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S. O. ADOKA, G. DIDA, D. N. ANYONA, A. S. MATANO, D. A. OTHERO and C. K. KANANGIRE

ABSTRACT

***Background*: Infections with mosquito-borne parasites are common in human populations inhabiting tropical regions of the world. Malaria is endemic along Kenyan Lake Victoria basin and its vectors are fresh water breeders. However, much less is known about the current spatial distribution and habitat characterisation of mosquitoes including vectors of malaria in the lake waters and adjacent terrestrial aquatic habitats.**

***Objectives*: To characterise mosquito larval habitats and to determine the spatial distribution of mosquito species in lake and land habitats, measure aquatic habitats' (water) physic-chemical parameters, enumerate the number of phytoplankton, zooplankton and fish species and determine their effects on the abundance of mosquitoes. This could allow larval control to be more effectively targeted at specific sites which in its turn could reduce malaria transmission in the area.**

***Design*: Cross-sectional study.**

***Setting*: The Kenyan Lake Victoria Basin.**

***Results*: There was heterogeneity in the relative abundance of *Anopheles* and *Culex* species in the aquatic habitats that were associated with land and lake. Although *Culex* species of mosquitoes were absent in different locations that were associated with the lake, they were abundant in different aquatic habitats in different locations on land. More *Anopheles* mosquitoes were found in quary and shoreline swamp puddles, flood plain, and stream edge puddles than natural swamps, rivers and permanent ponds habitats, P<0.001. There was no significant correlation between the abundance of *Anopheles* and physico-chemical parameters (Pearsons correlation, p>0.05). Also, there was no significant correlation of abundance *Anopheles spp.* mosquitoes and phytoplanktons, (P>0.05). However, a significant correlation was observed between phytoplankton and Dinoflagellates on land, P=0.014. *Clarias gariepinus* were more insectivorous compared to *Oreochromis niloticus*, which mostly fed on zooplankton and food remains. The most abundant mosquitoes in the lake were *Mansonia* followed by *Aedes* and *Anopheles* species, respectively.**

***Conclusion*: *Anopheles* species of mosquitoes breed in habitats associated with lake, although they are absent in deep permanent lake waters, even if it was heavily infested aquatic weeds. Similarly, they breed in temporary or seasonal aquatic land habitats adjacent such as open water pools, puddles and swamps, more so when infested by invasive aquatic weeds and other short vegetation. We recommend that, focus of malaria vector control should concentrate both on land and lake associated habitats. Health education and awareness programmes should be scaled up to inform the local communities on mosquito species ecology in relation to transmission of malaria and other mosquito- borne diseases. There is need to introduce certain local fish species (such as *Clarias gariepinus*) and other predators for biological control of mosquitoes breeding in the aquatic habitats near human habitation.**

INTRODUCTION

The prevalence of malaria in the western Kenya region is estimated at 16% (1), though clusters with prevalence rates as high as 50% do occur during the high transmission rainy seasons, when more mosquitoes breed in aquatic habitats (2). Therefore, mosquito larval habitat location and ecology is important in determining larval densities and species assemblage which in turn will influence malaria transmission in an area (3). Most observations of the larval habitats of *An. gambiae* s.l. the most important malaria vector in western Kenya region have a preference for temporary, sunlit pools (4), whereas *An. arabiensis* appears to exploit permanent, artificial habitats such as rice fields (5) and garden wells (6).

Breeding of mosquitoes in the aquatic habitats can be influenced by abiotic and biotic factors (7), some of which are dependent on certain locations. Habitat location is important because it can be influenced by local factors such as weather conditions (rainfall patterns, temperature), and even physio-chemical parameters such as pH, alkalinity, turbidity among others which will depend on adjacent land use and land degradation patterns (e.g. soil erosion, chemical pollutants) and soil or geological conditions. Species assemblages and abundance in specific locations can also be influenced by historical factors and population dynamics such as previous colonisation or non colonisation of the location or area by the particular species and how population increase or decrease depending on local environmental pressures. This can also be true for differential abundance of mosquito species in different locations. (6-8)

Several reports point out that aquatic weeds are associated with increase in abundance of mosquitoes. As an example from Africa, in Volta Lake in Ghana, West Africa, *Pistia* was found to harbour many mosquito larvae, among which *Aedomyia africana* dominated the fauna, followed by *Ficalbia splendens* and *Mansonia africana*. *Anopheles funestus*, a malaria vector, and *Aedomyia africana*, a vector of yellow fever, encephalitis and filariasis, were found commonly associated with *Pistia* in Volta Lake (9). Water hyacinth in Malaysia, where this plant is widespread, has been observed to harbour insect vectors of filariasis, e.g. *Mansonia uniformis, M. Indiana* and *M. annulifera*. Orr and Resh (10) investigated the influence of *Myriophyllum aquaticum* cover on *Anopheles* mosquito abundance, oviposition, and larval microhabitat and found that *Anopheles* larvae preferred patches with high stem densities over patches with few or no plant stems; and this preference correlated with differences in habitat quality such as increased refuge from predation and enriched food sources (8). The optimal habitat for anopheline mosquitoes apparently occurred above a threshold plant density of approximately 500 *Myriophyllum* stems m-2, and habitat heterogeneity produced by variability in the distribution and structure of aquatic vegetation strongly influenced the local distribution and abundance of anopheline mosquitoes (6).

Earlier studies on macrophyte-vector associations have, however, been contradictory. According to Pope (11), *Typha domingensis* marsh and flooded forest are habitats of immature *Anopheles vestitipennis*, and one, *Eleocharis* spp. marsh, is the habitat for immature *Anopheles albimanus*. In Cameroon, Kengne (12) found out that although macrophyte-based wastewater treatment systems dominated by *P. stratiotes* permitted the fixation of a great number of larvae to the macrophyte roots, only 0.02% of captured imagoes were *Anopheles gambiae*, suggesting that this wastewater macrophyte treatment system does not significantly contribute to the development of the malaria vectors.

The main abiotic factors that influence breeding habitats of mosquito larvae include water temperature, its chemical composition, water pH, depth and turbidity, while the biotic factors are mainly the predators, bacteria, fungi, and aquatic plants (7). Studies in Dakar, Senegal, showed that conditions that favoured *An. arabiensis* larvae in their breeding habitats were temperature greater than 27 ^{0}C, water depth of less than 40cm, high carbonate concentration, high water pH, and presence of water lettuce (6). In Asembo, Western Kenya, differences in habitats characteristics were observed in habitats with both *An. gambiae s.s.* and *An. arabiensis* compared to habitats with only one species (8). Similar results (6), found out that the occurrence and abundance of *An. arabiensis* larvae in permanent habitats (market-garden wells) in Dakar, Senegal, were determined by many physicochemical and biological variables. In Mbita point, western Kenya, water pH was shown not to determine the occurrence of anopheline mosquitoes (13). However, turbidity of water has been reported to have an effect on larval populations by influencing adult oviposition behaviour. Laboratory studies have further demonstrated that chemo-attractants from decaying organic matter may play a role in the oviposition behavior of gravid *An. gambiae* mosquitoes (15).

Phytoplanktons are free-floating organisms which are important in primary production within aquatic bodies. They are also food for zooplankton and other aquatic organisms. Cyanobacterial genera have been studied in various mosquito breeding sources (16). These photosynthetic prokaryotes are widely distributed in mosquito habitats and have been found in the guts of mosquito larvae. Cyanobacteria serve as food for mosquito larvae, (17). However, some algae can be toxic to mosquito larvae as previously reported (18).

Mosquito breeding in aquatic habitats is also largely influenced by the presence of predators (19).

These predators include larvivorous fish. Predation of larvae by larvivorous fish (19) and cannibalism among larvae (20) also influence the population dynamics of mosquito larvae and are factors that play a major role in population size (19). For example, in Ahero rice irrigation scheme, Kenya, Service (19) estimated larval mortality of *An. arabiensis* to be about 93% whereas in the Philippines and Thailand rice fields, it was estimated to be about 98% (20). Some of the larvivorours fish have shown potential as bio-control agents in rice fields (21).

Earlier studies (22) showed that *Oreochromis niloticus* and Haplochromines fish were more abundant in the water hyacinth mats compared to hippo grass and open water habitats. Also, there were more fingerlings of *O. niloticus* and Haplochromines within the water hyacinth mats compared to the same species within the hippo grass habitats and in the open waters showing that actually the aquatic mats in the lake waters were harboring abundant fish which can predate on the mosquito larvae. The larvivorous nature of *O. niloticus* is reported (23) where zooplankton and insects form the main food component in all the seasons (dry and short rainy). *Clarias gariepinus* fingerlings have also been reported to feed on insects including mosquito larvae / pupae (24) and act as biological control agents (25). This study was designed to determine the differential distribution of mosquito species in the lake and land locations in relation to abundance of phytoplankton and mosquitoes in aquatic habitats of western Kenya.

MATERIALS AND METHODS

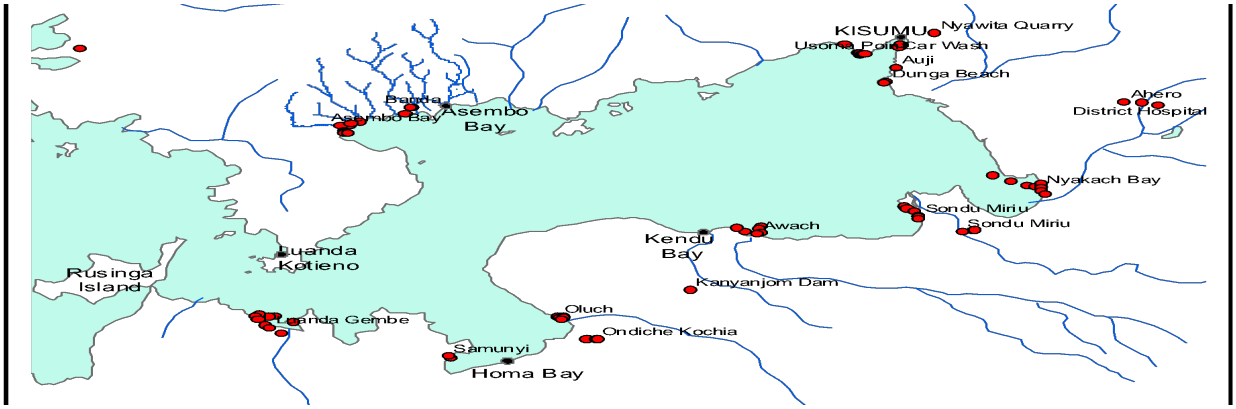
Study Locations and Habitats: Mosquito sampling was carried out from February to April, 2013 in locations and habitats within the Lake Victoria waters in the Nyanza gulf and the adjacent terrestrial areas within the basin (Figure 1). The area is situated between 24,350 and 34,551 E and latitudes 00, 02'N and 00, 11'S. The topography of the area is characterised by Hilly areas in the Southern and West and with a gentle slope towards Kano plains. The area has two main rainy seasons; the long rains from March to May and Short rains from October to December. Average annual rainfall is 1,200mm, and the minimum and maximum temperatures are 18^0C and 31^0C, respectively. The entire basin has a population of about 2,500,000 inhabitants (Kenya National Census, 2009).

Sampling and Determination of Mosquito Abundance: In the lake, sampling was done using boats. The locations were Asembo Bay, Homa Bay, Kendu Bay, Kisumu, Lwanda Gembe, Nyando Nyakach, Sondu Miriu and Usoma point. Habitat types in the lake were either in-shore or off-shore and were characterised into the following categories: hippo grass, open lake waters, hippo grass / water hyacinth (HG/WH), water hyacinth (WH), or Ambatch tree habitats. In-shore habitats were at the shoreline, and off-shore habitats were located about 500 metres away from the aquatic vegetation (macrophytes) or the shoreline. On land, sampling was done using 4-wheel vehicles and on foot. Sampling locations on land were: Ahero, Asembo, Auji, Dunga, Homa Bay, Kendu Bay, Kisumu, Luanda Gembe, Olambwe River, Osienala pond and Sondu Miriu.

Physical habitat types were broadly classified into ten categories: dams, stream edge puddles, natural swamp, permanent pond, shoreline swamp, temporary pond, quarry, river, flood plain, and roadside pond. Also on land, vegetation habitat types in the sampled locations were: hippo grass, hippo grass and other vegetation as non aquatic plants on land habitats were simply categorised as other vegetation since they were numerous and classifying them to species would have been a challenging task. Identification of the common aquatic plants was carried out by use of keys (27-28). In each location or habitat (whether physical or vegetation type), several sites were sampled to determine the mosquito species abundance, physico-chemical parameters and phytoplankton abundance.

A habitat was first inspected for the presence of mosquito larvae. When mosquito larvae were present, 20 dips were taken with a standard mosquito dipper (350ml). Mosquito larvae were then immediately preserved in 100% ethanol. In the laboratory at Maseno University, Department of Biomedical Science and Technology, all the larvae (3rd and 4^{th} instars) were examined microscopically, and anopheline larvae were further separated from Culicine larvae based on morphological characteristics (4). Adult mosquitoes were sampled using a battery- operated aspirator (CDC back pack aspirator model 1412). They were identified, then separated into anophelines and culicines and taken to the laboratory for confirmatory identification. The total number of mosquito species whether larvae or adults in their respective locations and habitats were counted and recorded in standard forms for the research.

Figure 1
Showing map of the Nyanza gulf showing areas sampled (shown in dots)



Determination of Phytoplankton Presence and Abundance: Samples for determination of phytoplankton were collected at the subsurface. The water samples (25 mls) were preserved in acidic Lugol's solution. A 1 ml phytoplankton sub-sample was placed in a rafter-cell chamber and left to settle. Representative numbers of strips were counted for algal abundance quantification. Phytoplankton species identification and enumeration was done using an inverted microscope at 400x magnification (Olympus Corporation, Tokyo, Japan). Phytoplankton taxa were identified using the methods of Huber – Pestalozzi (1968). Phytoplankton densities were estimated by counting all the individual Phytoplankton and whether the organisms were single celled, colonies or filaments. All data was then recorded in a standard form designed for the purpose.

Fish Sampling and Determination of Gut Contents: Fish sampling from the lake and land habitats was done by using an electro-fisher (Septa Operations, Philadelphia, USA). Electro-fishing activity was carried out using a Septa model unit which discharges voltages of up to 600 volts with accompanying Amperes of between 5 to 30 Amps. A pulsed mode of discharge was adapted for electrocution lasting 10 minutes at each attempt, and was repeated 10 times at each appropriate habitat site. Species identification for fish followed descriptions given (30) using morphometric and meristic characteristics. The gut contents of the fish was analysed to show which fish species could be suitable for biological control of mosquitoes.

The gut contents of fish was analysed following the methods of used by (31). The procedure entailed cutting open the fish and removal of stomach. The stomach was then preserved in 5% neutralised formalin for analysis. During analysis, a longitudinal cut was made across the stomach and contents transferred into a Petri dish. The contents were then kept for five minutes to remove excess formalin after which they were examined under Olympus binocular microscope. Identification of the gut contents was made and the number of food items in each stomach counted and expressed as a percentage of the gut content of each specimen examined, from which the total percentage composition was estimated. This was done to show which fish species could be suitable for biological control of mosquitoes.

Data Analysis and Presentation: Means of the data for the various sites for locations or habitats types were calculated for lake and land data analyses. To normalize the data for statistical analyses, the values were transformed using $\log_{10}$ plus 2 in Microsoft Excel. MSTAT-C software was used to calculate one way Analysis of Variance (ANOVA) – to show if there were variations between the locations, habitats, or vegetation types, and Bartetts test to determine departures from homogeneity of the values between the locations, habitats, or vegetation types. Pearsons correlations analysis was used to generate "r" values and determine linear relationships between the *Anopheles* abundance and physicochemical parameters (dissolved oxygen, pH, alkalinity, hardness, turbidity, conductivity, temperature and salinity), and abundance of phytoplankton. $P<0.05$ were considered statistically significant.

RESULTS

Differential Mosquitoes Abundance in Different locations in the lake: The analysis of data established that *Culex* species of mosquitoes were absent in the lake in different locations, Table 1. The most abundant mosquitoes in the lake were *Mansonia* followed by *Aedes*, then *Anopheles spp.* of mosquitoes. There was heterogeneity in the relative abundance of *Aedes*, *Anopheles* and *Mansonia* mosquitoes in the different locations in the lake waters, $p< 0.001$, Bartlett's test, Table 1.

Table 1
Mosquito species abundance in different locations associated with the lake

Locations (No. of sites)	Mean (±SD) No. of Mosquitoes Anopheles	Culex	Aedes	Mansonia
Asembo Bay (9)	0	0	0	10±8.2
Homa Bay (8)	1.3±1.4	0	0	2.6±4.1
Kendu Bay (7)	0	0	1±1.7	0.29±1.5
Kisumu (6)	0	0	0	6.67±10.6
Lwanda Gembe (8)	0.7±1.1	0	0	7.5±16.4
Nyando Nyakach (9)	0	0	0.76±2.3	1±1.8
Sondu Miriu (6)	0	0	1±2.8	0.33±1.2
Usoma point (6)	1.4±1.3	0	1.33±1.8	5.67±5.5
ANOVA	0.088	-	0.19	0.075
Bartlett's test	-	-	< 0.001	< 0.001

In contrast to the situation in the lake waters, *Anopheles* and *Culex spp*. of mosquitoes were abundant in the different aquatic habitats in different locations on land, while *Aedes and Mansonia* was absent, Table 2. There was heterogeneity in the relative abundance of *Anopheles* and *Culex spp* of mosquitoes in the aquatic habitats in different locations on land, $p < 0.0001$, Bartlett's test.

Table 2
Mosquito species' abundance in different locations on land

Location (No. of sites)	Mean (±SD) No. of Mosquitoes Anopheles ±SD	Culex ±SD	Aedes	Mansonia
Ahero (3)	12.3±11.2	11.7±12.6	0	0
Asembo (5)	11±14.3	8.8±17.5	0	0
Auji (3)	0	0	0	0
Dunga (5)	31±16.4	1±1.9	0	0
Homabay (4)	0	1.5±1.91	0	0
Kendubay (1)	0	0	0	0
Kisumu (3)	0.3±36.4	0.3±0.58	0	0
Luanda Gembe (3)	0	5±8.1	0	0
Olambwe river (1)	0	10	0	0
Osienala pond (1)	0	0	0	0
Sondu Miriu (4)	0	1±2.0	0	0
ANOVA	0.012	-	-	-
Bartlett's test	< 0.001	< 0.001	-	-

There were more *Anopheles* mosquitoes in quarry and shoreline swamps, floodplain and stream edge puddles compared to natural swamps, rivers and more permanent pond habitats. These differences were significant by Bartlett's test, $p < 0.001$. Table 3.

Table 3
Mosquitoes species abundance in different physical habitats on land

Habitats	Mean (±SD) No. of Mosquitoes Anopheles	Culex	Aedes	Mansonia
(No. of sites)				
Dam (5)	7.6±10.6	6±10.9	0	0
Stream edge puddles (10)	13±16.4	6±12.4	0	0
Natural Swamp (4)	5±10.0	4±7.0	0	0
Pond (2)	2±2.1	0	0	0
Shoreline swamp (2)	34±24.7	0	0	0
Temporary pond (5)	0	2±2.0	0	0
Quarry (2)	50±31.8	0	0	0
River (1)	0	10	0	0
Flood plain (1)	15	0	0	0
Roadside pond (1)	3	0	0	0
ANOVA	0.06	-	-	-
Bartlett's test	< 0.001	< 0.001	-	-

There were no *Culex spp*. of mosquitoes in the different vegetation habitats in the lake, though *Aedes and Mansonia* were abundant, Table 4. There was no difference in the relative abundance in the different habitats in the lake as shown by Bartlett's test, p =0.202, compared to relative abundance of *Aedes* mosquitoes, p< 0.001, Bartlett's test, Table 4.

Table 4
Mosquitoe species abundance in different vegetation and open water habitats associated with the lake

Habitats (No. of sites)	Mean (±SD) No. of Insects Anopheles	Culex	Aedes	Mansonia
Hippo grass (6)	0	0	1.02±2.4	6.2±8.0
Open water (26)	0	0	0.2±0.9	2.0±4.3
Hippo.G/Hycinth (14)	0.1±0.8	0	0.6±1.6	8.1±14.9
Water Hyacinth (10)	0	0	0.7±2.2	2.3±4.2
Ambatch zone (3)	2.9±0.7	0	0	11.3±9.9
ANOVA	-	-	-	0.144
Bartlett's test	-	-	< 0.001	0.202

Anopheles and *Culex* mosquitoes were uniformly abundant in different vegetation types on land, p >0.05, Bartlett's test, Table 5.

Table 5
Mosquito species abundance in different vegetation habitats on land

Vegetation (no. of sites)	Mean (±SD) No. of Insects Anopheles	Culex	Aedes	Mansonia
Hippo grass (4)	14.3±9.9	8.8±11.8	0	0
Hippo. G/Other veg. (7)	5±12.0	6±14.9	0	0
Water Hyacinth (2)	24±17.0	2±2.8	0	0
Hyacinth/Other veg (2)	33.5±24.7	0	0	0
Other vegetation (18)	9.6±19.2	2.1±3.9	0	0
ANOVA	0.2	-	-	-
Bartlett's test	0.9	0.18	-	-

Correlation of water Physico-chemical Parameters with Anopheles spp Abundance: All the physicochemical parameters analysed (DO, pH, alkalinity, hardness, turbidity, conductivity, temperature and salinity) varied between the locations on land, p<0.001, Bartlett's tests, Table 6.

Table 6
Variations of physico-chemical parameters in different locations on land

Location (No. of sites)	Mean (±SD) Values of the Physico-chemical Parameters Dissolved Oxygen (mg/l)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Turbidity (NTU)	Conduct (μS/cm)	Temp (^{0}C)	Salinity (mg/l)
Ahero (3)	2.7±0.1	8.5±0.2	162±11.1	147.3±4.2	15.2±7.8	503.3±188.2	25.1±0.6	0.2±0.1
Asembo (5)	6.37±0.8	7.26±0.5	117.6±97.8	206.4±267.7	53.34±35.5	124±33.0	26.3±1.9	0.16±0.36
Auji (3)	5.4±2.0	8.2±0.1	151.3±31.1	98.7±31.1	258.7±212.5	415.3±159.4	24.5±2.3	0.2±0.1
Dunga (5)	5±0.9	8±0.7	125±46.6	98±46.4	288±246.9	296±108.4	28±4.4	0
Homabay (4)	5.3±0.6	6.9±0.5	119±1.1	227.5±2.7	109.5±1,6	187±89.9	26.0±2.7	0.22±0.4
Kendubay (1)	5.64	7.67	46	44	55	207	29.4	0.1
Kisumu (3)	6.38±1.2	8.4±0.5	56.7±11.5	49.3±14.7	281.7±217.7	176.67±	24.4±	0.03±
Luanda Gembe (3)	1±0.7	7±1.5	307±300.2	64±55.6	±1027.	179±71.7	28±5.9	0
Olambwe river (1)	1.73	6.88	600	90	459.1	147	23.2	0.7
Osienala pond (1)	1.68	7.34	600	94	204.4	178	23.8	0.9
Sondu Mirie (4)	6±0.6	8±0.4	44±29.1	30±23.1	208±133.4	104±16.9	28±2.2	0
ANOVA	< 0.001	0.05	0.001	-	0.32	0.002	-	0.13
Bartlett's test	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

There were no significant correlation between abundance of *Anopheles* mosquitoes and hardness, alkalinity, temperature, conductivity, salinity, dissolved oxygen and pH on land, p>0.05, Pearsons correlation.

Correlation of Phytoplankton Presence and Abundance Anopheles spp: Abundance of phytoplankton (Chlorophyceae, Diatoms, Euglenoids, Zygnematids and Dinoflagellates) varied between different aquatic locations on land, p < 0.001, Bartlett's test, Table 7.
There were no significant correlations between abundance of *Anopheles* mosquitoes and Cyanobacteria, Chlorophyceae, Diatoms, Euglenoids and Zygnematids, p > 0.05, but significant correlations were observed with Dinoflagellates on land, p = 0.014, by Pearsons' correlation.

Table 7
Abundance of phytoplankton in different locations on land

Locations (No. of sites)	Mean (±SD) Phytoplankton Abundance Cyanobacteria	Cholopyceaeae	Diatoms	Euglemiods	Zynematids	Dinoflagellates
Ahero (3)	0.6±1.0	32.6±25.1	43.2±42.0	1.4±1.3	11.7±11.0	10.5±14.0
Asembo (5)	20.4±40.1	20.39±35.3	15.29±28.7	0.02±0.04	2.11±4.3	1.8±3.3
Auji (3)	41.6±47.0	29.4±31.4	10.2±12.1	12.4±18.4	4.4±7.2	2.1±2.8
Dunga (5)	38±20.6	28±12.7	25±12.0	3±4.1	1±0.7	6±10.0
Homabay (4)	5.4±10.6	28.87±40.2	13.19±20.9	1.72±2.2	0.82±1.6	0
Kisumu (3)	6.28±10.8	17.15±17.4	33.21±38.2	3.38±5.9	5.25±2.4	1.39±0.04
Luanda Gembe (3)	4±6.4	7±12.1	15±26.4	2±4.3	5±8.6	0
Osienala pond (1)	37.5	12.5	12.5	37.5	0	0
Sondu Miriu (4)	39±37.7	14±11.4	10±12.6	10±12.6	1±2.6	0
ANOVA	0.13	0.18	0.15	0.048	-	-
Bartlett's test	0.58	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

3.4 Gut Contents Analysis of Fish Collected from Lake and Land Habitats of Lake Victoria Basin of Kenya: Stomach content analysis showed that *Clarias gariepinus* were more insectivorous compared to other fish species, Table 8.

Table 8
Gut contents of different fish species caught from lake and land waters in different locations

		Percentage Gut Contents										
Fish Species	Length (cm)	No.	Empty	Plant remains	Insects	Molluscs	Worms	Zooplan-kton	Phytop-lankton	Fish remains	Food remains	Mud /debris
Barbas altianalis	10.7	1	0	0	0	0	0	70	0	0	30	0
Clarius gariepinus	10-20	3	1	0	90	10	0	0	0	0	0	0
	21-30	13	0	3.9	73.1	1.5	9.2	0	0	11.5	0	0.8
	31-40	4	1	0	100	0	0	0	0	0	0	0
	41-50	8	3	10	36	0	0	0	0	50	0	4
Clarius murei	9	1	0	0	5	0	5	0	0	0	90	0
Oreochromis	0-10	2	0	0	0	0	0	0	0	0	100	0
0leucostictus	10-20	14	0	0	7.1	0	0	5	6.8	0	81.1	0
Oreochromis niloticus	5.6	1	0	0	0	0	0	0	0	0	100	0
	10-20	17	2	3.3	28.7	0	0	36.7	20	0	11.3	0
	21-30	6	0	0	3.3	0	0	25	20	0	41.7	0
Protopterus aethiopicus	25	1	0	30	0	50	20	0	0	0	0	0
	46.9	1	0	70	30	0	0	0	0	0	0	0
Tilapia zillii	15.2	1	0	0	0	0	0	0	10	0	0	90

DISCUSSION

Only *Culex* species of mosquitoes were absent habitats that were associated with the lake in different locations. The most abundant mosquitoes in the lake were *Mansonia* followed by *Aedes* and then *Anopheles spp*. The absent of *Culex* and *Anopheles spp*., especially in deeper part of the lake might have been due to depth or turbulence of the waters. We suspect that few of the *Anopheles spp.* found at the lake edge habitats were those of the *An. funestus* group (no further identification was done), because of their morphological similarities with those species, while the rest of the *Anopheles spp.* found to be associated lake were mainly *An. gambiae s.l. Anopheles funestus* and *Anopheles rivulorum* are closely associated with aquatic vegetation including floating plants (9). This is consistent with past studies by Minakawa *et al* (14) who reported that the spatial heterogeneity in *An. gambiae s.l.* species composition may be affected either by many other variables, each of which has a small effect, or by other important variables that are yet to be determined under field conditions. In contrast to the situation in the lake waters where *Mansonia* and *Aedes* species dominated, *Anopheles* and *Culex spp*. of mosquitoes were abundant in the different aquatic habitats in different locations on land

There were more *Anopheles* mosquitoes on land in abandoned quarry and shoreline swamps, floodplain and stream edge puddles compared to natural swamps, rivers and more permanent pond habitats. The results were a pointer to the fact that these species of mosquitoes preferred calm stagnant waters in open sun-lit habitats as opposed to running or turbulent waters. There were no *Culex spp* of mosquitoes in the different vegetation habitats in the lake, though *Aedes*, *Mansonia* and few *Anopheles spp.* were abundant. There was no difference in the relative abundance of *Anopheles* and *Mansonia spp* in the different habitats in the lake. Lack of differences could have been due to the small number of samples obtained, and the results could therefore not certaily confirm or contrast several earlier reports that pointed out that aquatic weeds were associated with increase in abundance of different species of mosquitoes in man-made lakes (10-11) and also common belief and previous anecdotal reports that the water hyacinth in Lake Victoria is associated with high incidences of malaria within the Lake Victoria basin (29).

Anopheles and *Culex* mosquitoes were uniformly abundant in different vegetation types on land and the lake while *Aedes*, *Mansonia spp.* were abundant in the lake habitats. This is in agreement with earlier study done (22) which showed low abundance of malaria vectors (i.e. *Anopheles* species) associated with water hyacinth and other macrophytes in the Nyanza gulf of Lake Victoria. However, results of the current study still could not ascertain the common belief and previous anecdotal reports that water hyacinth in Lake Victoria is associated with high incidences of malaria within the Lake Victoria basin (29). This further calls for more extensive study on role of the lake habitats on malaria transmission in the Lake Victoria basin.

All the physicochemical parameters analysed (DO, pH, alkalinity, hardness, turbidity, conductivity, temperature and salinity) varied between the locations

on land. The same variations were observed in all land habitats ($p<0.001$), but there was no significant correlation between abundance of Anopheles species of mosquitoes and physicochemical parameters. There were no significant correlation between abundance of Anopheles mosquitoes and hardness, alkalinity, temperature, conductivity, salinity, dissolved oxygen and pH on land. However, past studies have shown that the main abiotic factors favouring mosquito larvae abundance include temperature, water chemical composition, its pH, depth, turbidity (5, 7, and 8) and it is not possible to pin point one physicochemical parameter (14).

Abundance of phytoplankton (Chlorophyceae, Diatoms, Euglenoids, Zygnematids and Dinoflagellates) varied between different aquatic locations on land,, but there were no significant correlations between abundance of Anopheles mosquitoes and Cyanobacteria, Chlorophyceae, Diatoms, Euglenoids and Zygnematids, but significant correlations were observed with Dinoflagellates on land, ($p = 0.014$, by Pearsons' correlation). Cyanobacteria species have been studied in various mosquito breeding sources (16). These photosynthetic prokaryotes are widely distributed in mosquito habitats and have been found in the guts of mosquito larvae. Cyanobacteria serve as food for mosquito larvae, (17). There were no significant correlations between abundance of Anopheles mosquitoes and Cyanobacteria, Chlorophyceae, Diatoms, Euglenoids and Zygnematids, $p>0.05$, but significant correlations were observed with Dinoflagellates on land.

Stomach content analysis showed that *Clarias gariepinus* were more insectivorous compared to other fish species,which mostly fed on zooplankton and food remains. This is consistent with earlier reports that *Clarias gariepinus* fingerlings feed on insects including mosquito larvae/pupae (24) and act as biological control agents (25). It is also consistent with earlier reports (23) who had reported the larvivorus nature of *Oreochromis niloticus* and Ofulla (22) who had reported abundance and presence of *Oreochromis niloticus* in water hyacinth mat compared to hippo grass and open waters, respectively.

Results from this study and those of previous studies, therefore imply that *Clarias gariepinus* could be a suitable fish for biological control of insects, such as mosquitoes in aquatic habitats. However, analysis on relationship between fish abundance and *Anopheles* mosquitoes found no significant correlation between the two, which needs further studies in more controlled environments.

In conclusion, further studies involving detailed analysis of abiotic and biotic factors influencing spatial variation of *Anopheles* larval distribution within the lake Victoria basin of Kenya is required, particularly the role played by infestation by water hyacinth. Moreover, an extensive survey of the expansive shoreline that may reveal the extent of malaria vectors invasion of the habitats associated with the lake, and this would also enable the general conclusion as to whether *Anopheles* species inhabit Lake Victoria.

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