Species composition and habitat characterization of mosquito (Diptera: Culicidae) larvae in semi-urban areas of Dhaka, Bangladesh

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Mosquito larvae are purely aquatic and develop in water bodies, the type of which is more or less specific to each species. Therefore, a study was carried out to identify the habitat characters of different mosquito species along with their species composition in semi-urban area of Dhaka in Bangladesh during the month of May and June 2012. A total of 6088 mosquito larvae belonging to 12 species (*Aedes aegypti*, *Aedes albopictus*, *Anopheles barbirostris*, *Anopheles pedtaeniatus*, *Anopheles vagus*, *Culex gelidus*, *Culex hutchinsoni*, *Culex quinquefasciatus*, *Culex tritaeniorhynchus*, *Mansonia annulifera*, *Mansonia uniformis*, and *Toxorhynchites splendens*) under 5 genera were collected from 14 different types of habitats. *Culex quinquefasciatus* was the dominant (21.7/500 ml) species followed by *Cx. tritaeniorhynchus* (10.53/500 ml). Dissolved oxygen and chlorophyll *a* were the preeminent predictors for the abundance of all collected mosquito larvae except *Ae. aegypti*. Water temperature was positively associated with the breeding of *An. vagus* ($r = 0.421$, $p = <0.001$), *An. barbirostris* ($r = 0.489$, $p = <0.001$) and *An. pedtaeniatus* ($r = 0.375$, $p = <0.001$). Water depth, distance from nearest house, emergent plant coverage, and alkalinity were found as the basis of larval abundance. Every *Culex* species and *Tx. splendens* ($r = 0.359$, $p = 0.001$) were found positively associated with chemical oxygen demand, while *Mn. annulifera* showed negative association ($r = -0.115$, $p = 0.0297$). This study also highlighted that various physicochemical factors affect the presence or abundance of mosquito larvae.

Keywords: Mosquito, Species diversity, Larval habitats, Physicochemical parameter, Semi-urban areas, Bangladesh

Introduction

Bangladesh is one of the most densely populated countries in the world and Dhaka is its capital. The city, in combination with localities forming the wider metropolitan area, is home to over 15 million.¹ Expansion of cities to rural peripheral areas and aggregate land cover changes in cities create dramatic differences in mosquito larval habitats, and this expansion necessitates modifications in strategies for controlling aquatic stages of mosquitoes.² The effect of changed land use by humans has long been recognized as a cause in the exacerbation of mosquitoes and mosquito-borne diseases. These modifications can be placed onto several broad and overlapping categories including water retention systems, deforestation, agricultural development, canal irrigation, and urbanization. In addition, human activities associated with each of these landscape modifications may contribute significantly to vector and disease transmission.^{3,4}

Absence of a proper and/or adequate disposal of wastes, bad sanitary and drainage systems, haphazard city growth

combined with resource constraints have contributed to the creation of many ideal mosquito breeding grounds, resulting a high density of mosquito populations.³ Ameen et al.⁵ mentioned the fact that mosquito problem is essentially an environmental and ecological problem, the propensity to ignore the importance of mosquito bionomics, sole dependence on insecticides for mosquito control, and at the same time insufficient knowledge about their susceptibility status seem to be responsible for the failure of mosquito control programs in the city areas. It is well known that under the influence of environmental conditions, a vector species may show changes in the seasonal distribution in the same area of dominance. The increase in density of a vector species is very much dependent on climatological factors favorable for its breeding, and adult survival.⁶

Mosquito larvae are purely aquatic and grow in water bodies, the type of which is more or less specific to each species. Several landscape components, such as land cover, vegetation characteristics, hydrologic networks, and human and animal population distributions may determine the presence and abundance of larvae, the dispersion of

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adult from breeding sites, and the abundance of adult mosquitoes in different habitats. Human activities that change the landscape, such as irrigated fields and land settlements, consequently may influence the temporal and spatial distribution of mosquitoes.⁷⁻⁹

The oviposition preferences of adult females and the survival ability of immature stages of mosquitoes in both biotic and abiotic environmental conditions of a given aquatic habitats regulate the abundance and distribution of mosquito larvae.¹⁰ Mosquito species vary in the type of aquatic habitats they prefer for oviposition based on location, the physicochemical condition of the water body, and the presence of potential predators.^{11,12} Aquatic vegetation can exert a significant influence on the reproduction of mosquitoes.^{13,14} Physicochemical factors that influence oviposition, survival, and the spatio-temporal distribution of vital disease vector species include salts, dissolved organic, and inorganic matter, degree of eutrophication, turbidity, presence of suspended mud, presence or absence of plants, temperature, light and shade, and hydrogen ion concentration.¹⁵⁻¹⁷ According to Yanoviak, several mosquito species show preference for specific habitat colors.¹⁸ Ovipositing female mosquitoes are known to compare among water bodies based on cues.¹⁹ Biotic factors can change a mosquito's oviposition behavior in several ways.²⁰ Mosquitoes may avoid ovipositing where inter specific competitors are existing, but are attracted to sites where other mosquito larvae are present.^{21,22}

Knowledge of mosquito breeding sites preference in water bodies over others is very important for sound mosquito control strategies.²³ Information of mosquito larval ecology is limited, and the knowledge is insufficient to achieve effective vector control through the means of larval control.²⁴ It is unidentified what causes heterogeneity in vector distribution and abundance, and how the mosquito larval abundance is regulated in the different aquatic habitat. Focusing efforts to larvae, however, requires sound knowledge of the local situation and the behavior of the vector. An understanding of the breeding habitats of vectors would be extremely relevant to vector control.^{25,26} Although a number of studies are available regarding larval oviposition sites all over the world but reports are very scanty in Bangladesh.²⁷⁻²⁹ Some basic information is lacking in this region regarding larval habitat preference and the physicochemical properties of the mosquito breeding habitats.

At present, there is no published report on the larval ecology and characteristics of breeding habitats of mosquito in Bangladesh. Therefore, the present study attempts to fill this information gap by determining the mosquito fauna, characterization of their oviposition sites, and the relative contributions of such larval habitats to mosquito populations of the study areas.

Methods

Study areas

Dhaka is located in the central Bangladesh at 23°42'0" north and 90°22'30" East, on the eastern banks of the

Buriganga river and at a height of 27 ft above mean sea level. The climate of this area is characterized by moderately high temperatures for about eight months in the year, with high humidity and heavy rainfall in summer (April–August). The average lowest temperature recorded was 8 °C and highest 38 °C while the relative humidity ranged between 61 and 90%. The average annual rainfall is about 2030 mm. The area gets most of its seasonal rainfall from the northeast monsoon during late September to mid-November.

Larval sampling and identification

Larval sampling was conducted in Savar (Bank town, Garua, JU, and Radio colony), Amin Bazar, Ashulia (Gokulnagar, Nabinagar, and Ambagan), Keranigonj (Hasnabad, Suvuidda, and Pachimdi) during this season (May and June 2012) to identify, quantify, and characterize the habitats where *Aedes* (*Ae.*), *Anopheles* (*An.*) or *Culex* (*Cx.*) mosquito breed. A habitat was first inspected for the presence of mosquito larvae and the coordinates were recorded using a GPS (Garmin Oregon 550) unit. Standard dipper (500 ml) having a long handle (30–35 cm) were used for collecting water samples from large breeding sites and three dips were taken each time from a site.^{30,31} The water sample was then filtered and the larvae were collected in a 150 ml plastic bottle. The bottle with larval specimen was labeled as sample number, date, and area name and transported to the entomology laboratory, Jahangirnagar University for counting and identification. The location, category of the breeding sites, and type of mosquito was noted in the data sheet. Whole water was collected and measured when a habitat containing small quantity of water. The larvae were counted and identified using morphological characteristics up to species using Nikon stereo zoom microscope.³²⁻⁴¹

Habitat characterization

The environmental variables, chemical and physical characteristics were measured with respect to larval habitats. Initially gross physical characteristics were evaluated visually. Among the environmental variables, water depth, water temperature, light condition, distance to the nearest house, canopy coverage, emergent plant coverage, turbidity, habitat type, and substrate type of the habitats were recorded for each habitat. The depth of water in each breeding habitat was obtained by lowering a meter rule to the bottom of the habitat at three locations and then calculating the means. Water temperature of the habitats was measured just before the samples were collected using mercury thermometer. Light conditions were visually categorized as fully exposed to sunlight or partially/totally shaded. Distance to the nearest house was measured with a tape when it was shorter than 100 m. Canopy and emergent plant coverage of breeding habitats were measured in percentage of water surface covered by placing a square frame (1 m²) with a grid (100 cm²) above the habitat.

Turbidity was measured by a portable turbidity meter. The habitat types included animal footprints, pond (water area larger than 50 m²), stream pool, puddle (water area less than 50 m²), water tank, cemented tank, drain, water logging, tire, and tire track. Substrate types were classified into muddy, sandy, gravel with soil, and artificial substrate without soil (e.g. concrete, plastic, or brick).

Chemical parameters like pH, dissolved oxygen (DO), chemical oxygen demand (COD), amount of chlorophyll *a*, and ammonia (NH₄) of the breeding habitats were tested on sites at the time of sampling. Minimum 150 ml of water was also collected from each of the habitat for physico-chemical analysis. Total hardness, alkalinity, and salinity were measured in the laboratory. The physicochemical parameters and various analytical methods employed for the determination of water quality.

Data analysis

Larval density was calculated by dividing the number of larvae by corresponding dip taken from a respective habitat. All larvae collected from the same container during the same inspection event were considered as one sample. Results for each species are reported as number of collections, not as number of larvae.

Distribution and density of mosquito larval populations were analyzed by the following way:

Distribution was determined as the percent of sampling sites in which a species was noted, according to the formula:

$$C = \frac{n}{N} \times 100\%$$

where *C* = distribution, *n* = number of sites of the species, *N* = number of all sites.

The following distribution classes were adopted from Dziêczkowski (1972):

C1 – sporadic appearance (constancy 0. 20%); C2 – infrequent (20.1–40%); C3 – moderate (40.1–60%); C4 – frequent (60.1–80%); C5 – constant (80.1–100%).

Density was expressed as percent of specimens of the species in the total sample, according to the formula of Dziêczkowski (1972) and Banaszak and Wi.niewski (1999).^{42,43}

$$D = \frac{l}{L} \times 100\%$$

where *D* = density, *l* = number of specimens of each mosquito species, and *L* = number of all specimens. The following density classes were described according to Trojan.⁴⁴

Satellite species (*D* < 1%); Subdominant species (1 < *D* < 5%); Dominant species (*D* > 5%).

Correlation between environmental variables

The environmental variables were classified into two categories: continuous and nominal variables. Continuous

variables included pH, DO, COD, amount of chlorophyll *a* present in water body, NH₄, total hardness, alkalinity, salinity, water depth, canopy coverage, emergent plants, and distance to the nearest house. Nominal variables include habitat type and substrate type. Among the ordinal variable only light condition was examined. We first examined the correlation between the environmental variables using simple correlation coefficients. Distances to the nearest house were not used in this analysis because there is no logical association between this variable and the other environmental variables. Association between nominal variables and continuous variables were assessed.

Association between environmental variables and the occurrence of mosquito larvae

Pearson correlation analysis was used to assess the relationship between mosquito larval densities and physico-chemical characteristics of the larval habitats, i.e. for each environmental variable, simple correlation between larval abundance, and individual parameters were first checked and only significant associations were further examined by step-up multiple logistic regressions to determine the best predictor variables associated with relative abundance of the larval species of mosquitoes.

Multivariate analysis of species and physicochemical factors

The environmental variables were not independent of each other. Therefore, association between mosquito occurrence/abundance and environmental variables, multiple linear or multiple logistic regressions analysis is more appropriate than simple linear or logistic regressions.⁴⁵ Multiple logistic regressions were done in the present study to determine the best predictor variables associated with relative abundance of the mosquito larval species. Contributions to significant multivariate effects were interpreted using standardized canonical coefficients. Canonical correspondence analyses (CCA) have been done using CANOCO 4.5 for Windows to further explore the associations between species abundance with physicochemical factors.^{46,47} The statistical significance of each environmental axis was evaluated by permutation tests. CCA was carried out in our study because physicochemical variables of water body may be highly correlated with one another.

For statistical analysis Microsoft Excel 2010, CANOCO 4.5 for Windows and SPSS® 16.0 (© SPSS Inc., Chicago, IL, 2007) was used. All statistical analysis was performed at 5% significance level.

Ethics statement

Ethical clearance was obtained from the head of each ward, office of the local government (No. PU/203/11) and the ethics committee of Bangladesh Medical Research Council. Verbal consent was taken from all of the household head for this study because majority of them were

Table 1 Number and corresponding percentage of various mosquito species (larvae) collected in different breeding habitats of semi-urban areas of Dhaka

Habitat type	<i>Ae. aegypti</i>	<i>Ae. albopictus</i>	<i>An. barbirostris</i>	<i>An. peditaeniatus</i>	<i>An. vagus</i>	<i>Cx. gelidus</i>	<i>Cx. hutchinsoni</i>	<i>Cx. quinquefasciatus</i>	<i>Cx. tritaeniorhynchus</i>	<i>Mn. annulifera</i>	<i>Mn. uniformis</i>	<i>Tx. splendens</i>	Total (%)
Canal	0	0	0	0	0	0	0	54 (18)	17 (5.67)	0	0	0	71 (1.17)
Cemented tanks	68 (3.24)	191 (9.10)	0	0	0	0	24 (2.67)	99 (4.71)	101 (4.81)	0	0	79 (3.76)	562 (9.23)
Ditches	0	0	5 (1.67)	10 (3.33)	23 (7.67)	11 (3.67)	6 (2)	6 (2)	5 (1.67)	0	0	0	66 (1.08)
Drains	0	0	0	0	0	0	248 (6.89)	1372 (18.29)	775 (10.33)	0	0	372 (6.20)	2767 (45.45)
Earthen jars	9 (37.50)	12 (50)	0	0	0	0	0	0	0	0	0	0	21 (0.34)
Earthen tubs	13 (15.28)	28 (34.44)	0	0	0	0	0	0	0	0	0	0	41 (0.67)
Plastic bucket	7 (17.5)	13 (32.5)	0	0	0	0	0	0	0	0	0	0	20 (0.33)
Plastic jars	9 (15)	13 (21.7)	0	0	0	0	0	0	0	0	0	0	22 (0.36)
Plastic pots	29 (29.58)	42 (43.33)	0	0	0	0	0	0	0	0	0	0	71 (1.17)
Ponds	0	0	29 (2.42)	38 (4.22)	90 (7.5)	45 (3.75)	15 (2.50)	27 (2.25)	23 (7.67)	40 (3.33)	25 (2.08)	0	332 (5.45)
Rice fields	0	0	118 (2.81)	172 (2.87)	394 (6.57)	255 (5.31)	26 (1.44)	131 (2.91)	94 (2.85)	74 (2.24)	50 (1.52)	0	1314 (21.58)
Tire trail	0	0	8 (2.67)	13 (4.33)	23 (7.67)	0	0	0	0	0	0	0	44 (0.72)
Tires	175 (53.4)	65 (20.63)	0	0	0	0	0	0	0	0	0	0	240 (3.94)
Water loggings	0	0	0	0	0	0	21 (7)	316 (21.07)	158 (10.53)	0	0	22 (3.67)	517 (8.49)
Grand total (%)	310 (5.09)	364 (5.98)	160 (2.63)	233 (3.83)	530 (8.71)	311 (5.11)	340 (5.58)	2005 (32.93)	1173 (19.27)	114 (1.87)	75 (1.23)	473 (7.77)	6088 (100)

illiterate. The ethics committee approved this consent procedure.

Results

Species composition and density

A total of 6088 mosquito larvae belonging to 12 species under 5 genera were collected from 84 sampling sites (Table 1). The name of the species and their percentage composition were: *Culex quinquefasciatus* (2005/32.93%), *Culex tritaeniorhynchus* (1173/19.27%), *Anopheles vagus* (530/8.71%), *Toxorhynchites splendens* (473/8.71%), *Aedes albopictus* (364/5.98%), *Culex hutchinsoni* (340/5.58%), *Culex gelidus* (311/5.11%), *Aedes aegypti* (310/5.09%), *Anopheles peditaeniatus* (233/3.83%), *Anopheles barbirostris* (160/2.63%), *Mansonia annulifera* (114/1.83%), and *Mansonia uniformis* (75/1.23%) (Table 1).

Abundance of mosquito species

No species were regarded as constant ($C = 80.1\text{--}100\%$). Two species (*Cx. quinquefasciatus* and *Cx. tritaeniorhynchus*) were frequent ($C = 60.1\text{--}80\%$), and two species (*Mn. annulifera* and *Mn. uniformis*) were sporadic in appearance. The remaining eight species *An. vagus*, *Tx. splendens*, *Ae. albopictus*, *Cx. hutchinsoni*, *Cx. gelidus*, *Ae. aegypti*, *An. peditaeniatus*, and *An. barbirostris* were infrequent ($C = 20.01\text{--}40\%$). According to the density criterion, five species (*Ae. aegypti*, *Ae. albopictus*, *An. vagus*, *Cx. quinquefasciatus*, and *Cx. tritaeniorhynchus*) were within the dominant class ($D > 5\%$). Six species (*An. barbirostris*, *An. peditaeniatus*, *Cx. gelidus*, *Mn. annulifera*, *Tx. splendens*, and *Cx. hutchinsoni*) were included in the subdominant class ($1 < D < 5\%$), and only *Mn. uniformis* was found as a satellite species ($D < 1\%$) (Table 2).

Physical characteristics of larval habitats

Plastic pots got highest mean (33.25 ± 12.27) of canopy coverage but cemented tank possessed the highest range (0–68%) of canopy coverage. Ponds, rice fields, ditches, and canals were observed without canopy coverage in the study areas. Ponds (694.04 ± 85.63) and rice fields (678.58 ± 37.8) acquired the highest mean of chlorophyll *a* content, while earthen tub got the lowest mean

(118.64 ± 18.94). Earthen jars, earthen pots, and plastic buckets were found close to the house because they might have been used in household activities. Majority of ponds and rice fields were away from the human dwellings. Largest emergent plant vegetation was observed in ponds (36.5 ± 13.43) and rice fields (16.45 ± 4.06). Canal elicits the highest (3.16 ± 0) turbidity followed by drain (0.46 ± 0.12), while plastic jar got the lowest (0.1 ± 0.1) mean. Water depth varied with the habitat types. Pond possesses the highest (15.25 ± 0.63) water depth among the habitats sampled while the lowest (2 ± 0) was earthen tub. Water temperatures of the ditches were highest (22 ± 0) as it was exposed to sunlit.

Chemical characteristics of larval habitats

Drains have the highest (22 ± 1.73) COD followed by rice fields (15.5 ± 1.14) and Earthen tubs (13.33 ± 3.33), COD were lowest (5 ± 0) in the tyre trail. Drain elicits the highest mean (104.16 ± 4.14) of total hardness and alkalinity (148.32 ± 9.04), while canal got the lowest of both (36 ± 0 and 36 ± 0 respectively) parameters. NH₄ (0.5–5) content and pH (3.7–9.4) range varied greatly in drains. Mean NH₄ content of drain was highest (1.4 ± 0.28) while canal possessed the lowest mean (0.2 ± 0). Cemented tank possessed highest mean of DO (7.47 ± 0.12) and pH (8.07 ± 0.19) contents while drain got the lowest (3.71 ± 0.13).

Correlation among physicochemical variables

Non-random associations among the environmental variables suggest that the variables examined were not independent (Table 3). Twenty-seven of 66 correlation coefficients (40.91%) were statistically significant, suggesting non-random association between the variables. Water temperature of the larval habitats was negatively correlated with canopy coverage because the habitat was under shed and was comparatively cooler. Non-random association was also observed between the nominal and continuous/ordinal variables. For instance, non-random association was detected between turbidity ($p = 0.037$), total hardness ($p = 0.02$), COD ($p = 0.008$), alkalinity ($p = 0.005$), emergent plant coverage ($p = 0.028$), and pH ($p = 0.008$) with substrate type. Emergent plant can only grow when the substrate type is muddy. Only canopy

Table 2 Distribution and density of mosquito species in semi-urban areas of Dhaka, Bangladesh

Species	Distribution (C)	Density (D)
<i>Ae. aegypti</i>	32.14	22.80
<i>Ae. albopictus</i>	32.14	20.49
<i>An. barbirostris</i>	23.81	1.68
<i>An. peditaeniatus</i>	29.76	2.44
<i>An. vagus</i>	30.95	5.55
<i>Cx. quinquefasciatus</i>	69.05	21.00
<i>Cx. hutchinsoni</i>	29.76	3.56
<i>Cx. tritaeniorhynchus</i>	60.71	12.29
<i>Cx. gelidus</i>	25.00	3.26
<i>Mn. annulifera</i>	17.86	1.19
<i>Mn. uniformis</i>	17.86	0.79
<i>Tx. splendens</i>	34.52	4.95

Table 3 Correlation coefficient among the environmental variables of mosquito larval habitats in semi urban area of Dhaka, Bangladesh

	Water temperature	Water depth	Emergent plant coverage	Canopy coverage	Turbidity	Total hardness	Chemical oxygen demand	Dissolve oxygen	Alkalinity	Chlorophyll <i>a</i>	pH
Water depth	-0.043	1									
Emergent plant coverage	0.402**	0.1	1								
Canopy coverage	-0.415**	-0.053	-0.248*	1							
Turbidity	-0.019	-0.035	-0.019	-0.077	1						
Total hardness	0.115	-0.077	0.265*	-0.047	-0.225*	1					
Chemical oxygen demand	0.053	-0.001	0.018	-0.141	-0.105	0.211	1				
Dissolve oxygen	0.003	-0.185	0.161	0.186	0	-0.350**	-0.499**	1			
Alkalinity	0.179	0.089	0.351**	-0.349**	-0.088	0.730**	0.271*	-0.397**	1		
Chlorophyll <i>a</i>	0.396**	0.094	0.337**	-0.406**	0.067	0.328**	0.285**	-0.299**	0.572**	1	
pH	-0.234*	0.249*	-0.125	0.16	-0.214	-0.144	-0.151	0.257*	-0.16	-0.234*	1
Ammonia (NH ₄)	0.008	0.328**	0.111	-0.109	-0.023	0.328**	0.043	-0.238*	0.442**	0.183	0.261*

*Significant at the 0.05 level.

**Significant at the 0.01 level.

Table 4 Pearson correlation of the physical variables used to characterize the aquatic habitats in relation to mosquito larval density

		Distance from near-est house	Water tem-perature	Water depth	Emergent plant cover-age	Canopy coverage	Turbidity	Chlorophyll a
<i>Ae. aegypti</i>	<i>r</i>	0.121	0.022	-0.248	-0.196	0.206	-0.079	-0.508
	<i>p</i>	0.274	0.844	0.023	0.073	0.06	0.476	<0.001
<i>Ae. albopictus</i>	<i>r</i>	-0.219	-0.296	-0.305	-0.231	0.633	-0.092	-0.553
	<i>p</i>	0.046	0.006	0.005	0.035	<0.001	0.406	<0.001
<i>An. vagus</i>	<i>r</i>	0.546	0.421	-0.06	0.445	-0.364	-0.086	0.565
	<i>p</i>	<0.001	<0.001	0.587	<0.001	0.001	0.437	<0.001
<i>An. barbirostris</i>	<i>r</i>	0.373	0.489	-0.047	0.35	-0.302	-0.075	0.475
	<i>p</i>	<0.001	<0.001	0.671	0.001	0.005	0.495	<0.001
<i>An. peditaeniatus</i>	<i>r</i>	0.482	0.375	-0.046	0.32	-0.319	-0.086	0.47
	<i>p</i>	<0.001	<0.001	0.677	0.003	0.003	0.436	<0.001
<i>Cx. quinquefasciatus</i>	<i>r</i>	-0.308	0.008	0.25	-0.249	-0.132	0.15	0.259
	<i>p</i>	0.004	0.945	0.022	0.022	0.232	0.172	0.017
<i>Cx. tritaeniorhynchus</i>	<i>r</i>	-0.306	-0.062	0.324	-0.276	-0.144	0.041	0.218
	<i>p</i>	0.005	0.572	0.003	0.011	0.191	0.713	0.047
<i>Cx. gelidus</i>	<i>r</i>	0.479	-0.105	-0.08	0.294	-0.322	-0.079	0.505
	<i>p</i>	0.0001	0.342	0.469	0.007	0.003	0.476	<0.001
<i>Cx. hutchinsoni</i>	<i>r</i>	-0.087	0.304	0.049	-0.162	-0.086	-0.052	0.176
	<i>p</i>	0.434	0.005	0.656	0.141	0.437	0.641	0.11
<i>Mn. annulifera</i>	<i>r</i>	0.238	0.397	0.14	0.432	-0.27	-0.053	0.433
	<i>p</i>	0.029	<0.001	0.203	<0.001	0.013	0.634	<0.001
<i>Mn. uniformis</i>	<i>r</i>	0.32	0.332	0.103	0.311	-0.252	-0.061	0.426
	<i>p</i>	0.003	0.002	0.351	0.004	0.021	0.582	<0.001
<i>Tx. splendens</i>	<i>r</i>	-0.404	-0.036	0.157	-0.286	0.015	-0.078	0.085
	<i>p</i>	<0.001	0.748	0.153	0.008	0.895	0.483	0.442

Notes: *r* = Pearson correlation coefficient; *p* = *p* - value.

Table 5 Pearson correlation of the chemical variables used to characterize the aquatic habitats in relation to mosquito larval density

		Total hardness	Chemical oxygen demand	Dissolve oxygen	Alkalinity	pH	Ammonia (NH ₄)
<i>Ae. aegypti</i>	<i>r</i>	-0.242	-0.292	0.396	-0.452	0.28	-0.059
	<i>p</i>	0.026	0.007	<0.001	<0.001	0.01	0.594
<i>Ae. albopictus</i>	<i>r</i>	-0.275	-0.211	0.46	-0.536	0.181	-0.208
	<i>p</i>	0.011	0.054	<0.001	<0.001	0.1	0.057
<i>An. vagus</i>	<i>r</i>	0.211	-0.106	0.343	0.396	-0.129	0.042
	<i>p</i>	0.054	0.338	0.001	<0.001	0.244	0.707
<i>An. barbirostris</i>	<i>r</i>	0.186	-0.074	0.283	0.354	-0.124	-0.008
	<i>p</i>	0.09	0.501	0.009	0.001	0.26	0.946
<i>An. peditaeniatus</i>	<i>r</i>	0.169	-0.127	0.295	0.347	-0.123	0.032
	<i>p</i>	0.123	0.251	0.007	0.001	0.263	0.773
<i>Cx. quinquefasciatus</i>	<i>r</i>	0.165	0.399	-0.844	0.168	-0.163	0.093
	<i>p</i>	0.133	<0.001	<0.001	0.127	0.139	0.4
<i>Cx. tritaeniorhynchus</i>	<i>r</i>	0.195	0.391	-0.782	0.179	-0.083	0.118
	<i>p</i>	0.075	<0.001	<0.001	0.104	0.453	0.238
<i>Cx. gelidus</i>	<i>r</i>	0.17	-0.013	0.284	0.359	-0.107	0.038
	<i>p</i>	0.122	0.905	0.009	0.001	0.333	0.734
<i>Cx. hutchinsoni</i>	<i>r</i>	0.038	0.406	-0.41	0.052	-0.097	-0.141
	<i>p</i>	0.731	<0.001	<0.001	0.639	0.379	0.201
<i>Mn. annulifera</i>	<i>r</i>	0.202	-0.115	0.217	0.293	-0.046	0.031
	<i>p</i>	0.065	0.0297	0.048	0.007	0.676	0.0781
<i>Mn. uniformis</i>	<i>r</i>	0.169	-0.155	0.2	0.252	-0.041	0.061
	<i>p</i>	0.124	0.16	0.068	0.021	0.071	0.0584
<i>Tx. splendens</i>	<i>r</i>	0.086	0.359	-0.601	-0.023	-0.067	-0.03
	<i>p</i>	0.438	0.001	<0.001	0.832	0.544	0.784

Notes: *r* = Pearson correlation coefficient; *p* = *p* - value.

coverage (*p* = 0.002) was found significant with habitat types (Table 3).

Association with mosquito larval abundance and physicochemical factors

Pearson correlation analysis was conducted to detect the relationship between the mosquito larval abundance

and environmental variables (Tables 4–5). Abundance of *Cx. quinquefasciatus* larvae was positively associated with water depth (*r* = 0.25, *p* = 0.002), COD (*r* = 0.399, *p* = <0.001) and chlorophyll *a* (*r* = 0.259, *p* = 0.017) and negatively associated with distance from nearest house (*r* = -0.308, *p* = 0.004) and emergent plant coverage (*r* = 0.249, *p* = 0.022). *Cx. tritaeniorhynchus* larval

abundance was found positively associated with water depth ($r = 0.324, p = 0.003$), COD ($r = 0.391, p < 0.001$) and chlorophyll *a* ($r = 0.218, p = 0.047$) and negatively correlated with distance from nearest house ($r = -0.306, p = 0.005$) and emergent plant coverage ($r = -0.276, p = 0.011$). *Cx. gelidus* showed positive relationship with emergent plant coverage ($r = 0.294, p = 0.007$), DO ($r = 0.284, p = 0.009$), chlorophyll *a* ($r = 0.505, p < 0.001$), and alkalinity ($r = 0.359, p = 0.0001$) while negatively associated with canopy coverage ($r = -0.322, p = 0.003$). *Cx. hutchinsoni* was found positively associated with COD ($r = 0.406, p < 0.001$) and water temperature ($r = 0.304, p = 0.005$) and negatively associated with DO ($r = -0.41, p < 0.001$). Larval abundance of *Ae. aegypti* was found positively linked with DO ($r = 0.396, p < 0.001$) and pH ($r = 0.280, p = 0.01$) and negatively correlated with water depth ($r = -0.248, p = 0.023$), total hardness ($r = -0.242, p = 0.026$), COD ($r = -0.292, p = 0.007$), alkalinity ($r = -0.452, p < 0.001$), and chlorophyll *a* ($r = -0.508, p < 0.001$). *Ae. albopictus* larval abundance showed positive relationship with canopy coverage ($r = 0.633, p < 0.001$) and DO ($r = 0.460, p < 0.001$), while negative relation was found with water depth ($r = -0.305, p = 0.005$), emergent plant coverage ($r = -0.231, p = 0.035$), total hardness ($r = -0.275, p = 0.011$), alkalinity ($r = -0.536, p < 0.001$), and chlorophyll *a* ($r = -0.553, p < 0.001$). Emergent plant coverage ($r = 0.445, p < 0.001$), DO ($r = 0.343, p = 0.001$), alkalinity ($r = 0.396, p < 0.001$), chlorophyll *a* ($r = 0.565, p < 0.001$), and water temperature ($r = 0.421, p < 0.001$) were found positively correlated with *An. vegus* larval abundance, while negative correlation was detected with canopy coverage ($r = -0.364, p = 0.001$). Abundance of aquatic stage of *An. barbirostris* was found positively linked with emergent plant coverage ($r = 0.350, p = 0.001$), DO ($r = 0.283, p = 0.009$), alkalinity ($r = 0.354, p = 0.001$), chlorophyll *a* ($r = 0.475, p < 0.001$), water temperature ($r = 0.489, p < 0.001$), and distance from nearest house ($r = 0.373, p < 0.001$) and negatively linked with canopy

coverage ($r = -0.302, p = 0.005$). Positive correlation was found between *An. peditaeniatus* and emergent plant coverage ($r = 0.32, p = 0.003$), DO ($r = 0.295, p = 0.007$), alkalinity ($r = 0.347, p = 0.001$), chlorophyll *a* ($r = 0.47, p < 0.001$), water temperature ($r = 0.375, p < 0.001$), and distance from nearest house ($r = 0.482, p < 0.001$), and negative correlation was detected with canopy coverage ($r = -0.319, p = 0.003$). DO ($r = 0.217, p = 0.048$); water temperature ($r = 0.397, p < 0.001$), emergent plant coverage ($r = 0.432, p < 0.001$), chlorophyll *a* ($r = 0.433, p < 0.001$) and alkalinity ($r = 0.293, p = 0.007$) were found positively correlated with *Mn. annulifera* while significant negative association were detected with canopy coverage ($r = -0.27, p = 0.013$) and COD ($r = -0.115, p = 0.0297$). *Mn. uniformis* was found to be positively associated with distance from nearest house ($r = 0.32, p = 0.003$), water temperature ($r = 0.332, p = 0.002$), emergent plant coverage ($r = 0.311, p = 0.004$), chlorophyll *a* ($r = 0.426, p < 0.001$), and alkalinity ($r = 0.252, p = 0.021$), and negative association was detected with canopy coverage ($r = -0.252, p = 0.021$). *Tx. splendens* was found to be positively associated with COD ($r = 0.359, p = 0.001$) and negative correlation with DO ($r = -0.601, p < 0.001$), distance from nearest house ($r = -0.404, p < 0.001$), and emergent plant coverage ($r = -0.286, p = 0.008$). Water turbidity showed insignificant negative correlation with *Ae. aegypti* ($r = -0.079$), *Ae. albopictus* ($r = -0.092$), *An. vagus* ($r = -0.086$), *An. barbirostris* ($r = -0.075$), *An. peditaeniatus* ($r = -0.086$), *Cx. hutchinsoni* ($r = -0.052$), *Cx. gelidus* ($r = -0.079$), *Mn. annulifera* ($r = -0.053$), *Mn. uniformis* ($r = -0.061$), and *Tx. splendens* ($r = -0.078$), while positive association was found with *Cx. quinquefasciatus* ($r = 0.15$) and *Cx. tritaeniorhynchus* ($r = 0.004$) (Table 4–5).

Multiple logistic regression equations were performed in order to explain how the environmental variables affect the population of mosquito larvae (Table 6). The result of multiple logistic regression equation showed that *Ae.*

Table 6 Multiple logistic regression equations for the estimated mosquito larval abundance in relation to statistically significant parameters in breeding habitat in Dhaka, Bangladesh

Mosquito species	Multiple regression equations	<i>p</i>	<i>R</i> ²
<i>Ae. aegypti</i>	$\hat{Y} = 60.703 - 0.239(\text{chl}) - 0.482(\text{alk}) - 0.265(\text{distance}) - 0.245(\text{w dept}) - 0.243(\text{w. temp})$	0.04	0.516
<i>Ae. albopictus</i>	$\hat{Y} = 55.988 + 0.318(\text{DO}) + 0.364(\text{canopy}) - 0.258(\text{w dept}) - 0.204(\text{w temp})$	0.01	0.696
<i>An. barbirostris</i>	$\hat{Y} = -3.891 + 0.391(\text{chl}) + 0.569(\text{DO})$	0.04	0.537
<i>An. peditaeniatus</i>	$\hat{Y} = -4.117 + 0.381(\text{chl}) + 0.507(\text{DO})$	0.00	0.573
<i>An. vagus</i>	$\hat{Y} = -13.816 + 0.454(\text{chl}) + 0.272(\text{alk}) + 0.578(\text{DO}) + 0.178(\text{w temp})$	0.02	0.762
<i>Cx. quinquefasciatus</i>	$\hat{Y} = 27.664 + 0.156(\text{chl}) - 0.275(\text{alk}) - 0.875(\text{DO}) + 0.162(\text{tur}) + 0.141(\text{w dept})$	0.03	0.809
<i>Cx. hutchinsoni</i>	$\hat{Y} = 0.016 - 0.255(\text{NH}_4) - 0.371(\text{DO}) + 0.242(\text{COD})$	0.04	0.312
<i>Cx. tritaeniorhynchus</i>	$\hat{Y} = 13.525 - 0.275(\text{alk}) - 0.711(\text{DO}) + 0.241(\text{hard}) - 0.172(\text{E. P. cov}) + 0.256(\text{w dept})$	0.03	0.729
<i>Cx. gelidus</i>	$\hat{Y} = -4.024 + 0.455(\text{chl}) + 0.581(\text{DO})$	0.00	0.579
<i>Mn. annulifera</i>	$\hat{Y} = -5.231 + 0.001(\text{chl}) + 0.276(\text{DO}) + 0.048(\text{w dept})$	0.04	0.472
<i>Mn. uniformis</i>	$\hat{Y} = -2.334 + 0.154(\text{DO}) + 0.001(\text{chl})$	0.02	0.393
<i>Tx. splendens</i>	$\hat{Y} = 1.341 - 0.957(\text{DO}) - 0.018(\text{alk})$	0.04	0.561

Notes: Variables intended in the equation: chl = Chlorophyll *a*, alk = alkalinity, distance = distance from nearest house, w dept = water depth of the habitat, w. temp = water temperature, DO = dissolve oxygen, canopy = canopy coverage, tur = turbidity, NH₄ = ammonia, COD = chemical oxygen demand, hard = total hardness, E. P. cov = emergent plant coverage, $\hat{Y}$ = density of respective mosquito larvae per 500 ml.

Figure 1 Relation between mosquito larval densities with sunlit condition of habitat types in Dhaka, Bangladesh.

aegypti requires lower alkalinity, chlorophyll *a*, water depth and water temperature, and short distance from house for its dominance ($p = <0.04$, $R^2 = 0.516$). These variables are more important in explaining the larval abundance of *Ae. aegypti* than other variables. Higher DO, canopy coverage, lower water depth and water temperature determined the density of *Ae. albopictus* ($p = <0.01$, $R^2 = 0.696$). Dominance of *Cx. quinquefasciatus* larvae were found with high chlorophyll *a*, turbidity, and water depth. Lower alkalinity and DO were also important for its profusion ($p = <0.03$, $R^2 = 0.809$). Higher COD but lower NH₄ and DO were required for the larval growth of *Cx. hutchinsoni* ($p = <0.04$, $R^2 = 0.312$). *Culex tritaeniorhynchus* was dominant where total hardness and water depth was high with low alkalinity, DO and emergent plant coverage ($p = 0 < 0.03$, $R^2 = 0.729$). Higher DO and chlorophyll *a* were the factors for dominance of *Cx. gelidus* ($p = <0.00$, $R^2 = 0.579$), *An. barbirostris* ($p = <0.04$, $R^2 = 0.537$), and *An. peditaeniatus* ($p = <0.001$, $R^2 = 0.573$), while *An. vagus* was dominant where alkalinity, chlorophyll *a*, DO, and water temperature was high ($p = <0.02$, $R^2 = 0.762$). Higher chlorophyll *a* and DO were the best predictors for the abundance of *Mn. annulifera* ($p = <0.04$, $R^2 = 0.472$) and *Mn. uniformis* ($p = <0.039$, $R^2 = 0.393$). Abundance of *Tx. splendens* ($p = <0.039$, $R^2 = 0.561$) may be predicted with low DO and alkalinity (Table 6).

Mosquito larval abundance in relation with sunlit condition of the mosquito larval habitats are presented in Fig. 1. *Aedes aegypti* and *Ae. albopictus* were found in shady and partial shady area with high mean density with shady habitat, while anopheles was not found in shady areas. *Culex* species was found in habitats exposed to sunlit, partial shady, and shady areas with high mean density in partial shady area. *Mn. annulifera* and *Mn. uniformis* were found only in exposed to sunlit area. *Tx. splendens* was abundant in partial shady areas while no *Tx. splendens* was found in exposed to sunlit area (Fig. 1).

Multivariate analysis of species and physicochemical factors

CCA ordination of larval habitats yielded two general environmental gradients: COD, water depth of habitat, turbidity, NH₄ vs. pH and DO, and canopy coverage vs. total hardness, chlorophyll *a*, alkalinity, water temperature, emergent plant coverage, and distance from the nearest house. These gradients revealed striking differences between genera. In general, these two gradients pointed to the mosquito assemblages, with *Ae. albopictus* and *Ae. aegypti* being more abundant in larval habitats with higher pH and DO but with lower turbidity, COD, NH₄ and lower water depth, whereas *Cx. quinquefasciatus*, *Cx. tritaeniorhynchus*, *Cx. hutchinsoni*, and *Tx. splendens* were more abundant in habitats with higher turbidity, COD, NH₄ and higher water depth, and lower pH, and DO. *An. barbirostris*, *An. peditaeniatus*, *An. vagus*, *Cx. gelidus*, *Mn. annulifera*, and *Mn. uniformis* were found associated with low canopy coverage but with higher total hardness, chlorophyll *a*, alkalinity, water temperature, emergent plant coverage, and distance from the nearest house. CCA showed a low species-environment correlation with eigenvalues (λ) of the first, second, third, and fourth axes of 0.72, 0.559, 0.031, and 0.022, respectively (Fig. 2). The eigenvalue is a reasonable measure of the strength of an ordination axis. It is actually equal to the (maximized) dispersion of the species scores on the ordination axis, and is thus a measure of importance of the ordination axis. The first ordination axis has the largest eigenvalue; the second axis is the second largest Eigenvalue, and so on. The eigenvalues of CCA all lie between 0 and 1. Values over 0.5 often denote a good separation of the species along axis.

Discussion

Variation in the mosquito abundance was also detected according to habitat types in the present study. *Ae. aegypti* was found most abundant in tyres and less in cemented

Figure 2 Ordination diagram of mosquito larval species and physicochemical variables of habitats sampled in Dhaka, Bangladesh, produced from Canonical Correspondence Analysis (CCA).

tanks, while *Ae. albopictus* was dominant in earthen jars and less density was observed in cemented tanks. The data evaluate that *Ae. albopictus* prefer close vicinity of house than *Ae. aegypti* for oviposition. WHO, however, reported that *Aedes* mosquitoes prefer to live in human dwelling.⁴⁸ *Ae. albopictus* typically breeds in tree holes and others small, restricted and shaded water collections surrounded by vegetation but also in peridomestic containers filled with water. Mostly anthropophilic, opportunistic container breeders are capable of using any type of artificial water container, especially discarded tires, but also saucers under flower pots, vases, bird baths, tin cans, plastic buckets, and other abandoned recipients and can however establish and survive in non-urbanized areas lacking artificial containers.^{49–51} *Ae. albopictus* was capable of breeding in a wide range of container types, except in concrete tanks with polluted water.⁵² Thavara et al. and Preechaporn et al. also reported that *Ae. albopictus* larvae were found in a wide range of artificial containers (plastic containers, earthen jars, used cans, tires, metal boxes, latex collecting cups, mud pots, etc.) and natural containers (tree holes, coconut shells, fruit peels, and plant axils).^{53,54} Bashar et al. reported that *Ae. albopictus* were found in all types of artificial and natural container and this species were found in high density in all the studied location.⁵⁵ Bashar et al. and Chen et al. studied the container breeding sites of mosquito larvae and indicated that *Ae. albopictus* was capable of breeding in a wide range of container types.^{52,56}

An. vagus was dominant in ditches and tire trials. Other two *Anopheles* species *An. barbirostris* and *An. peditaeniatius* were found as subdominant and prefer rice fields and ponds, respectively, as breeding habitat. Shililu et al. reported that anopheline habitats included rain pools, ponds, dams, swamps, and drainage channels at communal water supply points.¹¹ Adeleke found *Mn. uniformis* and

Tx. splendens as dominant species in ground pools and domestic containers followed by drains.⁵⁷

Water depth played a significant role in preferring the breeding habitat of mosquito. In the present study, *Cx. quinquefasciatus* and *Cx. tritaeniorhynchus* were found in high density where water depth was high, while *Ae. aegypti*, *Ae. albopictus*, preferred shallow water depth for oviposition. As *Aedes* mosquitoes are container breeders, they have the ability to adapt with small water content.^{52,56} Rohani et al. found that *An. maculates* preferred to breed in habitats like shallow pools (5.0–15.0 cm deep) with clear water, mud substrate and plants.⁵⁸ In this study, *Anopheles* species were found in habitats with relatively higher water depth.

Oviposition behavior of gravid female mosquitoes is an important factor that influenced mosquito species composition. Generally *Anopheles* larvae prefer open sunlit waters.³² In the present study, it was found that *Anopheles* larvae preferred both partially shady and exposed to sunlit area. This may vary due to the position of the sun during the sampling time. *Ae. albopictus*, *Ae. aegypti*, and *Tx. splendens* prefer shady area for oviposition. *Culex* larvae were found abundant where the habitat was partially exposed to sunlit except *Cx. gelidus*, which preferred sunlit exposed habitats. *Mansonia* larvae were found in open sunlit conditions or exposed to sunlight. Water temperature of open sunlit condition has often reached higher. De Meillon and McCrae reported that *Anopheles* species are tolerant to high water temperatures.^{59,60} The warm water in sunlit habitats may be an important factor for larval development because warm water accelerates their development.⁶⁰ In addition, warm temperatures may allow more microbes to develop, which provide food sources for the mosquito larvae.⁶¹

Canopy coverage was also responsible for the selection of the breeding habitats of mosquitoes as it affects the sunlit condition of the habitat along with the water temperature. *Ae. albopictus* preferred higher canopy coverage while *Cx. gelidus*, *An. vagus*, *An. barbirostris*, *An. peditaeniatius*, *Mn. annulifera*, and *Mn. uniformis* preferred lower canopy coverage for ovipositing. Okogun et al. suggested that mosquito larval density was highest in shady area.⁶² Yee et al. also found *Culex* larvae in the habitats associated with human population density and canopy coverage.⁶³

Emergent vegetation was known to have direct effects on some mosquito species by obstructing gravid females from ovipositing and supporting a greater diversity of aquatic predators.^{64,65} Emergent vegetation may also reduce the amount of sunlight reaching the water surface, resulting in lower temperatures. Reduced temperatures cause a decline in microbial growth upon which mosquito larvae depend on and increases the larval development time exposing them to greater risks of contact with potential predators and competitors.⁶⁶ To avoid these difficulties, *Cx. quinquefasciatus*, *Cx. tritaeniorhynchus*, and *Tx. splendens* prefer habitats without vegetation for ovipositing.

Similar type of results was obtained by Muturi et al. that *Cx. quinquefasciatus* larvae were negatively associated with emergent vegetation.⁶⁶ On the other hand *Cx. gelidus*, *An. vagus*, *An. barbirostris*, *An. peditaeniatus*, *Mn. annulifera*, and *Mn. uniformis*, prefer ovipositing in habitats with vegetation. As *Aedes* mosquitoes are container breeders, vegetation cannot affect their ovipositing behavior due to the fact that vegetation cannot grow without muddy substrate. These findings contradict with Tadesse et al. as they reported vegetation is important in explaining the presence and abundance of *Culex* and *Anopheles* larvae.⁶⁷

A clear association was observed in the study areas between the distance to potential breeding sites and larval density. *Cx. quinquefasciatus*, *Cx. tritaeniorhynchus*, *Mn. uniformis*, and *Tx. splendens* preferred to oviposit in habitats near house, while *An. vagus*, *An. barbirostris*, *An. peditaeniatus*, and *Mn. uniformis* preferred laying eggs in habitats with long distance from the houses. Barker et al. found that distance to nearest major larval habitat was not strongly related to *Culex* abundance within the <400-m range from larval habitats.⁶⁸ In the present study, the longest distance of habitat from nearest house was 2 m. Minakawa et al. reported that 90% *An. gambiae* were found to breed within 300 m of human habitation.⁶⁹ Similar findings were reported by Sattler et al. for *Anopheles* mosquito larvae in Dar es Salaam, Tanzania.⁷⁰ Hoek et al. suggested the use of a distance of 750 m as a cut-off point for developing a risk map of malaria in Sri Lanka.⁷¹

No significant relationship was depicted with the larval abundance and water turbidity. Former studies opined that *Anopheles* mosquito prefer clear water for ovipositing.⁵⁸ In turbid water *An. maculates* larvae were much more likely to be absent.⁵⁸ Robert et al. reported a similar finding with *An. ambiensis* breeding more in clear water; however, Gimnig et al. found higher *An. gambiae* larval densities with increasing turbidity.^{17,72} Mahmud stated that *Tx. splendens* larvae prefer to breed in turbid and distilled water.⁷³ Sattler et al. reported that turbid water was clearly associated with the presence of Culicines.⁷⁰

We found positive association of culicines with pH which is related to the findings of Adebote et al.⁷⁴ Tadesse et al. reported both anopheline and culicine larvae positively associated with pH.⁶⁷ Their findings contrast with Adebote et al. who reported the preference of anopheline species to low pH values and acidic nature.⁷⁴ Kengluetcha et al. found significant negative relation between pH and *An. dirus* and *An. kochi* density.⁷⁵ We did not find significant relation between larval abundance and pH of the habitats in the present study. These findings supported the results of Rohani et al.⁵⁸

Alkalinity may affect the density of mosquito larvae. *Cx. gelidus*, *An. vagus*, *An. barbirostris*, *An. peditaeniatus*, *Mn. annulifera*, and *Mn. uniformis* require higher alkalinity for their larval development, while *Ae. aegypti* and *Ae. albopictus* require low alkalinity. Similar observation was depicted by Rao et al.⁷⁶ They found that *Ae. albopictus*

preferred moderate alkalinity while *Culex* and *Anopheles* mosquitoes preferred high alkalinity.

Several authors have examined the influence of DO concentration on the abundance of *Anopheles* and *Culex* spp. with contradicting results.^{16,65,75,77} Grillet reported a positive association between DO and the abundance of *An. oswaldoi* and Amerasinghe et al. reported a negative association between DO and *An. culicifacies*.^{16,65} Similarly, Senior-White reported *Cx. vishnui* from hyper-oxygenated water, a finding that has recently been confirmed by Sunish et al.^{77,78} However, it remains unknown whether it is oxygen per se or an associated physicochemical or abiotic factor that influences the abundance of mosquito species. In the current study, we found that *Cx. gelidus*, *Ae. aegypti*, *Ae. albopictus*, *An. vagus*, *An. peditaeniatus*, *An. barbirostris*, and *Mn. annulifera* were positively associated with DO, while negative association was depicted with *Cx. hutchinsoni* and *Tx. splendens*. Oyewole et al. supported the idea that optimum DO might have contributed for survival and breeding of *Anopheles* mosquitoes.⁷⁹

The hardness of water is governed by the content of calcium and magnesium salts (temporary hardness), largely combined with bicarbonate and carbonate and with sulfates, chlorides, and other anions of mineral acids (permanent hardness). Kengluetcha et al. observed higher requirement of total hardness for the dominance of *An. minimus*. The present study depicted that *Aedes* larvae require lower total hardness for its habitat selection and larval growth.⁷⁵

We did not find any association with NH₄ and mosquito larval abundance, while Sanford et al. reported *Cx. tarsalis* larval abundance in wetlands enriched with ammonium nitrogen.⁸⁰ Bradley and Kutz found positive correlation with NH₄ nitrogen and overall mosquito abundance.⁸¹

The preponderance of *Ae. aegypti* can be predicted by lower chlorophyll *a*, alkalinity, water depth, water temperature, and distance from nearest house, while dominance of *Ae. albopictus* can be predicted with higher canopy coverage and DO, lower water depth, and water temperature. Higher chlorophyll *a*, turbidity, water depth, lower alkalinity, and low DO were the best predictors for *Cx. quinquefasciatus* larval abundance. *Cx. hutchinsoni* require lower NH₄, DO, and higher COD for its larval growth and survival. Lower alkalinity, DO, emergent plant coverage, higher total hardness, and water depth in the breeding sites led to an increase in population density of *Cx. tritaeniorhynchus*. Higher DO and chlorophyll *a* were the best predictors for larval abundance of *Cx. gelidus*, *An. barbirostris*, and *An. peditaeniatus*, while *An. vagus* was found abundant with higher chlorophyll *a*, alkalinity, DO, and water temperature. Higher chlorophyll *a* and DO are needed to develop *Mn. annulifera* and *Mn. uniformis* larvae. *Tx. splendens* was noted to prefer lower alkalinity and DO.

CCA did identify more general relationships that may be useful in predicting larval abundance patterns. Turbidity,

COD, and lower DO were predictive for *Culex* population except *Cx. gelidus*. *Anopheles* species can be affected by emergent plant coverage and distance from nearest house as well as *Mansonia* species. CCA ordination diagram plotted *Aedes*, *Culex*, *Anopheles*, and *Mansonia* species in different axis that may explain different requirement for different mosquito species. The fact that *Aedes* and *Culex* presence in tires are influenced by different suites of environmental variables which may be useful when designing vector control strategies, especially as these two groups vary in their capability to transmit disease.

Conclusion

DO and chlorophyll *a* were the leading predictors for the richness of all collected mosquito larvae except *Ae. aegypti*. Water temperature was clearly associated with the breeding of *An. vagus*, *An. barbirostris*, and *An. peditaeniatus*. Water depth, distance from nearest house, emergent plant coverage, and alkalinity were found as the basis of larval richness. *Culex* mosquitoes and *Tx. splendens* were found positively associated with COD, while *Mn. annulifera* showed negative association. The results suggest that the abundance of mosquito larvae may be determined by many variables, each contributing a small effect. The specific cues that trigger oviposition behavior in mosquitoes are largely unknown. A large number of variables may be correlated with other characteristics that act as cues for ovipositing females.

Conflict of interests

The authors declare no personal or financial conflicts of interests in the development, writing, and submission of this study.

Limitations

The study did not assess tree holes as a potential breeding habitat for *Ae. albopictus* mosquitoes and was not included in the survey. Because of methodological and logistical difficulties, some important abiotic factors such as phosphate, silica, bacteria, and presence of other invertebrates as competitor were not studied in the present study, although they have significant effect on mosquito breeding. A more comprehensive study targeting a large number of variables and a more elaborate method of estimating the diversity of other aquatic invertebrates over a longer period of time is warranted.

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