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Deepak Rawal
Assistant Professor, Department of Zoology, Mohanlal Sukhadia University, Udaipur, Rajasthan, India

Correspondence
Deepak Rawal
Assistant Professor, Department of Zoology, Mohanlal Sukhadia University, Udaipur, Rajasthan, India

A review on different strategies used for biological control of mosquitoes

Deepak Rawal

Abstract
More than 3000 species of mosquitoes are responsible for millions of death annually. Adult females of most species have proboscis to feed on blood of many hosts such as mammals, birds, reptiles, amphibians, fishes and even other arthropods. They use blood not for their own nourishments but as a source of protein for their eggs. In addition many species can ingest pathogens while biting and transmit them to host, which makes them vectors of many diseases like malaria, dengue, Chikungunya, Zika, encephalitis, yellow fever, filariasis, West Nile *etc*. Biocontrol agents may be predators, pathogens, parasites or competitors. Different biocontrol agents include fishes, tadpoles, lizards, cannibalistic mosquito species, dragonflies, bugs, mites, copepods, helminthes, planarians, bacteria, fungus *etc*. This review presents information on different biocontrol strategies used in past and present with their status and potential of use in mosquito control.

Keywords: Biological control, mosquitoes, vectors, larvivorous fishes

1. Introduction
Mosquitoes are cosmopolitan dipteran insects (Family-Culicidae) comprise of about more than 3000 species [1]. Their main characteristics are one pair of wings, three pairs of slender legs, one pair of antennae, slender segmented abdomen and elongated mouthparts. Their life cycle includes egg, larva, pupa and imago/adult stages. Generally both males and female feed on nectar and other plant sugars but in many species, mouthparts of females evolved to piercing the skin and sucking the blood of animal host. Adult females of most species have proboscis to feed on blood of many hosts such as mammals, birds, reptiles, amphibians, fishes and even other arthropods. They use blood not for their own nourishments but as a source of protein for their eggs. In addition many species can ingest pathogens while biting and transmit them to host, which makes them vectors of many diseases like malaria, dengue, Chikungunya, Zika, encephalitis, yellow fever, filariasis, West Nile *etc*. Mosquitoes are responsible for the millions of deaths worldwide every year. They use co_2, body odors and body temperature to find their hosts. All mosquitoes need water to breed so their control generally involves removal of standing water sources. Many researchers believe that global warming will increase their numbers in future. They are also important link in food chains of many animals including fishes, birds, bats, dragonflies, frogs *etc* [1].

Integrated control of mosquitoes means the joint use of biotic, physical and chemical measures to supplement natural enemies and other populations regulating factors (WHO). Biological control is a method of controlling pests using organisms and also involves active human role. Biocontrol includes larviciding and adulticiding. Biocontrol agents include predators, pathogens, parasites and competitors. Biological control usually involves three strategies *viz*., importation in which natural enemy of the pest is introduced to control them, augmentation in which large population of natural enemies are introduced for quick control and conservation in which natural enemies are maintained by regular reestablishment. Chemical control is also used widespread but in recent years environment protection agencies have banned on use on many insecticides which were previously used in mosquito control program. Nowadays biocontrol agents are preferred over chemical agents due to insecticide resistance, their less harmful effects and cost effectiveness. Biological control can also sometimes adversely affect biodiversity by attacking non target species [2].

2.1 Fishes in biological control of mosquitoes

Chandra *et al.* [3] demonstrate the potential of larvivorous fishes in biological control. They discuss some criteria for larvivorous fishes like fish must be small, hardy and capable of surviving in shallow waters among thick weeds where mosquitoes find suitable breeding sites. They must be capable of living in drinking water tanks without contaminating the water. They must be prolific breeder and must breed freely and successfully in confined waters. Larvivorous fish must be surface feeder and carnivorous in habit so they could prefer mosquito larva even in the presence of other food items. They should not be brightly colored. They should have no food value so that fish eating people ignore them. It is difficult to find a fish species that satisfies all these parameters. Yet they describe many potential indigenous and exotic larvivorous fishes as biocontrol agents *viz*; *Ahanius dispar* (Dispar topminnow), *Aplocheilus lineatus* (Malabar killie), *Aplocheilus panchax* (Panchax minnow), *Colisa fasciatus* (Giant gourami), *Colisa lalia* (Dwarf gourami), *Colisa sota* (Sunset gourami), *Chanda nama* (Elongated glass prechlet), *Oryzias melastigma* (Estuaring ricefish), *Danio rerio* (Zebra danio), *Macropodus cupanus* (Spiketailed paradise fish), *Carassius auratus* (Gold fish), *Gambusia affinis* (Top minnow), *Poecilia reticulate* (Guppy), *Nothobranchius guentheri* (Killifish), *Xenentodon cancila* (Freshwater gar fish), *Oreochromis mossambica* (Mozambique cichlid), *Oreochromis niloticus* (Nile Tilapia) *etc.* however some scientists believed that efficacy of using these fishes for mosquito population control is largely unproven and dubious, particularly for container breeding mosquitoes that reproduce in minute aquatic habitats which are unsuitable for fish. Further the use of exotic fishes for biocontrol has a high risk of escapes and invasions which can alter ecosystem and biodiversity [4].

Griffin and Knight [5] examines the potential of fish as biocontrol agents for mosquito larvae in mangroves. They shows that mangroves act as refuge habitat for small and juvenile fish and thus they can be significant predators of mosquitoes and may be effective biocontrol agents. The saltwater mosquito *Aedes vigilax* is abundant in coastal wetlands including mangroves and salt marshes. *Aedes vigilax* is a vector for arboviruses such as Ross River and Barmah Forest viruses. Gosh *et al.* [2] did the predation experiments using *Cyprinus carpio, Ctenopharyngodon idella, Clarias gariepinus* and *Oreochromis niloticus* against fourth instars *Anopheles stephensi* larvae and pupae. In their 24 hour experiment under laboratory conditions, the relative prey consumption rates of the four fish species were *Clarias gariepinus* > *Ctenopharyngodon idella* > *Cyprinus carpio* > *Oreochromis niloticus*. Predator efficacy was positively correlated with prey density.

2.2 Nematodes in biological control of mosquitoes

Platzer [6] showed that mermithid nematodes parasitizing mosquitoes have substantial potential for vector control. Mosquitoes are also utilized by filarioids as intermediate host but these nematodes have no promise for biological control. Most promising mermithids is *Romanomermis culicivorax.* Laurdeux *et al.* [7] shows that biological control agents have some efficacy against the target *Aedes* populations in some village areas. Generally mechanical methods were more efficient than use of the biological control agents. Despite the ecological challenges of controlling the *Aedes* vectors of dengue viruses and *Wuchereria bancrofti* in so many scattered islands, the French Polynesian experience shows that relatively simple methods can be integrated and applied effectively and economically.

2.3 Planarians in biological control of mosquitoes

Kar and Aditya [8] give the idea of biocontrol of mosquitoes by aquatic planarians (*Dugesia bengalensis*). Their observations revealed that planarians prefer larval forms of *Anopheles* and *Culex* than eggs and pupa. It is also noticed that planarians generally avoid very small mosquito larvae because of their fast movement. Out of the different stages of larval forms, they mostly prefer 2nd and 3rd stage of larval forms where the exoskeleton does not get as hardened as the imago.

2.4 Beetle in biological control of mosquitoes

Chandra *et al.* [9] assessed the predation potential of the larvae of beetle *Acilius salcatus* using the larvae of *Culex quinquefasciatus* as prey in the laboratory. They were also assessed under field conditions through augmentative release in ten cemented tanks hosting immature of different mosquito species at varying density. The dip density changes in the mosquito larvae were used as indicators for effectiveness of *Acilius salcatus* larvae. The larvae of beetle *Acilius salcatus* proved to be an efficient predator of mosquito larvae and may be useful tool for biocontrol of mosquitoes.

2.5 Anurans in biological control of mosquitoes

Raghavendra *et al.* [11] tells that frogs are an important part of the ecosystem with the role of insect and pest control including mosquitoes. They generalized the notion that 50 frogs can keep an acre of a rice paddy field free of insects. Most tadpoles are omnivorous and feed on microorganisms, algae, protozoan, larvae of insects, shrimps and eggs. Almost all species of adult frogs are carnivorous and consume annelids, gastropods and arthropods including mosquitoes. The tadpoles of anurans such as *Bufo, Ramanella, Euphlyctis, Hoplobatrachus, Polypedates etc* actively prey on the eggs of *Aedes aegypti*.

2.6 Bacteria in biological control of mosquitoes

Iturbe-Ormetxe *et al.* [12] reviews the use of *Wolbachia* as promising biological control of mosquito borne diseases. The *Wolbachia* is endosymbiotic bacteria that naturally infect 40% of insect species. Many strains of *Wolbachia* can invade and sustain themselves in mosquitoes and are able to reduce adult lifespan, alter reproduction and interfere with pathogen replication. *Wolbachia* infected *Aedes aegypti* mosquitoes have been released in areas of Australia to control outbreaks of dengue fever. Naturally occurring pathogen *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* are gram positive, aerobic, entomopathogenic soil bacteria that release insecticidal toxins that selectively target the larval stages of many mosquito species.

2.7 Fungi in biological control of mosquitoes

Entomopathogenic fungi such as *Lagenidium giganteum* produce infective spores (conidia) that penetrate the cuticle of mosquitoes, releasing toxins that result in their death. These infective spores are drought resistance and can readily be produce in bulk. Oocyst of Ascogregarina (a parasitic protozoon) releases sporozoite that disrupts the gut wall of mosquito larvae. The species of fungi such as *Metarhizium anisopliae* and *Beauveria bassiana* can kill adult mosquitoes [11].

2.8 Integrated biological control of mosquitoes
Benelli *et al.* [1] review the biological control of mosquito vectors by different organisms. They show that natural enemies feeding on mosquito larvae and pupae in aquatic environments can play a major role in reducing mosquito populations. Mosquito larvae and pupae are preyed by many aquatic organisms including fish, amphibians, copepods, odonates, water bugs, and even larvae of other mosquito species. Larvivorous fishes such as *Gambusia, Poecilia, Carassius, Aplocheilus etc* have been introduced in many countries for biological control of mosquitoes. Several species of copepods such as *Cyclops vernalis, Megacyclops formosanus, Mesocyclops guangxiensis, Mesocyclops longisetus* and *Mesocyclops thermocyclopoides* have been reported as active predators of mosquito young [10]. *Toxorhynchites* also known as elephant mosquito is a genus of cannibalistic mosquito that preys on the larvae of the other mosquitoes as well as other free swimming organisms.

Further odonates such as *Anax, Brachydiplax etc*, water bugs such as *Diplonychus*, and some lizards like *Hemidactylus* may also use in integrated vector management of mosquitoes. The sterile insect technique (SIT) is a genetic suppression strategy that involves treating large numbers of males with chemo sterilizing agents to generate chromosomal aberrations and dominant lethal mutations in sperms. These sterilized male insects are released and when they mate with the wild females produce no progeny. Other genetic methods also involve cytoplasmic incompatibility, chromosomal translocations, sex distortion and gene replacement [12].

3. Conclusions
However chemical control is harmful and biological control is more eco-friendly approach does not cause secondary harmful environmental effects. Predator prey relationship is the most important criteria to use biological control of mosquitoes. Many strategies are used from time to time by many researchers for biocontrol of mosquitoes. Every strategy missed an easy, long term and modern approach. Because it is a matter of million lives affected by mosquitoes we just can’t satisfy on management of mosquito population but we have to find a strong and permanent solution to control mosquitoes or vector borne diseases. I think the mosquitoes are not the bigger problems but the vector borne diseases are the main problems. As an organism mosquitoes have right to live by nature. I think if we eradicate mosquitoes from earth the pathogens will evolve to survive in different hosts. Instead of controlling more than 3000 perfect species of insects, we must focus on the few diseases caused by them and their treatment and cure by developing new drugs, vaccines and boost immunity. Nowadays prevention and fear of mosquitoes is million dollar industry which is also diverting us from perfect solution. In this case I must say that cure is better than prevention.

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