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Spatial Variation in Habitat Productivity Indices, Larval Age-structure Composition and Species diversity of *Culex* Mosquito Species in Minna, Nigeria

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Abstract

This study was carried out to evaluate larval habitat productivity indices, age-structure distribution and diversity indices of Culex mosquito populations in Minna, Nigeria. Mosquitoes were systematically collected from conventional mosquito breeding habitats using Dipping method. Data collected were analysed for habitat productivity, Culex larval breeding indices, age structure distribution and diversity indices in the study area. Five (5) Culex mosquito species were encountered; Cx. quinquefasciatus, Cx. salinarius, Cx. tarsalis, Cx. restuans and Cx. nigripalpus. Analyses revealed spatial variation in habitat productivity indices. Larval breeding indices also revealed that the Cx. species exhibited varying biology, and adaptability to the habitats sampled. Age structure analyses of the collected larvae showed preponderance of late larval instars. There were strong negative correlations between mosquito species abundance and some physicochemical parameters. Species diversity indices also varied among the habitats and locations. The indices investigated indicated that mosquito habitats in Minna are well established and suited for proliferation of Cx. mosquito populations. There is, therefore, need for urgent larval source management to reduce human vector contacts and forestall future outbreak of vectored diseases.

***Keywords**: Breeding Indices, Distribution, Ecology, Physicochemical.*

INTRODUCTION

Culex mosquitoes belong to the Order Diptera and Family Culicidae. They are one of the three major groups of mosquitoes responsible for transmitting pathogens of important debilitating public health diseases. The *Culex* mosquitoes have remained vector for an assortment of diseases such as Lymphatic filariasis, and arboviral diseases including Japanese Encephalitis and West Nile diseases. These diseases continue to ravage areas where the vector species are established and even introduced (Cator *et al.*, 2020).

Female members of this genus were initially not considered epidemiologically important as the other two groups (*Anopheles* and *Aedes* mosquitoes), as they typically obtain blood-meals from birds instead of humans, and (Carvajal-Lago *et al.*, 2021). However, their implication in spread and sustenance of rural and urban mosquito borne disease have stimulated research into their biology (Briegel, 2003).

The biology of mosquitoes, including *Culex* mosquitoes vary from one location to another (spatial), and between seasons (temporal). For effective control, therefore, adequate information and understanding of the biology of local vector species is important. With worldwide reports of class- and cross-resistance by mosquitoes to various World Health Organisation (WHO) recommended insecticides (Olayemi *et al.,* 2011), attention has been diverted to larval source management (LSM) as a cost-effective and efficient control strategy for mosquitoes (Ukubuiwe *et al.*, 2013).

For effective LSM control interventions, however, mosquito larval surveillance is important for elucidating species composition and breeding site preference of vector species populations. Larval survey is pivotal in understanding the dynamics of disease epidemiology such as changes in vector density, distribution and vectorial capacity, and effectiveness of control strategies (Jesha *et al.*, 2015).

Larval surveillance also determines distribution and contribution of breeding sites to mosquito population within a locality; identifying high risk areas and predicting impending disease outbreaks, as well as facilitating appropriate, timely and evidenced-based intervention decisions (Jacob and Joao, 2012).

Presence of mosquito larvae in a habitat is a product of two major factors: female species' oviposition choice and larval stages' survivorship (Fischer and Schweigmann, 2004). Female mosquitoes use a variety of sensory cues, such as olfactory, tactile and visual, to locate potential oviposition sites (Nignan *et al.*, 2022). Female responses to these cues often culminate in the selection of high quality larval habitats which maximize reproductive success of the species (Fillinger *et al.*, 2004). However, survival of hatched-out larvae depends on availability of food resources, tolerances to physico-chemical factors and severity of intra- and interspecific interactions (Kain *et al.*, 2021). Larval survivorship, on the other hand, plays a major role in determining the preponderance of mosquitoes in a locality. Dominance of early (first and second) larval instars in a habitat indicate attractiveness of such habitat to gravid female. Greater proportion of the late (third and fourth) larval instars and pupae are closely related to specific environmental factors that favours immature growth and survival (Yee *et al.*, 2010).

Mosquito ecological studies employ various indices in determining the trend of vector species' development and habitat suitability for development of species (Fischer and Schweigmann, 2008). Some of these include the Absolute (ABI), Mosquito (MBI), Relative (RBI), and General Breeding Indices (GBI) (Jacob and Joao, 2012). These indices are important in understanding the dynamics of a vector species in a locality. These indices also provide information on number of mosquitoes breeding in a locality, proportion of water bodies used for breeding, relative proportion of breeding sites occupied by a given vector species and abundance of breeding sites of a given species in relation to the number of water bodies where mosquitoes are found in a locality (Jacob and Joao, 2012). Larval age-structure classification indicates the frequency of oviposition of female adult species or the suitability of habitats for the development and success of immature (Yee *et al.*, 2010).

Species diversity in an ecological community takes account of the total number of species encountered in a sample (richness), and how the species abundances are distributed among the species (evenness) (Oguoma *et al.*, 2010). Two indices commonly used are the Shannon-Weiner diversity and Simpson's dominance Indices. The Shannon-Weiner diversity measures the order and number of individuals observed for each species in the ecosystem within the community (Oguoma and Ikpeze, 2008; Doherty *et al.*, 2011). Simpson's Dominance Index, on the other hand, measures the chance of two organisms taken from the environment are members of the same species (Ogbeibu, 2005).

Information on breeding and diversity indices will, no doubt, serve as baseline for implementing evidence-based vector control strategies. This study was, therefore, designed to evaluate the larval habitat productivity indices and age-structure distribution and diversity indices of *Culex* mosquitoes in Minna, Nigeria. The information generated will be vital in understanding the population dynamics of the mosquito genus in relation to potential of disease transmission in the study area and areas with similar ecological settings.

MATERIALS AND METHODS

Study period

The study was conducted during the late rainy season of 2014 (August to November, 2014) and early rainy season of 2015 (April to July, 2015).

The study area and sampling locations

The study was carried out in Minna, the capital of Niger state, north central Nigeria. Located within longitude 6^o 33' E and latitude 9^o 27 ' N, covering a land area of 88 km^2, it has an estimated human population of 1.2 million. Minna is known especially for the production of rice and water yam; two major staple foods in the study area and Nigeria at large. The area has a tropical climate with mean annual temperature, relative humidity and rainfall of 30.20 °C, 61.00 % and 1334.00 mm, respectively. The climate presents two distinct seasons; a rainy season between May and October and a dry season (November - April). The vegetation in the area is typically grass dominated savannah with scattered trees.

Four sampling stations were selected for larval mosquito collection to represent the general ecotype of the study area namely; Bosso, Maikunkele, Chanchaga, and Gidan Kwano.

Bosso (9° 39′ 12″ N and 6° 30′ 58″ E) is a densely populated urban settlement situated about 4.25 miles (6.84 km) from Minna. The inhabitants are mostly civil servants and traders. The settlement serves as host to students' hostel facilities of the temporary site of the Federal University of Technology, (FUT) Minna. The settlement has a large numbers of small scale industries. It is sparsely covered with grasses but has tree covers, which are wide apart. The house types found are majorly cement brick types, with good drainage system.

Maikunkele **(**9° 37′ 60″ N and 6° 25′ 58″ E**)** is a less populated area located about 9.72 miles (15.64 km) from Minna, the State Capital of Niger State. Its inhabitants are mostly farmers, and business men and civil servants that resides but work in other part of Minna Metropolis and environs. It has very thick vegetation located at the outskirt of the settlement. The house types are mixed, made up of cement bricks, muds and huts.

Chanchaga (9° 32′ 0″ N and 6° 35′ 58″ E) is a densely populated area which is 5.51 miles (8.87 km) away from Minna city. It is the seat of the Niger state College of Education, the Army Barracks, and host of other institutions and small scale industries. The settlement has moderately good network of drainage system, with the house types mostly cement bricks. The vegetation is of low grass cover.

Gidan Kwanu (9° 33′ 0″ N and 6° 26′ 15″ E) is a rural and sparsely populated area, located about 13.8 miles (22.20 km) from the state capital. The settlement has large tree coverings and lowland grasses. It has poor network of water drainage facilities. The houses are mainly mud types with few cement brick houses. The inhabitants are mostly farmers and petty traders, also resident are the students of the permanent site of the Federal University of Technology, Minna (Ukubuiwe *et al.*, 2012; 2013).

Description of mosquito breeding habitats

Five (5) mosquito larval breeding habitats were sampled in all four (4) sampling locations. These habitats include rice fields, rain pools, septic tanks, drainages and large water bodies. The rice fields include all natural and irrigated paddy rice fields, being agronomically managed to cultivate rice. This habitat type lasted beyond 3 months, with rainfall or irrigation serving as their major sources of water. Organic contents were mainly determined by edaphic factor and partially by manure and fertilizer types used by the farmers for cultivation of crops.

Rain pools include small to medium collection of water on the ground such as ditches, rocks pools, tyre tracks, run offs. These were transient and may not exist for more than 3 months. Most of these water bodies were rain deposited, with some accumulates from domestic wastes runoffs, thus, their organic contents would vary significantly. Large water bodies include lakes, ponds, swamps, streams, rivers, canals, which lasted for most part of the year. They are mostly natural or man-made and advanced aquatic ecosystems.

Septic tanks include sewage water collection points and sludge. These are largely sourced from domestic waste water from human dwellings. They occurred throughout the year and are loaded, consistently, with domestic faecal wastes, rich in organic contents. The drainages include water collections in drainage systems. They were largely formed by domestic water from human dwellings. Their existence, however, was determined by rainfall and artificial sources of water from anthropogenic activities. Most of the drainages lasted beyond 3 months.

Selection and mapping of *Culex* mosquito breeding habitats

Within the sampling stations/settlements, conventional breeding sites were searched for, randomly selected and marked for the collection of mosquitoes. The breeding sites were grouped on the basis of size, duration of existence, degree of anthropogenic activities, source and level of organic pollution.

From each sampling station, five (5) representative habitat type each for rice fields, rain pools, septic tanks and drainages was selected. Due to terrain and availability of large water bodies, four (4) each were sampled from

Bosso and Maikunkele, while, three (3) and two (2) were sampled from Chanchaga and Gidan Kwano, respectively. These resulted in the study of ninety-three (93) habitats from all the The coordinates of the habitat as marked using a hand-held Global Positioning System (GPS), [Garmin GPSMAP® 60CSx] are tabulated in Table 1. These Coordinates were obtained by taking the value of X (Longitude), Y (Latitude) stations/settlements; comprising of thirteen (13) large water bodies and twenty (20) each of rice fields, rain pools, septic tanks and drainages.

and Z (Elevation) value in order to determine the topography of the marked points (Chang *et al.*, 2009) (Table 1 and Figure 1).

Table 1a: Coordinates of Selected Habitats (Rice fields, Rain pools, and Septic Tanks)

Location	Rice Fields			Rain Pools			Septic Tanks		
	X	Y	Z	X	Y	Z	X	Y	Z
Bosso	6º30′35.69″	9º39′47.48″	288	6º30′47.18″	9º39′19.12″	279	6º30′25.49″	9º39′13.99″	285
	6º30′40.39″	9º39′26.11″	285	6º31′6.06″	9º39′13.06″	279	6º30′30.41″	9º39′16.43″	267
	6º30′46.24″	9º39′20.11″	279	6º30′31.43″	9º39′11.97″	276	6º30′50.57″	9º39′10.84″	276
	6º30′48.42″	9º39′17.09″	279	6º30′40.1″	9º39′9.31″	273	6º31′6.48″	9º39′2.69″	289
	6º30′42.16″	9º39′9.10″	275	6º31′6.45″	9º39′2.41″	292	6º31′11.02″	9º38′59.8″	289
Maikunkele	6º29′1.14″	9º41′11.59″	292	6º28′59.84″	9º41′14.36″	299	6º29′1.14″	9º41′11.59″	292
	6º29′0.32″	9º41′14.59″	298	6º28′59.24″	9º41′14.64″	300	6º29′ 0.32″	9º41′14.59″	298
	6º29′2.32″	9º41′18.80″	303	6º29′3.39″	9º41′17.4″	300	6º 29′ 2.32″	9º41′18.8″	303
	6º29′1.02″	9º41′23.45″	302	6º29′3.79″	9º41′21.82″	296	6º 29′ 1.02″	9º41′23.45″	302
	6º29′1.14″	9º41′11.59″	292	6º29′4.28″	9º41′23.76″	304	6º 29′ 1.14″	9º41′11.59″	292
Chanchaga	6º34′49.6″	9º33′59.11″	243	6º34′40.61″	9º34′40.61″	243	6º34′44.69″	9º34′6.02″	240
	6º34′55.94″	9º 34′0.64″	236	6º34′44.54″	9º34′6.71″	241	6º34′51.78″	9º33′58.55″	238
	6º34′53.17″	9º 34′9.39″	241	6º34′46.33″	9º34′1.73″	239	6º34′50.44″	9º33′58.11″	239
	6º34′35.65″	9º34′12.33″	244	6º34′56.14″	9º33′58.58″	235	6º34′56.61″	9º33′58.66″	230
	6º34′36.03″	9º34′13.39″	246	6º34′46.02″	9º34′1.95″	244	6º34′50.88″	9º33′57.77″	242
Gidan Kwano	6º28′7.98″	9º32′25.93″	228	6º28′11.2″	9º32′24.34″	223	6º 28′ 10.46″	9º32′24.44″	224
	6º28′10.61″	9º32′24.58″	228	6º28′12.6″	9º32′24.1″	217	6º28′10.3″	9º32′23.62″	223
	6º28′11.69″	9º32′22.72″	226	0222226	1055742	226	6º28′10.45″	9º32′23.23″	223
	6º28′13.62″	9º32′19.64″	214	0222234	1055740	226	6º28′11.57″	9º32′22.34″	221
	0222227	1055721	228	0222210	1055742	228	0222239	1055746	228

X = Longitude (ºE), Y = Latitude (ºN), Z = Elevation (m)

Table 1b: Coordinates of Selected Habitats (Large Water Bodies and Drainages)

Location	Large Water Bodies			Drainages		
	X	Y	Z	X	Y	Z
Bosso	6º30′36.53″	9º39′47.48″	294	6º30′41.82″	9º39′7.53″	273
	6º30′48.19″	9º39′17.65″	294	6º30′38.76″	9º39′9.1″	277
	6º30′39.23″	9º39′9.38″	284	6º30′51.52″	9º39′11.02″	278
	6º31′41.51″	9º38′32.02″	263	6º31′39.56″	9º38′36.13″	261
				6º30′41.82″	9º39′7.53″	273
Maikunkele	6º29′1.41″	9º41′11.59″	291	6º28′53.16″	9º40′58.48″	234
	6º29′0.85″	9º41′15.57″	296	6º29′4.2″	9º41′21.74″	300
	6º29′0.71″	9º41′23.15″	299	6º28′54.55″	9º40′58.53″	295
	6º29′19.85″	9º40′47.84″	290	6º28′56.06″	9º 41′ 2.46″	295
				6º 29′ 3.58″	9º41′17.59″	300
Chanchaga	6º34′55.78″	9º33′58.6″	231	6º34′44.38″	9º34′7.1″	245
	6º34′52.54″	9º34′9.1″	244	6º34′43.96″	9º34′8.98″	253
	6º34′36.05″	9º34′14.66″	246	6º34′24.06″	9º34′14.36″	252
				6º34′23.06″	9º34′16.04″	247
				6º34′13.31″	9º32′24.44″	224
Gidan Kwano	0222325	1055400	217	6º28′7.93″	9º32′24.67″	232
	0222042	1055438	224	6º28′11.92″	9º32′22.7″	222
				6º28′8.98″	9º32′26.89″	232
				0222290	1055476	220
				0222049	1055442	223

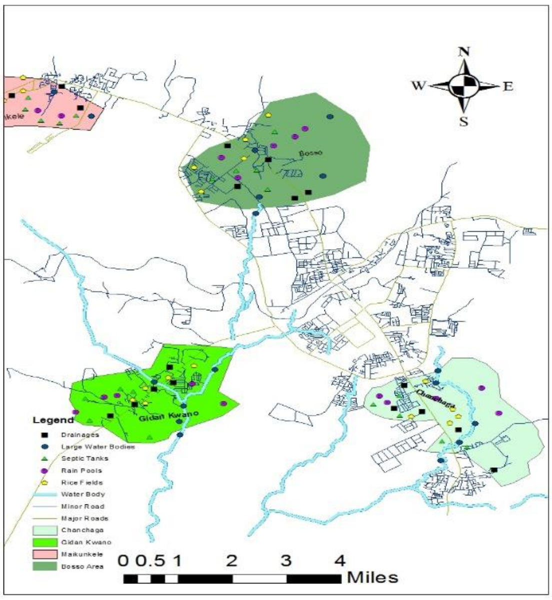

Figure 1. Map of Study Area (Minna) showing the Sampling Stations (Maikunkele, Bosso, Gidan Kwano and Chanchaga)

Collection, preservation and identification of mosquito species

Dipping Method as described by Olayemi and Ande (2009) was employed in collecting mosquito larval species. Briefly, a 350 ml dipper was used for sampling and collection (20 dips per habitat). It was lowered gently at about angle of about 45^{o} to minimize disruption of the water surface and gently lowered to cause the water and nearby larvae to flow into the dipper. Care was taken not to spill water when raising the dipper from the water. Larvae collected with the dipper were transferred to a well-labelled bottle with information on site, habitat type, time of collection, and date of collection. The larvae collected were transported to the Entomological laboratory of the Department of Animal Biology, Federal University of Technology, Minna, for identification and further analyses. Specimens were preserved in 4% formaldehyde solution and identified under a light microscope using the keys of Hopkins (1952).

Productivity of *Culex* mosquito larval habitats

The productivity indices of *Culex* breeding habitat were estimated according to the methods of Ribeiro *et al.* (1980) as reported by Jacob and Joao (2012). The following indices were adopted:

***Mosquito Breeding Index (MBI)*:** The MBI estimates the number of mosquito that breed in a locality. This was obtained by dividing the total number of immature mosquitoes (larvae and pupae) collected by the total number of dips performed. Value obtained is divided by the number of mosquito breeding sites sampled in the locality. Mathematically, it is expressed as:

$$\text{Breeding Index} = \frac{\text{TLP}}{\text{ND}} \times \text{NB}$$

Where, TLP = total number of larvae and pupae collected

ND = total number of dips performed

NB = Number of mosquito breeding sites sampled

General breeding index (GBI): The GBI is a ratio of number of breeding sites with immature (larvae and pupae) and the total number of breeding sites sampled. It, therefore, estimates the proportion of water bodies used for breeding by mosquitoes in a locality. It is expressed mathematically as:

$$General\ Breeding\ Index = \frac{NBWI}{NB}$$

Where, NBWI = Number of breeding sites with immature life stage

NB = Number of breeding sites surveyed.

***Absolute Breeding Index (ABI)**:* This is a species-specific index, and represents the relative proportion of breeding sites occupied by a given vector species in a locality. It is a ratio of the number of breeding sites positive for that species and the total number of breeding sites surveyed, and mathematically expressed as:

$$Absolute\ Breeding\ Index = \frac{NBP}{NB}$$

Where, NBP = Number of breeding sites positive for the species

NB = Total number of breeding sites surveyed.

Relative breeding index (RBI): This is also a species-specific index that indicates the abundance of the breeding sites of a given species in relation to the number of water bodies where mosquitoes are found in a locality. It is a ratio of the number of breeding sites positive for a species and the total number of breeding sites positive for mosquitoes in the locality. It is expressed, mathematically, as

$$Relative\ Breeding\ Index = \frac{NBP}{TNBP}$$

Where, NBP = Number of breeding sites positive the species

TNBP = Total number of breeding sites positive for mosquitoes.

Larval age structure distribution of *Culex* species

The age structure distribution involved categorisation of collected *Culex* mosquitoes into early (first, LI, and second, LII) and late larval instars (LIII and LIV). Relative abundance of larval age groups for each species collected was expressed as a simple percentage of total species collected.

$$\text{Species Relative Abundance} = \frac{x}{y} \times 100$$

Where, x = number of larval age group of a species

y = Total number of larvae of the species collected.

Shannon-Wienner diversity index (*H*) was estimated mathematically as:

$$H = -P_i \, In P_i$$

Where, P_i = proportion of a species relative to the total number of species encountered. The resulting product was summed across species and multiplied by -1.

Simpson's dominance Index (*C*), was estimated mathematically as:

$$C = \Sigma \left(\frac{ni}{N}\right)_2$$

Where n_i = number of individual species

N = total numbers of individuals; and

Σ = summation

Culex species diversity and dominance indices

Larval Species diversity and dominance indices of mosquito larval species were determined using Shannon-Wienner diversity index (*H*), and Simpson's dominance index (*C*), respectively.

Data Analyses

Data collected were subjected to statistical analyses, using SPSS computer software for Windows, version 16.0, (Install Shield Corporation, Inc.). The mean values of parameters studied for the different larval habitat were compared for statistical significance using ANOVA, at p=0.05 level of significance. Duncan Multiple Range Test (DMRT) was used to separate statistical significant mean values. Canonical Correspondence Analysis (CCA) was employed to determine the relationship between the larval instars and physico-chemical factors measured in the habitats.

RESULTS

Mosquito (MBI) and general breeding (GBI) indices

Analyses showed variation of these indices for the sampling locations in Minna. Chanchaga and Maikunkele had the highest MBI and GBI values, respectively. On the other hand, Maikunkele and Bosso had the lowest values. For Minna as a study area, mean values of 560.56 and 0.68 were obtained for MBI and GBI, respectively (Table 2).

Table 2: Mosquito and general breeding indices of *Culex* mosquitoes in Minna

Location	Indices	
	Mosquito Breeding Index	General Breeding Index
Bosso	628.13	0.66
Chanchaga	633.44	0.68
Maikunkele	457.19	0.72
Gidan Kwano	523.50	0.67
Mean (Minna)	560.56	0.68

Absolute (ABI) and relative (RBI) breeding indices of *Culex* mosquito species

Analyses showed variation of these indices among the five (5) *Cx.* species encountered (*Cx. quinquefasciatus, Cx. nigripalpus, Cx. salinarius*, *Cx. tarsalis* and *Cx. tarsalis*) in the study locations in Minna. *Culex quinquefasciatus* had the highest ABI and RBI values in the sampling locations; this is closely followed by *Cx. salinarius*. On the other hand, *Cx. nigripalpus* had the lowest mean ABI and RBI among all the species in all stations (Table 3).

Table 3: Absolute and relative breeding indices of *Culex* mosquito species in Minna

Parameter	Species	Sampling Station Bosso	Gidan Kwano	Chanchaga	Maikunkele	Mean (Minna)
	Cx. quinquefasciatus	0.80	0.80	0.80	0.80	0.80
Absolute	*Cx. salinarius*	0.76	0.72	0.80	0.80	0.77
Breeding	*Cx. tarsalis*	0.68	0.76	0.72	0.48	0.66
Index	*Cx. restuans*	0.56	0.52	0.68	0.68	0.61
	Cx. nigripalpus	0.52	0.60	0.60	0.60	0.58
	Cx. quinquefasciatus	1.00	1.00	1.00	1.00	1.00
Relative	*Cx. salinarius*	0.95	0.90	1.00	1.00	0.96
Breeding	*Cx. tarsalis*	0.85	0.95	0.90	0.60	0.83
Index	*Cx. restuans*	0.70	0.65	0.85	0.85	0.76
	Cx. nigripalpus	0.65	0.75	0.75	0.75	0.73

Age structure distribution of *Culex* mosquitoes in conventional breeding habitats in Minna

Among the life stages encountered, late life stages comprising of third (LIII) and fourth (LIV) instars were the most encountered. While early life stages (LI and LII instars) were the least encountered (Table 4). Also, among all larval instars, *Culex quinquefasciatus,* was, consistently, the most encountered *Culex* mosquito species, followed, consistently, by *Cx. salinarius,* while *Cx. restuans* and *Cx. nigripalpus,* were the least encountered species as LI and LII and *Cx. tarsalis,* was the least encountered as LIII and LIV (Figure 1).

Table 4: Relative abundance of age structure distribution of *Culex* mosquito species in Minna, Nigeria

Life Stage (Larvae/ dip) Early: LI	Early: LII	Late: LIII	Late: LIV
3.44±4.64^{a*}	22.13±13.79^{b}	56.56±23.07^{c}	67.17±22.83^{d}
[2.30]**	[14.81]	[37.84]	[44.94]

LI-LIV= First to fourth larval instars.

*Values followed by same superscript alphabet in a row are not significantly different at P<0.05 according to Duncan Multiple Range Test (DMRT) following Analysis of Variance (ANOVA).

Values in **[ ]** represents percentage composition of a species among the larval instar.

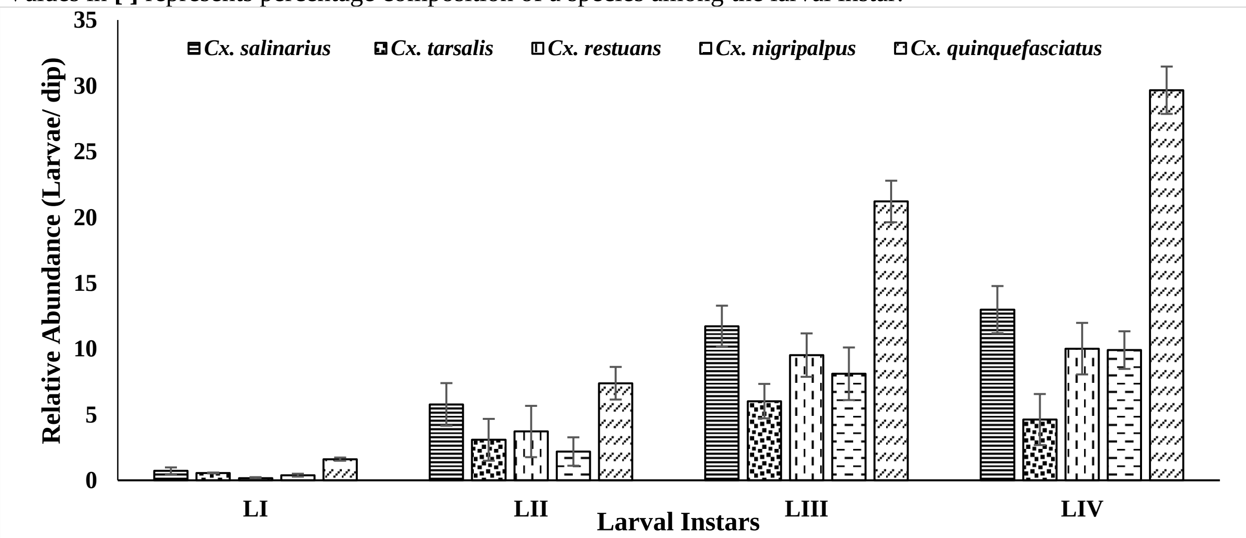

Figure 1: Age Structure Distribution of *Culex* Mosquito Species in Minna, Nigeria

Canonical correspondence analyses for mosquito species' age structure distribution and physico-chemical parameters

The relationship between the mosquito life instars and physico-chemical factors in conventional mosquito breeding habitats in Minna are shown in Figures 2a and b. Among the physico-chemical factors, hydrogen ion concentration (pH) changed the most, followed by Temperature and Alkalinity (Figure 2a). The result also showed that Alkalinity, Electrical Conductivity, and Total Dissolved Solid were positively correlated, while temperature and pH were negatively correlated. Similarly, Nitrate contents and Dissolved Oxygen fluctuated most among the habitats, while all factors (DO, BOD, COD, Phosphate and Nitrate Contents) were negatively correlated (Figure 2b).

Also, the presence of late and early life stages of *Cx. quinquefasciatus* were strongly influenced by Alkalinity, Electrical Conductivity, and Total Dissolved Solid. While, the early stages of *Cx. nigripalpus* and *Cx. salinarius* were mostly influenced by temperature (Figure 2a). However, the presence of early stages of *Cx. quinquefasciatus,* and late stages of *Cx. salinarius* were mostly influenced by DO, while the late stages of *Cx. quinquefasciatus* was mostly influenced by BOD (Figure 2b).

***Culex* mosquito species diversity (*H*) and dominance (*C*) indices in Minna**

Analyses revealed variations in *H* and *C* indices for the *Culex* mosquito population encountered in Minna, Nigeria. *Culex* mosquito species encountered in Minna had mean *H* and *C* values of 0.6011 and 0.2941, respectively largely contributed by *Cx. quinquefasciatus* and *Cx. salinarius. Culex quinquefasciatus* had the highest mean *H* and *C* values among the species encountered in the study area, this is, closely, followed by *Cx. salinarius,* while *Cx. tarsalis* had the least of the values (Tables 5 and 6).

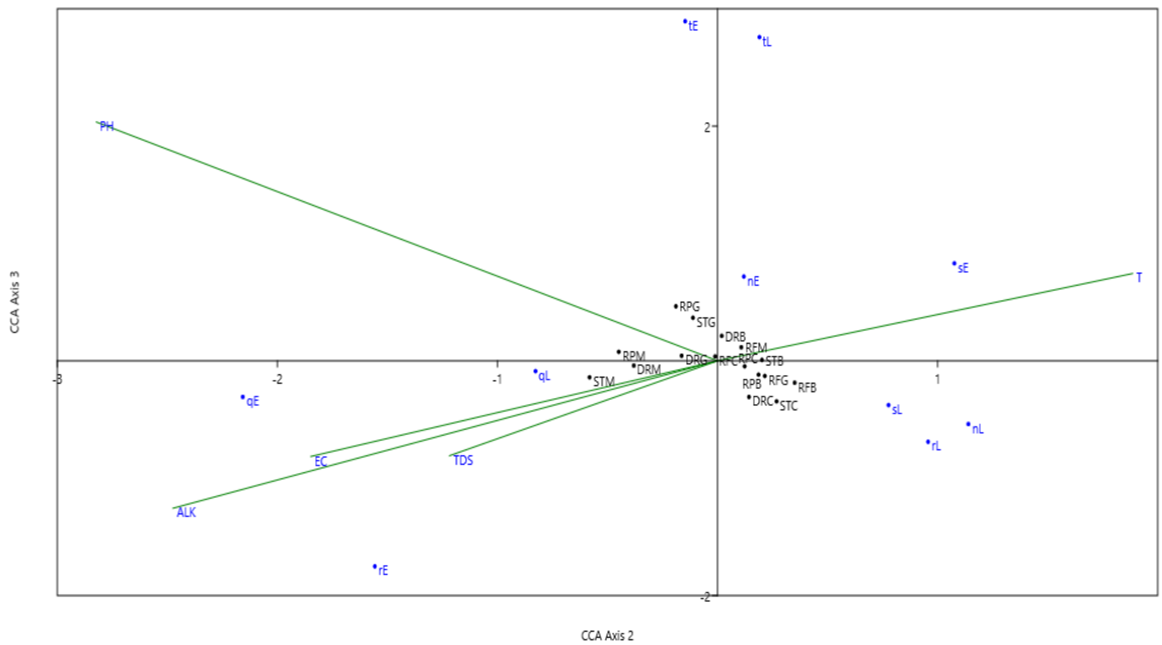

Figure 2a. Correspondence Canonical Analysis (CCA) biplots for mosquito species larval stages and physico-chemical factors measured in conventional mosquito breeding habitats in Minna. n = 80. For each axis, the amount of variation explained by each axis is shown. Arrows indicate the direction and relative importance of the environmental factors; Habitats (STM–Septic Tanks in Maikunkele, RFM–Rice Fields in Maikunkele, RPM-Rain Pools in Maikunkele, DRM–Drainages in Maikunkele, STC–Septic Tanks in Chanchaga, RFC–Rice Fields in Chanchaga, RPC-Rain Pools in Chanchaga, DRC–Drainages in Chanchaga, STB–Septic Tanks in Bosso, RFB–Rice Fields in Bosso, RPB-Rain Pools in Bosso, DRB–Drainages in Bosso, STG–Septic Tanks in Gidan Kwano, RFG–Rice Fields in Gidan Kwano, RPG-Rain Pools in Gidan Kwano, DRG–Drainages in Gidan Kwano). (n –*Culex nigripalpus,* q –*Cx. quinquefasciatus,* s –*Cx. salinarius,* t –*Cx. tarsalis,* r. -*Cx. restuans*); (E- Early Instar, L- Late Instar). Environmental Factors (T- Temperature, PH- pH, TDS-Total Dissolved Solid, EC-Electrical Conductivity, ALK-Alkalinity, PHO- Phosphate, NIT- Nitrate, BOD-Biological Oxygen Demand, COD-Chemical Oxygen Demand, DO-Dissolved Oxygen).

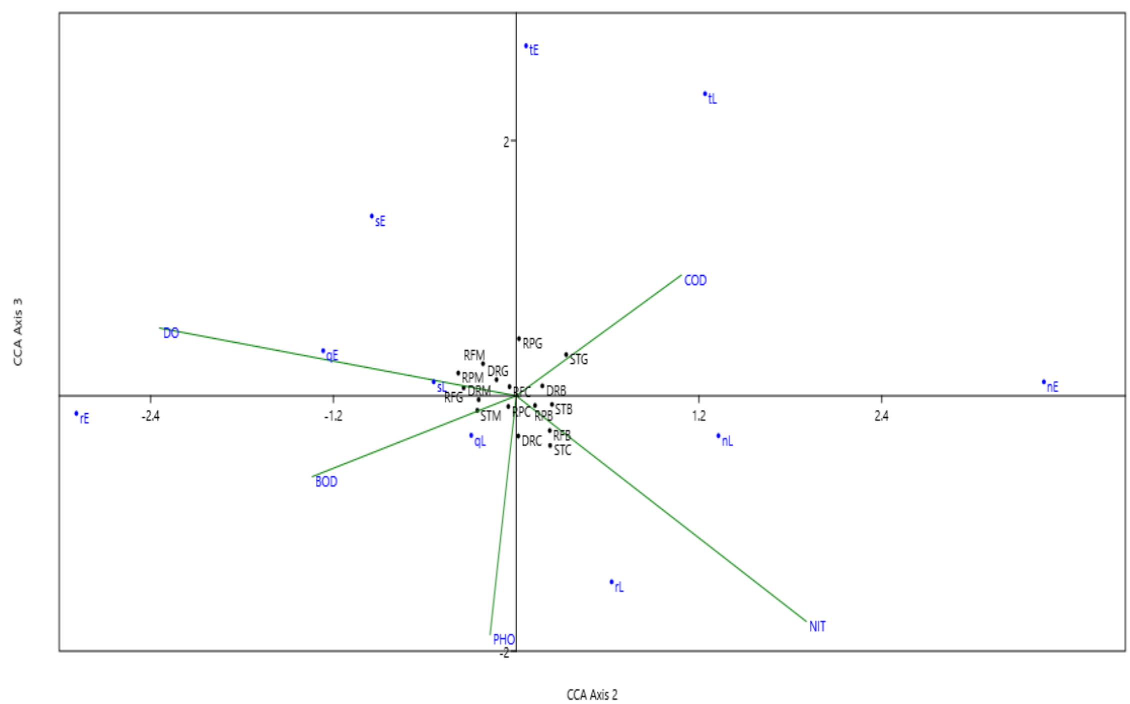

Figure 2b. Correspondence Canonical Analysis (CCA) biplots for mosquito species larval stages and physico-chemical factors measured in conventional mosquito breeding habitats in Minna. n = 80. For each axis, the amount of variation explained by each axis is shown. Arrows indicate the direction and relative importance of the environmental factors; Habitats (STM–Septic Tanks in Maikunkele, RFM–Rice Fields in Maikunkele, RPM-Rain Pools in Maikunkele, DRM–Drainages in Maikunkele, STC–Septic Tanks in Chanchaga, RFC–Rice Fields in Chanchaga, RPC-Rain Pools in Chanchaga, DRC–Drainages in Chanchaga, STB–Septic Tanks in Bosso, RFB–Rice Fields in Bosso, RPB-Rain Pools in Bosso, DRB–Drainages in Bosso, STG–Septic Tanks in Gidan Kwano, RFG–Rice Fields in Gidan Kwano, RPG-Rain Pools in Gidan Kwano, DRG–Drainages in Gidan Kwano). (n –*Culex nigripalpus,* q –*Cx. quinquefasciatus,* s –*Cx. salinarius,* t –*Cx. tarsalis,* r. -*Cx. restuans*); (E- Early Instar, L- Late Instar). Environmental Factors (T- Temperature, PH- pH, TDS-Total Dissolved Solid, EC-Electrical Conductivity, ALK-Alkalinity, PHO- Phosphate, NIT- Nitrate, BOD-Biological Oxygen Demand, COD-Chemical Oxygen Demand, DO-Dissolved Oxygen).

Table 5. Larval Species Diversity (*H*) of *Culex* Mosquito Populations in Productive Habitats in Minna

***Culex* Species**	**Habitat**				**Mean (Minna)**
	Rice Fields	**Rain Pools**	**Septic Tanks**	**Drainage**	
Cx. salinarius	0.1539	0.1432	0.1147	0.1293	0.1353
Cx. tarsalis	0.0902	0.1020	0.0709	0.0906	0.0884
Cx. restuans	0.1285	0.1068	0.0969	0.1335	0.1164
Cx. nigripalpus	0.1009	0.0914	0.1367	0.1076	0.1092
Cx. quinquefasciatus	0.1532	0.1529	0.1464	0.1549	0.1518
Total	0.6267	0.5962	0.5656	0.6160	0.6011

Table 6. Larval Species Dominance (*C*) Indices of *Culex* Mosquito Populations in Productive Habitats Minna

Culex Species	Habitat: Rice Fields	Rain Pools	Septic Tanks	Drainage	Mean (Minna)
Cx. salinarius	0.1067	0.0498	0.0260	0.0285	0.0528
Cx. tarsalis	0.0083	0.0187	0.0106	0.0127	0.0126
Cx. restuans	0.0336	0.0248	0.0197	0.0332	0.0279
Cx. nigripalpus	0.0159	0.0172	0.0429	0.0165	0.0231
Cx. quinquefasciatus	0.1018	0.1875	0.2289	0.1928	0.1777
Total	0.2662	0.2981	0.3281	0.2838	0.2941

Discussion

Mosquito and general breeding indices of mosquitoes in Minna

The present study revealed spatial variations in these indices among the study locations. Bosso and Chanchaga had relatively higher MBI, while Maikunkele had the lowest values. This implies that more mosquitoes bred in Bosso and Chanchaga, than Maikunkele and Gidan Kwano. This is not surprising, as Bosso and Chanchaga are more populated, having higher anthropogenic activities which creates habitats for mosquito breeding. More so, these habitats are often laden with organic matters, which supports development of mosquitoes. Interestingly, Maikunkele – a less populated area – had the highest GBI than other study locations, while, Bosso – a more populated area, with higher human activities – had the lowest GBI. Higher GBI value for Maikunkele implies that the settlement had more proportion of water bodies that mosquitoes use for breeding than other study location, and may indicate suitability of these habitats for mosquito breeding.

The study also revealed that, although, less mosquitoes bred in Maikunkele during the study period, more of its habitat were utilized by mosquito for breeding. This information is important for the implementation of site-specific mosquito control strategies in the study area, as control of mosquitoes is usually site-specific.

Absolute and relative breeding indices of mosquitoes in Minna

The present study revealed that the *Culex* species populations encountered in Minna, had variable ABI and RBI. *Culex quinquefasciatus* mosquito species bred more than other species encountered in the study area; this species was closely followed by *Cx. salinarius.* The versatility of these two species among the larval habitats could have been either due to specialised adaptation strategies within the habitats or due to the habitat types sampled. Bataille *et al.* (2009) had reported ubiquitous nature of these species and their disease transmission potentials. This information presents serious epidemiologically threat to the inhabitants of the sampling stations and study area, in general, as urban transmission of lymphatic filariasis is sustained by these species. Unfortunately, this disease has been reported as endemic in the study area (Adamu *et al.* (2020) possibly, sustained by these species. *Culex nigripalpus* had the lowest values for ABI and RBI and may suggest poorly adaptation of the species to the sampled habitats or, probably, habitat of choice of the species were not sampled during the present study. It is therefore recommended that an elaborate study on all available larval habitat type in the study area be carried out to ascertain the true breeding status of this species.

There are, presently, no documented records of these breeding indices (i.e., ABI and RBI) in the study area or elsewhere in Nigeria. However, the ABI and RBI values obtained for the sampling stations in this study were higher than those reported by Sia-Su *et al.* (2016) in Laguna, Philippines. These differences could be attributed to the higher number of habitat types sampled and the higher numbers of species encountered in the present study.

The study also revealed spatial variation in the ABI and RBI in the area. In all study locations, *Cx. quinquefasciatus* was the most established mosquito species. In Bosso and Gidan Kwano, *Cx. nigripalpus* and *Cx. tarsalis*, were, respectively, the least established. Whereas, in Chanchaga and Maikunkele, *Cx. restuans* was the least established. The present study has shown that the *Cx.* mosquito species encountered in Minna during the study period, exhibited varying biology, and adaptability to habitats. This information is key for selection of site-specific intervention protocols for reducing vector species' populations in the study area.

Age structure distribution of *Culex* mosquitoes in conventional breeding habitats in Minna

In the present study, all larval instars of the five *Cx.* mosquitoes encountered were present in the productive larval habitats sampled in Minna. The late larval instars (LIII and LIV) were most preponderant, accounting for over 80% of all instars encountered; while the early larval instars (LI and LII) were lower in number. Preponderance of late larval mosquito instars suggests suitability of the sampled habitats for mosquito development, and, hence, higher maternal reproductive success of the species in the area. The presence of early larval instars in all sampled habitats indicates high attractiveness of these habitats to the gravid females of these species.

Further, presence of all life stages in sampled habitats suggests general suitability of the sampled habitats to these life stages of the species. Among the larval instars, the species with the least distribution of early instars was *Cx. nigripalpus,* while *Cx. quinquefasciatus* had the highest for both sets of instars. This may probably indicate lesser adaptability of *Cx. nigripalpus* and greater adaptability of *Cx. quinquefasciatus* to the habitats than other species as revealed its breeding indices.

The presence of all life stages of the mosquito species is not surprising, as earlier studies have shown these species breed well in the habitat types sampled (Reiskind and Wilson, 2004). It could also stem out of the attractiveness of the habitats to gravid females and/ or suitability of the habitats to the survival of the immature forms (Grech *et al*., 2013).

The epidemiological importance of these findings on age structure of *Culex* mosquitoes in Minna is that the breeding habitats are suited for the development of the various species encountered; evident from the preponderance of the late larval stages. Further, the very high density of *Cx. quinquefasciatus* showed a greater adaptability of the species to the eco-conditions of the study area. This information is important bearing in mind the vectorial capability of this species in the spread of lymphatic filariasis (Kain *et al.,* 2021).

***Culex* mosquito population diversity indices in Minna**

In the present study, *Cx. quinquefasciatus* had the highest values for Shannon-wiener diversity, *H*, and Simpson's dominance, *C*, indices, while *Cx. tarsalis* had the least values of these indices. The value obtained in this study for the dominant species (*Cx. quinquefasciatus*) was higher than that reported by Oguoma and Ikpeze (2008) for *An. gambiae* (the reported dominant species). In their study, Olayemi *et al.* (2014), reported lower *H* and *C* values for the most (*Cx. pipiens*) and least (*Cx. nigripalpus*) dominant *Cx.* species in the same study area.

Olayemi *et al.* (2014) had reported higher *H* and *C* values for the study area (Minna). Similarly, Oguoma and Ikpeze (2008) also reported higher *H* values in Gezawa, Kano (North- Western Nigeria). The *H* value reported in this study were, however, higher than those reported by Oguoma *et al.* (2010) for *Anopheles* mosquitoes in three villages in Owerri North, Imo State (South-Eastern Nigeria). The *C* values recorded in this study were, however, higher than those reported by the Oguoma and Ikpeze (2008), but lower than those reported by Olayemi *et al.* (2014) for the study area and Oguoma *et al.* (2010) in three villages (Owalla, Owaelu and Umunahu) in Imo State, Nigeria.

Overall, Minna, Niger state, North-Central Nigeria is rich in the diversity of *Culex* mosquitoes, some of which have been incriminated as major vector of diseases of public importance in the stage, Nigeria and other regions of the world. Further, with the economic role played by the city in rice production, there is thus, an urgent need for massive larval source management or development of protocols that will reduce vector species' proliferation. This is to forestall future outbreak of disease in the study area as importation, introduction and reintroduction of disease pathogens into the population is inevitable.

Conclusion

The study revealed differences in breeding indices in the study area. *Culex quinquefasciatus* was the relatively most established mosquito species in the study area, with site-specific variation in least established species. The *Cx.* mosquito species encountered in during the study period, exhibited varying biology, and adaptability to habitats. There were site-specific variations in breeding indices. The habitats were highly suitable for development of the *Cx.* species as mostly late life larval instars were encountered. Finally, there were habitat- and site-specific variation in diversity indices measured for the study area. The information generated in the present study is important for development and effective implementation of vector control interventions, which should be habitat- and site-specific.

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Conflict of Interest

The authors declare that they have no competing interests

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