International Journal of Innovative Studies in Aquatic Biology and Fisheries (IJISABF)
Volume 1, Issue 1, June 2015, PP 1-14
www.arcjournals.org

Spatial and Temporal Variations in the Abundance and Diversity of Phytoplankton in Lake Manyara, Tanzania

[1*]Kihwele, E.S., [2]Lugomela, C., [2]Howell, K.M., Nonga, H.E.

[1]Tanzania National Park, Arusha, Tanzania.

[2]University of Dar es Salaam, Dares Salaam, Tanzania

[3]Department of Veterinary Medicine and Public Health, Sokoine University of Agriculture, Morogoro, Tanzania.

[*]*kihwele2001@yahoo.co.uk*

Abstract: *This study evaluated the temporal dynamics of phytoplankton species diversity and abundance in relation to some physico-chemical parameters in Lake Manyara for a period of fourteen consecutive months (between July 2007 and August 2008). The aim was to relate the temporal variability in the physico-chemical parameters of the lake to the abundance and diversity of phytoplankton. Three sampling sites were established in the lake, and data were collected once every month. Electrical conductivity, salinity, water temperature, dissolved oxygen; turbidity, transparency and pH were measured in-situ using a water quality checker Water samples for nutrients and phytoplankton abundance and species composition were analysed at the University of Dar es Salaam. In the laboratory, the concentration for inorganic nutrients were determined using a Shimadzu UV-spectrophotometer. Salinity and pH values in the lake ranged from 0.1 ‰ to 40 ‰ and from 6.23 to 10.67 respectively. However, there were shift in phytoplankton community dominance between Anabaena sp to Arthrospira sp likely due to differences in salinity and pH thresholds requirements. Nitrate, phosphate and ammonium concentrations ranged from 0.5 to 3.2 µg/l, 0.5 to 570 µg/l and 0.5 to 10.5 µg/l respectively while conductivity varied between 8.7 to 84.5 mS/cm. Other cyanobacterial genera, Phormidium, Oscillatoria, Spirulina, Aphanocapsa and Synechoccocus were also common. The results indicated that phytoplankton assemblage was positively correlated with ammonium, phosphate, dissolved oxygen, conductivity and nitrate*.

K**eywords:** *Alkaline Saline lake, Cyanobacteria, Arthrospira, Microcystin, physico-chemical parameters, Lesser Flamingo.*

1. INTRODUCTION

Lake Manyara is a shallow alkaline soda lake located beneath the cliffs of the Manyara Escarpment, on the edge of the Rift Valley some 130 km west of Arusha town, Tanzania. The lake is home to an incredible array of bird life that thrives on its brackish waters. In particular, thousands of pink Lesser Flamingo (*Phoeniconaiais minor)* stop and graze in the lake, making colorful specks and becoming one of the most important tourist attractions. However, this tourism potentiality is adversely affected by unpredictable changes in flamingo population abundance, probably caused by changes in the water quantity and quality (TANAPA, 2005).

Lesser flamingos are the filter feeder and known to be the principal primary consumers of the prolific phytoplankton in the water column of the alkaline rift valley lakes of East Africa (Tuite, 1979; Vareschi, 1979). Jenkins (1957) and Melack (1976) reported that the planktic cyanobacterium, *Arthrospira fusiformis* constitutes the main diet for the Lesser Flamingo. This cyanobacterium usually dominates most the rift valley soda lakes such as Nakuru, Bogoria, Elmenteita, Manyara, Natron and Lake Momela (Vareschi 1978, Melack, 1976; Melack and Kilham, 1974; Kaaya, 2007, Krietniz *et al.*, 2003) thereby attracting hundreds and thousands of these birds. A study by Lugomela et al. (2006) described a number of phytoplankton communities predominated by cyanobacterial blooms in Lake Manyara.

Many studies on phytoplankton of the Rift Valley soda lakes in East Africa have been conducted (Jenkins, 1932; Melack and Kilham, 1974; Vareschi, 1979; Kaaya, 2007). The high abundance and diversity of phytoplankton is a result of high salinity, and pH values observed in these alkaline saline lakes (Melack and Kilham, 1974; Vareschi, 1979). Most of the phytoplankton communities in tropical alkaline saline lakes are often enhanced by high nutrient concentrations such as phosphorus and nitrogen coupled with higher temperature, radiation, abrupt pH variation and salinity (Oduor and Schagerl, 2008). The dynamics of phytoplankton are a function of many environmental processes such as temperature, light, nutrient availability and mortality factors that affect species diversity and abundance (Chalinda et al., 2004). Kaaya (2007) also observed phytoplankton community structure in Momela lakes to relate to changes in nutrients, salinity and pH influencing the species composition and biomass. These responses to changes in the water environment have caused phytoplankton in the lakes to be an important biological indicator of the water quality. Ross (1955) attributed phytoplankton distribution patterns in most lakes mainly to oscillations in wind-induced vertical mixing, increased discharges in rivers feeding the lakes, rainfall and associated changes such as increased turbidity, nutrients and flushing rates.

In recent decades, there have been changes in the ecohydrological health of the Lake Manyara ecosystem caused by increased water abstraction for irrigation developments, degradation of catchment forests and increased siltation caused by unsustainable and poor land use practices in the upper catchments (Kihwele and Moronda, 2004). In addition, increased population growth, expansion and development for new agricultural land in the surrounding areas of Lake Manyara pose a great threat to the lake's water quality due to increased use of agrochemicals like fertilizers and pesticides. Since Lake Manyara is the low point of a catchment area of the basin located at the depression of the rift valley, it acts as a sink for various pollutants coming from agricultural and tourist activities resulting in the prominent changes in physical and chemical properties of the water (Yanda and Madulu, 2005). This occurs because of the interaction between the lake and the up-stream land users that lead to nutrient enrichment of the lake (UNEP, 2005). Some of these chemicals result in nutrient enrichment, which affect the biota of the lake, particularly the phytoplankton. The ecohydrological health of Lake Manyara is dynamic and constantly changes with seasons and the changing weather and climate conditions of the area.

There is a paucity of knowledge on spatial and temporal dynamics in the limnology of Lake Manyara. In addition, there is limited information on the cyanobacterial abundance and diversity in the lake. Thus, the objectives of this study were to evaluate the temporal dynamic of phytoplankton biomass in relation to physico-chemical parameters in Lake Manyara.

2. MATERIALS AND METHODS

2.1. Study Area and Sampling Sites

This study was conducted in Lake Manyara National Park which is located in Manyara and Arusha Regions (3^0 30' S and 35^0 45' E), situated between and including party of the lake Manyara and the steep rising escarpment of the western wall of the Great Rift valley (Figure 1), Tanzania. Lake Manyara, a brackish lake is the biggest perennial wetland, approximately 40km long by 13km wide with maximum depth of less than 2 meters. The main source of water for the lake is through precipitation and run-off from upper catchment. There are a number of rivers which drain into the lake namely Mto wa Mbu, Simba, Kirurumo, Msasa, Endabash, Ndala, Iyambi, Magara, Kiru and Makuyuni which are also used for agriculture. The climate of the area is semi arid with two distinct rainy seasons, short rains in October to December and long rain during March to May with a mean annual rainfall of about 700 mm (Rohde and Hilhorst, 2001).

Three near-shore sampling sites (about 200 m from the shoreline) were established and monthly sampling was done from July 2007 to June 2008. The established sampling sites were at Jangwani (03^o 25' 23.1'' S; 035^o 50' 43.7''E), Endala (03^o 28' 41.2''S; 035^o 47' 33.2''E) and Maji Moto (03^o 37' 44.4''S; 035^o 44' 36.9''E) (Figure 1).

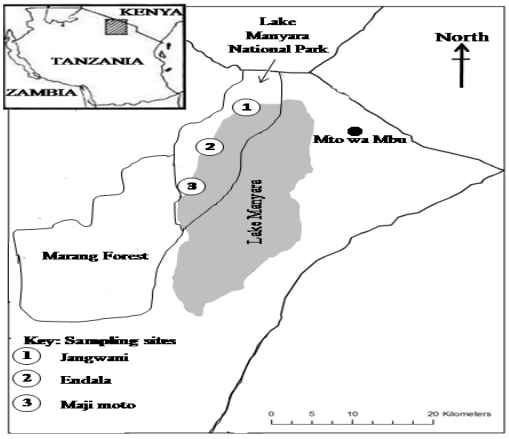

Figure1:*Map showing the location of Lake Manyara and sampling sites (insert: map of Tanzania with shaded region indicating the location of the study area).*

2.2. Physico-Chemical Parameter Measurements

Physico-chemical water parameters such as water temperature, pH, conductivity, salinity and dissolved oxygen were measured *in situ* using a portable water quality checker (Horiba U-10, Japan). Water transparency was measured using a white Secchi disc of 20 cm diameter. Water samples for nutrient determination were collected from the water surface and immediately filtered through a 0.45 µm pore sized membrane (Millex-GS Millipore filters, France). Water samples were then stored in cool boxes at 4^{o}C and transported to the laboratory for analysis. In the laboratory the concentrations of the inorganic nutrients (Nitrates, Nitrites, Ammonium and Phosphates) were determined using a spectrophotometer (UV-1601 SHIMADZU, Japan) with a 1 cm cuvette following the APHA, (2005) procedures.

2.3. Phytoplankton Sampling and Species Identification

A 20-µm mesh sized plankton net was used to concentrate phytoplankton samples for qualitative analysis. The net was lowered to the bottom of the lake and hauled vertically so as to capture different phytoplankton in the water column. The samples were then kept in 50 ml dark glass bottles and preserved using formalin to a final concentration of 4%. In the laboratory, microalgae identification was done using a light microscope following the morphological descriptions given by Desikachary (1959), Prescot (1978), Anagnostidis and Komárek (1985, 1988), Komárek and Anagnostidis (1986), and Hasle and Syversten (1997).

3. RESULTS

3.1. Physicochemical Characteristics of Lake Manyara

Water transparency ranged from 2.5 cm in March to 19.5 cm recorded in May (Figure 2a). However, water transparency was not determined for six months at station 1, for four months at station 2 and for three months at station 3 because of very low water depth due to drying of the lake. Water temperature was lowest (19.1^{o}C) in June 2008 and highest (37.5^{o}C) in January 2008 (Figure 2b) while Salinity values ranged from a lowest value of 0.1‰ as recorded in November and December 2007 at site one to 40‰ in November 2007 at site three (Figure 2c). Electrical conductivity ranged from lowest value (8.7 mS/cm) in September 2007 and highest (84.5 mS/cm) in November 2007 (Figure 2d). Water pH ranged from 6.23 as recorded in November 2007 to 10.67 in July 2007 and March 2008 (Figure 2e). Significantly, high pH levels were observed during the dry season compared to rainy season ($p = 0.046$). Dissolved oxygen ranged from 0.5 mg/l in February 2008 to 20 mg/l recorded in October 2007 (Figure 2f).

Concentration of ammonium in the water ranged from a minimum value of 0.5 µg/l as recorded in September 2007 to a maximum value of 10.5 µg/l in May 2008 (Figure 3a). Significantly higher concentrations of ammonium ($p = 0.001$) were recorded during the rainy season compared to the dry season. Nitrate concentration was lowest (0.5 µg/l) in September 2007 and highest (3.2 µg/l) in July and August 2007 (Figure 3b) while Phosphate concentration ranged from a lowest value of 0.5 µg/l recorded in November 2007 to a highest value of 569.3 µg/l in February 2008 (Figure 3c). Significantly higher levels of phosphate ($p = 0.008$) were recorded during the rainy season compared to the dry season.

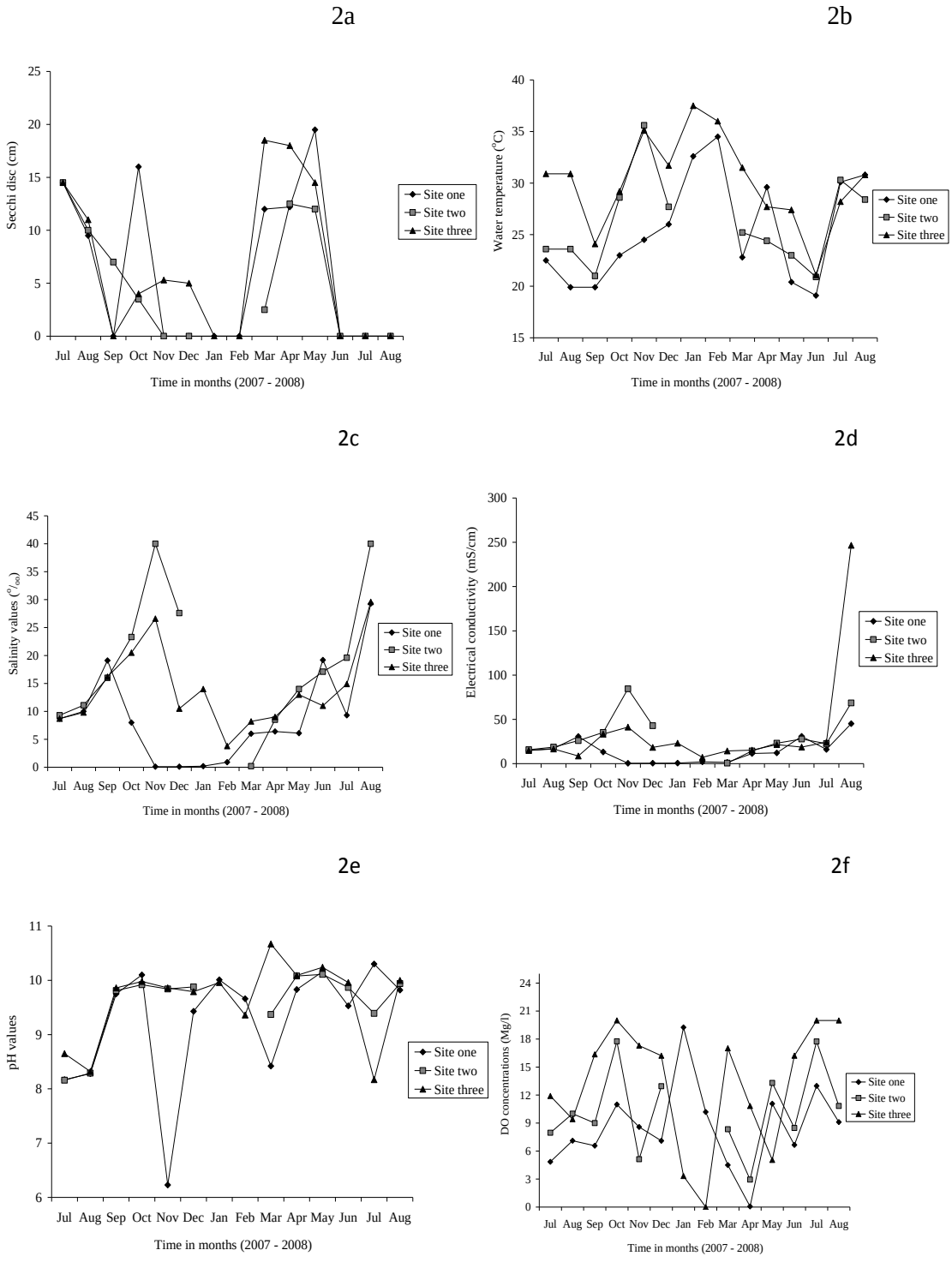

Figure2. *Temporal variations in the physical chemical parameters (Secchi disc (a), Water temperature (b), Salinity (c), Electrical conductivity (d), pH (e), and Dissolved oxygen (f) in Lake Manyara between July 2007 and June 2008.*

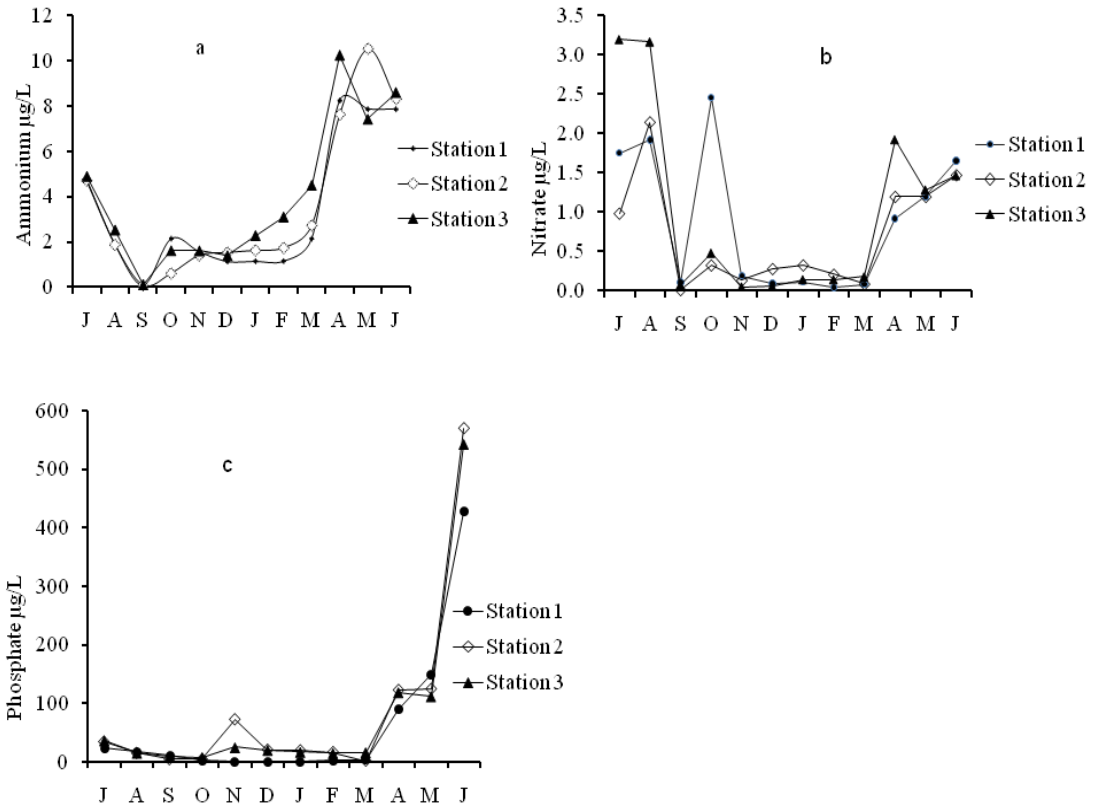

Figure3: *Temporal variations in the concentration of inorganic nutrients: Ammonium (a), Nitrate (b), and Phosphate (c) in Lake Manyara between July 2007 and June 2008.*

3.2.Phytoplankton Species Composition

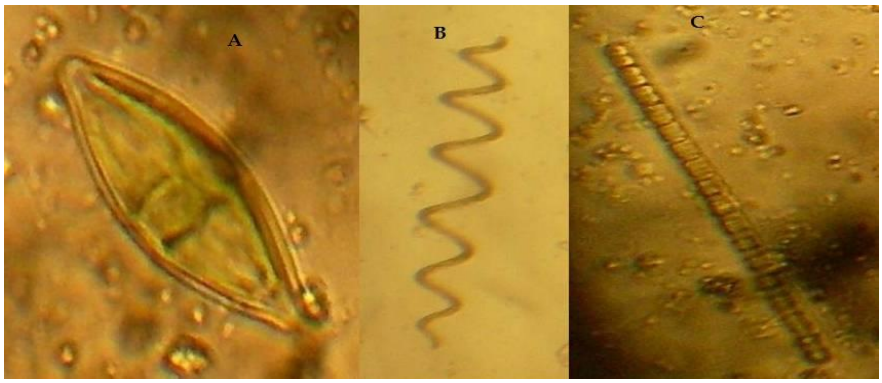

Plate1: *Phytoplankton species (A = Navicula sp., B = Arthrospira fusiformis, C = Phormidium sp) observed during the study*.

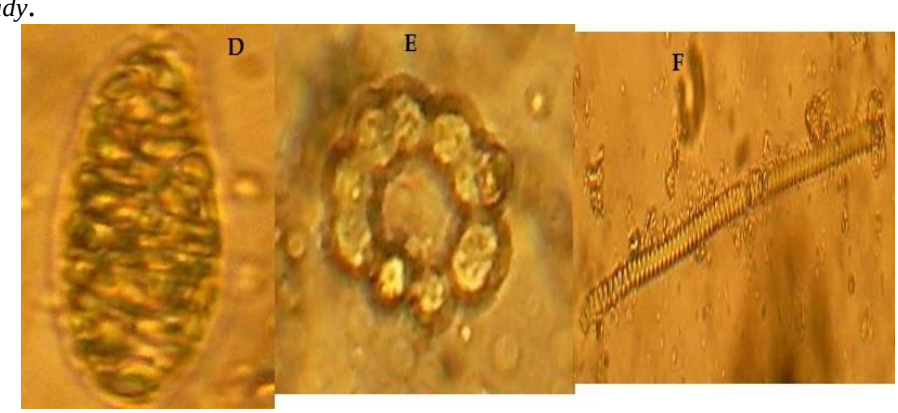

Plate2: *Phytoplankton species (D = Chlorophyte, E = Anabaena sp., F = Spirulina sp.) observed during the study.*

Table1: *List of phytoplankton taxa identified at three sites during the study period (x = present, – = Absent)*

Species Name	Site one	Site two	Site three
Arthrospira sp	x	x	x
Anabaena sp	x	x	x
Nostoc sp	x	x	x
Microcystis sp	x	x	x
Chlorogonium sp	x	x	x
Chrolophyte	x	x	x
Ankistrodesmus sp	x	—	x
Aphanocapsa sp	x	x	x
Oscilatoria sp	x	x	x
Spirulina sp	x	x	x
Phormidium sp	x	x	x
Navicula sp	x	x	x
Euglenophyte	x	x	x
Synechoccocus sp	x	x	x
Bacillariophyte	x	x	x
Cryptomonas sp	—	x	x
Cylindrospermum sp	x	x	x
Spirogira sp	x	—	—
Total	**17**	**16**	**17**

Table2:*A list of phytoplankton taxa identified at site one during the study period (x = present, – = absent)*

Phytoplankton name	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Bacillariophyta														
Unidentified bacillariophyceae	–	–	–	–	x	x	–	x	x	–	x	–	–	–
Navicula sp	–	–	–	–	x	x	x	x	x	x	x	x	–	x
Chlorophyta														
Ankistrosdesmus sp	–	–	–	–	x	x	–	–	–	–	–	–	–	–
Spirogyra sp	–	–	–	x	x	x	x	–	–	x	x	–	–	–
Chlorogonium sp	–	–	–	–	x	x	x	–	–	–	–	–	–	–
Unidentified chlorophyceae	–	–	–	–	x	x	x	–	–	–	x	x	x	–
Cyanophyta														
Anabaena sp	x	x	x	x	–	–	–	x	–	x	x	–	–	x
Aphanocapsa sp	–	–	x	–	x	x	x	x	–	x	–	–	–	–
Arthrospira sp	–	–	–	x	–	–	–	x	–	x	x	x	x	x
Cylindrospermum sp	–	–	x	–	x	x	–	–	x	–	–	–	–	–
Microcystis sp	–	–	x	–	x	x	x	x	–	x	x	–	–	x
Nostoc sp	–	–	–	–	–	–	–	–	–	x	x	–	–	–
Oscilatoria sp	–	–	x	–	x	x	x	x	–	–	x	x	x	x
Phormidium sp	–	x	x	–	x	x	x	–	–	–	–	–	–	–
Spirulina sp	–	–	x	x	x	x	x	x	–	x	–	–	–	–
Synechoccocus sp	x	–	–	x	–	–	–	–	–	–	x	–	–	x
Euglenophyta														
Unidentified euglenophyceae	–	–	–	–	x	x	x	x	–	x	–	–	–	–
Total	2	2	7	5	12	12	10	9	3	9	9	4	3	6

Table3: *A list of phytoplankton taxa identified at site two during the study period (x = present, – = absent)*

Phytoplankto name	Jul	Aug	Sept	Oct	Nov	Dec	Mar	Apr	May	Jun	Jul	Aug
Bacillariophyta												
Unidentified bacillariophyceae	x	x	x	x	x	x	x	–	–	–	–	–
Navicula sp	–	–	–	–	x	x	–	x	x	x	x	x
Chlorophyta												
Chlorogonium sp	–	–	–	–	–	–	–	–	x	–	–	–
Unidentified chlorophyceae	–	–	–	–	–	–	–	–	–	x	x	–
Cryotophyta												
Cryoptomonas	–	–	x	x	–	–	–	–	–	–	–	–
Cyanophyta												
Anabaena sp	x	x	x	x	x	x	–	x	x	x	x	x
Aphanocapsa sp	–	–	–	–	x	x	–	–	x	x	–	x
Arthrospira sp	–	–	–	x	x	x	–	x	x	x	x	x
Cylindrospermum sp	x	–	–	x	–	–	–	–	–	–	–	–
Microcystis sp	–	–	–	x	x	x	–	x	x	x	x	x
Nostoc sp	x	–	–	x	x	x	–	–	–	–	x	–
Oscilatoria sp	–	–	–	–	x	x	–	x	x	–	x	–
Phormidium sp	–	–	–	–	x	x	–	–	–	–	x	–
Spirulina sp	–	–	–	–	x	x	–	–	–	–	x	–
Synechoccocus sp	–	–	–	–	–	–	–	–	x	x	x	x
Euglenophyta												
Unidentified euglenophyceae	–	–	–	–	x	–	x	–	–	–	–	–
Total	4	2	3	7	11	10	2	5	8	7	10	6

Table4*: A list of phytoplankton taxa identified at site three during the study period (x = present, − = absent)*

Phytoplankton Name	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mar	Apr	May	Jun	Jul	Aug
Bacillariophyta													
Unidentified bacillariophycea	x	x	x	x	x	–	–	–	–	–	–	–	–
Navicula sp	–	–	–	–	x	x	x	x	x	x	x	–	x
Chlorophyta													
Ankistrosdesmus sp	–	–	–	–	–	–	–	–	–	–	–	–	x
Chrologonium sp	–	–	–	–	–	–	x	–	–	–	–	–	–
Unidentified chlorophyceae	–	–	–	–	–	x	x	–	–	x	x	x	x
Cryoptophyta													
Cryotomonas	–	–	x	–	–	–	–	–	–	–	–	–	–
Cyanophyta													
Anabaena sp	x	x	x	x	x	x	x	x	–	x	x	x	x
Aphanocapsa sp	–	–	–	–	x	x	–	–	–	–	–	x	x
Arthrospira sp	–	–	–	x	x	x	x	x	x	x	x	x	–
Cylindrospermum sp	–	–	x	–	–	–	–	–	x	–	–	–	–
Microcystis sp	x	–	x	x	x	x	x	x	x	x	x	x	x
Nostoc sp	–	–	–	–	x	x	–	–	–	–	x	x	–
Oscilatoria sp	–	–	–	–	x	x	x	–	x	–	–	x	–
Phormidium sp	–	–	–	–	x	x	x	–	x	x	x	x	–
Spirulina sp	–	–	–	–	x	–	x	–	–	–	–	–	–
Synechoccocus sp	–	–	–	–	–	–	–	–	x	x	x	–	x
Euglenophyta													
Unidentified euglenophyceae	–	–	x	–	–	–	–	–	–	–	x	x	–
Total	3	2	6	4	10	9	9	4	7	7	9	9	7

Table5: *T-Tests comparison of species diversity between the study sites*

Tested sites	t	df	p(α 0.05)	Comments
Site one Vs Site two	-32.533	160546.327	0.001>p	Significant difference
Site one Vs Site three	86.514	175240.095	0.001>p	Significant difference
Site two Vs Site three	168.601	339048.553	0.001>p	Significant difference

A total of eighteen phytoplankton species were identified during the current study of which the maximum number of 12 species were encountered during November and December 2007 at site one while the minimum number of 2 species was recorded during March 2008 at site two (Table 2). Seventeen species of phytoplankton belonging to 4 classes were recorded at Site one and three while a total of 16 species belonging to 5 classes were recorded at site two (Table 1). At site one, species of the genera *Oscillatoria, Phormidium, Anabaena* and *Microcystis* as well as pennate diatoms of the genus *Navicula* were the most common species throughout the study (Table 2) while at site

two, the most common phytoplankton species were *Anabaena* and *Arthrospira* and *Navicula* sp. (Table 3). At site three, phytoplankton of the genera *Anabaena, Microcystis* and *Arthrospira* were the most common (Table 4). Other species observed at all sampling sites included *Nostoc, Aphanocapsa, Ankistrodesmus, Chrologonium, Spirulina*, *Cylindospermum, Synechoccocus* and *Cryptomonas*. However, there were other phytoplankton belonging to the taxa Chlorophyceae, Euglenophyceae, and Bacillariophyceae, which could not be identified. These were seen at all the sampling sites. Diversity index was high at site two (H' = 0.497, t = 86.514) than at site one (H' = 0.421, t = -32.533) and site three (H' = 0.215, t = 168.601) and a significant difference in the diversity index was obtained between the three sites (Table 5).

4. DISCUSSION

4.1. Spatial and Temporal Variations In the Physicochemical Properties of the Lake

The temporal changes in some of the physicochemical characteristics observed during this study are attributed to seasonal chemical gradients of dilution caused by rainfall and high evaporative concentration cycles that were related to changes in the lake water levels. Based on rainfall distribution pattern and evaporative cycles, the water budget of the lake becomes a function of precipitation, evaporation and seasonal inflows from rivers and streams (Oduor and Schagerl, 2007). Being located in semi arid region of Tanzania with annual rainfall below 600 mm, Lake Manyara experiences high temperatures which affect the rate of water loss through evaporation. Generally, evaporation rates within the shallower saline lakes are assumed to be higher than that of the fresh water lakes due to the concentrations of calcium and sodium salts. Kihwele et al (2012) estimated the

rate of loss of freshwater in open waters through evaporation to be 10 mm per day, which alkaline saline lakes like Lake Manyara is expected to be more than 10 mm per day being accelerated by high salt concentrations and its bigger water surface area on shallow depth. This reduction in water drives the physical and chemical characteristics of the lake to respond towards the changes in lake water levels. As a shallow lake, the temporal fluctuations in the measured parameters were strongly linked with the hydrological cycle within the catchment area, as previously reported by Kihwele and Moronda 82004). The drying of the lake observed at site two during January and February 2008 regardless of substantial amount of rainfall recorded at Magugu weather station during the same period implies that the rainfall had no influence of lake level.

The observed temporal fluctuations in secchi disc readings were slightly associated with the changes in the water level of the lake as a reflection of seasonal rainfall distribution pattern. Secchi disc readings were considerably lower at site two probably due to sediment disturbances by the wading Lesser Flamingo which were more abundant at this area comparatively to areas where sites one and three were located. On contrast, the comparatively high secchi disc readings recorded at site one was due to the influence of the inflows of fresh water from Simba river which feeds the lake through this site. The generally low secchi disc readings recorded in Lake Manyara during this study when compared to other lakes, e.g., in Lake Momela (Kaaya, 2007) and Nakuru, Elmentaita and Bogoria lakes in Kenyan (Ballot et al., 2004, 2005) could be due to the shallowness of lake which resulted in easy re-suspension of sediments/mud due to wind action and/or wading flamingo and other aquatic birds.The inflows of organic materials from the catchment by the rivers feeding the lake during wet season which ultimately decompose may have contributed to low secchi disc readings recorded. This observation is supported by Oduor et al (2003) who associated the high turbidity with the daily re-suspension of the sediments by the winds coupled with shallowness of Lake Baringo.

High water temperatures observed at site three as compared to other sites studied were attributed by the hot springs that feed the lake throughout the area where site three was located. The 75^0C and 70^0C water temperatures of the two hot springs which were recorded by Lugomela et al (2006) within the shores of the lake around site three, were assumed to be the same during this study and are considerably related with the high water temperatures observed at site three probably due to the discharge of sodium bicarbonate and silicon dioxide. Besides this spatial variations, pronounced temporal variation in the water temperatures was noted throughout the study period. High water temperatures recorded were enhanced by the surface water heating through absorption of infrared radiation due to high concentrations of suspended solids in the water column (Oduor et al., 2003). However, the spatial variation in water temperatures observed among the three sites may be attributed to the difference in sampling time as well as drastic decline in the lake water level.

Lake Manyara is characterised with very high pH, salinity and alkalinity caused by sodium carbonate salts. The high pH and salinity values can be associated with the nature of the parent bedrock that affects the chemistry of the water as well as low water level that resulted into elevated salt concentrations. High water temperatures observed during this study might have catalysed ionization of salts leading to high pH values. Lake Manyara, being endorheic in nature, superimposed with its shallowness and daily wind influence, have combined forces making it experiences high concentrations in most of the solute variables due to net accummulation and resuspension from the sediments (Oduor and Schagerl, 2008) which acounts to the observed high values of pH and salinity.

High salinity values recorded at site two which peaked to maximum value of 40 ‰ during November 2007 and August 2008 were likely due to abruptly evaporative concentrations of salts. Our observation is supported by Lugomela et al (2004) who observed high salinity of 360 ‰ at an isolated pool in a drying part of the Lake Manyara that was also associated to evaporative concentrations due to lake dry-out. While the lower salinity values at site one were probably due to the dilution by fresh water from the Simba River at this station. This was also the case for lower pH values which were recorded with comparatively lower values at site one as opposed to other sites.

The significant positive correlation between salinity and dissolved oxygen concentrations suggests that in alkaline saline water, phytoplankton composition and abundance have optimal thresholds of salinity. Each phytoplankton community respond differently to these thresholds whereby salinity ranges beween 20 ‰ and 40 ‰ are optimal for cyanobactria blooms, with ultimately higher primary productivities (photosynthesis). The high productivity in turn results into increased oxygen gas production that dissolve into water as dissolved oxygen.

The prominent fluctuation in the dissolved oxygen noted during the study period might have been caused by changes in the phytoplankton composition and abundances. The drastic drop in dissolved oxygen concentrations to anoxic levels during February 2008 at site three and April 2008 at site one were likely attributed with decomposition of organic materials brought by inflows of rivers as well as cyanobacteria blooms.

The current study recorded higher concentrations of phosphate, nitrate, nitrite and ammonium which were comparable to the values previously reported by Lugomela et al., (2006) in Lake Manyara, Empakay and Momela; and Kaaya (2007) in Lake Momela, Tanzania. However, Ballot et al. (2004, 2009); and Schagerl and Oduor (2008) recorded considerably higher values of nitrate and phosphorus in Nakuru, Bogoria and Elmentaita lakes in Kenya compared to our observation in Lake Manyara. The high nutrients concentrations recorded during dry season at Lake Manyara could be due to the release from the soil substrate and droppings from water birds that were observed to be in large numbers during the study period. Similarly, recycling from dead plants and phytoplankton and droppings from wildlife that could have been washed by rain storm are believed to have significant contribution to the elevated levels of nutrients during the dry periods.

Very high mammal population in Lake Nakuru National Park was reported by Oduor and Schagerl (2007) to contribute to the nitrogen through droppings in the lake. Fleming and Fraser, (2001) measured the nutrient content of faeces from five species of gulls and found that the daily total production of total phosphorus per bird ranged from 38 mg in black – headed gull (Larus ridibundus) to >115 mg in herring gull *(Larus argentatus)*. On the other hand, Gould and Fletcher (1978) found that the daily total production per bird of total Kjeldahl nitrogen ranged from 608 mg in black-headed gull to 1819 mg in herring gull faeces. Therefore the presence of grey-headed gull *(Larus cirrocephalus)* in Lake Manyara (Kihwele, 2005) are likely to contribute significantly to total phosphorus and Kjeldahl nitrogen levels observed in the lake thereby affecting water quality. The birds such as Lesser Flamingo, Pelicans, Yellow billed storks, Gulls and Egyptian gees that sometimes during favorable conditions that inhabit Lake Manyara in substantial numbers can have potential contributions of ammonia, nitrates, phosphates and nitrites. Therefore faeces droppings from these birds have considerable contributions to escalated nutrient levels in the water column. This is evident as higher nutrients concentrations were observed during May - August 2008 coincidentally corresponding with large numbers of the Lesser Flamingo.

Thus, the role of water birds particularly the Lesser Flamingo in the nutrient budget of the lake cannot be ignored. For example, Don and Donovan (2002) observed that a single geese may produce up to 1.57 g/day and 0.49 g/day dry weight of total nitrogen and total phosphorus, respectively. Kihwele (2005) reported Egyptian geese *(Alopochen aegyptiacus)* to have the higher abundance (527 birds counted during January 2005) of all the species of the family Anatidae found in Lake Manyara. If assumed the total nitrogen and phosphorus production levels by Don and Donovan (2002) are also produced by Egyptian geese, then 827.39 g/day and 258.23 g/day dry weight of total nitrogen and total phosphorus respectively, were deposited into the lake during January 2004. Therefore it is assumed that similar contributions of nitrogen and phosphorus nutrients from Lesser Flamingo and other waterbird faeces at Lake Manyara may also be of considerable importance. However, it is overemphasized that the degree of nutrient budget contributed by water birds differs from one bird species to the other depending on the size of the bird, time spent in water as well as the type of food that a particular bird species eats. Therefore, in terms of an overall nutrient budget, the proportions of the nutrients contributed via waterbirds faeces become a part of the internal nutrient load of the lake.

4.2. Influence of Physicochemical Factors on the Variations in Phytoplankton Diversity and Abundance in Lake Manyara

The findings of this study showed that Lake Manyara was inhabited by different phytoplankton species dominated by cyanobacteria with noticeable changes between months. The phytoplankton community changes were characterized by dominance shifts between the cyanobacteria, *Anabaena* sp and *Arthrospira* sp. During the study period, *Anabaena* sp dominated the phytoplankton abundance in the lake during 2007 and a shift in the dominance of *Anabaena* sp towards the dominance of *Arthrospira* sp was observed during March to August 2008. This kind of shift in phytoplankton

species dominance was also observed by other researchers, Ballot et al, (2004; 2009) in Lake Naivasha; Schagerl and Oduor, (2008) in Lake Nakuru; Krienitz and Kotut (2010) in Nakuru, Bogoria and Oloidien lakes; and Kaggwa et al, (2013) in Lake Nakuru.

The dominance of the cyanobacterium, *Arthrospira* sp observed during this study is a characteristics for most of the alkaline saline lakes. For example, Lugomela et al., (2006) described a number of species of phytoplankton in Lake Manyara that were also dominated by cyanobacterium, *Arthrospira fusiformis*. Other studies in similar alkaline lakes in Kenya also reported a dominance of cyanobacteria species in particular, *Arthrospira fusiformis* (Ballot et al., 2004, 2005; Kotut et al., 2006; Krienitz and Kotut, 2010). The dominance of cyanobacteria in saline lakes over other phytoplankton species may be due to several factors. The high lake salinity and pH which are beyond tolerance thresholds for microalgae have been suggested to limit many other algal species in Kenyan saline lakes (Melack 1978; Vareschi 1982).

Other, competitive advantages of cyanobacteria in the lakes may be their ability to regulate their buoyancy, to fix atmospheric nitrogen by some species and to store phosphorus (Jacoby et al., 2000; Oliver and Ganf, 2000). In addition their allelopathic potentials may further enhance their development even under low nutrient level (Singh et al., 2001). Thus, when cyanobacterial blooms occur, irradiance is reduced in the water column, reducing the growth of other producers that cannot maintain a position near the water surface as they cannot regulate buoyancy (Scheffer et al., 1997). Furthermore the observed occurrence of benthic cyanobacteria species such as *Oscillatoria, Phormidium, Nostoc* and *Synechoccocus* during this study is likely due to their adaptability potentials to survive in low secchi disc reading. This is because, these benthic cyanobacteria are known to be efficient in utilization of low light intensities and have more CO_2-uptake kinetics (Scheffer et al., 1997), thus cannot be limited by low secchi disc readings.

In tropical areas such as Lake Manyara basin where there are only small inter-annual temperature variations throughout the year, irradiance and presence of nutrients may be the main environmental factors driving the phytoplankton abundance and species composition (Vonshak and Tomaselli, 2000). Many species of phytoplankton can form blooms provided that there are suitable conditions at that particular time. Most of these physicochemical water parameters recorded during this study were comparably within the range required for optimal growth and development of cyanobacteria (Vonshak and Tomaselli, 2000). For example the temperature values recorded during this study ranged from 24 to 35^{o}C which are within the optimal range of around 25–28^{o}C for bloom forming cyanobacteria in nature (Dokulil and Teubner, 2000; Whitton and Potts, 2000).

The low water transparency observed, due to re-suspension of sediments favored cyanobacteria species over other phytoplankton because of their ability to float on water surface as they possess gas vacuoles for buoyancy regulation (Walsby, 1978; 1994). This turbid and low water level was also the reason for observed benthic cyanobacterial (*Phormidium, Oscillatoria, Spirulina, Aphanocapsa, Cylindrospermum* and *Synechoccocus* sp) in the water. However, high salinity during dry season corresponded with the higher abundance of cyanobacteria in particular the *Arthrospira* species. The dominance of *Arthrospira* sp. during the dry season is perhaps due to their stability to tolerate a wide range of salinities because of their osmotic adjustment ability and mechanisms of internal pH regulations (Vareschi, 1982; Vonshak and Tomaselli, 2000). The occurrences of *Anabaena* and *Microcystis* species in Lake Manyara can probably indicate their adaptive tolerance ability to high salinity and pH as well as their ability to proliferate under low nutrient concentrations.

The high nutrient concentrations, particularly in the dry season, influenced phytoplankton species composition and succession. High values of phosphates and ammonium observed during May - August 2008 coincided with *Arthrospira* sp dominance that replaced *Anabaena* sp dominance of the phytoplankton community. This is justified by strong positive correlation observed between the *Arthrospira* sp with the concentrations of ammonium, nitrate and nitrite. As the lake water level receded, the decrease in the numbers of *Anabaena* sp and the increase in the numbers of *Arthrospira* sp, *Spirulina* sp, *Phomidium* sp, *Navicula* sp, *Microcystis* sp and *Oscilatoria* sp were observed which coincided with increased nutrients concentrations in the water. For example Darley (1982) observed higher concentrations of ammonia of between 0.5-1 µmol l^{-1} to limit the uptake of nitrates by cyanobacteria. This is because the phytoplankton possibly conserve energy by utilizing ammonium

instead of nitrates as the latter need to be reduced by the algae to ammonium before incorporation into amino acids. Therefore, inorganic nutrients such as ammonium, nitrate, nitrite and phosphorus are drivers and possibly regulate the temporal and spatial diversity and composition of phytoplankton in Lake Manyara. However, their synergetic interactions with other limnological variables influence their blooms, and species successions in aquatic environments (Hecky and Kilham, 1988). Proliferation in cyanobacteria species composition observed during the dry seasons which coincided with high nutrient concentrations in the lake, suggest that deficit in nutrients is likely limiting the growth of cyanobacteria. These conditions are known to be influenced by oxygen concentration, the alkalinity level and pH of the water (Søndergaard et al., 1990, Jones and Grant, 1999). The cyanobacteria observed during wet season, and during periods of low nitrate and nitrite level are possibly nitrogen fixers. Some cyanobacterial species (Mugidde, 1993; Walsby, 1994; Istvanovics et al., 2000; Oliver and Ganf, 2000;) have the ability to fix nitrogen, store phosphorus and regulate their buoyancy thereby withstanding extreme nutrients limitations. The relatively low nutrient level recorded in certain months during this study suggests the ability of some cyanobacteria to exist in limited nutrient levels**.**

5. CONCLUSION

The shift and succession in the phytoplankton species diversity in the lake are likely to be caused by the unstable environmental conditions of the lake that resulted from rainfall distribution pattern and high water use within the basin. The physico-chemical characteristics of the lake are suggested to be the drivers for the phytoplankton diversity and abundances in the lake. The study further therefore suggests that, the soluble reactive phosphorus and ammonia regulate the temporal and spatial abundance of phytoplankton, their blooms and species successions in aquatic environments. This study suggests that, the shift and succession in phytoplankton species composition and diversity are interrelated with the variations in the physico-chemical factors of the lake. It is concluded that, ammonium, phosphate, dissolved oxygen, conductivity and nitrate were the key variables influencing phytoplankton abundance in Lake Manyara.

RECOMMENDATIONS

- The changes in the water quality of the lake affected phytoplankton species composition and diversity that in turn affected the abundance. Therefore, this study recommends more research on phytoplankton ecology.
- The spatial and temporal variations in the concentration of nutrients are likely to be a result of various factors such as the nature of the parent bedrock, adsorption from the sediments, nutrients load and effluents from human uses as well as excretion from aquatic birds. It is recommended that, research on the nutrient budget of the lake should be undertaken.
- The study also recommends that, a monitoring programme on water quality and quantity need to be established. This would assess the rate of eutrophication in relation natural and anthropogenic factors and its impacts on primary producers in the lake.
- Activities taking place at the basin wide catchment have implications on the long-term survival of the lake and its inhabitants. Strategic environmental assessment is recommended for the sub-basin to reduce siltation and resolve water use competition issues.

ACKNOWLEDGEMENTS

Tanzania National Park and ACM-UDSM Fellowship kindly supported this study, and University of Dar Es Salaam played a facilitation role. We thank the Director General of Tanzania National Parks (TANAPA), the kind assistance we received from the Chief Park Warden at Lake Manyara National Park is highly acknowledged.

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AUTHORS' BIOGRAPHY

Emilian Kihwele is a Senior Park Ecologist heading the ecological monitoring department at Serengeti National Park. He has obtained his MSc in Wildlife ecology from the University of Dar es salaam. He has 15 years working experience as an ecologist and research focusing on limnology and water resource management. He has published more than eight papers in Journals and proceedings. He is also working as a registered environment impact assessor as well as environmental flows assessment expert.

H.E. Nonga is a Senior Lecturer in the Department of Veterinary Medicine and Public Health, Sokoine University of Agriculture (SUA), Tanzania. He obtained his PhD from the Norwegian School of Veterinary Science, Norway in 2011. He has over 10 years of research and teaching experience at SUA and his research interests include food-borne/zoonotic diseases, environmental- and public health. He has contributed more than 46 articles in local and international scientific journals and has supervised 2 PhD and 22 master students.