# Review of complementary impact of using aquatic insect predators in mosquito biocontrol

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**Abstract**

Mosquitoes are the most important blood-sucking arthropods of their annoyance and transmission pathogens of many serious and fatal human diseases, accounting for more than 17% of all infectious diseases. Globalization and climate changes have enhanced the dispersal of native mosquito species and endemic diseases and invasive new habitats. Mosquitoes have a complex life cycle, in which adults are terrestrial and select aquatic habitats for egg oviposition and immatures development. *Culex* spp. differ from Anophelin and *Aedes* species in that they can grow in brackish or mild organic polluted water. For mosquito control, the aquatic stages can be more easily controlled than flying adult insect pests. In recent decades, insect pest control has focused on biological control, which is an ecologically acceptable and practical alternative to insecticides in mosquito vector control. Predaceous insects are more efficient in pest control. Hematophagous mosquito populations in many temporary and permanent water resources can be controlled by laboratory cultivation and maintenance of the entomophagous insects that naturally inhabit aquatic ecosystems or introduction from other fauna. Also, the nonconsumptive effect of the predators reduces the vector fitness and alters the egg oviposition behavior of the gravid females. Understanding the mosquito (prey)-predator relationship and cohabitation can establish and choose effective mosquito predators. Today, there are applications of mosquito predators, besides promising others in mosquito vectors of borne diseases control programs. Most of these aquatic predators have been identified as mainly belonging to the following orders: Diptera (Culicidae, Chaoboridae, Ephydridae, and Chirinomidae), Coleoptera (Dytiscidae and Hydrophilidae), Hemiptera (Notonectidae, Coroxidae, Nepidae, Belostomatidae), and species from the suborders Anisoptera and Zygoptera of the Odonata order. This review reports the most applied and promising insect mosquito predators by their predation capacity and surplus killing. Also gives scope for oviposition avoidance by females as one strategy in mosquito control.

**Keywords:** Mosquitoes, Oviposition avoidance, Mosquito predators, Surplus killing

## 1. Introduction

Mosquitoes are belonging to the culicid family; this family had been divided into Culicinae and Anophilinae subfamilies: These two subfamilies were diverged approximately 217 Ma from a common blood-feeding ancestor [1]. The mosquitoes are holometabolous insects, their immature stages are inhabiting the aquatic environment, which abundant in fresh water, and after metamorphosis, the adults are leave water bodies. Thereby, they are transfer biomass and nutrients to the land, strengthening the linkage between terrestrial and aquatic ecosystems [2]. In addition, micro-reservoirs inhabited by mosquitoes can themselves become interesting model objects of trophic ecology [3, 4].

Mosquitoes are important insects not only as nuisance biters, but also as vectors of many serious and fatal diseases [5], the genera *Anopheles, Aedes*, and *Culex* are the most problematic vectors of most important pathogens, such as malaria, dengue, West Nile virus, chikungunya, yellow fever, fiariasis, tularemia, dirofiariasis, Japanese encephalitis, Saint Louis encephalitis, Western equine encephalitis, Eastern equine encephalitis, Venezuelan equine encephalitis, Ross River fever, Barmah Forest fever, La Crosse encephalitis, and Zika fever, Keystone virus and Rift Valley fever [6-8].

Malaria caused by Plasmodium parasites, is consider one of the most life-threatening infectious diseases around the world, it is transmitted by infected female Anopheles mosquito bites [9]. In Iraq, malaria was endemic disease at beginning of 20th century, moreover, malaria in the First World War (WWI) was an unexpected adversary [10]. During the WWI (1914-1918) in Iraq, British army failure to protect themselves against malaria disease [11], about 59,323 cases were reported in mixed allied troops of 889702 – 969388 exposed military population at WW1, with 0.76% fatal percentage all infected cases [12]. However, Iraq has been free of malaria since about 40 years ago [13, 14], most of the Middle East Region countries are malaria-free as no indigenous cases of infection have been described in recent years [15].

According to guideline of World Health Organization, the traditional pest management is mostly practiced by using conventional synthetic chemical insecticides, such as organochlorine and organophosphate compounds. The frequent application of synthetic chemical insecticides for controlling mosquitoes is limited because they develop resistance against these insecticides, pollution of the water resources, and adverse effects on non-target organisms [16-18].

Moreover, vector populations have expanded their geographical ranges, and invasive new biogeographical regions, the lack of effective treatments or vaccines has meant that the development of vector control methods is essential in the fight against mosquito-transmitted diseases [19]. The biological control method of mosquitoes is representing the best alternatives to synthetic insecticides for arrest vector population under threshold levels [20]. Biological control was mainly by larval predators such as fish, predatory insects like dragonfly naiads and *Toxorhynchites* larvae; microcrustaceans; bacterial larvicides such as Bti; plant-based mosquitocides; and green-fabricated nanoparticles [21, 22]. Biological control of mosquito larvae with predators and other biocontrol agents would be a more-effective and eco-friendly approach, avoiding the use of synthetic chemicals and concomitant damage to the environment. Manipulating or introducing an auto-reproducing predator into the ecosystem may provide sustained biological control [23].

The predator can be defined as an organism which hunts and consume other organism as a food [24]. Aquatic predators are the group of insects having dynamic role in food chain and food web in the ecosystem, also, aquatic predators play major role in aquatic ecosystems and related disciplines [25]. Although most aquatic insect predators are opportunists, certain prey sizes or types may be preferred, suggesting predator influence on prey community structure [26]. Some prey species can behave differently from others, certain species can adapt to predation risk while others might not be able to do so [27]. Mosquito predators are more consuming larvae than pupae, due to the indication of pupae to exhibit rapid tumplines action when had been startled [28]. The predator efficiency is determined by water body volume, larval instars and predator density [29].

Mosquito predators by polyphagous feeding habit with advantage and disadvantage; Advantage is that these predators can survive when mosquito larvae are rare or absent, while a disadvantage is that they may not reduce mosquito larvae due to availability of alternative preys. The second negative effect on predation by polyphagous predators is the presence of other invertebrate and vertebrate predators that may reduce the abundance of the predaceous insects [30]. The third difficulty is predators may interfere through chemical or other cues; for instance the hydrophlilid *Tropisternus lateralis* [31], and the phantom midge *Chaobous albatus* [32]. The predators are avoid egg laying in pools with fish. However, when facing the risk of predation, *Ae. aegypti* larvae spent more time near the container's edges and exhibited discrete feeding behaviors or avoidance of the risk of predation. Conversely, in the absence of predation risk, larvae explored the entire container, swimming vigorously [33].

Wasteful killing, in which aquatic prey is killed but not eaten, has been identified in several genera and species of odonate naiads and in larvae of many species of the mosquito genus *Toxorhynchites* [34].

## 2. Oviposion avoidance

Oviposition attractants and deterrents can potentially be used for manipulation of mosquito behavior by making protected resources unsuitable for mosquitoes [35]. In mosquito reproduction, predator avoidance during oviposition is common [36]. The mosquitoes have not parental care, so the choice of the oviposition site can be significant effects on the survival of their offspring, therefore, the gravid *Culisetes longiareolata* female avoided *Anisops sardea* in artificial pools for egg laying selection [37]. Many aquatic insects are negatively response to the predator cues; they are able to detect the presence of potential predators of their progeny [38]. The predatory prey relationship is mainly detected by the releasing of kairomones by predators present in aquatic habitat, where mosquitoes are going to laid eggs or not, if kairomones detected by mosquitoes it doesn't lay eggs in the such habitat [39]. Experimentally, the sight cues of the predator image of *Toxorhynchites splendens* beside other aquatic predators can repel gravid *Ae. Aegypti* oviposition [40].

In the field experiment, two *Culex* spp. avoided ovipositing in the largest containers in the presence of dragonfly- predators [41]. But the genus *Aedes* in particular seems to show little avoidance of oviposition with predators [42]. The predaceous dragonfly naiads of *Anax imperator* caused 52% reduction in mosquito, *Culiseta longiareolata* oviposition in outdoor artificial pools [43]. Anopheles mosquitoes are malaria transmitter, their females on average oviposited 70% more eggs in predator-free habitats, while the presence of the predators backswimmers (*Anisops sardea* and 5 species of Notonectidae) and dragonfly naiads induced shift in oviposition of *Anopheles* spp. [44]. The caged *Anopheles gambiae* and *Culiseta longiarelata* graved females were found strongly avoid oviposition in containers for *An. Gambiae* and pools for *Cs. longiarelata* inhabited with *Notonecta maculata* predator [45, 46]. In the permanent water resources inhabit with predators, the mosquitoes; *Cx. pipiens, Cx. restuans* and *Cx. trasilis* are avoid predator cues [47, 48].

On the other hand, the predators like *Toxorhynchites* are beneficial biocontrol, by directly reducing prey density and increasing bacterial food prey via added organic matter as feces and partially eaten victims. Therefore, *Toxorhynchites* predators are do as attractants of ovipositing more to bacterial by-products of *Toxorhynchites* feeding, therefore, *T. theobaldi* attracts *Ae. aegypti* with suggesting that oviposition attraction is cued by bacteria [49]. There is also evidence some predators might actually attract ovipositing mosquito females [50].

## 3. Predator insects

### A) Diptera

#### a) Culicidae

The larvae of some mosquitoes are obligate or facultative predators that attack other mosquito larvae [51, 52], but they are poorly studied as a control for dangerous mosquito species. The exception is representatives of genus *Toxorhynchites*. In some studies, representatives of genus *Lutzia*, which inhabit phytotelmata and other micro-aquatic habitats, are studied and are also considered promising agents for mosquito control [53, 54]. In the laboratory, *Lutzia fuscana* larvae have significantly more feeding preference for *Ae. aegypti* larvae, in presence togather both *An. stephensi* and *Cx. quinquefasciatus* larvae, and consuming an average of 5-19 *Ae. aegypti* larvae per day [55]. Moreover, *Lutzia tigripes* larvae might be the most efficient mosquito predator and it candidate for releasing in wild to mosquitoes control for they can survive and well adapted to the any habitats whether polluted or non-polluted water bodies [54].

The larvae of *Toxorhynchites* are voracious predators and have ability to consume thousands of larvae of mosquito vectors. Additionally, late instar larvae of *Toxorhynchites* show prepupal compulsive killing behavior against prey larvae. *Toxorhynchites* larvae have ability to resist starvation and survive weeks without prey, especially at late instars [56]. Also, the *Toxorhynchites* larvae are one of the preferable biological control, due to sharing with prey same aquatic habitat, this predator is frequently coexisted together with *Ae. Aegypti* and *Ae. Albopictus* in aquatic habitat [57]. The experience of controlling the number of blood-sucking mosquitoes using *Toxorhynchites* is described in detail in several reviews [58, 56, 52, 59].

Adults of *Toxorhynchites* has ability to locate cryptic domestic and natural container habitats for oviposition. Rearing and maintenance of *Toxorhynchites* under laboratory conditions are possible. These aforementioned unique characteristics led many scientists to suggest that *Toxorhynchites* has potential to be utilized as an alternative mosquito control method against container-inhabiting mosquito vectors of pathogens. For instance, *Toxorhynchites rutilus* larvae were used for the biological control of container mosquito pests in New Orleans [60], until New Orleans Mosquito Control settled on deployment of a tropical predator species (*Toxorhynchites amboinensis*), which yielded better coverage of both natural and artificial containers [61]. Although the use of *Toxorhynchites* alone to eradicate mosquito vector populations has limited success, incorporating *Toxorhynchites* with other integrated mosquito control tools (e.g., insecticidal agents) may enhance the outcomes of control against the populations of mosquito vectors [58, 62].

*Toxorhynchites* spp. show a strong preference for ovipositioning into the same containers as *Ae. aegypti* and *Ae. albopictus* and a single *T. rutilus* larva are reported to eliminate a few hundred to 5,000 prey larvae. Fore there, It was postulated that, *Ae. aegypti* has less ability to perceive cues from predation and could not successfully alter its behavior to reduce predation risk compared with *Ae. albopictus* and *An. sinensis*. This study was suggested that *T. splendens* is a suitable biocontrol agent in controlling dengue hemorrhagic vector, *Ae. Aegypti* [56]. From the heavily urbanized metropolis of Houston and surrounding Harris County, Texas, the native mosquito, *Toxorhynchites rutilus septentrionalis* (Dyar and Knab) is a proven effective larval mosquito predator, and aggressive feeding behavior. Therefore, it is considered a beneficial organism worth releasing to reduce naturally localized container-breeding mosquito populations.

Experimentally, in a research examined prey choices by *T. splendens*, the behavioral responses of *Ae. aegypti, Aealbopictus*, and *An. sinensis* larvae when exposed to the predator. The results show that *T. splendens* prefers to consume *Ae. aegypti* larvae even in presence both *Ae. Albopictus* and *An. Sinensis* larvae. The larvae exhibited different behavioral responses when *T. splendens* was present, which suggests vulnerability in the presence of predators, "thrashing" and "browsing" activities were greater in *Ae. aegypti* larvae. Such active and risky movements could cause vulnerability for the *Ae. aegypti* larvae due to increasing of water disturbance.

**b) Chaoboridae**

Among other Diptera, larvae of the family Chaoboridae can be important consumers of true mosquito larvae in micro-aquatic habitats. In contrast to larger predators, they can eat all mosquito larvae instars, and not only the last one. Laboratory and field studies indicate that chaoborids can be effective biocontrol agents. Recently, it has been proposed to use *Chaoborus* larvae in combination with copepods.

It has been shown that colored water is more attractive to female mosquitoes to lay eggs than uncolored water, while *Chaoborus* is successful in catching larvae in both cases. This means that small artificial reservoirs with dark water, into which *Chaoborus* are introduced, can be used as a kind of "egg traps": mosquitoes will actively lay eggs in such habitats where predators can consume young larvae.

**c) Corethrellidae**

Corethrellidae receive the popular name of frog-biting midges due to the habit of their females of feeding on the blood of anuran amphibians. Corethrellidae females need blood to complete egg maturation, an important characteristic of the group is that its larvae are predators of other small aquatic invertebrates, such as mosquito larvae, and may also play a relevant role in the population control of human disease vectors. They are known to consume mainly the early stages of mosquitoes and are also capable of being so-called compulsive killers. *Corethrella* larvae (Corethrellidae) have also been studied as mosquito control agents, selective predation by *C. appendiculata* may influence the relative abundances and community structure of larval mosquitoes in treeholes or other container habitats, quantify consumption rates of small mosquito prey by *C. appendiculata*, which were shown here to consume approximately 200 first-instar *A. albopictus* larvae during the third and, especially, fourth instar.

**d) Ephydridae**

The shore fly larva (*Ochthera chalybescens*) preyed on mosquitoes at all stages except eggs, moreover, mosquitoes larva size and type of water could not effect on the feeding habit of this fly, this fly has ability to consume 18 larvae per day and it is also one of the best biological control for *An. gambiae*, which is the vector of African malaria disease. *O. chalybescens*, play a more important role in reducing populations of *An. gambiae* in small temporary habitats than in rice fields because the flies are more abundant in small temporary habitats.

Predators consuming mosquito larvae in phytotelmata are also found in other Diptera families; (Chironomidae, Ceratopogonidae, Corethrellidae, Tipulidae,Periscelididae, Syrphidae, Muscidae, Calliphoridae and Sarcophagidae). However, they have not been studied as potential agents of biological control.

**B) Coleoptera**

**a) Dytiscidae**

All dytiscid beetles are carnivorous for at least part of their life-cycle. Their larvae are exclusively predaceous, whereas adults may also feed as scavengers. The known predacious genera of this family are: *Acilius, Agabus, Colymbetes, Cybister, Eretes, Graphoderus, Hydaticus, Ilybius, Laccophilu* and*, Rhantus*. Both larvae and adults of Dytiscidae are considered ubiquitous top predators in lentic systems, particularly in fishless waters. Species of the genera *Dytiscus*, *Laccophilus*, *Agabus* and *Rhantus* have been reported as potential agents of biological control.

Adults of most dytiscid species are capable of active dispersal due to their ability to fly and many are pioneers occupying freshly-formed waters.

Dytiscidae family have name "the predacious diving beetles or called water tigers" are show a preference to feed on mosquito larvae. Since some dytiscid species can significantly decrease Culicidae populations of mosquito larvae, they are probably important in the natural control of these dipterans. They are also found in urban areas, which is of paramount importance since urbanization decreases species diversity and favours *Ae. albopictus* population growth.

The effects of dytiscid predation on food webs and mosquito populations are dependent on several abiotic and biotic conditions, including vegetation structure, habitat complexity, and temperature. Some dytiscid species selectively feed on certain prey types relative to others, larval and adult dytiscids are also predators of mosquito larvae and thus frequently investigated as potential agents for mosquito suppression, *Colymbetes paykulli* Erichson chose mosquito larvae more often than *Daphnia* spp. It was reported that *C. tritaeniorhynchus* female mosquitoes avoided laying eggs in dytiscid-conditioned water and that smaller mosquitoes emerged from dytiscid-conditioned water as a result of lowered larval activity. Also, significant decrease in larval density of different mosquito species was observed 30 days after the introduction of *Acilius sulcatus* larvae, while the removal of *A. sulcatus* resulted in a significant increase in larval density. Interest in dytiscids for their mosquito suppression abilities has spurred research, that examines natural patterns in assemblages of dytiscids and culicids. Selective predation by larvae *Agabus* (Coleoptera: Dytiscidae) on mosquitoes: support for conservation based mosquito suppression in constructed wetlands. A significant decrease in larval density of different mosquito species was observed 30 days after the introduction of *A sulcatus* larvae, while the removal of *A. sulcatus* resulted in a significant increase in larval density.

**b) Hydrophilidae**

Hydrophilidae are common predators in ground pools, permanent and temporary ponds, and artificial mosquito breeding sites and were reported from phytotelmata as well. Although they can reduce mosquitoes densities in some pools. *Hydrochara affinis* (Coleoptera: Hydrophilidae), a water scavenger beetle, was recently identified as a natural and effective agent for biological mosquito control; it was reported to exhibit high rates of mosquito larvae predation. Predation efficiency and preference of the hydrophilid water beetle, *Hydrochara affinis* (Coleoptera: Hydrophilidae), larvae on two mosquito species, *Cx. pipiens molestus* and *Ochlerotatus togoi*, were tested under laboratory conditions. As a result, the predation curves of *H. affinis* on two mosquito species were logarithmic; and the number of consumed prey increased as the number of predator instars were increased. As predicted from the predation curves, the estimated maximum number of *Cx. pipiens molestus* and *O. togoi* consumed by a third instar larva of *H. affinis* per a day was 926 and 304 larvae, respectively. the differences in consumed prey number between predator instars and prey species were caused by handling time rather than attack rate. Handling time decreased rapidly as the predator larvae grew, and that of *O. togoi* was twice longer than that of *Cx. pipiens molestus*.

**C) Aquatic hemiptera**

Aquatic hemiptera are able to both fresh and polluted aquatic habitats, therefore, hemipteran predators are dominant predators. Various families of aquatic and semiaquatic bugs from Hemiptera order including: Gelastocoridae, Naucoridae, Nepidae, Belostomatidae and Notonectidae are important for biological control of mosquitoes. Notonectids or backswimmers have been considered the most promising biocontrol. The greater values of search capacity represent the better entomophagous insects, revealing hemipterans of the family Notonectidae and especially *N. irrorata* as the most successful and thus the best candidates for biological control programs.

The role of hemipteran predators in controlling mosquito larvae has been recognized since 1939 in New Zealand, when stock troughs with *Anisops assimilis* were found to be free of mosquitoes whereas puddles in depressions surrounding the troughs contained mosquitoes. One of the important factors in reducing immature mosquito population and considered promising in mosquito control, the differences in foraging preferences to contribute to long-term species coexistence in aquatic predatory hemipterans.

**i) Notonectidae**

Notonectidae (backsuimmers) are a family of water bugs that are known to be important predators of mosquito larvae and have great potential in the biological control of vector mosquitoes. An experiment was conducted to assess mosquito larvae predation by *Anisops breddini*, a species common to Southeast Asia, it was found that the predation rates of *Ae. Aegypti* and *Armigeres moultoni* were recorded in context of prey density, predator density, predator size and prey type. Predation rates were strongly affected by prey type and less by prey density and predator density.

Release of notonectid *A. sardea* will effectively control *Cx. pipiens molestus* by predation and beside decreases generations number of through immature stages extension. Laboratory observations on the predatory activity of *A. bouveri* (Hemiptera: Notonectidae) indicate more feeding on the anopheline mosquito larvae alone, but it was also observed that the predation decreases when alternative food was available along with mosquito larvae. *Notonecta peruviana* demonstrated selectivity for larvae of *Ae. aegypti* especially at the highest densities, attributed to the inefficient anti depredation response, active mobility and smaller size compared to those of *Cx. quinquefasciatus*. The functional response (FR) demonstrated the success of *N. peruviana* in the larval control of culicid mosquitoes, prioritizing the type of prey; thus, promoting the need for its applicability in the field. The water bug *Sigara hogarroca* found that it has great potential bioefficacy and active predation for control of mosquitoes larvae in aquatic and semi aquatic habitats.

**ii) Nepidae**

In the aquatic community, The possible influence of apparent competition on mosquito prey consumption by three water bugs (Heteroptera: Nepidae): *Ranatra elongata, R. fiiformis*, and *Laccotrephes griseus* was assessed under laboratory conditions, where these predators and prey coexist, mosquito larvae may benefit from apparent competition that reduces their vulnerability to predators, While the field study was revealed a significant decrease in larval density, The identity of the alternative prey appears to be an important factor for shielding the vulnerability of mosquito prey to the generalist insect predators. For study predation efficiency, the adults of *Nepa cinerea* were tested for its biocontrol efficiency against the instars of *Ae. aegypti*, *Ae. albopictus* and *Cx. quinquefasciatus*. More preference was given to the III instar with regard to stage preference, and *Ae aegypti* followed by *Aedes albopictus* and *Cx. quinquefasciatus* with reference to the experimental vector species. The predatory impact and the clearance rate were high in *Ae. aegypti* followed by *Ae. albopictu*s and *Cx. quinquefasciatus* with values ranging from 14.05 to 15.70; 14.63 to 15.15; 14.83 to 15.05; and 2.64 to 2.71; 2.29 to 2.54; 1.43 to 2.17 per larvae per day predator respectively. Therefore, it can be concluded that *N. cinerea* adults could be used as an additional biocontrol agent against the vectors of dengue and filaria agents. Biocontrol potential of Nepidae bug, *N. cinerea* against immature stages *of An. stephensi*, *An. culicifacies*, *Cx. quinquefasciatus* and *Ae. aegypti* was studied under laboratory conditions. It was found that *N. cinerea* had the highest predation against *An. stephensi* followed by *An. culicifacies*, *Cx. quinquefasciatus* and *Ae. Aegypti*. From the analysis, it was found that *N. cinerea* has good predation efficacy. It can be used as a biological control agent to control of mosquito breeding in integrated disease vector control program.

**iii) Belostomatidae**

This field trial indicated that *Diplonychus indicus* can be used successfully in reducing the immature stages of *Ae. aegypti* followed by suppression in adult emergence, this is the first report on the utility of this mosquito predator against dengue vectors. *D. indicus* is considered an efficient predator even at high mosquito prey density, unlike the backswimmers, *Notonecta undualta* and *A. bouverii*, where the predation rate is known to diminish from low- to high-prey density. The predator came to the level of satiation only after consuming a large number of mosquito larvae (10–56/hour). Also, *D. indicus* has been reported to be an efficient predator of mosquito immature in many laboratory studies.

**4. Odonata**

Odonata naiads are generalists and voracious predators that detect their prey by means of compound eyes and mechanoreceptors and suddenly capture them with the labium or labial palps. Odonata naiads are polyphagous and efficient predator for mosquito control, they prefer clean non polluted aquatic habitats. The measured predation rates of dragonfly naiads were mostly higher than those of damselfly naiads. Therefore, Libellulidae (Anisoptera) naiads are more efficient predator of mosquito larvae and pupae of the *Culex* genus due to the higher feeding rate than Coenagrionidae (Zygoptera), this finding is related to that Libellulidae as active hunters, and consume culine pupae and larvae faster than Coenagrionidae. In filled tree holes habitat, mosquito larvae are the most common prey, size-selective predation by the odonate naiads is a likely explanation for this result; large mosquito larvae were less abundant in the predator treatment than in the controls. Polymerase chain reaction analysis was performed, to determine whether mosquito predators in wetland habitats feed on *An. gambiae* larvae? From 330 predators was 54.2%. The order of positive rate was the highest in Odonata (70.2%), this study demonstrates that the polymerase chain reaction method can determine whether aquatic mosquito predators feed on *An. gambiae* larvae if the predators have undigested *An. gambiae* in their midgut. Odonate naiads are voracious predators and may be useful natural control agents, while they are found in high degree of conspecific and inter specific predation that may reduce their overall predation efficiency. Also, the predation rate of *Crocothemis erythraea* is reduced by chemical cues from *Anax imperator*, but the response of *Ischnura evansi* to *C. erythraea* was statistically non-significant. However, the intra-guild interactions may limit the effectiveness of odonates as predators of mosquitoes, and mediated via chemical predation signals. In comparison with other predator taxa, Coenagrionidae (damselflies) naiads have the potential to reduce the survival and density of *An. funestus* larvae and most efficient predators, than followed by Notonectidae (backswimmers), while Aeshnidae (dragonflies) predators being the least efficient.

The odonate naiads could be a good source of biological agents for the management of the mosquitoes at larval stages, under laboratory conditions. Predatory potential of five odonate nymphs namely: *Anax parthenope, Bradinopyga geminate, Ischnura forcipata, Rhinocypha quadrimaculata*, and *Orthetrum sabina* were evaluated during 24 hr. against the 4th instar larvae of the dengue vector mosquito, *Ae aegypti*. The number of *Ae. aegypti* larvae consumed varied significantly among the five species, and at different levels of water volume, the number of larvae consumed was decreased with increasing search area or water volume. The predatory efficacy of naiads of six coexisting odonate species; *Ischnura. elegans, Trithemis aurora, Pantala flvescens, Libellula fulva, Sympetrum decoloratum* and *Crocothemis servilia* was studied by using the 3$^{rd}$ instar larvae of *Cx. quinquefasciatus* as prey. Feeding rate of naiads of each odonate species was positively correlated with increase in predator and prey density but was negatively correlated with increase in water volume, it was found that predatory ability of damselfly and dragonfly nymphs, it was concluded that *I. elegans, T. aurora, P. flavescens, L. fulva, S. decoloratum* and *C. servilia* nymphs can play an important role in the eco-friendly control of the *Cx. quinquefasciatus* mosquito, and *P. flavescens* naiad is more efficient predator of *Cx. quinquefasciatus* 3rd instar larvae. The predation performance of the odonate naiad was significantly higher during the daytime as compared to night-time. The naiads predation potential of the odonates; *Ceriagrion coromandelianum* and *Brachydiplax chalybea chalybea* on the 2nd and 4th instar larvae of *C. quinquefasciatus* was evaluated under simulated natural conditions in the laboratory. The predation capacity (prey consumption) was varied between vegetated and open habitat conditions and between the days as reflected through the Clearance Rate. Thus, the use of naiads of *C. coromandelianum* and *B. chalybea chalybea* can facilitate conservation and biological control simultaneously under suitable habitat conditions.

Two different prey species; larvae of the mosquito *Armigeres moultoni* and *Ae. Aegypti* were exposed to predation by odonte naiads; *Coenagrion kashmirum, Sympetrum durum, Rhinocypha signipennis, Ischnura forcipata* and *Aeshna flavifrons*, predation rates showed a positive non-linear relationship with prey densities and a negative non-linear relationship with predator densities, also estimated that the mean predation rates per predator were 6.2 individuals per 24 h for dragonfly naiads and 5.1 for damselfly naiads, predator size showed that this variable strongly affected predation rates, especially in dragonflies. The rate of consumption was found in increasing order with respect to older instars, the consumption rate by a dragonfly *Pantala flaviscens* (Fab.) naiad ten instars on an average, 11, 14, 18, 20, 22, 24, 27 and 30 second instar larvae of *Aedes* mosquitoes within 24 hr. In Complementary field-based experiments, the biological control potential of the naiads of three common urban odonates (*C. servilia, Ischnura senegalensis, Orthetrum sabina*), fourth instar *Ae. albopictus* mosquito larvae had been used as prey. The results were revealed substantial size-selective predation by odonate larvae on mosquito larvae, and high consumption rates of mosquito larvae by odonate larvae *A. albopictus* larvae in 24 h), which were comparable to those recorded in larvivorous fish, such as *Gambusia affinis* and *Poecilia reticulata*, for their potential predation, which were caditated as biological control agents of mosquitoes. The rate of consumption was dependent on the size of the prey and the density of the predator, the predatory impact of *Bradinopyga geminata* was more for the first instar *Ae. aegypti*, owing to its size and energy requirements. To conclude, *B. geminata* is an efficient bio-control agent for container breeding *Ae. aegypti* and can be an effective tool in the integrated vector control programme.

In West Benga, the naiads of 5 odonate species *Aeshna flavifrons, Coenagrion kashmirum, Ischnura forcipata, Rhinocypha ignipennis* and *Sympetrum durum* in were evaluated under the semifield conditions. Results showed, the mosquito density after 15 days of introduction had been reduced [21]. In a study carried out in Sri Lanka, predatory efficacy of naiads of five dragonfly species i.e., *Anax indicus, Gynacantha dravida, Orthetrum sabina sabina, Pantala flavescens* and *Tholymis tillarga* were tested against *Ae. aegypti* larvae and the highest predation rates were observed in *Anax indicus* followed by *Pantala flavescens*. The latter has been recommended as the best potential biological agent to control dengue vectors in the field considering its wider distribution and notable predation. the dragonfly species *Crocothemis servilia* and *Rhyothemis variegate* are exhibited considerable predation potential against the immature stages of the *Cx. quinquefasciatus* mosquito.

## 5. Surplus killing

Several studies have demonstrated consumptive and nonconsumptive effects of predators on prey populations, The nonconsumptive effects of aquatic ecosystem are more pronounced than in terrestrial habitats. Wasteful killing, in which aquatic prey are killed but not eaten, has been identified in several genera and species of odonate naiads and in larvae of many species of the mosquito *Toxorhynchites* (Culicidae), Surplus or 'wasteful' killing of the mosquito *Toxorhynchites* spp. occur in tree holes and other phytotelmata. Among *Toxorhynchites*, wasteful killing is most often observed in the fourth instar and is most intense among prepupal stage, peaking in incidence 1–2 days prior to pupation and coinciding with a decrease in prey consumption. *Corethrella* (Corethrellidae) larvae are capable of being so-called compulsive killers. Surplus killing by the predatory midge *Corethrella appendiculata*, which cohabits treeholes and artificial containers together with larvae of *T. rutilus*, after provided with an *Ae. Albopictus* larval mosquito prey, surplus killing was observed only in the fourth instar of *C. appendiculata*, peaking in intensity in the final 24 hr. prior to pupation, but in *T. rutilus* exhibit surplus killing prior diapausing period, as observed for *Toxorhynchites* spp., and is not associated with the pupation. Wasteful killing in odonates is prey density dependent.

## 6. Conclusion

Mosquitoes are vector of a wide range of infective agent disease, these agents are distributed between arbovireses and parasites, as well as their annoyance behavior during flying and feeding habit. One of the protection methods are representing by interfering and decreasing reproduction aquatic habitats or broken mosquito holometabolous life cycle, The present presentation review is deal with eco-friendly mosquito control by larval inset predators. In east Asia, *Culex* spp. are the dominant mosquito species inhabiting wide range of temporary and permanent water resources with low quality parameters, while *Anopheles* spp. are inhabiting only the reducing fresh water bodies. The change of the weather in the last decades, valleys, streams and tributaries are became out of flooding, therefore only scarce conditions are proper for *Aedes* spp. development.

In the field research, it was found that notonectid mosquito predators are abundant in water bodies inhabiting *Culex* larvae, these predators are very proper and promising biocontrol for native and invasive mosquito species. Howevre, Notonectidae surface aquatic predators are tolerating polluted water, and they can easily disperse away by functional wings, besides, all mosquito notonectid predator stages are predators, and high clearance rate, therefore have effective clearness.

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