhibition of the enzyme acetylcholinesterase. Most mosquito control insecticides in use today belong to this group.

In 1952, carbamate insecticides began to be used. Among the first compounds was Sevin®. Propoxur is an example of a carbamate currently in use against mosquito adults. Carbamates have essentially the same mode of action as organophosphorous compounds.

Botanicals such as pyrethrins have been widely used, primarily because of their quick-knockdown properties and low mammalian toxicity. These compounds have highly complex organic structures, which reflect their plant origins. They act primarily against the central nervous system of insects.

Pyrethroids are yet another group of insecticides that are used against mosquitoes. Their mode of action is very similar to pyrethrin. Although some of these compounds have been in the chemical arsenal for years, as a whole they are rather contemporary, and current interest in the group is high. Recently developed pyrethroids have shown stability to light and oxidation, making them more effective than earlier pyrethroids. However, their mode of action is generally the same as DDT, and the probability of resistance development is quite high. Resmethrin and allethrin are synthetic pyrethroids currently used in vector control.

Insect growth regulators (IGRs) are considered a novel approach to insect control. Their use against mosquitoes began with the use of methoprene in the early 1970s. The term IGR has been applied to compounds with several modes of action, but the basic effect of growth regulators is the interruption of normal metamorphosis in insects. IGRs typically accomplish this by inhibiting chitin synthesis or deranging hormonal levels so that molting cannot occur. Methoprene is the only IGR currently registered for mosquito control.

## Resistance

Resistance is brought about by Darwinian selection. In essence, resistance comes about only when a high level of mortality is attained within a population that does not have a static gene pool. Floodwater mosquitoes are less likely to develop resistance than are short-range flying species since their migration habits introduce new genes into the population. Unfortunately, resistance to insecticides continues to be a major problem. Resistance to control by DDT was noted in the saltmarsh *Aedes* of Cocoa Beach, Florida, in 1948. A year later, the development of DDT resistance in *Aedes nigromaculis* (Ludlow) was demonstrated in California. In 1951 resistance showed up in mosquitoes not only to DDT but also to toxaphene and cyclodiene-type organochlorines. Since it appeared in all the agricultural areas but not in uncultivated hinterlands, the resistance evidently was due mainly to insecticides applied to crops (7).

In response to resistance, parathion and malathion were substituted as larvicides in California and Florida. During the 1950s the organochlorines DDT and HCH were still used effectively in New Jersey; and in Minnesota, DDT could be applied as pre-emergent dust or granules before the spring thaw. By the early 1960s more than three-fourths of the total amount of insecticides applied in the United States against mosquitoes were organophosphorous compounds, principally malathion.

For all the environmental and resistance problems associated with its use, DDT has certainly made a positive impact on human health protection. In 1957, the World Health Organization administered the World Malaria Eradication Campaign. Through the use of DDT in this program, the number of deaths in the world from malaria was estimated to have dropped from about 2.5 million per annum to less than 1 million per year by 1968. The savings each year of more than 1 million lives, mainly those of children in Asia and Latin America, was a great humanitarian achievement to be credited to the use of insecticides. But by 1968, the development of DDT resistance had been detected in many mosquitoes, necessitating the switch to organophosphorous compounds such as malathion. In Central America, the resistance problem in 1968 was severe, and DDT was replaced by the carbamate insecticide propoxur. This occurred in agricultural areas where the mosquito had become resistant to malathion as well as DDT. But this anophiline quickly developed propoxur resistance. It is possible that the pyrethroids will prove an effective residual replacement, but resistance to residual applications of pyrethroids has been induced in laboratory selection experiments.

Brown (7) states that resistance can be expected sooner or later with any larvicide; laboratory experiments have produced strains of *Culex* highly resistant to permethrin and to the IGR, methoprene. The full variety of suitable organophosphorous compounds must be exploited as long as possible. Periodic susceptibility tests detect the development of resistance and investigate cross-resistance to ascertain which organophosphorous compounds are still effective.

Insecticides have enabled mosquito management personnel to decisively control nuisance populations of mosquitoes, improve the quality of living, and protect human health. Criticisms have been made on environmental grounds, but critics have not questioned overall effectiveness. Since insecticides must be used for the foreseeable future despite their previously mentioned problems, it behooves scientists to develop better guidelines to minimize these detriments.

## Biological Control

Biological control is another strategy that has been utilized in mosquito management. Many applications of biological control are currently being employed and/or investigated. Service (8), in his memorial lecture to the American Mosquito Control Association Annual Meeting, stated that the bacteria, *Bacillus thuringiensis* (H-14) (formerly known as *israelensis*), and *Bacillus sphaericus*, were the most famous biological control agents for mosquitoes. Control of mosquito larvae through the application of an endotoxin-containing bacterium to the breeding source is one method of biological control used currently. A strong case could be made for these bacteria being classified as insecticides rather than as biological control agents since the actual mortality agents are the toxins contained in the bacteria. In fact, these bacteria, which act as stomach poisons, have commonly been referred to as microbial insecticides. They do not persist in the environment and must be repeatly applied. An environmentally compatible control agent, these bacteria are selective for mosquito larvae and a few other dipteran larvae.

Considerable research is being conducted to determine cost effective application methods for these bacteria. Sandoski et al. (9) developed a novel technique to aerially apply *B. thuringiensis* as undiluted material at a rate of 1.5-3 oz/acre to rice fields for approximately $0.29/A. This represents a substantial savings over conventional larvaside applications.

Many fish species have been used as predators of mosquito larvae. No less an authority than T.D. Mulhern, the executive director of the AMCA (6), states that of all biological agents used in mosquito control the most functional is the mosquitofish, *Gambusia affinis* (Baird & Girard). This live bearer has been introduced virtually all over the world. It is used extensively in California rice fields for mosquito control. In addition to massive release programs, this fish is often cultured by mosquito abatement districts and given free to homeowners for release in urban permanent waters. The fish itself is no panacea but can be integrated into effective management programs. However, there are several major obstacles to the extensive use of fish in mosquito control. The greatest difficulty lies in the economical production of the fish in large numbers. Many researchers have reported on a variety of techniques for mass rearing, but the expense of maintaining large rearing ponds or artificial containers such as minnow vats is still often prohibitive.

*Toxorhynchites* mosquitoes also are currently used in mosquito control (10). Mosquitoes in this genus are predators in the larval stage, and the adult female does not take a blood meal. *Toxorhynchites* are mass reared and released to deposit eggs in treeholes or containers inhabited by certain pest mosquitoe larvae. Service (8) states that although there is no doubt that *Toxorhynchites* can destroy large numbers of larvae, their future use as biological control agents is less clear. For instance, their spatial and temporal distributions do not overlap well with prey, their life cycle is 2-3 times longer than the preys', their eggs cannot withstand desiccation, and they disperse relatively little. Nevertheless, *Toxorhynchites* exhibits potential for vector reduction. The present system for rearing of this predator is space and labor intensive and has proved successful for small-scale research-oriented programs, but it is not yet practical in a large-scale operation program. There are other mosquito species that are predators such as *Psorophora ciliata* and *Psorophora howardi*. Unfortunately, these are fierce biters as adults.

Mermethid nematodes have been extensively studied, particularly *Romanomeris culicivorax* (Mermethodae:Nematoda). They have shown promise in reducing populations of immature mosquitoes, especially anophelines. These nematodes are normally specific to mosquitoes and have the potential to recycle (11). They can tolerate normal larvicidal dosages of insecticides and can be easily reared. However, transfer of nematode eggs to the field in large numbers has proved difficult and inconsistent (12).

With regard to genetic control, which will be mentioned briefly as a form of biological control, Service (8) states that bioengineering offers exciting possibilities. It might be possible to improve toxin yields in commercial preparations of *Bacillus thuringiensis* or to transfer the gene coding for the toxin to naturally occurring bacteria that persist longer in biological habitats.

The release of male or female mosquitoes possessing an inheritable factor for partial sterility into a natural population is another theory for control. Mosquitoes, with high fecundity and population densities, do not offer the best targets for genetic control. Realistically, this approach currently appears suitable for only small or localized programs.

The judicious use of pesticides remains imperative in control methodology, but a program optimizing non-chemical applications offers the best method for long-term success. A systems approach is needed regardless of the strategies used. The answer to successful mosquito abatement lies in the application of Integrated Pest Management.

## References


1. Botrell, D.G. 1979. *Integrated pest management.* U.S. Government Printing Office, Washington, D.C. 20402.
2. Gerhardt, R.R., Dukes, J.C., Falter, J.M., and Axtell, R.C. 1973. *Public opinion on insect pest management in coastal North Carolina.* North Carolina Ag. Ext. Serv. Ext. Misc. Publ. 97, North Carolina Sea Grant Program. UNC-SG-73-03.
3. Olson, J.K. 1979. Application of the concept of IPM to mosquito control programs. *Mosq. News.* 39:718-23.
4. Meek, C.D., and Hayes, G.R. 1984. *Mosquito control training manual.* Louisiana Mosquito Control Assn. New Orleans, LA. 151 pp.
5. Shisler, J.D., and Harker, W. 1981. Source reduction as an economical approach to mosquito managment. *Mosq. News.* 41:419-23.
6. Mulhern, T.D. 1973. *The third era of mosquito control in California has just begun.* Proc. Forty-first Annual Conf. Calif. Mosquito Control Assn., Inc. pp. 75-78.
7. Brown, A.W.A. 1980. What have insecticides done for us? *Mosq. News.* 40:333-38.
8. Service, M.W. 1983. Biological control of mosquitoes — has it a future? *Mosq. News.* 43:113-20.
9. Sandoski, C.A., Yates, M.M., Olson, J.K., and Meisch, M.V. In Press. Evaluation of Beecomist® applied *Bacillus thuringiensis* (H-14) against *Anopheles quadrimaculatus* and *Psorophora columbiae* in rice fields.
10. Fochs, D.A., Sackett, S.R., Dame, D.A., and Bailey, D.L. 1983. The ability of *Toxorhychites amboinensis* (Doleschall) to locate and oviposit in artificial containers in an urban environment. *Environ. Entomol.* 12:1073-77.
11. Peterson, J.J., and Willis, O.R., 1972. Results of preliminary field applications of *Reesimermis nielseni* (Mermithidae: Nematoda) to control mosquito larvae. *Mosq. News.* 32:312-16.

General reference:

Levy, R., Garrett, W.D., Chizzonite, J.J., and Miller, T.W., Jr. 1980. Control of *Culex* spp. mosquitoes in sewage treatment systems of southwestern Florida with monomolecular organic surface films. *Mosq. News.* 40:27-35.