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BIOLOGICAL CONTROL OF MOSQUITOES USING PREDATORY INVERTEBRATES: A REVIEW

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Abstract

Mosquitoes are important vectors of several human and animal diseases, including malaria, dengue, chikungunya, Zika, lymphatic filariasis and Japanese encephalitis. The widespread use of chemical insecticides has led to insecticide resistance, environmental contamination and adverse effects on non-target organisms, necessitating the development of sustainable alternatives. This review highlights the role of predatory invertebrates, with special emphasis on insects, in the biological control of mosquito populations. It examines the biology, predatory potential, field applications, advantages and limitations of major insect predators, including *Toxorhynchites splendens*, dragonfly and damselfly nymphs, diving beetles and backswimmers. The review also discusses the successful use of cyclopoid copepods (*Mesocyclops longisetus* and *Macrocyclops* spp.) against container-breeding mosquitoes. Available studies indicate that these predators can effectively suppress mosquito populations when integrated with habitat management, microbial larvicides and other components of Integrated Vector Management (IVM). Conservation and augmentation of indigenous predator communities offer an environmentally safe, sustainable and economically viable approach to long-term mosquito management.

Keywords- Biological control, mosquitoes, predatory invertebrates, *Toxorhynchites splendens*, dragonfly nymphs, cyclopoid copepods.

Introduction:

Predator–prey interactions are among the most fundamental ecological processes regulating the abundance and distribution of organisms in natural ecosystems. Predators regulate prey populations, thereby maintaining ecological balance and contributing to biodiversity conservation

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and ecosystem stability. This natural regulatory mechanism forms the scientific basis of biological control, wherein natural enemies are utilised to suppress pest populations below economically or medically significant levels (Huffaker & Messenger, 1976; Begon *et al.*, 2006). Among these natural enemies, predatory invertebrates have attracted considerable attention because of their abundance, ecological adaptability and ability to provide sustained suppression of mosquito populations. A wide range of predatory invertebrates has been investigated for mosquito control; however, their effectiveness varies according to habitat characteristics, prey preference, ease of mass production and operational feasibility (Lacey & Orr, 1994) (Table 1).

Mosquitoes are among the most important vectors of human and animal diseases, transmitting pathogens responsible for malaria, dengue, chikungunya, Zika, yellow fever, Japanese encephalitis, West Nile fever and lymphatic filariasis. Owing to their serious public health importance, mosquito management has largely depended on chemical insecticides such as organophosphates, pyrethroids, carbamates and insect growth regulators. Although these insecticides have been effective in reducing mosquito populations, their indiscriminate and prolonged use has resulted in insecticide resistance, environmental pollution, adverse effects on non-target organisms and ecological imbalance (Service, 2012; WHO, 2012). These limitations have encouraged the development of environmentally safe alternatives, particularly biological control, as an important component of Integrated Vector Management (Lacey & Orr, 1994; WHO, 2004).

Table 1. Insects and other invertebrate predators that have been investigated or used for the biological control of mosquito larvae.

Sr. No.	Predator (Invertebrate)	Group	Target Mosquito Species	References
1	*Toxorhynchites splendens*	Mosquito (Culicidae)	*Aedes aegypti*, *Ae. albopictus*, *Culex quinquefasciatus*	Steffan & Evenhuis (1981); Collins & Blackwell (2000)
2	*Toxorhynchites rutilus*	Mosquito	*Aedes aegypti*, *Ae. albopictus*	Focks *et al.* (1982); Collins & Blackwell (2000)
3	*Toxorhynchites brevipalpis*	Mosquito	*Aedes aegypti*	Steffan & Evenhuis (1981)
4	*Anisops* spp.	Backswimmer (Hemiptera: Notonectidae)	*Anopheles*, *Culex*, *Aedes*	Shaalan *et al.* (2009)
5	*Notonecta* spp.	Backswimmer	*Anopheles*, *Culex*	Campbell *et al.* (2025)
6	*Diplonychus indicus*	Giant water bug (Belostomatidae)	*Culex quinquefasciatus*, *Anopheles stephensi*	Prabakaran (1992)
7	*Diplonychus annulatum*	Giant water bug	*Culex*, *Anopheles*	Shaalan *et al*, (2009)
8	*Laccotrephes*	Water scorpion	Mosquito larvae	Shaalan *et al*, (2009)

	griseus	(Nepidae)		
9	*Ranatra* spp.	Water stick insect	Mosquito larvae	Shaalan *et al.* (2009)
10	*Mesovelia vittigera*	Water treader (Mesoveliidae)	Mosquito larvae	Shaalan *et al.* (2009)
11	*Microvelia* spp.	Water strider	Mosquito larvae	Shaalan *et al.* (2009)
12	*Hydrometra* spp.	Water measurer	Mosquito larvae	Shaalan *et al.* (2009)
13	Dragonfly nymphs	Odonata: Anisoptera	*Anopheles*, *Aedes*, *Culex*	Lien & Tsai (1986); Sebastian *et al.* (1990); Mandal *et al.* (2008); Norma-Rashid & Saleeza (2014); Choo *et al.* (2021);
14	Damselfly nymphs	Odonata: Zygoptera	Mosquito larvae	Saha *et al.* (2012);
15	Diving beetles (*Cybister*, *Dytiscus*)	Coleoptera: Dytiscidae	Mosquito larvae	Lundkvist *et al.* (2003)
16	Water scavenger beetles (*Hydrophilus* spp.)	Hydrophilidae	Mosquito larvae	Shaalan & Canyon (2009)
17	Whirligig beetles (*Gyrinus* spp.)	Gyrinidae	Mosquito larvae	Shaalan & Canyon (2009)
18	Predaceous diving beetle larvae	Dytiscidae	Mosquito larvae	Lundkvist *et al.* (2003)
19	Copepods (*Mesocyclops aspericornis*)	Crustacea	*Aedes aegypti*	Kay *et al.* (2002)
20	*Mesocyclops longisetus*	Copepod	*Aedes aegypti*	Marten *et al.* (1994)
21	*Macrocyclops albidus*	Copepod	*Aedes albopictus*	Marten (1990)
22	*Macrocyclops distinctus*	Copepod	*Aedes aegypti*	Marten *et al.* (1994)
23	*Cyclops vernalis*	Copepod	*Aedes* spp.	Marten (1990)
24	Freshwater planarians (*Dugesia* spp.)	Platyhelminthes	Mosquito larvae	Melo and Andrade (2001)
25	Freshwater leeches (*Erpobdella* spp.)	Annelida	Mosquito larvae	Shaalan & Canyon (2009)

26	Water mites (Hydrachnidia)	Arachnida	Mosquito larvae	Shaalan & Canyon (2009)
27	Aquatic spiders (*Dolomedes* spp.)	Arachnida	Mosquito adults and larvae	Shaalan & Canyon (2009)
28	Freshwater shrimp (*Macrobrachium* spp.)	Crustacea	Mosquito larvae	Collins & Resh (1989)
29	Crayfish (*Procambarus* spp.)	Crustacea	Mosquito larvae	Collins & Resh (1989)
30	Freshwater amphipods (*Gammarus* spp.)	Crustacea	Mosquito larvae	Shaalan & Canyon (2009)

Toxorhynchites spp- Among the various predatory insects investigated, *Toxorhynchites* species have received the greatest attention because of their highly specialised predatory behaviour against mosquito larvae. *These* are among the best-known insect predators used in the biological control of mosquitoes. Unlike other mosquitoes, adults do not feed on blood but obtain nourishment from nectar, honeydew and fruit juices, making them harmless to humans and animals. Their larvae, however, are highly predaceous and feed on the immature stages of mosquitoes, particularly *Aedes aegypti*, *Aedes albopictus* and *Culex quinquefasciatus*, making them valuable biological control agents against important disease vectors (Steffan & Evenhuis, 1981; Collins & Blackwell, 2000; Donald *et al.*, 2020).

Among the species, *Toxorhynchites splendens* (Wiedemann), commonly known as the elephant mosquito, is widely distributed in South and Southeast Asia and parts of Oceania. Females lay eggs singly in water-filled natural and artificial containers such as tree holes, bamboo stumps, coconut shells, discarded tyres and domestic water-storage containers, which are also preferred breeding habitats of *Aedes* mosquitoes (Steffan & Evenhuis, 1981). This close overlap between predator and prey habitats greatly enhances its effectiveness under field conditions.

Field evaluations have demonstrated the practical utility of *T. splendens* in mosquito control. In India, releases into domestic water-storage containers resulted in successful establishment of predator populations and significant reduction of *Aedes aegypti* larvae without chemical insecticides (Panicker *et al.*, 1983; Collins & Blackwell, 2000). *Similar success was reported from Thailand, where periodic releases of Toxorhynchites splendens effectively suppressed Aedes aegypti on Sa-Med Island (Vongtangswad et al., 1983; Collins & Blackwell, 2000).* In Malaysia, predator establishment in cemetery flower vases and other artificial containers significantly reduced *Aedes albopictus* breeding, demonstrating its usefulness in urban environments (Steffan & Evenhuis, 1981; Collins & Blackwell, 2000). Community-based programmes across Southeast Asia further confirmed that *T. splendens* can complement source reduction and Integrated Vector Management strategies for sustainable control of dengue vectors (Collins & Blackwell, 2000; Donald *et al.*, 2020).

Despite these advantages, *T. splendens* has certain limitations. Successful establishment requires adequate mosquito prey, while cannibalistic behaviour complicates large-scale mass rearing. The predator performs best in permanent or semi-permanent water containers and is less effective in temporary breeding habitats that dry rapidly. Moreover, indiscriminate insecticide use may eliminate predator populations along with mosquito larvae, reducing long-term effectiveness (Collins & Blackwell, 2000; Donald *et al.*, 2020).

Odonata nymphs- Besides predatory mosquitoes, dragonflies and damselflies represent another important group of aquatic insect predators with considerable potential for mosquito control. They are among the most effective natural predators of mosquito larvae and have been extensively studied as biological control agents under both laboratory and field conditions. Their prolonged aquatic nymphal stage, high predatory efficiency and wide distribution in freshwater habitats make them valuable components of sustainable mosquito management programmes (Corbet, 1999; Saha *et al.*, 2012; Norma-Rashid & Saleeza, 2014; Jinguj *et al.*, 2020).

The predatory potential of dragonfly nymphs has been confirmed in several laboratory and field investigations. A single nymph is capable of consuming large numbers of mosquito larvae during its development, while adult dragonflies also prey upon flying mosquitoes, thereby suppressing mosquito populations during both aquatic and terrestrial stages of the mosquito life cycle (Corbet, 1999).

In Myanmar, releases of *Crocothemis servilia* nymphs into domestic water-storage containers significantly reduced *Aedes aegypti* populations, demonstrating the feasibility of incorporating dragonflies into community-based dengue control programmes (Sebastian et al., 1990). *In India, several indigenous odonate species have demonstrated significant predatory potential against mosquito larvae under laboratory and semi-field conditions. Species such as* ***Ceriagrion coromandelianum*** *and* ***Brachydiplax chalybea chalybea*** *have shown high predation rates against Culex quinquefasciatus (Saha et al., 2012), while more recent field mesocosm studies have demonstrated similar potential for* ***Orthetrum sabina*** *and* ***Crocothemis servilia*** *(Choo et al., 2021).*

In the Indian subcontinant, indigenous odonate species effectively suppressed *Culex quinquefasciatus* and *Anopheles* mosquitoes under semi-field conditions, highlighting the importance of conserving native predator populations (Lien & Tsai, 1986; Sebastian *et al*., 1990; Mandal *et al.*, 2008; Saha *et al.*, 2012; Norma-Rashid & Saleeza, 2014). Ecological investigations in Panama also showed that naturally occurring dragonfly and damselfly nymphs inhabiting tree holes significantly reduced *Aedes*, *Anopheles* and *Culex* larvae without chemical intervention. **A subsequent global meta-analysis further confirmed that dragonfly and damselfly naiads significantly reduce larval populations of** *Aedes***,** *Anopheles***, and** *Culex***, supporting their integration into biological mosquito control programmes.** Their quantitative synthesis analysed 485 effect sizes from 31 studies involving 47 odonate species and nine mosquito species.

Dragonflies possess several advantages as biological control agents. They occur naturally in most freshwater ecosystems, provide prolonged larval control, do not contribute to insecticide resistance and cause no environmental pollution. Moreover, they are compatible with Integrated Vector Management (IVM) programmes and are generally regarded as beneficial, non-biting insects (Corbet, 1999; WHO, 2012).

However, dragonflies are generalist predators that also feed on other aquatic invertebrates. They are difficult to mass rear and are most effective in permanent or semi-permanent water bodies. Their populations may also decline following indiscriminate insecticide application (Corbet, 1999). Nevertheless, a recent global meta-analysis confirmed that dragonfly and damselfly nymphs consistently reduce mosquito larval populations across different mosquito genera, supporting their conservation and integration into habitat-based Integrated Vector Management programmes for sustainable mosquito control.

Cyclopoid Copepods– Although insects constitute the largest group of predatory invertebrates used in mosquito control, certain non-insect invertebrates, particularly cyclopoid copepods, have also demonstrated remarkable operational success. Cyclopoid copepods, particularly *Mesocyclops longisetus* and *Macrocyclops* spp. (especially *M. albidus*), are among the most successful crustacean biological control agents used against container-breeding mosquitoes such as *Aedes aegypti* and *Aedes albopictus* (Kay *et al.,* 2002). These minute freshwater crustaceans occur naturally in ponds, wells, domestic water-storage containers, discarded tyres and flower pots, where they actively prey upon first- and second-instar mosquito larvae. An adult copepod can consume 20–40 newly hatched larvae per day, and its rapid reproduction enables the establishment of self-sustaining populations that provide continuous suppression of mosquito larvae.

Field studies have demonstrated their effectiveness in mosquito control. In Honduras, *M. longisetus* reduced *Aedes aegypti* populations by more than 98% in domestic water containers. Similar success was reported from Colombia, Florida and Louisiana, where *Mesocyclops* and *Macrocyclops* effectively suppressed *Aedes*, *Culex* and *Anopheles* mosquitoes, particularly when integrated with *Bacillus thuringiensis israelensis* (Bti) and other components of Integrated Vector Management (IVM) (Marten, 1990; Kay *et al.*, 2002).

Despite their proven efficacy, copepods mainly prey upon early larval instars and require relatively stable aquatic habitats. Their survival may be adversely affected by frequent drying of breeding sites, poor water quality and indiscriminate insecticide use. Therefore, cyclopoid copepods are most effective when used as part of Integrated Vector Management rather than as stand-alone mosquito control agents (WHO, 2012).

Different predatory invertebrates occupy different ecological niches and therefore complement rather than replace one another. *Toxorhynchites* spp. are particularly suitable for container-breeding mosquitoes, dragonfly nymphs perform best in permanent wetlands and ponds, whereas cyclopoid copepods are highly effective in domestic water-storage containers. Their combined use, together with microbial larvicides and habitat management, can provide broader and more sustainable mosquito suppression than any single biological control agent alone.

Discussion:

Despite considerable progress in the use of predatory invertebrates for mosquito control, several scientific and operational challenges remain to be addressed before these biological control agents can be widely adopted in routine vector management programmes. Most studies have been conducted under laboratory or semi-field conditions, whereas long-term field evaluations across diverse ecological regions remain limited. Further multi-location studies are required to assess the effectiveness, persistence and seasonal dynamics of indigenous predators under varying climatic and environmental conditions, particularly in tropical countries such as India (Lacey & Orr, 1994; WHO, 2012).

One of the major constraints is the lack of efficient and cost-effective mass-rearing techniques for important insect predators such as *Toxorhynchites splendens* and dragonfly nymphs. Cannibalism among *Toxorhynchites* larvae and the prolonged aquatic development of odonate nymphs restrict their large-scale production and field deployment. Research on improved rearing methods, artificial diets and automated production systems would greatly enhance their operational feasibility (Collins & Blackwell, 2000; Donald *et al.*, 2020).

Further investigations are also needed to understand predator–prey interactions under natural conditions. Factors such as habitat complexity, vegetation, water quality, prey density, interspecific competition and climate variability can significantly influence predatory efficiency. Long-term ecological studies are therefore essential to determine the sustainability of predator populations and their impact on mosquito suppression without adversely affecting non-target aquatic fauna.

Although cyclopoid copepods have demonstrated remarkable success against container-breeding *Aedes* mosquitoes, comparatively little information is available on the biological control potential of several indigenous aquatic insects and other invertebrates occurring in India. Comprehensive surveys and evaluation of native predator diversity may identify locally adapted species with greater ecological compatibility and operational value (Saha *et al.,* 2012).

Future mosquito management should increasingly adopt an integrated approach by combining predatory invertebrates with microbial larvicides such as *Bacillus thuringiensis israelensis* (Bti), habitat modification, community participation, and emerging technologies including *Wolbachia*-based control, the Sterile Insect Technique (SIT), remote sensing and GIS-based vector surveillance (WHO, 2012; Donald *et al.,* 2020). Strengthening habitat conservation, community awareness and ecological restoration will also promote the persistence of indigenous predator populations. Such multidisciplinary strategies are expected to improve the sustainability, cost-effectiveness and environmental safety of mosquito control programmes while reducing dependence on chemical insecticides.

Conclusion:

Mosquito-borne diseases continue to pose a serious public health challenge, underscoring the need for sustainable and environmentally safe vector control strategies. The increasing incidence of insecticide resistance, coupled with growing concerns over environmental contamination, has renewed interest in the use of predatory invertebrates as biological control agents (Lacey & Orr, 1994; WHO, 2012). Among the invertebrates reviewed, *Toxorhynchites* spp. and cyclopoid copepods have demonstrated the greatest operational success, whereas dragonfly nymphs offer considerable potential through conservation-based mosquito management. No single predatory invertebrate is suitable for all mosquito breeding habitats. The selection of biological control agents should therefore be based on the target mosquito species, breeding habitat, ecological conditions and operational feasibility. Conservation and augmentation of indigenous predator populations, combined with habitat management, microbial larvicides, and other components of Integrated Vector Management, offer one of the most practical and environmentally sustainable approaches for long-term mosquito control (WHO, 2012). Continued research, habitat conservation and community participation will further strengthen the role of these natural enemies in future mosquito management programmes.

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