Chapter 10

BIOLOGICAL CONTROL OF MOSQUITOES

Natural Biological Control

The most important biological control of mosquitoes is happening continuously in nature. Birds, bats, spiders, and various flying insects prey on adult mosquitoes. Beetles, ants, isopods (pill bugs), cockroaches, and other scavenging animals prey on their eggs. Many kinds of aquatic animals such as fish and miscellaneous invertebrates prey on mosquito larvae and pupae. Larvae, also, are vulnerable to a number of parasites and pathogens.

Although all of these natural enemies are, in the aggregate, important for reducing mosquito populations in nature, the predators of larval-stage mosquitoes control these pests most effectively. Most aquatic sites where mosquitoes might breed do not produce a significant number of mosquitoes due to natural predation. This control is particularly associated with permanent water, where many species of aquatic animals abound (including predators of mosquito larvae). Although some species of mosquitoes (e.g., *Culex salinarius*) can breed in permanent water where dense vegetation protects them from fish, a large part of mosquito production comes from temporary water. Temporary water provides mosquito larvae a relatively safe place to develop before predators have a chance to become established.

Human-assisted Biological Control

Human-aided biological control is a matter of assisting the natural enemies of mosquitoes to do their job where they have not managed to do the job on their own. Although all mosquito life-stages have natural enemies, operational biological control has been directed entirely toward the aquatic stages of mosquitoes. The main reason is that the aquatic habitats of mosquito larvae and pupae are discrete water bodies to which natural enemies can be introduced. The habitats of adult mosquitoes are more extensive, and, therefore, more difficult to stock with natural enemies. In addition, biological control has focused on aquatic stages of mosquitoes because it is easier to supply the animals for biological control. The enemies of mosquito larvae are easier to collect or produce in large numbers than the enemies of adult mosquitoes.

Biological control usually brings to mind the introduction to mosquito breeding sites of natural enemies. Most of this chapter is concerned with that type of biological control. A major advantage of biological control, when it works well, is that a single treatment (i.e., introduction of the appropriate organism) can provide control for an extended period of time.

Keeping Wet Areas Wet & Dry Areas Dry

It is, however, important to keep in mind that there are many ways in which mosquito control operators can encourage natural biological control without resorting to introductions. For example, if water cannot be drained from a site, it may be best to manage the site in such a way that water is present all the time, because permanent water provides the best habitat for predators. For sites that must alternate between wet and dry, access ditches can help predators to colonize quickly when the site does have water. Another way to provide predators for habitats that have wet-dry cycles is to have a permanent holding pond that serves as a reservoir whence predators can disperse into the surrounding area whenever it is flooded.

Controlling Pollution

*Cx. quinquefasciatus* preferentially breeds in ditches that are polluted in some manner because the larvae can survive in this kind of water, but most of its predators cannot. Furthermore, *Cx. quinquefasciatus* is most prolific in polluted water due to the nutrient materials.

Judicious Use of Pesticides

Broad-spectrum pesticides should not be applied around mosquito-breeding sites unless absolutely necessary, because pesticides can kill predators of mosquito larvae. Before larviciding, sites should be inspected to verify that they have enough larvae to warrant treatment. Sites without a significant number of larvae are probably under natural biological control and should not be disturbed. Even permanent water sites with first- and second-instar larvae present are probably under biological
control if fourth-instar mosquito larvae and pupae are absent. If larviciding is necessary, it should be done with a larvicide that is specific to mosquito larvae [e.g., Bacillus thuringiensis var. israelensis (B.t.i.) or a larviciding oil].

**Predators of Mosquito Larvae**

Numerous predators of mosquito larvae (and pupae) have been investigated for mosquito control, including fish, turtles, tadpoles, cyclopoid copepods, tadpole shrimp (*Triops*), aquatic bugs (notonectids and belostomatids), aquatic beetles (dytiscids), dragonfly and mayfly nymphs, planarians, and hydra. Only fish and cyclopoid copepods have gone into operational use because they have two essential properties for control operations. First, there is a suitable source of supply. Fish and copepods can be collected from large natural populations or mass-produced at a reasonable cost. Second, when introduced to breeding sites, these predators multiply to numbers that are large enough to kill virtually all mosquito larvae, and they maintain their numbers for long periods of time.

Many of the predators that have not been introduced to operational use are unable to maintain in nature populations that are large enough to eliminate mosquito larvae on a consistent basis. Moreover, many of the predators are not available from a convenient source of supply in nature, and mass production of some of the predators is expensive, because they have complex life cycles.

**Fish**

Fish have been in widespread use for more than seventy years (Fig. 42). One reason that some kinds of fish are so effective for mosquito control is that they eat a variety of aquatic animals, in addition to mosquito larvae. Having a broad diet allows these fish to maintain themselves in numbers sufficient to eat almost any number of mosquito larvae that might periodically appear.

It is common practice to trap or net fish for mosquito control from anywhere they happen to be naturally abundant in order to transport them to sites where they are needed. A single species of fish may be captured or multiple species may be used. Many kinds of fish are effective for mosquito control, but *topminnows* (*Poeciliidae*) and *killifish* (*Cyprinodontidae*) are used most frequently because they are small and often have abundant sources of supply, making them convenient to capture and transport, and they usually thrive in large numbers when introduced to mosquito-breeding habitats.

A single species of topminnow, *Gambusia affinis* (the mosquito fish), has been so effective for mosquito control that it has been used more than all other species of fish combined. *Gambusia* is particularly useful because it thrives in a broad array of aquatic habitats including freshwater, brackish water, clean water, or polluted water; and it tolerates a wide range of temperatures (1-38°C).

The recommended stocking rate for *Gambusia* is 0.5-1.5 pounds per acre (pound = ca. 500 fish). Control is usually rapid, though maximum control may be achieved only after the fish have had a month or two to build up their numbers. For example, *Gambusia* usually builds up to about 5000 fish/acre in rice fields. Sometimes the stocking is in smaller numbers (e.g., 0.2 pound/acre) if it is possible to wait an extra few weeks for the fish to build up their numbers.

*Guppies* (*Poecilia reticulata*) are a topminnow that is used for mosquito control in some of the conditions where *Gambusia* is not suitable, such as excessively polluted water. Guppies have a major limitation. They can survive only in water above 10°C and thus need to be reintroduced into control areas at least once a year.

“Least killifish” (*Heterandria formosa*) are a common topminnow in Louisiana marshes. They can provide effective mosquito control at sites where the water is sometimes so shallow that it barely covers the soil.

Fish are only practical if there is an economical source of supply. Many mosquito control districts collect their fish from a site where they are naturally abundant. Sometimes a site with a high level of biological production (e.g., a sewage oxidation pond) is stocked with fish to create a source of supply. Some mosquito control agencies employ the relatively costly alternative of intensive fish culture because they do not have a natural source or they want to be sure of the supply. The methods for fish culture are well established (see Fishes in California Mosquito Control).
Control, published by the California Mosquito and Vector Control Association).

Fish can be transported on trucks safely in concentrations of 0.5-1.5 pounds of fish per gallon of water if aeration is provided. Aeration can be achieved by bubbling air (oxygen) through the water, or by means of a rotating paddle that is enclosed by a screen guard to prevent injury to the fish.

It is common for fish to eliminate almost all mosquito larvae, but there are situations where fish are not so effective. For example, in aquatic vegetation, larvae can hide from fish. Some vegetation (e.g., Spartina grass in marshes) can be so thick that the fish have no access at all. Fish may also be temporarily ineffective when aquatic animals other than larvae become so abundant that the fish prey on those animals instead of the mosquito larvae. Fish cannot survive for long in an aquatic habitat that is very small (e.g., a discarded tire), nor can they survive when a site dries up.

**Copepods**

Cyclopoid copepods are particularly suitable for some of the mosquito breeding habitats where fish will not work. Copepods are tiny crustaceans, about one millimeter in length, that are abundant in nature almost everywhere there is water (Fig. 43). They are voracious predators, and the largest species (Mesocyclops, Macrocyclops, and Megacyclops) prey on first-instar mosquito larvae. Smaller species of copepods, which are sometimes common to many places where mosquito production is high, are not large enough to be effective predators of mosquito larvae.

Because copepods are so small, they thrive in habitats that are too small for fish. They can also move easily through the middle of thick aquatic vegetation that fish cannot penetrate. Copepods can survive when a site dries up, provided the soil retains some moisture, and reemerge when a site floods, just in time to consume hatching mosquito larvae.

Copepods have a broad diet that includes phytoplankton, protozoa and other small animals of equivalent size, it is typical for natural populations of copepods to be sufficiently large to kill any mosquito larvae encountered, regardless of the size of the larval population.

Copepods are convenient and inexpensive to produce and transport in large numbers. The best established use of copepods is for control in discarded tires. They can survive in tires as long as the tires retain moisture, which can be periods of months or years. Tires in wooded or otherwise shaded areas are particularly suitable. The best species for tires is *Mesocyclops longisetus*, and the best season during which to introduce it to tires in Louisiana is spring. Copepods can be introduced into tires with a backpack sprayer.

![Cyclopoids are predators of mosquito larvae.](image)

A single fertilized adult female introduced into a tire will produce enough offspring in two months to control any hatching of mosquito larvae. Placing as few as 50 to 100 adults per tire will provide immediate control of all new *Aedes* larvae that hatch within the tire, and they will continue to kill all larvae as long as they survive in the tire. If a tire is newly discarded (and therefore completely clean inside), it may be necessary to put a small amount of food (e.g., a few grains of rice) in the tire to sustain the copepod population. If there are mosquito larvae in the tire at the time of introduction and immediate control of late instar larvae is desired, it is best to apply *B.t.i.* (10,000 ITU per tire) simultaneously in order to kill any larvae too large for the copepods to kill. Only one application of *B.t.i.* should be required, as the copepods will deal with any subsequent hatching of mosquito larvae.

Among groundwater sites, copepods are most effective in discrete pools (e.g., flooded vacant lots, swales, or woodland pools) that have water for at least a few months. For sites that have water during the fall, winter, and spring, it is best to use *Macrocyclops albidus*, a species that is tolerant of winter temperatures; *Macrocyclops* should be introduced as soon as the site has water in the fall. After introduction, copepods usually increase their numbers by about one hundredfold with each generation (2-3 weeks) until they reach the limit of the food supply at the site. They will usually survive at a site until it dries out completely.

Once *Mesocyclops*, *Macrocyclops*, or *Megacyclops* have developed large populations in ground pools, the pools will usually have a small number of mosquito larvae at most. However, control
is not always complete, because copepods are not very effective predators of some species of Culex, particularly Cx. salinarius. In addition, control of any mosquito species can be incomplete in large, ecologically heterogeneous habitats (e.g., marshes, rice fields, or residential ditches) because copepod abundance in these habitats can be spatially patchy and change with the seasons.

Cannibal Mosquitoes

Toxorhynchites mosquitoes are large, non-biting mosquitoes that breed in containers. Their larvae prey on other mosquito larvae in the containers (Fig. 44), and some species of Toxorhynchites can be mass-produced in the laboratory for introduction into containers. They can be introduced as eggs or larvae, but the most effective way is to release gravid females so that they can deposit their eggs in containers. The great strength of Toxorhynchites is the ability of females to find inconspicuous containers, including ones that are inaccessible to mosquito control operators. A single treatment with Toxorhynchites will last for about three weeks, which is the time it takes Toxorhynchites larvae to pupate.

Larvae of Toxorhynchites rutilus, a native species of Louisiana, are common during the summer months in tree holes, tires, and other containers, where they make a significant natural contribution to mosquito control. Because naturally occurring numbers of Tx. rutilus are not sufficient to eliminate mosquito larvae from all containers, mass release of Tx. rutilus at critical times of the year (e.g., the beginning of the mosquito season) might augment natural control. Unfortunately, mass production of the Louisiana variety (Tx. rutilus septentrionalis) has not yet been possible, though mass production of the Florida variety (Tx. rutilus rutilus) has been achieved.

Toxorhynchites amboinensis is an exotic species that has been mass produced successfully and released with encouraging results. During a seven-week study in New Orleans, Ae. aegypti populations were reduced 95% when adult female Tx. amboinensis were released in conjunction with ground ULV treatments. Comparable Ae. aegypti populations were reduced by only 30% when malathion was used without Tx. amboinensis.

The major limitation of Tx. amboinensis is that it cannot reproduce to maintain a long-term field population under Louisiana conditions. It is therefore necessary to release large numbers of Tx. amboinensis every few weeks to maintain control. The release rate should be about 50 adult female Toxorhynchites per acre. Another limitation of all Toxorhynchites species is the tendency of the larvae to cannibalize one another when larvae of other species are eliminated from the habitat.

Because of the cost, Toxorhynchites have a specialized role in mosquito control. Toxorhynchites must be focused on specific locations, and they should not be used alone. Toxorhynchites should be used in conjunction with conventional source reduction to control hidden and inaccessible containers that are not eliminated through other means (e.g., plugged rain gutters that collect rainwater or tree holes in woodlots near residential areas).

Figure 44. Toxorhynchites larvae will feed on other mosquito immatures.
Parasites and Pathogens

Numerous parasites of mosquito larvae have been tested for mosquito control, including nematodes (mermithid worms) and parasitic protozoa (Microsporicia, Tetrahymena, Lambornella, Helicosporidium), but none has proven suitable for operational use so far. Because heavy parasitic infestations of mosquito larvae are not common in nature, it is not possible to release a small number of parasites to multiply and spread throughout a mosquito population. Only releasing very large numbers of parasites can attain high rates of infection. The cost of producing such large numbers is impractical for mosquito control, especially for parasites that have a complex life cycle requiring an elaborate production process.

As with parasites, mosquito larvae heavily infested by pathogens are not common in nature. Again, sizable quantities of pathogens must be produced to have any impact on populations. Fortunately, however, pathogens can be produced in very large quantities at a reasonably low cost. A variety of fungi (Lagenidium, Coelomomyces, Cuclincinomyces, Metarhyizium), bacteria (Bacillus), and viruses have been investigated for mosquito control. One of them (B.t.i.) is in operational use.

B.t.i. has expanded to widespread use since it became commercially available in 1976. It kills most species of mosquito larvae, and it usually provides a 100% kill if applied in sufficient quantity. B.t.i. is easy to mass-produce, convenient to store and transport, and it can be applied in the same way as a chemical larvicide.

B.t.i. is not biological control in the conventional sense of a living organism that reproduces itself to maintain long-term control. Commercial formulations of B.t.i. consist of toxic particles from the B.t.i. bacteria, not live bacteria. Mosquito larvae are killed when they consume the particles, which damage the lining of their stomachs. A special advantage of B.t.i. and the other mosquito pathogens is their high target specificity. B.t.i. kills only larvae of mosquitoes and closely related flies. It has no damaging effects on plants or other animals.

B.t.i. comes in four forms: a wettable power, a liquid suspension of the wettable powder, pellets, and doughnut-shaped briquettes. Perhaps the most serious limitation of the liquid, wettable powder, and pellets formulations is that a single application kills mosquito larvae only for a day or two. The B.t.i. toxins actually retain their effectiveness for a long time, but within a few days, the B.t.i. particles settle to the bottom where mosquito larvae cannot ingest them in sufficient quantity to be killed. To maintain control, it is therefore necessary to reapply B.t.i. every 7-10 days. B.t.i. briquets kill larvae for several weeks by continuously releasing B.t.i. particles, but they are quite expensive.

In practice, the effectiveness of B.t.i. is reduced if (1) there is thick vegetation that prevents B.t.i. particles from dispersing to all of the larvae, (2) the water is organically polluted, or (3) the water contains a large quantity of particulate matter that the larvae consume in favor of the B.t.i. Under these conditions, it is necessary to apply B.t.i. at several times the normal dose to achieve appreciable results.

Another pathogen in use is Bacillus sphaericus. When mosquito larvae inevitably develop resistance to B.t.i., B. sphaericus should be an acceptable backup. It is easy to produce and it actually possesses two significant advantages over B.t.i. It works well in organically polluted water and it continues to kill mosquito larvae for weeks or longer if conditions are right.