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Environmental constraints on macrophyte distribution and diversity in a tropical endorheic freshwater lake (Lake Baringo, Kenya)

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Abstract
The structure of macrophyte assemblages can be affected by myriad factors, including physical and chemical characteristics of the water body. However, knowledge on the environmental factors affecting macrophyte diversity in endorheic freshwater lakes is limited. In this study the patterns of plant species diversity and composition and their potential determinants in Lake Baringo, Kenya, is described. Macrophyte sampling in Lake Baringo was done monthly from January 2015 to April 2016 using quadrats (1 m × 1 m) placed along transects perpendicular to the shoreline. Water temperature, pH, conductivity, dissolved oxygen (DO), salinity and alkalinity were measured *in situ* at each of the sampling sites. Findings revealed that macrophyte species composition and assemblage exhibited significant spatial differences ($P<0.05$), where areas near river inlets had higher species composition and percentage cover. The findings improve the understanding of floristic patterns and plant biodiversity in the lake.

Keywords: Macrophyte assemblages, physical chemical variables, floristic patterns, rift valley, limnology

1. Introduction
Lakes offer a wide variety of ecological services, including water supply, nutrient retention [1] and habitats for many aquatic plants and animals, which interact as a balanced ecosystem. Endorheic lakes, in particular, are known to be vulnerable ecosystems through time, because their hydrological budget is mostly ruled by evaporation due to the absence of a surficial drainage output. As a result, endorheic lakes are very sensitive to changes in air temperature and precipitation and thus they deserve special attention in the on-going debate about the possible effects of environmental change on biodiversity. The aquatic macrophytes including macroalgae of the divisions Chlorophyta (green algae), Xanthophyta (yellow-green algae), Rhodophyta (red algae), the ‘‘blue-green algae’’ (Cyanobacteria), Bryophyta (mosses and liverworts), Pteridophyta (ferns) and Spermatophyta (seed-bearing plants) are in intimate contact with the lake environment because their roots are either in the sediment or immersed/floating in the water [2-4]. These plants include emergent macrophytes (plants that are rooted in submersed soils or soils that are periodically inundated), floating-leaved macrophytes (plants rooted to the lake bottom with leaves that float on the surface of the water), submersed macrophytes (plants that grow completely submerged under the water, with roots or root-analogues in, attached to, or closely associated with the substrate) and free-floating macrophytes (plants that typically float on or under the water surface) [2, 5, 6]. Ecological importance of aquatic macrophytes include: provision of energy to herbivore and detritivore food webs [7], influencing the physical and chemical conditions of the water column [8, 9] and nutrient cycling [10, 11]. Aquatic macrophytes serve as a base of aquatic food-chains and therefore they aggressively contribute to the promotion and maintenance of food webs and services in freshwater ecosystems [12]. Their population response to environmental changes renders them important bioindicators of environmental conditions and long-term ecological changes in water quality [13-16].
Distinctive features of macrophyte populations in aquatic ecosystems are defined by their structural attributes such as species composition, the types and distribution of different growth

forms, abundance and diversity. These attributes respond to factors such as the physical and chemical characteristics of the water body [17-23], environmental factors [21, 24-26] biological factors [27-30], hydrological regime [31-34] as well as suits of human activities [35-38].

Factors potentially influencing macrophyte community distribution and variation in freshwater systems have been considered at various scales [5, 21, 24, 32, 39]. First, there is the large, regional scale [32, 40-42] where these community characteristics are usually primarily driven by geography-related factors (e.g. temperate versus tropical climate). Second, is medium or catchment scale, where, for example, hydrological and chemical variation in the system may be important [21, 43, 44]. Third, is small scale, related to environmental features of specific habitats and communities, and the biological interactions at this level [24, 45]. A number of studies have investigated the effects of environmental variables on the macrophyte distribution in many forms of freshwater lakes, but little is known about the dynamics of these communities in freshwater endorheic lakes. In this study, the general patterns of aquatic macrophyte diversity in Lake Baringo, were described. Firstly, the species richness and life forms of aquatic macrophytes at different parts of the lake was examined. Further, the changes in vegetation composition relative to environmental changes were analyzed.

Lake Baringo, a freshwater lake in the Kenyan Rift Valley, is fed by perennial and ephemeral rivers, direct rainfall, and hot springs within Ol Kokwe Island, near the centre of the lake. The lake has no surface outlet and despite high evaporation rates it maintains fresh waters [46]. The lake faces human-induced changes as a result of land- and water-use [47-48]. The perturbations include: poor agricultural systems on the catchment that lead to soil erosion, changes in hydrology due to water abstraction for horticulture, domestic use, and industrial use. Although significant efforts have been made, many restoration programs have failed because of a lack of knowledge about the crucial environmental factors and how they regulate the macrophyte community in the lake. In view of the significant role played by macrophytes in freshwater ecosystems, understanding and quantifying the environmental factors that influence their distribution patterns, will improve management practices in this wetland of international importance.

2. Materials and Methods

2.1 Study area

Lake Baringo is located between latitude 0°30’N and 0°45’N and longitude 36°00’E and 36°10’E (Fig. 1) and lies approximately 60 km north of the equator at an altitude of 900 metres above sea level. It has a mean depth of 4.7 m with the deepest point being about 11.0 m at high water levels [49]. Other morphometric and hydrological characteristics of Lake Baringo are summarized in Table 1. The lake area has two rainy seasons and a mean annual rainfall of 635 mm. The surface area covers slightly over 130 km^2 [50]. The catchment area which is about 6820 km^2 includes a large part of the western escarpment of the Rift Valley, where most of the water is derived from. In the lake are five major islands, the biggest being the volcanic Kokwa Island, from which a number of hot-springs discharge into the lake. In this study, the lake was apportioned into three ecological zones based on earlier studies, the southern, central and northern. The southern zone drains rivers Molo, Endau, Perkerra, and Ol-Arabel. The central zone has only River Mukutan draining its waters into the lake via the eastern side. The northern zone is characterized by stony substrata, but the deepest part of the lake.

2.2 Sampling sites

A total of nine sampling sites were established for the current surveys. Thus, in the southern zone there were three sites: Salabani (S1), Ngambo (S2) and Kiserian (S3). In the Central zone the sites were BMU (C1), Kokwa Island (C2) and Long'icharo (C3); whereas the three sites at the northern side include Katuuit (N1), Loruk (N2) and Komolion (N3).

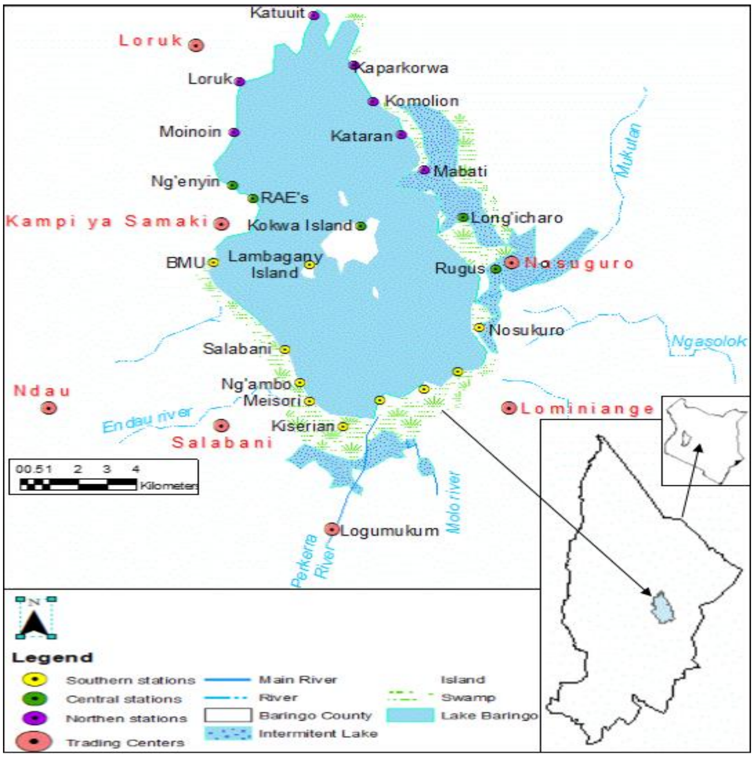

Fig 1: Map of Lake Baringo showing macrophyte study stations

Table 1: Mean morphometric characteristics of Lake Baringo, during the study period

Feature	Unit	Measures
Surface area	km^2	130
Lakeshore length	km	24
Lake width	km	12
Catchment area	km^2	6820
Precipitation	Mm $year^{-1}$	700
Water volume	m^3	825×10^6
Mean ambient temperature	°C	26.2
Rainfall	mm	500-1100
Basin discharge	$m^3 s^{-1}$	180–250
Evaporation	$m^3 s^{-1}$	1500–2000
Underground seepage	$m^3 s^{-1}$	50–150

2.3 Sampling for aquatic macrophytes

Macrophyte sampling in Lake Baringo was done monthly from January 2015 to April 2016. The macrophytes were sampled using quadrats (1 m × 1 m) that were placed along transects perpendicular to the shoreline. The number of transects in each sampling site ranged from one to five. Within each transect, the distance between successive quadrats was constant, and the number of quadrats per transect varied from five to sixteen. This procedure takes into account habitat area and the size of the macrophyte stands, ensuring a representative inventory of aquatic flora. In addition, this procedure accounts for the variation of spatial distribution in the margins, allowing the investigation of associations between macrophyte assemblage attributes and environmental variables. Inside each 1 m × 1 m quadrat, macrophyte species were visually scored for percent cover to provide an estimate of abundance. Rakes were used to sample the submersed macrophytes. The collected specimen were transported to the University of Eldoret, where the plants were identified according to specified key and illustrations [51]. Despite some taxa not identified to species level, for the sake of simplicity, the term species was used to represent taxonomic units.

2.4 Determination of environmental parameters

Environmental parameters, namely water temperature, pH, conductivity, dissolved oxygen (DO) concentration, salinity and alkalinity were measured *in situ* at each of the sampling sites, using a calibrated JENWAY 3405 electrochemical analyzer (Barloword Scientific Ltd, Essex, UK), with independent probes for each variable. Turbidity was measured using turbidity meter (Thermo Scientific™ AQ4500 Turbidity Meter, UK). Nitrates, dissolved organic phosphates and dissolved organic carbon followed protocols in APHA 2005 [52].

2.5. Data analysis

Physico-chemical parameters were presented as means ± SEM. Spatial differences in the values of the physico-chemical parameters were determined using One Way ANOVA. Vegetation distribution was determined as median cover among the sites sampled during the study period. Spatial differences, in the cover of the plant species was analyzed using Kruskall-Wallis test. A sites × vegetation species matrix was constructed during comparison of species attributes among sites [53] before carrying out a hierarchical cluster analysis. An average linkage method was selected with the cophenetic correlation criterion and the optimum number of clusters (k). Based on the macrophyte measures, the similarities of the measured parameters were compared among sites using exploratory cluster analysis. The dichotomous classification technique expressed the measured parameters in an ordered table, constructed from site–variable matrix. The outputs are viewed as dendrograms that illustrate sampling sites exhibiting similar species composition. For ease of comparison, the scale was reduced to percentage by dlink/dmax*100. Principal Component Analysis (PCA) was used for determining the relationships between the individual vegetation species attributes and the measured physical and chemical (environmental) variables [54]. PCA assigns a loading value to each variable on each factor (principal component, PC) and the same assignment is given to the scores (environmental variables). The multicollinearity for PCA was determined using variance decomposition proportions [55]. The software STATISTICA 10.0 (ver. 10) (Stat Soft, Inc., Tulsa, OK) was employed in all the analysis including the multivariate statistical analysis.

3. Results

An overview of the physical and chemical variables in Lake Baringo observed at the inlet sites (S1, S2, S3), central sites (C1, C2, and C3) and northern sites (N1, N2 and N3) are shown in Table 2. All the physical and chemical parameters demonstrated significant (P < 0.05) spatial variations. Sites S1, S2 and S3 located near inlets exhibited significantly lower temperature, pH, conductivity, salinity, alkalinity and DOC but had higher turbidity, TDS, DO, NO_3-N and DOP. The northern sites had significantly (P < 0.05) higher temperature, pH, conductivity and alkalinity.

A total of 30 plant species belonging to 16 families were identified at the nine sampling sites in Lake Baringo between January and December 2015 (Table 3). Overall, the family Poaceae had the highest number of species (five) followed by Cyperaceae with four species whereas Pappilionaceae and Onagraceae had three species each. A total of seven families had a single species each. In terms of life forms, 67% of the plant species were emergents followed by free floating type (17%). The submerged macrophyte type was represented by four species belonging to three families, whereas the floating rooted type had the least representation by species. It was observed that the southern zone of Lake Baringo was relatively rich in macrophyte species (29 species) compared with the central (22 species) and northern zones (21 species). The temporal differences in the mean [range] of macrophyte species in Lake Baringo is also presented in Table 3. There were significant spatial differences in the percent vegetation cover among sites (P<0.05) except for *Pistia stratiotes*, *Paspalidium germinatum* and *Polygonum setosulum*. There was a higher percentage cover of *Hygrophylla auriculata*, *Ceratophyllum submersum*, *Cyperus laevigatus*, *Utricularia inflexa*, *Nymphaea lotus*, *Aeschenomene cristata*, *Typha domingensis* and *Eichhornia crassipes* at the southern sites. Meanwhile *Pycreus nitidus* and *Ludwigia stolonifera* occurred only at the sites located within the southern part of the lake. Percentage cover of *Aeschenomene pfundii* was highest at sites located at the northern part of the lake. Based on the percentage cover data, the Euclidean clustering of the sampling sites based on the vegetation separated the sites as shown in Figure 2. Based on the vegetation species cover recorded, sites C3, S1 and S3 displayed close similarity; as was N1 and N2. Meanwhile sites C2, S2 and N3 were dissimilar with each other and also displayed distance similarity compared to the other sites.

Table 2: Summary of physico-chemical parameters (mean values + SD) in Lake Baringo at different sampling sites during the period between January and December 2015

	Sampling sites								
Variables	**S1**	**S2**	**S3**	**C1**	**C2**	**C3**	**N1**	**N2**	**N3**
Temperature (°C)	25.6 ± 1.4	26.8 ± 1.3	25.7 ± 0.9	24.7 ± 0.7	24.5 ± 1.1	24.8 ± 0.9	24.2 ± 0.8	24.2 ± 1.2	23.5 ± 0.6
pH	7.44 ± 0.07	7.56 ± 0.14	7.65 ±0.11	7.88 ± 0.12	7.97 ± 0.09	7.95 ± 0.14	8.72 ± 0.11	8.42 ± 0.09	8.57 ± 0.10
Conductivity (µS cm^{-1})	601.2 ± 55.6	612.3 ± 29.2	622.2 ± 65.6	889.2 ± 71.2	892.1 ± 60.2	1101.2 ± 50.2	1199.3 ± 90.2	1171.2 ± 88.9	1167.9 ± 89.2
Turbidity (NTU)	47.4 ± 5.1	50.2 ± 6.7	61.2 ± 7.6	30.2 ± 4.5	37.4 ± 4.1	36.8 ± 3.4	24.8 ± 4.5	26.7 ± 5.4	27.8 ± 3.9
TDS (mg/L)	212.3 ± 26.5	198.0 ± 20.9	204.5 ± 21.3	157.0 ± 19.4	189.0 ± 16.7	165.0 ± 20.3	153.0 ± 16.5	155.0 ± 17.8	153.2 ± 18.5
DO (mg/L)	5.52 ± 1.02	5.43 ± 0.98	5.73 ± 0.96	4.62 ± 0.77	4.83 ± 0.86	4.71 ± 0.83	4.63 ± 0.78	4.73 ± 0.93	4.65 ± 0.99
Salinity (‰)	0.46 ± 0.09	0.52 ± 0.12	0.53 ± 0.08	0.58 ± 0.09	0.56 ± 0.08	0.57 ± 0.07	0.56 ± 0.08	0.57 ± 0.07	0.54 ± 0.08
Alkalinity (mg/L)	124.5 ± 13.4	129.2 ± 19.2	134.2 ± 20.3	199.2 ± 23.3	191.2 ± 19.8	190.2 ± 21.2	228.2 ± 18.8	225.2 ± 23.4	234.7 ± 19.2
NO_3-N (mg/L)	8.2 ± 1.3	8.0 ± 1.1	8.9 ± 1.3	6.1 ± 1.1	5.6 ± 0.9	5.6 ± 0.8	2.4 ± 0.3	2.5 ± 0.5	2.4 ± 0.3
Dissolved Organic P [DOP] (mg/L)	2.8 ± 0.9	2.6 ± 0.8	2.3 ± 0.7	1.8 ± 0.3	1.7 ± 0.4	1.6 ± 0.3	1.2 ± 0.2	1.3 ± 0.3	1.1 ± 0.2
Dissolved organic carbon [DOC] (mg/L)	6.5 ± 1.5	7.8 ± 1.2	6.6 ± 1.1	8.7 ± 1.8	8.6 ± 1.5	9.1 ± 1.6	8.4 ± 1.1	8.2 ± 1.2	8.6 ± 1.4

Table 3: Macrophyte species composition, habitat forms and percent cover (range) at the southern stations (S1, S2 and S3), central stations (C1, C2 & C3) and northern stations (N1, N2 & N3) of Lake Baringo during the study

Family	**Species**	**Habit/Form**	**Percent cover ranges at the study stations**								
			S1	**S2**	**S3**	**C1**	**C2**	**C3**	**N1**	**N2**	**N3**
Acanthaceae	*Hygrophylla auriculata* (Schum.) Heine	Emerged	1-5	1-5	5-10	-	1-3	1-5	-	-	-
Araceae	*Pistia stratiotes* L.	Free floating	4-15	11-20	30-50	10-15	10-15	15-20	5-10	5-15	5-15
Asteraceae	*Adenostemma caffrum* DC.	Emerged	1-3	-	1-5	-	-	-	-	-	1-3
Azollaceae	*Azolla nilotica Decne* ex Mett.	Free floating	-	5-10	5-10	-	-	-	-	-	-
	Azolla pinnata R. Br.	Free floating	-	-	5-10	-	-	-	-	-	-
Ceratophyllaceae	*Ceratophyllum dermasum* L.	Submerged	44-60	35-53	33-36	24-42	31-54	30-60	30-50	10-20	10-20
	Ceratophyllum submersum L.	Submerged	50-75	50-75	15-25	30-40	50-75	30-60	20-35	30-50	30-50
Chlorophyceae	*Spyrogyra* sp	Submerged	-	-	10-20	0-5	5-10	-	-	-	-
Convolvulaceae	*Ipomoea aquatica* Forsk	Emerged	10-20	-	10-20	-	20-30	15-25	10-15	-	10-15
Cyperaceae	*Cyperus articulatus* L.	Emerged	-	-	10-20			10-20	-	-	-
	Cyperus laevigatus Makaloa	Emerged	20-30	20-30	20-30	-	-	20-30	-	15-20	-
	Cyperus rotundus L.	Emerged	-	15-30	15-30			1-5	-	1-5	-
	Pycreus nitidus (Lam.) J. Raynal.	Emerged			20-30	-	-	-	-	1-5	-
Lentibulariaceae	*Utricularia inflexa* Forssk.	Submerged	5-10	-	10-20	-	-	1-5		1-5	1-5
Nymphaeaceae	*Nymphaea lotus* L.	Free floating	10-20	20-33	20-30	5-14	11-18	20-25	10-15	-	-
Onagraceae	*Ludwigia abyssinica A. Rich*	Emerged			1-5	1-5	1-5			10-15	-
	Ludwigia leptocarpa (Nutt.) Hara	Emerged	20-30	-	-	1-3	-	-	-	-	-
	Ludwigia stolonifera (Guill & Perr) P.H. Raven	Emerged/Rooted floating			18-25	-	-	-	-	-	-
Pappilionaceae	*Aeschenomene cristata* Vatke	Emerged	30-50	30-40	25-40	10-20	10-20	30-45	10-15	20-35	50-75
	Aeschenomene pfundii Taub	Emerged	0-4	20-30	20-30	0-3	1-2	10-15	5-20	25-40	25-60
	Sesbania sesban (L.) Merril	Emergent	16-25	-	-	1-3	-	-	1-5	1-5	1-5
Poaceae	*Echinochloa stagnina (Retz.) P. Beauv.*	Emergent			22-28	1-5	5-10	-	-	-	-
	Leersia hexandra Sw.	Emerged	20-30	20-30	30-60	-	-	30-40	-	20-30	18-24
	Panicum repens L.	Rooted floating	-	-	-	-	11-14	9-14	10-16	10-15	-
	Paspalidium germinatum (Forsk) Stapf.	Emerged/Rooted floating	30-40	10-24	11-18	-	17-30	-	30-50	12-22	25-50
	Rottboelia exaltata L.f.	Emerged/Rooted floating	0-3	4-8	30-55	-	14-25	3-12	-	30-50	28-52
Polygonaceae	*Polygonum salicifolium* Willd.	Emerged	2-10	3-12	3-10	-	-	-	1-5	3-9	3-11
	Polygonum setosulum	Emerged	4-9	11-16	4-16	5-18	7-17	5-15	3-11	4-22	13-20
Typhaceae	*Typha domingensis* Pers.	Emerged	10-30	12-28	12-29	5-25	5-25	5-30	5-9	3-16	5-21
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	Free floating	10-20	20-30	10-20	3-5	7-11	10-20	2-3	2-3	2-3

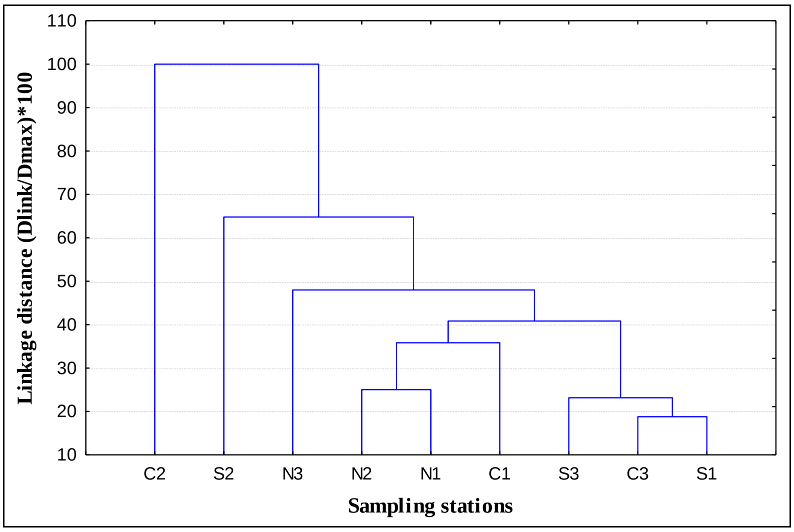

Fig 2: Dendrogram illustrating classifications of stations based on vegetation cover (scaling to dlink/dmax*100) in Lake Baringo during the sampling period.

The relationships among environmental variables and vegetation species cover within the lake are shown in Figure 3. Four principle factors (eigen values > 1) were extracted to explain the variability in the PCA and together, two main factors explained 58.5% of the total data variance. Species such as *Echinochloa stagnina*, *Azolla pinnata*, *Typha domingensis*, *Pistia stratiotes* and *Polygonum setosulum* were positively associated with the DOC, alkalinity and conductivity. Meanwhile the *Nymphaea lotus*, *Ceratophyllum submersum*, *Adenostemma caffrum*, *Ludwigia leptocarpa*, *Rottboelia exaltata*, *Azolla nilotica*, *Cyperus laevigatus*, *Cyperus articulatus*, *Cyperus rotundus* and *Paspalidium germinatum* were associated with temperature, pH, TDS and DO. *Ipomoea aquatica*, *Spyrogyra sp*., *Ludwigia abyssinica*, *Polygonum salicifolium*, *Sesbania sesban* and *Utricularia inflexa* were associated with salinity, NO_3-N, DOP and turbidity. *Hygrophylla auriculata*, *Eichhornia crassipes*, *Aeschenomene pfundii* and *Hygrophylla auriculata* were not associated with any environmental variable.

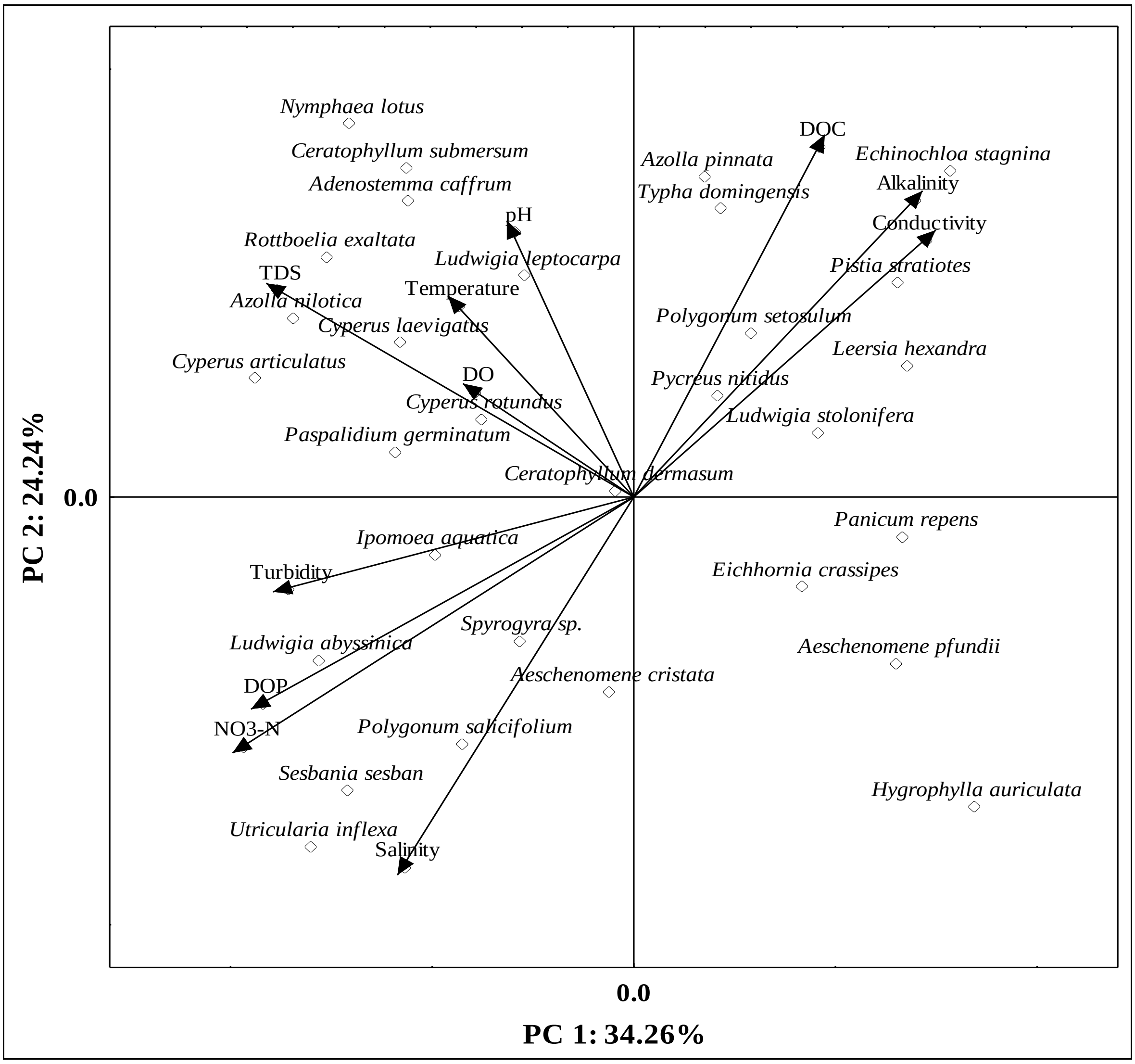

Fig 3: Results of Principal Component Analysis (PCA) on complete environmental variable vectors and species structure in Lake Baringo during the study period.

4. Discussion

The Lake Baringo environment displayed considerable spatial variation, where sampling sites situated near the inlets had higher turbidity, TDS, DO, NO_3-N and DOP but lower pH, conductivity, salinity, alkalinity and DOC. Most of the physical and chemical water quality parameters are similar to studies conducted earlier within the same lake [56]. Previous studies in the lake indicate that variation in water quality variables are related to prevailing weather changes driven mainly by the rainfall pattern within the catchment [57] as well as presence of hydrothermal recharge in the northern part of the lake [46]. The differences in water temperature at different sites therefore were due to the inflow of cooler water into the lake from the catchment. Deeper water in the sites located at the northern parts of the lake translates to relatively larger water mass which takes longer to warm up and cool down. The relatively high pH at the northern sites is due to high concentrations of carbonate salts, typically sodium carbonate (and related salt complexes), giving rise to high alkalinity. Nevertheless, the high pH in this lake compared to many freshwater lakes could be attributed to lack of any surface outlet. Although there is emerging evidence of underground outlet in this lake [46], such outlets may not be sufficient to prevent accumulation of salts in water. The relatively low pH at the inlet sites could therefore be attributed to inflow of freshwater from the incoming rivers Molo, Ol Arabel, Endau and Perkerra. The same reason could be linked to the lower conductivity, salinity and alkalinity at the inlet sites compared to more offshore areas because of the inflow of freshwater with low dissolved substances. The high turbidity, TDS and DOP recorded in the lake especially at the inlet sites was attributed to the resuspension of the organic matter in the inflow water mainly from areas experiencing diverse human activities such as logging, charcoal burning, livestock farming and other agricultural activities [47, 48, 58, 59] Therefore the heterogeneity of the environmental variables across the sampling sites within the lake can be characterized by the sites located in the southern zones and apparent lack of outlets for sites in the central and southern parts of the lake.

There are no previous studies reporting on macrophytes in Lake Baringo. In the present study, 16 macrophyte families and 30 aquatic vascular plant species were identified in Lake Baringo with majority of the families being represented by just a single species. This indicate low number of macrophyte families compared to other tropical freshwater lakes [60, 9]. The highest macrophyte species composition was recorded around River Molo mouth and the central zone around Ruko conservancy probably due to rich inflow of nutrients into the lake from the catchment areas. Species belonging to the families Cyperaceae and Poaceae were the dominant groups and with wide distribution in the sampled sites, which has also been reported in other tropical waterbodies [6, 60-66]. Poaceae and Cyperaceae, which are among the best-represented families, are also the most important families in other freshwater ecosystems due to their ability to tolerate wide range of environmental conditions [61, 66-69]. Occurrence of several families with few species indicates that the growing conditions are favorable for survival of a few species of macrophytes. This study also established a mixture of macrophyte life forms, with a dominance of emergent forms. Such forms are important in freshwater ecosystems [70-76], suggesting macrophyte adaptation to conditions of the freshwater as opposed to saline conditions. Dominance of emergent species is an expected finding in many tropical lakes, due to nutrients in the water column that can support their growth. Free-floating species were the second most important group in terms of frequency of occurrence. The elevated frequency and richness of this group may be directly associated with the high nutrient status of the lake [77-80].

This first detailed floristic characterization for the Lake Baringo, which is an endorheic freshwater lake, suggest a unique pattern of macrophyte species distribution in terms of percentage cover, with the highest cover for most species being observed near the inlets sites. This suggests that the inflow of freshwater with nutrients from the catchment drives the vegetation community structure of the lake. Any combination of high DOP, NO_3-N, TDS and low DO could explain the high percentage occurrence of macrophytes near the inlet sites. It is important to note that there were four dominant species in terms of percent cover: *Ceratophyllum dermasum*, *Ceratophyllum submersum*, *Cyperus laevigatus* and *Eicchornia crassipes*, which may be attributed to their prolific multiplication and growth habit in nitrogen and phosphorus rich waters [81]. Moreover, the proliferation of the *E. crassipes*, a weed that thrives under conditions of contaminated or nutrient rich water [82-84] showed the extent to which water in these locations was nutrient rich. Nonetheless, there is no previous study that has determined how diverse environmental factors drive the macrophyte assemblage in the lake.

The findings of this study on the relationships between aquatic macrophytes and environmental variables established that four principle factors (eigen values > 1) explained the variability in macrophyte assemblage. Different combinations of environmental variables are necessary to explain different assemblage attributes. Species such as *E. stagnina*, *A. pinnata*, *T. domingensis*, *Pi. stratiotes* and *Po. setosulum* were explained by variation in DOC, alkalinity and conductivity as they have been associated to grow better in areas with high carbon content and low pH [85], while *Nymphaea lotus*, *Cer. submersum, A. caffrum, L. leptocarpa*, *R. exaltata*, *A. nilotica*, *Cyp. laevigatus*, *Cyp. articulatus*, *Cyp. rotundus* and *P. germinatum* were caused by variation in temperature, pH, TDS and DO. Some of these plants have been established to grow in nutrient deficient waterbodies and therefore appear not dependent on the nutrients for survival [86]. Some species such as *I. aquatica*, *Spyrogyra sp*., *L. abyssinica*, *Po. salicifolium*, *Ses. sesban* and *U. inflexa* were associated with salinity, NO_3-N, DOP and turbidity. Temperature, pH, TDS, DO, alkalinity, conductivity, salinity, NO_3-N, DOP and turbidity are important explanatory variables of macrophyte richness and that combinations of different processes generate different patterns of macrophyte richness in the lacustrine habitats. For example, depth may have been important to explain the macrophyte richness because macrophytes are commonly organized along depth gradients in the littoral zone of water bodies [62]. Indeed, as diversity of plant species increases, community structure changed due to complementary interactions with the environmental factors.

5. Conclusion
The present results showed that a simple set of variables was sufficient to explain macrophyte assemblages in a relatively small subtropical lake. Thus, a combination of factors including physical and chemical variables was an important explanation of richness and community structure. A combination of water quality and nutrients, best explained macrophyte richness. The possibility that such species depend exclusively on certain conditions in the lakes, suggests that the sites of the Lake Baringo should be considered important areas for assessing their ecological role in the lake.

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