

RESEARCH ARTICLE

Ecology and Predatory Efficiency of Aquatic (Odonate) Insect over the Developmental Stages of Mosquitoes (Diptera: Culicidae)

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Abstract

Mosquitoes of the genera *Aedes*, *Anopheles* and *Culex* are considered relatively dangerous among the individuals of family Culicidae, because they cause significant public health threat all over the world. Predatory efficiency of the confirmed predators (Odonata: Aeshnidae) by *in vitro* experiments on the developmental stages of the mosquitoes namely, *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus* with reference to the duration of the prey availability, changes in the relative preference or selectivity of predators over the mosquito larvae at different stages (I, II, III and IV instars larvae and pupae) of development, changes in the relative consumption rate of the predators with reference to the species of mosquitoes, attack rate and success rate of the predators on the larval mosquitoes were investigated. Seasonal (month-wise) dynamics of each of the selected predators in some familiar freshwater bodies in Coimbatore, for two consecutive years i.e. from January 2009 to December 2011, relationship (correlation), if any, between physico-chemical parameters of the water and the abundance of the predators in the water bodies and the range of co-efficient of association, between and among the different species of the predators were also investigated. Relative incidence of larval mosquitoes of genera *Aedes*, *Anopheles* and *Culex* in the selected water bodies and the range of co-efficient of association between the predator and prey were also investigated. The results of the predatory capacity of *Anax* nymph on the larvae and pupae of the mosquitoes for 24 h and 1 h of dragonfly showed the highest predation rate against I instar larvae of the mosquito compared to that of the capacity of other predators tested in the present study. Total consumption rate of 7 predatory individuals towards I instar of *C. quinquefasciatus* was 501 out of 700 i.e. 72% was fed in 24 h.

Keywords: Mosquitoes, predatory efficiency, prey, freshwater bodies, *Anax* nymph, instar larvae.

Introduction

Mosquitoes (from the Spanish or Portuguese word for little fly) belong to the family Culicidae of the order Insecta. They are the common pest in every corner of the globe, since they have evolved to adapt to virtually any climatic condition (Reiter and Springer, 1987; Mahadev *et al.*, 2004). Adult female mosquitoes lay their eggs in standing water, which can be a salt-marsh, a lake, a puddle, a natural reservoir or an artificial water container such as a plastic bucket (Panicker *et al.*, 1978; Zuharah and Lester, 2010). Mosquitoes eggs hatch to become larvae and then pupae i.e. the life-cycle includes egg, larva, pupa, and adult (Shalan and Canyon, 2009). The first three stages are aquatic and last 5-14 d, depending on the species and the ambient temperature (Ameen, 1985). Larvae develop through four stages or instars, after which they metamorphose into pupae. Mosquito larvae have a well-developed head with mouth brushes used for feeding, a large thorax with no legs and a segmented abdomen. Larvae breathe through spiracles located on the eighth abdominal segment or through a siphon and therefore, must come to the surface frequently.

The larvae spend most of their time feeding on algae, bacteria and other microorganisms in the surface microlayer (Kohler *et al.*, 1997). They dive below the surface only when disturbed. Larvae swim either through propulsion with the mouth brushes or by jerky movements of the entire body giving them the common name of 'wigglers' or 'wrigglers'. At the end of each instar, the larvae molt, shedding their skin to allow for further growth. The pupa is comma-shaped, when viewed from the side and is commonly called a 'tumbler'. The head and thorax are merged into a cephalothorax with the abdomen circling around underneath. As with the larvae, pupae must come to the surface frequently to breathe, which they do through a pair of respiratory trumpets on the cephalothorax. However, pupae do not feed during this stage. After a few days, the pupa rises to the water surface, the dorsal surface of the cephalothorax splits and the adult mosquito emerges as the pupa floats at the water surface. The pupa is less active than larva. The variation of the body size in adult mosquitoes depends on the density of the larval population and food supply within the breeding water.

Adults live for 4-8 weeks (Hawley, 1985; Harzsch and Hafner, 2006). Mosquitoes have mouthparts that are adapted for piercing the skin of plants and animals. While males typically feed on nectar and plant juices, the female needs to obtain nutrients from a 'blood meal' before she can produce eggs (Steinwascher, 1982). Adult mosquitoes usually mate within a few days after emerging from the pupal stage. In most species, the males form large swarms, usually around dusk and the females fly into the swarms to mate. Males live for about a week, feeding on nectar and other sources of sugar. After obtaining a full blood meal, the female will rest for a few days while the blood is digested and eggs are developed (Harzsch and Hafner, 2006). This process depends on the temperature but usually takes 2-3 d. Once the eggs are fully developed, the female lays them and resumes host seeking. The cycle repeats itself until the female dies. While females can live longer than a month in captivity, most do not live longer than 1-2 weeks in nature. Their lifespan depends on temperature, humidity and also their ability to successfully obtain a blood meal while avoiding host defenses (Jones, 1964; Jones and Grab, 1964). Length of the adult varies but is rarely greater than 16 mm (0.6 in) and weight up to 2.5 mg (Harzsch and Hafner, 2006). With regard to host location, carbon dioxide and organic substances produced from the host, humidity, and optical recognition play important roles. First, the mosquito exhibits a non-specific searching behavior until the perception of host stimulants; then it follows a targeted approach. Female mosquitoes hunt their blood host by detecting carbon dioxide (CO₂) and 1-octen-3-ol from a distance. Prior to and during blood feeding, they inject saliva into the bodies of their source(s) of blood. This saliva serves as an anticoagulant; without it, the female mosquito's proboscis would quickly become clogged with blood clots. Mosquito saliva negatively affects vascular constriction, blood clotting, platelet aggregation, angiogenesis and immunity and creates inflammation (Ribeiro and Francischetti, 2003). Mosquito saliva also contains enzymes that aid in sugar feeding and antimicrobial agents to control bacterial growth in the sugar meal (Rossignol and Lueders, 1986) and proteins (Valenzuela *et al.*, 2002). One promising application is the development of anti-clotting drugs based on saliva molecules, which might be useful for approaching heart-related disease, because they are more user-friendly blood clotting inhibitors and capillary dilators. Mosquitoes of the genera *Aedes*, *Anopheles* and *Culex* are considered relatively dangerous among the individuals of family Culicidae, because they cause significant public health threat all over the world. The female mosquitoes, wherever available, feed on humans and are therefore vectors for a number of infectious diseases affecting millions of people every year (Reiter and Springer, 1987; Collins and Blackwell, 2000; Enserink, 2010).

It has been proposed that vector-borne diseases (VBDs) could shift their range in response to climate change (Leaf, 1989; Shope, 1991; Patz *et al.*, 1996; Carcavallo and De Casas, 1996). Mosquitoes transmit some of the world's worst life-threatening and debilitating parasitic and viral diseases including Yellow fever, Dengue fever, Polyarthritis, Rift valley fever, Ross River fever, Encephalitis, Chikungunya and notably Malaria (Mitchell, 1995; Enserink, 2010). These diseases are on the rise in many tropical and subtropical areas (WHO, 1999). The mosquito-borne diseases are mostly of the zoonotic variety (Kramer and Bernard, 2001). The first chikungunya outbreak occurred in Kerala during 2006 affecting 14 districts, followed by another during May, 2007 affecting almost whole of the State. Four of the worst affected districts were Pathanamthitta, Idukki, Kottayam and Thrissur. The symptoms recorded were fever, headache, myalgia, arthralgia, itch/rash, oedema, eye congestion, eye pain, oral ulcers, distaste, nausea, vomiting and hemorrhage (Thiruvengadam *et al.*, 1965; Ravi, 2006). Yellow fever is a fearsome systemic illness characterized by high levels of virus in the blood, jaundice, midzonalcoagulative necrosis (apoptosis) of the liver, renal failure, myocardial injury, hemorrhage and shock with case fatality rates as high as 50% (Papaevangelou and Halstead, 1977; Enserink, 2010).

The reproductive success of mosquitoes depends in a large part on the ability of gravid females to locate and select oviposition sites that will support the growth and development of their offspring. Depending on the situation, source reduction could be used to manage mosquito population by eliminating the breeding grounds, removing unused tires or buckets, clearing clogged gutters, repairing leaks around faucets, regularly changing water in bird baths, filling and draining puddles, swampy areas and tree stumps (Omlin *et al.*, 2007; Howard and Omlin, 2008). Walker and Lynch (2007) stated that the vector larvae particularly in human made habitats can significantly reduce malaria transmission. To reduce the larval mosquito populations in residential areas, the Dept. of Health services of different countries urge individuals to adopt such physical control methods. Eliminating such mosquito breeding sites can be extremely effective and permanent way to reduce mosquito populations without resorting to insecticides. However, source reduction must be accomplished by individual house owners and also needs cooperative efforts of Govt. and public who must be appropriately trained and educated, which may not be possible in parts of the developing world where human population is on high and government agencies are not sufficiently equipped. Chemical control, use of synthetic insecticides, is still the most convenient and indispensable method all over the world. The extensive application of synthetic pesticides has however caused irreparable hazards to the environment and humans.

World Health Organization (WHO) has estimated that annual number of acute poisonings caused by pesticides is 3 million. Moreover, in developing countries additional problems like lack of understanding of their proper use, non-availability of suitable application equipment and inadequate storage conditions have intensified the risk out of indiscriminate use of synthetic insecticides. The use of conventional pesticides has also been shown to cause a high negative effect on non-target organisms. In addition to these environmental issues, insecticide resistance has also become the greatest problem in the control of many medically important mosquito species. The mosquitoes of genera *Aedes*, *Anopheles* and *Culex* have been known to develop resistance against a variety of Organochloride (OC), Organophosphorus (OP), Carbamate (C) and Pyrethroid (P) insecticides. Against these backdrops, ecology and predatory efficiency of aquatic (Odonate) insect over the developmental stages of mosquitoes (Diptera: Culicidae) was investigated in this study.

Materials and methods

Study location and duration: Seasonal (month-wise) dynamics of each of the selected predator in some familiar freshwater bodies in Coimbatore for two consecutive years i.e. from January 2009 to December 2011 was carried out in this study.

Predator: *Anax junius* nymph belongs to the family Aschnidae and order Odonata of the class Insecta. The young, called a naiad or aquatic nymph dwells on the bottom of the pond, sprawled out in a spider like fashion. They can be found in many aquatic habitats either sluggish or fast running freshwater creeks, rivers, stream and lakes. The naiad has modified mouth parts. They are able to push the fluids in their body into their heads very rapidly which causes the mouthpart to shoot forward with amazing speed. A dragonfly has a life span of more than a year, but adults live for just a few weeks. The larvae or nymph takes 4 weeks to several months to grow large enough to become into adult (Plate 1a and b).

Plate 1a and b. Adults of *Anax junius* nymph, one of the 7 types of aquatic insects prevalent in Coimbatore region, predatory to developmental stages of mosquitoes.



Prey: Larvae at different stages of development viz. I, II, III, IV instars and pupae of three species of mosquitoes, *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus* were selected as prey because of their world-wide role in transmitting disease causing organisms, rather than other Dipterans. The larvae of the mosquitoes were collected from the water bodies nearby and reared in the laboratory until they emerge into adults. They were then identified to their species and maintained in separate cages. The adult mosquitoes were fed with blood as described below and allowed to oviposit. The larvae hatched out of the eggs were grown up to the required instar stages and used for the experimental purpose.

Methods of rearing larval and adult mosquitoes:

The larvae and adult mosquitoes of each species were reared separately as described by Kumar *et al.* (1991) and Lyimo *et al.* (1992). The adult mosquitoes were maintained in a cage of size, 1 cu. ft. The cage was made up of steel frame wrapped with mosquito netting. The cage had a provision (a hole) for handling of materials and animals placed inside. The hole was guarded with a cloth sleeve which was useful to close suddenly after being used. A total number of 20 mosquitoes with a sex ratio of 1:1 (Vasuki, 1992) were regularly maintained in the cage for continued supply of eggs. The females were fed with blood of chick every alternate day at 6.00 p.m. Both females and males were provided with 10% glucose solution as described by Villani *et al.* (1983) on cotton wicks. The cotton was always kept moist with the solution and changed every day. Theodar and Parsons (1945) noticed that glucose as well as ordinary sugar appeared equally attractive to the mosquitoes. An egg trap (cup) lined with filter paper containing pure water was always placed at a corner of the cage. This arrangement facilitated mosquitoes oviposit and made collection of eggs easier. The stock was replaced by new set of mosquitoes every 15 d. For proper replacement, pupae were placed inside the cage. The larvae of all selected species of mosquitoes were reared in plastic cups. They were daily provided with commercial fish food *ad libitum*. Water was changed alternate days. The breeding medium was regularly checked and dead larvae were removed at sight. The normal cultures as well as breeding cups used for any experimental purpose during the present study were kept closed with muslin cloth for preventing contamination through foreign mosquitoes. Predators and mosquito larvae were collected and surveyed from the familiar lakes viz. Kovaipudur Lake, Kurichi Lake, Singanallur Lake, Sulur Lake and Ukkadam Lake which are around Coimbatore town, TN, India.

Estimation of attack and success rate of predators over prey: Predatory behavior of every type of the predator used in the present study was observed in terms of attack rate and success rate.

As the prey larvae found active between the surface and bottom of water in the experimental container, most of the time, the predator either moved towards the prey and put its effort to catch it or awaited the prey to come near and operated its preying mechanism. Either of the attempts to catch the prey was termed attack and the frequency of attack was recorded as attack rate. This attempt ended with success in taking in the prey or failure. If the predator successfully devoured the prey, the related record was termed consumption (killed) rate. One individual of any of the predator type was placed in a glass container contained 500 mL of water and 25 larvae (I/II/III/IV instar/pupae) of either *Aedes* or *Anopheles* or *Culex* mosquitoes. The movement of both the predator and prey was carefully watched for 2 h continuously as suggested by Scott and Murdoch (1983). The number of attempts made by the predator to capture the prey was counted directly for 2 h as well as number of prey remained unconsumed at the end of 2 h was recorded. The experiment was replicated 3 times for a species of predator with respect to every larval/pupal stage of each mosquito species. The mean value was recorded as attack rate and consumption (killed) rate, respectively. Mean Attack Rate = Number of interactions between the predator and any prey in 2 h divided/Number of replicates. Mean consumption (killed) rate = Number of prey consumed in 2 h/Number of replicates. From the data obtained, success rate was calculated by dividing the mean value of the later by the former i.e. the number killed (consumed) divided by the number attacked according to Scott and Murdoch (1983) and expressed in percent.

Seasonal abundance and density of the predators: A weekly survey was carried out during the period from January 2010 to December 2011 to reveal the abundance and density of the insect predators of mosquito larvae in the lakes selected for the present study. The description of tools and the procedure adopted by Murdoch *et al.* (1984) and Shaalan *et al.* (2007) were consolidated and followed as per the present need. Nine quadrates were marked as eight along the border approximately at equal distance from one another i.e. between any two and one at the center of the lake. The approximate area of one quadrate is 1 sq. m which was more or less equal to the size of the net used. First, the net was operated from bottom to surface three times at each quadrate so as to collect the insects in water. The insects, if any, along with suspended materials transferred to the container with some amount of lake water. The net was then applied in a manner to scrap the floor down the area of each quadrate three times in random and the content was transferred to the containers. The insect at the center quadrate was collected with the help of fishermen who were appropriately trained to operate the net. During most of the occasions the floor of the center quadrate could not be reached due to high water level.

The content from each lake was brought to the laboratory, diluted and the insects were collected, washed and identified. The insects of interest to the present study alone were counted species-wise and recorded. The data were then grouped month-wise in order to calculate abundance, density and relative abundance of each type of the predator as explained by Michal (1984).

$$\text{Abundance} = \frac{\text{Total No. of individuals of a species}}{\text{No. of quadrates in which they occurred}}$$

$$\text{Density} = \frac{\text{Total No. of individuals of a species}}{\text{Total No. of quadrates used in sampling}}$$

$$\text{Relative abundance} = \frac{\text{No. of individuals of a particular species}}{\text{Total No. of individuals of all spp. present}}$$

Estimation of relative incidence of mosquito larvae: The relative incidence of larvae of the mosquitoes, *Aedes* spp., *Anopheles* spp. and *Culex* spp. was recorded for the period, January 2010-December 2011, from the water bodies under the present study by Dip method using a 250 mL dipper of 1 mm mesh as suggested by Laird (1988). The collection was made once a week and the data were pooled month-wise to compute the relative incidence.

Estimation of coefficient of association between and among the predators and between predator and prey: Coefficient of association was estimated to understand the prey-predator relationship between the insect predators and mosquito larvae as well as the range of relationship in the incidence between and among the different types of predators in their habitat observed during the period of this study using Yule's 2x2 contingency table as described by Michal (1984) (Table 1).

Table 1. Yule's 2x2 contingency table.

		Species B	
Species	Present	Absent	
Present	type a	type b	
Absent	type c	type d	

type a—where both species were present in the sample.
type d—where both species were absent in the sample.
type b and c—where one of the species was present and the other absent.

Table 1. Predatory capacity of *Anax junius* nymph on the larvae (I to IV instar) and pupae of *Aedes aegypti* for 24 h.

Exp. No	Developmental stages (instars) of mosquito									
	I		II		III		IV		Pupae	
	A	B	A	B	A	B	A	B	A	B
1	496	70.85	477	68.14	486	69.42	423	60.42	453	64.71
2	493	70.42	481	68.71	476	68.00	467	66.71	440	62.85
3	487	69.57	489	69.85	471	67.28	467	66.71	462	66.00
4	463	66.14	472	67.42	473	67.57	483	69.00	473	67.57
Mean	484.75	69.24	479.75	68.53	476.5	68.06	460	65.71	457	65.25
SD	14.95	2.13	7.18	1.02	6.65	0.94	25.79	3.68	13.97	1.99
SE	7.48	1.06	3.59	0.51	3.32	0.47	12.89	1.84	6.98	0.99
CR	18.18		18.12		18.09		17.94		17.91	
%*	69		69		68		66		65	

A–Total number of larvae consumed by seven predators, 1,2,3,4–Number of trials, B–Consumption by one predator, CR–Clearance Rate, %*–Consumption.

The contingency table shows 3 possible observations.

1. If a positive association exists between the species, observations of type a and d will predominate.
2. If there is a negative association between the species, most of the samples will fall in the type b and c categories.
3. If there is no association between them, all 4 types will be observed equally.

The strength of the association between the two species in a contingency table can be estimated by calculating the coefficient of association using the formula:

$$\sqrt{AB} = \frac{ad-bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

Where, \sqrt{AB} is the coefficient of association of the species A and B. The coefficient varies from -1 (negative association or repulsion) to +1 (positive association or affinity). The coefficient is zero when there is no association. In order to measure the coefficient of association the existence of mosquito larvae and predators together/single/absent in at least four quadrates per month during the survey period were taken into account.

Results

The results of the predatory capacity of *Anax* nymph on the larvae and pupae of the mosquitoes for 24 h and 1 h of dragonfly showed the highest predation rate against I instar larvae of the mosquito compared to that of the capacity of other predators tested in the present study. Total consumption rate of seven predatory individuals towards I instar of *C. quinquefasciatus* was 501 out of 700 i.e., 72% was fed in 24 h. The preference of this predator was more or less equal towards the larvae at all developmental stages of other mosquitoes except the consumption rate or pupae of *A. stephensi* (247.50) and *C. quinquefasciatus* (367.75) which was statistically significant compared for other instars (Tables 1-6).

Mean consumption per predator in 24 h on I to IV instar and pupae of the *A. aegypti* was 69.24, 68.53, 68.06, 65.71 and 65.25. CR with reference to the volume of the medium for this predator on I instar to pupae of *C. quinquefasciatus* was 18.33, 18.03, 18.00, 17.94 and 16.99 respectively. The percent consumption of the *Anax* nymph on I instar larvae of *Culex* in 1 h was the greatest (81%) of its predation over the larvae of other species of mosquito. However, percent consumption of the predator on pupae was significantly lower (31, 39 and 35%) compared to the other larval stages which was ranging from 63 to 81%. *Anax junius* nymph showed higher attack rate towards larvae rather than pupae, which was attempted at the rate between 14.0 and 14.3 for aedine and culine and that for anopheline pupae it was 21.0 (Tables 1-6). Among the different stages of larvae, those at I instar were easily attacked as displayed by the maximum mean value of attack, 32.3 for *Aedes*. Ultimate consumption of pupae was also less. *Anax junius* nymph also showed a similar pattern of success over the II to IV instar stage larvae of the three species of mosquitoes 84.6, 91.3 and 83.3%, 91.3, 88.3 and 88.3% and 90.3, 93.3 and 90.6% respectively. Abundance and density of *A. junius* nymph were estimated in Kovaipudur Lake for 2009 and 2010. It was found that the highest abundance of predators was at 55.0, 56.0, 61.6 and 56.2, 56.5, 61.4 in October, November, December for 2009 and 2010, respectively. It was evident from the data that the density was high in the range of 18.3-20.5 in October, November, December and low about 53 in August, 7.2 and 9.4 during 2008 and 09. The chi-square results implied that both the parameters between the years were independent. The survey of abundance and density of *A. junius* nymph in Kurichi Lake was made and found that the abundance of the predators was higher 110, 125, 141.6, 156.6 in September, October, November, Dec 09 and it was at its peak, 136.6, 145, 150 in October, November, Dec 10 (Tables 1-6). The same pattern in density of predators, 41.6, 47.2, 53.2 and 45.5, 48.3, 50.0 in October, November, December 09 and 10 was noted.

Table 2. Predatory capacity of *Anax junius* nymph on the larvae (I to IV instar) and pupae of *Anopheles stephensi* for 24 h.

Exp. No	Developmental stages (instars) of mosquito									
	I		II		III		IV		Pupae	
	A	B	A	B	A	B	A	B	A	B
1	457	65.28	476	68.00	462	66.00	468	66.85	240	34.28
2	462	66.00	468	66.85	458	65.42	456	65.14	268	38.28
3	415	59.28	401	57.28	407	58.14	389	55.57	241	34.42
4	470	67.14	456	65.14	432	61.71	434	62.00	241	34.42
Mean	451	64.42	450.25	64.31	439.75	62.81	436.75	62.39	247.50	35.35
SD	24.58	3.51	33.84	4.83	25.56	3.65	34.80	4.97	13.67	1.95
SE	12.29	1.75	16.92	2.41	12.78	1.82	17.40	2.48	6.86	0.97
CR	17.85		17.85		17.76		17.73		15.29	
%*	64		64		63		62		35	

Table 3. Predatory capacity of *Anax junius* nymph on the larvae (I to IV instar) and pupae of *Culex quinquefasciatus* for 24 h.

Exp. No	Developmental stages (instars) of mosquito									
	I		II		III		IV		Pupae	
	A	B	A	B	A	B	A	B	A	B
1	505	72.14	505	72.14	500	71.42	496	70.85	368	52.57
2	519	74.14	448	64.00	476	68.00	448	64.00	380	54.28
3	482	68.85	439	62.71	458	65.42	430	61.42	370	52.85
4	498	71.14	481	68.71	428	61.14	462	66.00	353	50.42
Mean	501.00	71.56	468.25	66.89	465.50	66.49	459.00	65.56	367.75	52.53
SD	15.38	2.19	30.43	4.34	30.34	4.33	27.92	3.98	11.14	1.59
SE	7.69	1.09	15.21	2.17	15.17	2.16	13.96	1.99	5.57	0.79
CR	18.33		18.03		18.00		17.94		16.99	
%*	72		67		67		66		53	

Table 4. Predatory capacity of *Anax junius* nymph on the larvae (I to IV instar) and pupae of *Aedes aegypti* for 1 h/d.

Exp. No	Developmental stages (instars) of mosquito									
	I		II		III		IV		Pupae	
	A	B	A	B	A	B	A	B	A	B
1	132	18.85	124	17.71	138	19.71	146	20.85	51	7.28
2	122	17.42	132	18.85	132	18.85	145	20.71	56	8.00
3	137	19.57	130	18.57	128	18.28	131	18.71	53	7.57
4	142	20.28	134	19.14	134	19.14	126	18.00	55	7.85
Mean/CR	133.25	19.03	130	18.56	133	18.99	137	19.56	53.75	7.67
SD	8.53	1.22	4.32	0.61	4.16	0.59	10.03	1.43	2.21	0.31
SE	4.26	0.61	2.16	0.30	2.08	0.29	5.01	0.71	1.10	0.15
%*	76		74		76		78		31	

Table 5. Predatory capacity of *Anax junius* nymph on the larvae (I to IV instar) and pupae of *Anopheles stephensi* for 1 h/d.

Exp. No	Developmental stages (instars) of mosquito									
	I		II		III		IV		Pupae	
	A	B	A	B	A	B	A	B	A	B
1	141	20.14	130	18.57	136	19.42	116	16.57	80	11.42
2	128	18.28	117	16.71	120	17.14	120	17.14	62	8.85
3	139	19.85	123	17.57	120	17.14	101	14.42	73	10.42
4	122	17.42	119	17.00	114	16.28	101	14.42	56	8.00
Mean/CR	132.50	18.92	122.25	17.46	122.50	17.49	109.50	15.63	67.75	9.67
SD	9.03	1.29	5.73	0.82	9.43	1.34	9.94	1.42	10.78	1.53
SE	4.51	0.64	2.86	0.41	4.71	0.67	4.97	0.71	5.39	0.76
%*	76		70		70		63		39	

Table 6. Predatory capacity of *Anax junius* nymph on the larvae (I to IV instar) and pupae of *Culex quinquefasciatus* for 1 h/d.

Exp. No	Developmental stages (instars) of mosquito									
	I		II		III		IV		Pupae	
	A	B	A	B	A	B	A	B	A	B
1	156	22.28	132	18.85	145	20.71	146	20.85	70	10.00
2	147	21.00	122	17.42	124	17.71	115	16.42	52	7.42
3	139	19.85	133	19.00	128	18.28	125	17.85	59	8.42
4	122	17.42	112	16.00	126	18.00	126	18.00	63	9.00
Mean/CR	141	20.13	124.75	17.81	130.75	18.67	128	18.28	61	8.71
SD	14.44	2.06	9.84	1.40	9.63	1.37	12.98	1.85	7.52	1.07
SE	7.22	1.03	4.92	0.70	4.81	0.68	6.49	0.92	3.76	0.53
%*	81		71		75		73		35	

The least values were recorded to be 53.2, 17.55 in August 08 for abundance and density respectively. Chi-square results indicated that both the parameters are dependent for both 2009 and 2010. The abundance and density of *A. junius* nymph in Singanallur Lake were estimated in 2009 and 10. The analyses inferred that the abundance was higher at 316, 321, 366 and 273, 278, 296.6 in October, November, December 08 and 09. The lowest values were found to be 140.0 and 136.6 in August 08 and 09. The density also showed a similar order. The highest density of 105.5, 106, 122 and 91, 92.7, 98.8 was recorded in October, November, December for 2009 and 10. The chi-square values indicated both abundance and density expressed dependence between 09 and 10 (Tables 1-6).

Discussion

An intensive search was made to find out aquatic insect predators of immature forms of mosquitoes available in the water bodies in Coimbatore area, TN. The most familiar and relatively bigger lakes were selected for the present study. *Anax junius* nymph was found readily consuming all of the developmental stages (I, II, III and IV instar larvae and pupae) of mosquitoes such as *A. aegypti*, *A. stephensi* and *C. quinquefasciatus*. In the present study, the nymph of dragonfly showed the highest predation rate against I instar larvae of the mosquito compared to that of the capacity of other predators tested in the present study. The percent consumption of the *Anax* nymph on I instar larvae of *Culex* in 1 h was the greatest (81%). Other predators taken in the present investigation never showed such a remarkable predation rate against the larvae of any of the mosquitoes studied here. Some of the previous studies observed that nymphalodonates are voracious predators of mosquito larvae in controlled settings and small natural habitats (Fincke *et al.*, 1997; Lacey and Orr, 1994; Stav *et al.*, 2000; Yanoviak, 2004). Sebastian *et al.* (1980) found that complete elimination of all *A. aegypti* larvae and pupae were achieved between day 4 and 9 depending on the density of aquatic stages of mosquitoes present per container when dragonfly larva, *Labellula* sp. was used.

The larval stages were found to last 2-3 months in the containers. This long life coupled with high predation rate is likely to make dragonfly larvae highly successful predators and could be used in biological control of *Aedes* mosquitoes. Sebastian *et al.* (1990) conducted a pilot field study, involving periodic augmentative release of predaceous larvae of a dragonfly, *Crocothemis servilia*, to suppress *A. aegypti* during the rainy season in Yangon, Myanmar. Singh *et al.* (2003) indicated that dragonfly nymphs have good predatory potential and can be used as a biological control agent for control of mosquito breeding. The use of odonate nymphs in temporary pools or larger habitats can be a potential biological resource in regulating the larval population of the vector and pest mosquitoes (Mandal *et al.*, 2008). The maximum Odonata diversity in Kamalapuram tanks might be due to their larger size (Arulprakash and Gunathilagaraj, 2010).

Conclusion

To conclude, the aquatic insect *Anax junius* prevalent in Coimbatore region were found to be the potential predator of the immature important species of mosquitoes. Despite the difference in the rate of predation, it would be useful in the control of mosquitoes if they are systematically manipulated and distributed. It is suggested that to achieve using these predatory insect in natural breeding sites of mosquitoes, further studies on the reproductive ability, survival, longevity, adaptability to waters with different physico-chemical characters, dispersal, interspecific and intraspecific association etc. of every predator type are required.

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