Lakes and Reservoirs: Research and Management 2014 **19**: 11–23

Spatial variations in nutrients and other physicochemical variables in the topographically closed Lake Baringo freshwater basin (Kenya)

Henry Ouma[1†] and Job Mwamburi[2*]
[1]Kenya Marine and Fisheries Research Institute, Baringo Field Station, P. O. Box 31-30406, Kampi ya Samaki,
[2]Kenya Marine and Fisheries Research Institute, P. O. Box 1881-40100, Kisumu, Kenya

Abstract

Spatial physicochemical parameters were determined from 39 sampling sites distributed throughout Lake Baringo during December 2010. Mean values of temperature, dissolved oxygen concentration and electrical conductivity decreased successively with depth, while the pH remained constant. Only the turbidity values increased marginally with depth. Of the surface water parameters, mean (range) values of dissolved oxygen (DO), pH, electrical conductivity, water transparency and turbidity were 6.9 (4.5–8.4) mg L^{-1}, 8.3 (7.8–8.5), 573 (556–601) $\mu S\ cm^{-1}$, 33 (28–37) cm and 43.3 (32.7–54.6) NTU, respectively. Mean and range values of total nitrogen (TN), nitrate-nitrogen (NO_3-N), ammonia nitrogen (NH_4-N), total phosphorus (TP) and soluble reactive phosphorus (SRP) were 788.4 (278–4486) μg L^{-1}, 4.5 (2.4–10.0) μg L^{-1}, 42.6 (33.8–56.3) μg L^{-1}, 102.9 (20.3–585.3) μg L^{-1} and 23.5 (15.2–30.5) μg L^{-1}, respectively. Dissolved silica concentrations ranged from 19.7 to 32.7 mg L^{-1}, with a mean value of 24.7 mg L^{-1}. The chlorophyll-a concentrations were quite low, ranging from 1.4 to 4.9 μg L^{-1}, with a mean value of 4.2 μg L^{-1}. In contrast to previous reported values, a key finding in the present study is a relatively high water transparency, indicating a relatively clear water column, due possibly to the fact that the sampling was conducted during the dry period. The nutrient levels remained low, and the chlorophyll-a concentration also was an almost all time low value. A TP value of 20 μg L^{-1} and higher confirms strongly eutrophic conditions prevailing in the lake, with an extremely low potential for fish production and low species diversity, consistent with other studies. The results of the present study, therefore, reinforce the database for future management and monitoring plans for the Lake Baringo ecosystem, which lies adjacent to known geothermally active zones and a saline Lake Bogoria.

Key words

Lake Baringo, nutrients, physicochemical parameters, rift lake, turbidity, water.

INTRODUCTION

Lake Baringo is a relatively small, closed basin freshwater lake (≈ 130 km^2 surface area), located in the eastern arm of the Great Rift Valley in Africa. The lake catchment area is increased and at a relatively high altitude, making the area highly vulnerable to surface water and wind erosion of the loose fine soil on the land surface. Thus, the rivers draining the basin contain sediments of extreme textures, including very fine, aeolian and volcanic ash, which are transported in suspension to the lake where they settle in accordance with Stokes Law (Onyando 2003). The estimated sediment yield of the Lake Baringo basin, extrapolated from erosion studies of Perkerra catchment, is 10.38 million t $year^{-1}$ (Onyando 2003; Onyando *et al.* 2005).

Eutrophication processes in lakes have been linked to land use activities in lake drainage basins, where management of non-point sources remains a major challenge. The water status of lakes can be assessed with the observation of various parameters, including biological elements, hydromorphological parameters and the physicochemical condition of the water. Physicochemical

---

*Corresponding author. Email: jjmghanga@yahoo.co.uk

Accepted for publication 12 January 2014.

†Present address: Department of Zoology, Maseno University, P. O. Box 333, Kisumu, Kenya.

Doi: 10.1111/lre.12052

variables are key components of water quality criteria for various uses, thereby usually providing relatively good indications of stressors in lake ecosystems and point sources of organic pollution. Because the photic zone is the most biologically active area in a lake, changes in light penetration have direct and indirect effects in lake productivity cycles.

Studies elsewhere have tried to relate the prevalence of waterborne diseases and water quality (Muyodi *et al.* 2009), and to characterize often-dominant algal group, cyanobacteria (Kotut *et al.* 2006; Metcalf *et al.* 2006; Sitoki *et al.* 2012), which are potentially toxic to humans and animals and also can degrade the ecological and aesthetic values of water. Such effects are typically more severe in lakes experiencing relatively longer periods of extreme hydrological variations, with accompanying catchment impacts.

Recent studies in the Lake Baringo basin indicated the lake is characterized by low oxygen concentrations, with increasing salinity, turbidity and eutrophic conditions (Muli *et al.* 2007). It also was determined that most of the suspended and dissolved matter in the lake was of riverine origin, which contributes significant quantities of organic matter into the lake ecosystem. Blue-green algae were widespread, dominating the algal community in most areas of the lake. It is noted, however, that comprehensive limnological investigations on Lake Baringo have generally been quite limited, except for those of Kallqvist (1987), Patterson and Kiplagat (1995), Odhiambo & Gichuki 2000; Oduor *et al.* (2003); Ballot *et al.* (2003), Tarits *et al.* 2006; Kotut *et al.* (2006), Oduor and Schagerl (2007), and ongoing KMFRI expeditions (Muli *et al.* 2007), compared to the limnological research on other relatively small Rift Valley basins (Hubble & Harper 2002; Hickley *et al.* 2004; Mergeay *et al.* 2005; Yasindi & Taylor 2005; Owen *et al.* 2008; Ballot *et al.* 2009; Oyoo-Okoth *et al.*2011) with similar characteristics and environmental challenges. Other relatively large freshwater lakes, such as Lake Victoria (Hecky *et al.* 1994; Kishe 2004; Mugidde *et al.* 2005; Sitoki *et al.* 2010), have considerable historical limnological databases, enabling easy tracking of significant water quality changes. Lake Baringo is a relatively small Rift Valley lake, within a highly faulted rift zone, and potential influences from underground flows and hot springs. Because previously reported limnological data were based on very few sampling sites, a more detailed survey with a higher sampling density was initiated to obtain useful spatial and temporal data, to generate more useful ecological and water quality information. The present study is part of an ongoing mapping of the lake breeding areas and fishing zones, to lessen conflicts in managing the lake resources. These results also are of value in assessing nearby Lake Naivasha and other highly vulnerable shallow tropical arid lakes likely to be impacted by climate changes, and which also experience severe water quality degradation, yet remain very important in the regional hydrological cycle. In addition, Lake Baringo and its inflowing river waters are used for domestic purposes, watering livestock and irrigation.

Shallow Rift Valley lakes are often characterized by high seasonal water level fluctuations, with a high influx of terrestrial inputs and inundation of lakeshore areas, sometimes even causing the displacement of communities surrounding the lake. Such extreme seasonal variations can have significant ecological influences on topographically closed basin freshwater lakes, attributable to resulting water quality changes. Prior to the 1990s, water hyacinth was not an ecological challenge to most of the surface waters in this region. Its high nutrient demand, however, was easily met in most eutrophic aquatic ecosystems. The proliferation of water hyacinth in freshwater lakes, for example, is related to increasing nutrient inputs, with related problems becoming evident in nearby Lake Naivasha, another freshwater Rift Valley lake. Because semi-arid areas are water stressed, any processes that exacerbate water losses from such important water sources must be appropriately managed to ensure sustainability of the lake resource. Thus, understanding the nutrient sources and dynamics in these lakes is important for developing appropriate management actions, and also for understanding how underwater ecological changes and observed seasonal water level variations contribute to overall aquatic habitat quality. Accordingly, the specific objectives of the present study were to identify and assess changes in the physicochemical parameters of Lake Baringo, including studying the south-to-north zonal variations in these parameters. The design of the present study provides a lake-wide data collection network that previously did not exist. The limnological information presented herein is intended to enhance the development of geographical information system (GIS) information tools for future management of the lake and its resources, as well as meaningful basin monitoring plans. The information presented herein also provides a useful scientific database for updating future water quality modelling studies and increasing our understanding of how climatic changes are affecting relatively small aquatic ecosystems worldwide, especially eutrophic lakes located near known active geothermal areas, which may also influence aquatic biodiversity and which are vulnerable to colonization by water hyacinth.

MATERIALS AND METHODS

Description of study area

Lake Baringo is located between 00°30′N and 00°45′N, and 36°00′E and 36°10′E, lying ≈ 60 km north of the equator at an altitude of 975 m above sea level. Its surface area is small, compared to its catchment area of 6820 km^2. The lake is 21 km long by 13 km wide, with its depth varying from an average of about 3 m, to a maximum depth of ≈ 7 m at the deepest point, at high water levels.

The Molo and Ol Arabel are the main rivers flowing into the lake, with smaller inflowing tributaries being the Endao, Perkera and Mukutan Rivers. The lake has no known outflowing river. Groundwater linkages within the several Rift Valley lakes were previously examined by Betcht *et al.* (2005), with the lake water balances indicating groundwater outflows from freshwater Lake Naivasha and Lake Baringo, and groundwater inflows for all others. Lake Baringo waters remain fresh, despite lacking a surface outlet, having a shallow depth and the high net evaporation characterizing the Rift Valley floor. Although long debated (e.g. see Gregory (1921); Barton *et al.* (1987)), recent hydrological evidence supports the original suggestion by Gregory (1894) that some lake water is lost by seepage through the fracture lake floor, with Dunkley *et al.* (1993) estimating this outflow could exceed 10^8 m^3 $year^{-1}$.

The Lake Baringo catchment lies within an active tectonic setting with some recent volcanic activities. The catchment encompasses much of the volcanic highlands, including Mau Highlands to the southwest, Tugen Hills to the west, Holocene Korosi Volcano to the north and the Laikipia Border Fault Escarpment to the east. Most of the sediment production in the catchment is from steep slopes with erodible soils (Odada *et al.* 2006), including the foot slopes of Tugen hills around Cheberen and Tenges. The soil erosion rates in these areas are as high as 205.79 t ha^{-1} $year^{-1}$. Soil erosion is quite low in other areas, averaging 2.21 t ha^{-1} $year^{-1}$. The eroded soils are deposited on the flat lower reaches of the drainage basin and in the lake. There also is considerable aerial deposition of wind-driven dust particulate materials into the lake especially by the evening northeasterly winds.

According to Odada *et al.* (2006), sedimentation is considered the main threat to the lake. It slowly reduces both the depth and surface area of the lake, in addition to destroying aquatic animal habitats. Lake Baringo's most noticeable feature is its extreme turbidity, attributable mainly to incoming solid materials resulting from low vegetation cover related to deforestation and overgrazing (Odada *et al.* 2006; Lwenya & Yongo 2010). It is exacerbated by high intensity, sporadic rainfall on steep slopes. Two-thirds of the total catchment (8655 km^2) area have been used for grazing in recent years, with the rest of the land under agriculture. There is <1% forest. All the grazing area and two-thirds of the agricultural land are environmentally degraded, comprising almost 90% of the lake catchment. The Baringo District population is estimated to be 360 000, growing at an annual rate of ≈ 2.65%. Associated livestock numbers are correspondingly large, including ≈ 900 000 goats, 200 000 sheep and 300 000 cattle (Hickley *et al.* 2004). These features result in considerable concern regarding the sustainability of the lake ecosystem and its small fishery if its catchment degradation is not adequately addressed.

As a shallow, topographically closed basin that exhibits significant inter-seasonal hydrological influences, the chemical and physical environment of the lake water is a key to the exhibited in-lake ecological responses and may be a reliable indicator of both human impacts and wider climatic change influences. It is necessary, therefore, to better focus on identifying and analysing those variables signifying some form of ecological stress and which require further monitoring in view of the high potential of other hydrothermal solutions. Thus, to better understand the relationships involving aquatic production and the interactions among the species inhabiting these areas, accurate long-term data are required to make more reliable predictive solutions and beneficial management decisions for the dependent aquatic communities, as well as the sustainability of the Lake Baringo ecosystem as a whole.

Sampling programme

The lake was sampled from 13 to 19 December 2010. An extreme dry period, with flushes of precipitation during the short wet season, proceeded the sampling period, with a resultant reduced lake surface area. The rains normally lead to increased water inflows and lake surface area, sometimes accompanied by lakeshore flooding.

The lake was divided into three zones in the present study, namely southern, central and northern. Thirty-nine sampling sites were distributed equally within the three lake zones, each zone containing 13 sites (Fig. 1). The southern zone receives most of the freshwater river input into the lake and has several peripheral swamps, while the northern zone does not have any river water inputs. The central zone separates the above two zones, being

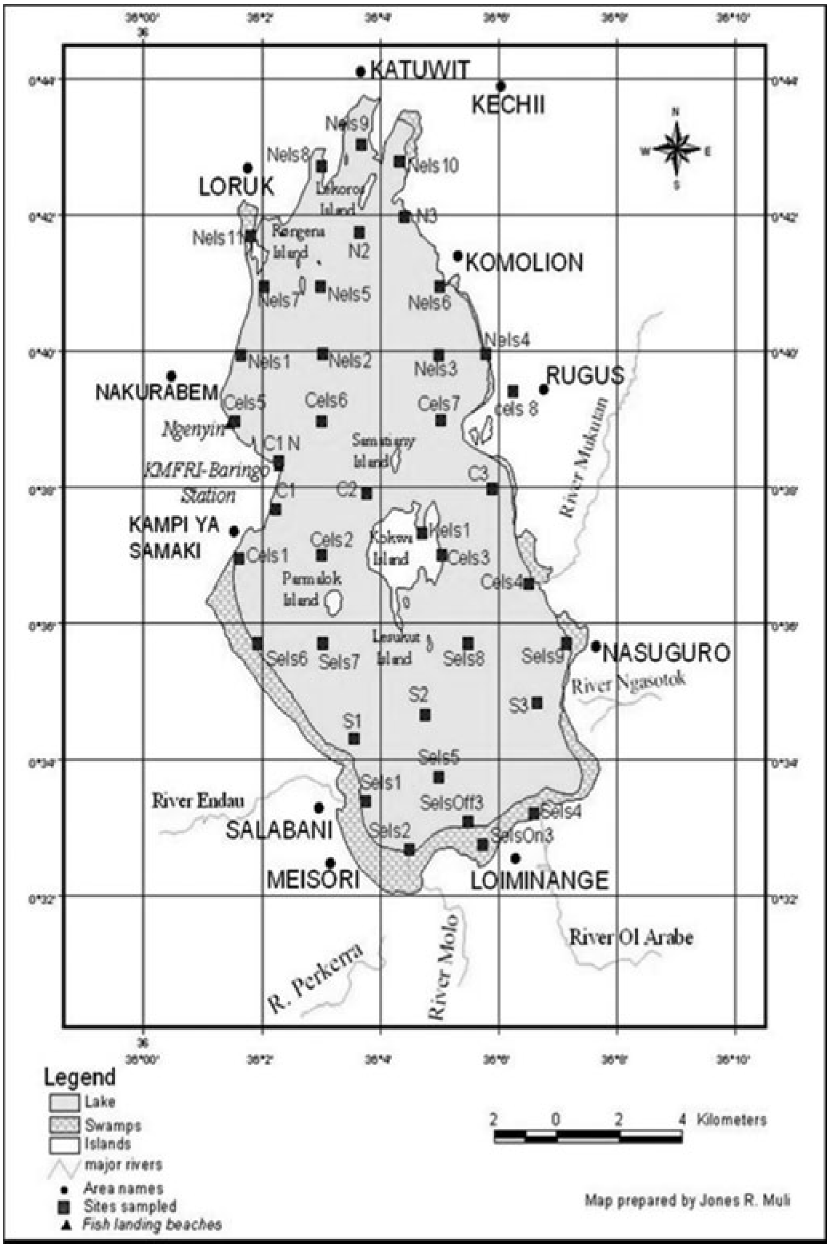

Fig. 1. Map of Lake Baringo and in-lake sampling sites, Kenya.

intermediate, and with several adjacent islands. Hot springs are known to exist on Kokwe Island.

Physicochemical measurements

Secchi depth (water transparency)

Light penetration into the water column was measured with a 25-cm-diameter Secchi disk with alternate white- and black-painted quadrants. The disc was lowered from the side of the boat away from the direct sunlight, with the depth of disappearance and reappearance taken from a calibrated lowering string.

In situ measurements

The maximum water depth was determined with a graduated weighted string, whereas the water temperature, dissolved oxygen concentration (DO), electrical conductivity, turbidity and pH were determined with a conductivity–temperature–depth (CTD) metre, fitted with a probe (CTD 90 Sea & Sun Technology® GmbH, Trappenkamp, Germany). Profiles of these parameters were made at 1-m-depth intervals at deeper sampling sites.

Laboratory analyses

Water samples were collected below the water surface (≈ 0.1 m) to avoid collecting floating particulate materials. A 50-mL portion of each water sample was immediately analysed for total alkalinity and total hardness by titration with 0.02 N HCl to a final pH of 4.5 and with 0.02 N EDTA, respectively (APHA 1985). An aliquot of the water sample was filtered through a membrane filter (0.45 μm pore size) for chlorophyll-a analysis. A few drops of magnesium carbonate slurry were added to the sample to facilitate filtration and to prevent the development of acidity during extraction. The filter papers were folded on adsorbent pads, put in labelled aluminium foil and kept in a darkened desiccator. Chlorophyll-a was extracted using acetone, and its absorbance was read at wavelengths of 750, 665, 640 and 630 nm on a spectrophotometer (Model Genesys 10S VIS, Thermoscientific, Madison, WI, USA).

Nutrients were analysed using the methods outlined by Wetzel and Likens (1991). The freshly collected water samples were filtered through membrane filters (0.45 μm pore size) to determine the soluble reactive nutrient species. Ammonium was determined with the phenol hypochlorite method, using nitroprusside as a catalyst. Nitrate and nitrite were measured with the cadmium reduction method. Total nitrogen (TN) was analysed with unfiltered water samples, via digestion with concentrated sulphuric acid (by autoclave procedure) to convert organic nitrogen to ammonium nitrogen (NH_4-N), with subsequent analysis for TN carried out, as outlined for NH_4-N. Phosphate phosphorus (PO_4-P) was measured with the ascorbic acid method.

For total phosphorus TP (analysis), the unfiltered water samples were oxidized with hot 5% potassium persulfate ($K_2S_2O_8$) in distilled water. The tubes (samples, standards and blanks) were autoclaved for 30 min. They were further cooled to room temperatures with the tube caps slightly loosened. The TP concentration was then determined using the methods described above for inorganic phosphate.

The total dissolved solids (TDS) concentrations were determined by filtering the water sample through a 47-mm GF/C filter paper (APHA 1985). The filtrate was evaporated slowly at 60 °C, with the resultant residues weighed to constant weight and recorded. The total suspended solids (TSS) concentrations were determined by filtering the water sample (0.45 m pore size), with the particulate matter retained on the filter paper dried in the same temperature regime and then weighed to constant weight (APHA 1985).

The biological oxygen demand (BOD_5) values were obtained by taking water samples in two known volume BOD bottles. One of the bottles was fixed and titrated immediately for dissolved oxygen concentration, while the other one was incubated for 5 days at room temperature, thereafter also being titrated for dissolved oxygen concentration. The difference between the two titrations is the biological oxygen demand (BOD_5) value for the water sample, noting that only a limited number of water samples were analysed for BOD_5 (i.e. southern zone – 4; central zone – 3; northern zone – 5).

The dissolved silica concentration was determined with the heteropoli-blue method (APHA 1985). A diluted water sample was treated with a 0.25 mol L^{-1} hydrochloric acid (HCl), followed by EDTA, ammonium molybdate and finally sodium sulphite solutions. The concentration of the yellow-coloured complex formed within 10 min was determined photometrically.

Statistical analysis

The correlations, means and standard deviations of the determined physicochemical parameters were calculated with Excel and SPSS statistical packages, where applicable (SPSS Inc., Armonk, NY, USA). Zonal comparisons were made using the mean values of the surface water data.

RESULTS

Figure 2(a–j) summarizes the mean (± standard deviation) values of the measured physicochemical parameters for the three lake zones. The total sampled water depth ranged from 1.6 to 6.6 m, with a mean value of 4.9 m, confirming the shallowness of the lake basin. Thus, most of the measured parameters did not reveal any significant differences among the three zones samples, or between the surface, 1 and 2 m water depths. Inter-zonal data indicate the lake deepens in a northward direction, with a mean water depth ranging from 4.3(southern end) to 5.5 m (northern end). The water turbidity decreased with increasing sampling site depth (Fig. 2a). The water temperature ranged from 19.7 to 28.8 °C, with a mean value of 26.5 °C. The inter-data (Fig. 2b) indicate the lowest mean temperature value that was measured in the central zone (26.0 °C), while the highest value was recorded in the southern zone (27.1 °C).

The DO concentrations ranged from 4.5 to 8.4 mg L^{-1}, with a mean value of 6.9 mg L^{-1}. Relatively lower levels were observed in the northern end (Fig. 2c). The DO concentrations in the surface water and the 1 and 2 m depths were different at $P < 0.05$ significance level ($F_{0.05;\ 2,\ 36}$; $P = 2.8 \times 10^{-6}$, $n = 39$). The DO concentrations exhibited a relatively high correlation with turbidity

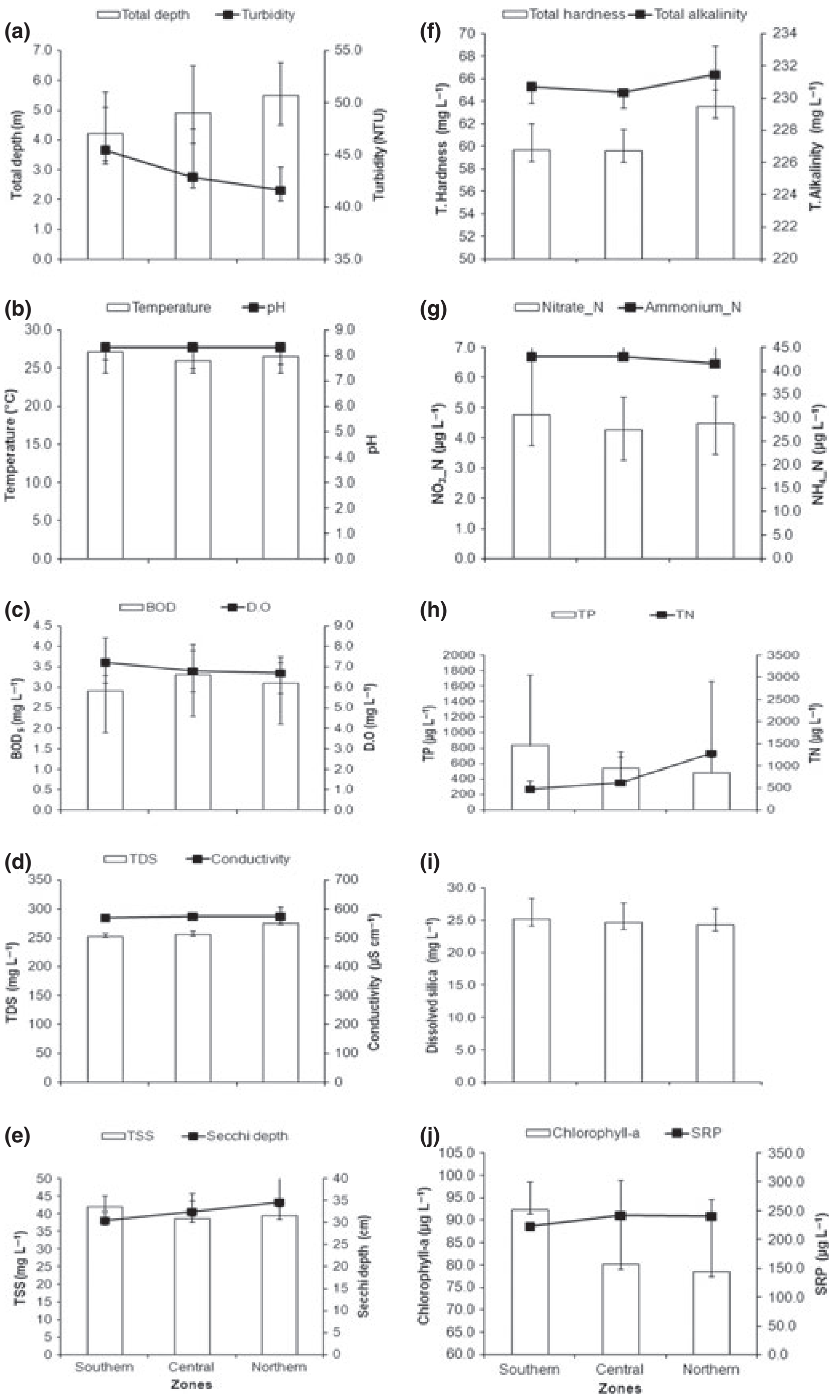

Fig. 2. (a–j) Summary of mean (±standard deviation) values of measured physicochemical parameters for the three lake zones in Lake Baringo.

levels (*r* = 0.59). The BOD_5 concentrations (Fig. 2c) ranged from 2.4 to 3.8 mg L^{-1}, with a mean of 3.3 mg L^{-1}. It is noted that only a limited number of water samples (*n* = 12) were analysed for BOD. The inter-zonal data indicated the central zone of the lake had increased BOD_5 concentrations (3.3 mg L^{-1}), compared to 2.9 mg L^{-1}, in the southern end, and 3.1 mg L^{-1} for the northern zone, being attributed to the human and animal occupation of the islands, all of which are located in the central part of the lake (Fig. 2c).

The pH values ranged from 7.8 to 8.5, with a mean value of 8.3. The parameter varied only marginally across the three lake zones (Fig. 2b), with mean values of 8.3 for all three lake zones. The electrical conductivity values ranged from 556 to 601 μS cm^{-1}, with a mean value of 573 μS cm^{-1}. The southern zone exhibited a relatively lower mean conductivity (570 μS cm^{-1}), while the central

Table 1. Pearson correlation coefficients (*r*) between surface water parameters and nutrient concentration in Lake Baringo

	TN	NO_3N	NH_4N	TP	SRP	SiO_2	Chla
Depth (m)	0.22	0.14	0.15	−0.00	0.11	−0.21	0.26
Temperature (°C)	0.14	−0.051	−0.16	0.15	0.087	−0.052	−0.004
DO	0.077	−0.001	−0.33*	0.17	0.30	−0.038	0.24
BOD_5	−0.50	−0.62	−0.12	0.30	−0.37	−0.22	−0.11
pH	0.068	0.090	−0.012	0.36	−0.093	−0.37*	0.48**
Conductivity	−0.10	−0.17	−0.32*	−0.21	−0.032	0.013	−0.59**
Secchi depth	0.34	0.12	−0.093	−0.42*	0.34	0.090	−0.33
Turbidity	−0.22	0.073	0.19	0.12	0.19	−0.022	0.40*
TSS	−0.32	0.062	0.24	0.005	−0.33*	0.38*	0.07
TDS	−0.053	0.15	−0.084	−0.068	0.077	0.11	−0.10
Hardness	0.30	−0.036	−0.22	−0.22	−0.20	−0.12	−0.44**
Alkalinity	0.24	0.34*	−0.19	0.011	0.034	−0.11	0.077

* and ** indicate significant correlation ($P < 0.05$; $P < 0.01$) using 0.05 and 0.01 significance level (two-tailed test); $n = 39$, except for BOD_5 where $n = 12$; TN, total nitrogen; NO_3N, nitrate-nitrogen; NH_4N, ammonia nitrogen; TP, total phosphorus; SRP, soluble reactive phosphorus; SiO_2, silica; Chla, chlorophyll-a; DO, dissolved oxygen; BOD_5, biochemical oxygen demand; conductivity, electrical conductivity; TSS, total suspended solids; TDS, total dissolved solids.

and northern zones had similar values of 575 and 574 μS cm^{-1}, respectively. The electrical conductivity in the surface water and at the 1 and 2 m depths were different at $P < 0.05$ significance level ($F_{0.05;\ 2,\ 36}$; $P = 2.7 \times 10^{-22}$, $n = 39$).

The inverse relationship (correlation coefficient = −0.23) between the Secchi depth and turbidity (Table 1) was evident. The water transparency values ranged from 28 to 37 cm, with a mean value of 33 cm. The values were found to be significantly different in the three zones ($F_{0.05;\ 2,\ 36}$; $P = 0.01$, $n = 13$). The water transparency exhibited a relatively high correlation ($r = 0.60$) with water depth. The turbidity values ranged from 32.7 to 54.6 NTU, and a mean value of 43.3 NTU. The mean zonal water turbidity decreased in a north-to-south direction. Similarly, the Secchi depth measurements also exhibited an increasing trend from south to north.

The total dissolved solids and total suspended solids concentrations ranged from 242 to 354 mg L^{-1}, and 28 to 52 mg L^{-1}, respectively, with mean values of 261 and 40 mg L^{-1}, respectively. The zonal comparison indicates a south-to-north increasing trend for TDS, whereas the TSS (Fig. 2d,e) exhibited a reducing trend, except for a slightly higher value of 39.4 mg L^{-1} in the northern zone, compared to the central zone mean value of 39 mg L^{-1}. Only the zonal TDS concentrations were significantly different ($F_{0.05;\ 2,\ 36}$; $P = 0.00$, $n = 13$). The TSS concentrations exhibited very low, but positive, correlations with the water turbidity ($r = 0.026$) and TDS ($r = 0.011$).

Figure 2f highlights the changes in the total water hardness and alkalinity, which ranged from 55 to 71 mg L^{-1} (mean of 61 mg L^{-1}), and 211 to 257 mg L^{-1} (mean of 231 mg L^{-1}), respectively. Both of these parameters exhibited an anticipated south-to-north increasing trend, as they coexist in concomitant proportions in natural freshwater environments. The total water hardness values were significantly different ($F_{0.05;\ 2,\ 36}$; $P = 0.01$, $n = 13$) in the three lake zones.

The NO_3-nitrogen concentrations ranged from 2.4 to 10.0 μg L^{-1}, with a mean value of 4.5 μg L^{-1}. The NH_4-N concentration ranged from 33.8 to 56.3 μg L^{-1}, with a mean value of 42.6 μg L^{-1}. A similar level of ammonium nitrogen in all the lake zones was noted in the zonal comparison, being 43.1 μg L^{-1} in the south zone, 43.2 μg L^{-1} in the central zone and 41.6 μg L^{-1} in the north zone. The zonal comparison data (Fig. 2g) also indicate similar NO_3-N levels in all three lake zones, ranging from 4.7 μg L^{-1} in the southern zone to 4.3 μg L^{-1} in the central zone. The total nitrogen concentration exhibited a comparatively high range of 278 to 4,486 μg L^{-1}, with a mean value of 788 μg L^{-1}. Four of the 39 water samples examined for TN (one from central zone, C1; the other three from the northern zone, Nels 6, N2 and N3) exhibited very high concentrations (2914 μg L^{-1}, 3926 μg L^{-1}, 3926 μg L^{-1} and 4486 μg L^{-1}, respectively), compared to the other results, all being far <1000 μg L^{-1}. The TP concentration range was 20–585 μg L^{-1}, with a mean of 103 μg L^{-1}. The zonal comparison (Fig. 2h) indicated a south-to-north decreasing trend for total phosphorus from 139 to 80 μg L^{-1}. The SRP concentration range was 15.2–30.5 μg L^{-1}, with a mean of 23.5 μg L^{-1}. The zonal comparison indicates SRP (Fig. 2j) increases in a northward direction, from 22.3 μg L^{-1} in the south to 24.2 μg L^{-1} in the central and 24.1 μg L^{-1} in the north zone. The dissolved silica concentration ranged from 19.7 to 32.7 mg L^{-1}, with a mean of 24.7 mg L^{-1}. The mean zonal comparison indicated a reducing silica level (Fig. 2i) in the south-to-north direction, progressing from 25.1 mg L^{-1} in the south to 24.3 mg L^{-1} in the north.

The phytoplankton biomass, expressed as the chlorophyll-a concentration, ranged from 1.4 to 4.9 μg L^{-1}, with a mean value of 4.2 μg L^{-1}. The pH showed a relatively high correlation with the chlorophyll-a concentration ($r = 0.48$). Chlorophyll-a is a parameter in the present study that exhibited a similar level of almost all values in all the lake zones, although a south-to-north decreasing progression trend from 4.4 μg L^{-1} in the south, to 3.9 μg L^{-1} in the north, is detectable.

DISCUSSION

Lake Baringo experiences extreme effects of high solar radiation during the dry seasons. The key factor influencing the surface water temperature in this semi-arid zone was the sampling time. In May and August 2000, Oduor *et al.* (2003) observed that temporal variations in most of the limnological variables were related to the hydrological regime and climate conditions, although no significant diel patterns could be detected in these variables, except for temperature and dissolved oxygen concentration. According to Ngaira (2005), the lake has become slightly saline due to high evaporation rates caused by high temperatures that reach 39 °C. Evaporation is extremely high in this region, ranging between 2100 and 2800 mm annually (Ngaira 2005). The depth of the lake decreased from 5 m in 1978 to 1.7 m in 1995, due to prolonged drought spells and water abstractions, attributable to the changing climate trends towards drier conditions (Ngaira 2005). Such observed periodic changes are supported by the other historical evidence from stratigraphic records, which reveal the presence of two abrupt dry episodes at ≈ AD 1650 and AD 1720 in East Africa that led to drying up of the lake (Kiage & Kam-biu 2009). The record also shows evidence of a third period of desiccation at ca. AD 1880, resulting in lowering of the lake water level (Kiage & Kam-biu 2009).

The southern zone of the lake is more active biologically, compared to the rocky lined northern shores. Macrophyte-lined zones and rocky areas are both suitable as fish breeding areas, which also attract other fish predators. Terrestrial-littoral vegetated southern shores are sources of organic material from plant detritus, etc., with extra organic loads from both river and surface runoff contributing oxygen-demanding loads capable of influencing the water DO concentrations. Variations could easily be accounted for, however, by the diel photosynthesis process.

Since most of the permanent inflowing rivers are connected to the lake at the southern zone, a significant quantity of suspended particulate material being loaded to the lake through these river channels is expected. Extra particulate materials also enter through aerial deposition and the open, un vegetated rocky edges of the lake. Based on previous studies, and the present study, lake and river waters were found to contain variable TSS concentrations. According to Tarits *et al.* (2006), the permanent rivers and lake water exhibited similarly large masses of suspended sediments, up to 800 mg L^{-1}, with organic matter accounting for 30.7% of the total sediment in the lake water. A deviation in the current TSS concentration is attributed mainly to the sampling in the present study during the dry period.

Lake Baringo is similar to other arid zone freshwater lakes wherein the pivotal role of hydrology and high evaporative losses (Brian 2001) is evident, in addition to the potential geothermal influences. In addition to maintaining higher lake water levels, inflow streams also are important in moderating hypersaline conditions developing during periods of low rainfall and high evaporation (Odhiambo & Gichuki 2000). As river water mixes with lake water, changes in lake water physical characteristics may be more pronounced in the south than the northern side, often being due to wind-induced turbulent movements. Towards the north, the lake water appears clearer, due to settling of suspended particles in the water column, compared to the immediate zone of river – lake interactions in the south. According to the findings of Hickley *et al.* (2004), Secchi depth measurements for Lake Baringo over the past 20 years have been in the range of 3.5–13 cm. The period of greatest water transparency was in 1998, following the El Nino rains. Kallqvist (1987) recorded 5–7 cm in 1976–1977 and 20 cm in 1979. The 1979 value was the same as that reported by Beadle (1932) for 1931. The comparative Secchi depth measurement in August 2003 reading was ≈ 3 cm. This observation highlights the fact that the Secchi disk measurements in the present study are significantly above those obtained in the past, with the turbidity values also remaining among the lowest. This could be due partly to the dry spell prevailing in the lake environment in the period prior to and up to the sampling time of the present study. Further, it appears the lake water column is getting clearer over time.

The lake was sampled in dry weather, thereby receiving reduced surface inflows of nutrients from the catchment. Moreover, much of the immediate surrounding catchment area exhibits a relatively low usage of fertilizers, as commercial agriculture is not widely practiced around the lake. This results in low nitrate inflows into the lake, apart from the irrigation scheme on the southern tip. Some previous workers obtained higher mean levels of NO_3-N for Lake Baringo than observed in the present study, including 169 μg L^{-1} (Oduor *et al.* 2003) and 104 μg L^{-1} (Muli *et al.* 2007).

Nutrients occur in surface waters in various concentrations, in either dissolved or particulate forms, and as inorganic or organically bound species. There could be a nitrogen-loading source in the northern part of the lake, especially organic nitrogen from the forest vegetation surrounding the lake. Thus, further investigation, with a view to establish whether or not the nitrogen source can be identified or confirmed, is warranted. Considering the mean total nitrogen concentration in the lake water is 788 μg L^{-1}, while the combination of the mean values of nitrate and ammonium nitrogen only total about 47.1 μg L^{-1}, the need to further establish in what form most of nitrogen exists is evident. There is also a need to find the concentration of organic nitrogen, as well as the nitrite form of nitrogen, in Lake Baringo.

The measured dissolved (SRP) concentrations in Lake Baringo (mean and standard deviation 24.9 ± 8.3 to 59.7 ± 38.5 μg L^{-1}; Sitoki *et al.* (2010)) to values obtained in other larger lake ecosystems, for which overall TP values of 83.7 ± 65.1 to 96.1 ± 27.9 μg L^{-1} (Mugidde *et al.* 2005) and 82.6 ± 0.7 to 164.0 ± 15.5 μg L^{-1} (Kishe 2004) were reported. The dissolved silica concentration range in the present study was above levels previously reported by Oduor *et al.* 2003 (15 mgL^{-1}) and Muli *et al.* 2007 (7.05 mg L^{-1}). Tarits *et al.* (2006), however, reported similar dissolved silica concentrations (0.2 μm filtered lake water) ranging from 16.0 to 23.6 mg L^{-1}, similar to those reported for Lake Baringo. The suspended sediment P and silica contents in the lake and river water ranged from 0.10 to 0.13% P, and 52.3 to 52.8% SiO_2, respectively (Tarits *et al.* 2006). Tarras-Wahlberg *et al.* (2002) also reported values of 0.09–0.24% P, and 49–61% SiO_2 in sediments of inflowing rivers for Lake Naivasha. Studies conducted in 2003 to the present on Lake Baringo indicate TP concentrations ranging between 164.5 and 1646.5 μg L^{-1}. Most phosphorus in freshwaters is in a particulate phase of living biota, primarily algae and higher aquatic plants, with part of the colloidal and particulate fraction being lost by the productive zone by sedimentation, and part being hydrolysed to soluble orthophosphate (Wetzel & Likens 1991). Total phosphorus concentrations in waters can range from < 0.01 mg L^{-1} in small near pristine mountain streams to over 1 mg L^{-1} in heavily polluted rivers (Hart *et al.* 1992). In-lake chemical processes, exchanges and the external inflow of particulate materials most likely play an important role in defining the chemical composition of lake waters, especially in regard to nutrient levels, with eutrophication of the water system being sustained from diverse nutrient sources in the catchment. In the north-to-south progression for Lake Baringo, however, phosphorus in its various forms may become increasingly assimilated by the ongoing metabolic processes in the lake, thereby being removed from the water column.

The phytoplankton biomass, expressed as chlorophyll-a concentration, exhibited almost similar concentration in all three zones in Lake Baringo, with a decreasing trend as one moved northwards. It also is noted that the southern zone exhibited more increased temperatures during the sampling period. Thus, the chlorophyll-a concentration could be attributed the higher temperature regime in the zone. Schagerl and Oduor (2003) previously reported mean chlorophyll-a concentration of 55 μg L^{-1}, as well as a low diversity of algae and cyanobacteria in Lake Baringo. A high level of light penetration of 70 ± 10–240 ± 10 cm (Kishe 2004; Sitoki *et al.* 2010) has been reported for large and deeper inland lakes. In the inshore areas, where the water conditions may approximate existing conditions in Lake Baringo, the chlorophyll-a concentration was much higher, ranging from 10.8 ± 6.7 to 16.8 ± 8.6 μg L^{-1}. Other relatively clear Rift Valley freshwater lakes with characteristics similar to Lake Baringo exhibited water transparency values ranging from 40 to 130 cm, which may mean the primary productivity is still relatively lower, due to lowered light penetration into the water column (i.e. reduced photic zone) because of highly turbid waters, even though high nutrient concentrations were also noted.

The nutrient concentrations in Lake Baringo exhibited only low correlations with some lake water physical and chemical characteristics (Table 1). Based on previously monthly data, however, increased dissolved nutrient concentrations were seen at the inset of rains and flooding from May to June (Odhiambo & Gichuki 2000), with the natural drawdown areas being flooded, as well as plant nutrients from grass and dung being rapidly released into the water. A comparison between previous data and the current study results supports the known phenomenon of shallow lake responses to seasonal influences and climatic conditions of the area. Ballot *et al.* (2003) also reported high mean total phosphorus (1.0 mg L^{-1}) and mean total nitrogen concentrations (2.8 mg L^{-1}) typical of hypertrophic lakes. Based on TP concentrations, and the lake classification scheme of Vollenweider (1968), as modified by Wetzel (1983), the lake is still eutrophic. The N:P ratio also can be used to indicate the phytoplankton nutrient status of a water body. According to Guildford and Hecky (2000), a TN:TP ratio <20 indicates the maximum phytoplankton biomass is normally nitrogen-limited, while cases in which the ratio is >50 indicates the phytoplankton will likely be phosphorus-limited. Total nitrogen and TP ratios in Lake Baringo were highly variable, with the TN:TP ratio ranging from 0 to 5 at most sampling sites. The highest ratio, found only for three in-lake sites, was 10–11. Neither the low TN:TP ratio nor the low dissolved inorganic N:SRP ratio can explain the dominance of the non-nitrogen fixing algae, *Microcystis* (Sitoki *et al.* 2012). It is possible that physical factors, such as the relationship of the euphotic zone to the mixing depth, and/or variations in turbidity (organic and mineral seston), rather than TN:TP ratios, regulate phytoplankton composition in the lake. In fact, it is likely that *Microcystis* has an advantage over *Anabaena* in shallow waters under turbid and polymictic conditions, and even under N-limiting conditions (Sitoki *et al.* 2012). Under nitrogen-limited conditions, phytoplankton species with the ability to fix inorganic di-nitrogen from the atmosphere normally have an advantage over other algal species, therefore dominating the phytoplankton composition in the lake (Guildford *et al.* 2003; Mugidde *et al.* 2003). *Microcystis aeruginosa* is the most common potential toxic cyanobacterium in freshwater lakes (Kotut *et al.* 2006; Sitoki *et al.* 2012), including Lake Baringo, being dominant for a large part of the year (Kotut *et al.* 2006). Accordingly, special attention must be given to phosphorus as an important nutrient for cyanobacterial dominance (Kotut *et al.* 2006).

The zooplankton community structure and distribution pattern in the lake are largely related to both physicochemical and biotic conditions prevailing in different ecological habitats. Recent evidence for this conclusion was provided by (Omondi 2011), who reported a number of environmental parameters being correlated with the abundance of different zooplankton species, as well as a significant difference in zooplankton abundances between the sampling sites ($P < 0.001$) and among sampling months ($P < 0.001$).

CONCLUSIONS

The most important finding of the present study is the relatively high water transparency and the lowest ever-recorded turbidity for Lake Baringo, noting the sampling period coincided with dry conditions around the lake. Notwithstanding the above findings, previous studies have established that Lake Baringo productivity has been hindered by the prevailing inorganic turbidity in the surface water, coupled with low nutrient availability which, as witnessed in this study (i.e. low NO_3 levels), are possible causes for the lake's low fish productivity, especially tilapines (Kallqvist 1987; Schagerl & Oduor 2003).

The mean values of TDS, pH, NO_3-N, total NO_3-N + NH_4-N and PO_4-P in Lake Baringo water are within maximum allowable concentrations and guidelines used by various organizations (UK 1984; ANZECC 1992; WHO 1993; EMCA 2006) to evaluate drinking water quality. The mean turbidity and TSS concentrations, however, exceed EC standards (Chapman 1992) for the protection of aquatic life. The overall mean concentration data indicate some physicochemical variables in Lake Baringo water were more prone to variations than others (e.g. TN and TP). The underlying causes for the high variations of these particular elements will become more evident with more comprehensive surveys other than during the dry period. Although the spatial coverage of sampling sites was considered adequate, the lakes need further investigation of these findings, including the reasons they occurred, and especially the possible influence of eroded animal manure from grazing livestock, internal nutrient sources and exchanges in the relatively small, closed basin of Lake Baringo.

The results of the present study indicate the two nitrogen species examined (NH_4 and NO_3) only comprises ≈ 6% of the total nitrogen (TN), while the soluble phosphate (PO_4) is only about 23% of the total phosphorus (TP). This indicates a serious need to determine the other nutrient species in Lake Baringo (i.e. nitrite and organic forms of nitrogen; suspended and organic forms of phosphorus) and the possible long-term temporal influences.

RECOMMENDATIONS

Lake Baringo is a shallow lake, being only ≈ 6.7 m at its deepest point, based on the present study. It is still among the few freshwater sources in the semi-arid northern section of the eastern arm of the Rift Valley, however, being located in an area with a unique geological setting and a high potential for geothermal development. The lake water is often greatly influenced by high seasonal fluctuations in water inflows and high evaporation due to the shallowness of the topographically closed basin. The extreme climatic conditions appear to augment the magnitude of the changes in hydrological flows and the limnological conditions. Thus, the changing lake water level is likely to affect important littoral macrophyte-lined fish breeding zones. Water hyacinth was not a problem in most of the Rift Valley lakes prior to 1980. Lakes Victoria and Naivasha currently support large mats of the water weed, however, with significant economic and ecological impacts. Due to the close proximity of the two small freshwater lakes, namely Lakes Naivasha and Baringo, it is necessary to monitor the spread and proliferation of such weeds in these surface waters. Monitoring the sources and dynamics of nutrient influxes also will aid in developing appropriate measures for managing such invasive species (e.g. water hyacinth) and for understanding aquatic species biodiversity, especially in areas in close proximity to geothermal waters. The Lake Baringo fishery also is characterized by stunting of tilapines and by low species diversity. This sensitivity and high vulnerability of the lake ecosystem must be considered when conducting any future monitoring surveys, to establish meaningful seasonal influences or patterns and sources of nutrient loadings, especially from the already-established, GIS-marked lake-wide sampling sites. Thus, it is recommended that the lake bathymetry be updated and that studies directed to sediment P bioavailability and more nutrient species (especially nitrite-N, organic-N, suspended and organic forms of phosphorus) be undertaken to identify the major sources of the highly variable TN and TP concentrations in the lake.

Although several studies have been conducted to document the aquatic ecology of Lake Baringo, only a few of these studies have attempted to document meaningful data that will enable better understanding of some of the ecological problems of the lake, especially low fish production and low aquatic species diversity.

Scattered information on the wider catchment does exist, but is not well integrated with lake monitoring studies. Further, no previous continuous lake monitoring has been undertaken, other than some localized surveys and reports. Catchment influences are thought to be of significance because of the high vulnerability of surrounding areas to the impacts of different human activities and natural erosional processes of loose surface soils. These elements are valuable sources of important nutrients that can cause increasing eutrophication of inland lakes, as well as being a factor influencing primary productivity and the development of cyanobacterial blooms. Continuous monitoring of nutrients in surface waters will assist mangers, researchers and other lake stakeholders to better understand the subsequent ecological changes within the lake waters, as well as other influences on the aquatic biodiversity, fish production and sustainability of the Lake Baringo ecosystem.

Information on lake water quality changes also is of value in lake basin modelling, lake and basin monitoring plans, maintenance of good freshwater quality and development of specific biological indicators, particularly when integrated with other relevant ecological information and data. Efforts to developing and managing other water-related resources in the area also will benefit from long-term documented information and data regarding Lake Baringo and its inflowing rivers, as well as similar water systems in the region. Planting trees in the high-altitude catchment areas drained by the two permanent rivers is both a national and community concern in restoring the river water sources. Similar small shallow fresh water lakes in semi-arid areas elsewhere, which are considered highly vulnerable ecosystems, but which exhibit a potential fishery, can benefit from the results of such studies, particularly if they exhibit related water quality problems. Ecological changes also can be a good indicator of both ambient environmental degradation and wider climatic changes.

ACKNOWLEDGEMENTS

The authors wish to acknowledge financial support from the Director, KMFRI, under the Lake Baringo expeditions, and the KMFRI technical staff for the collection and analysis of samples during the study. Thanks also are due to the KMFRI-Kampi Ya Samaki Station Coordinator and Lake Baringo Research Expedition (LABRE) project coordinator, for their assistance and coordination of the expeditions. Special thanks are also due to all those who reviewed this manuscript.

REFERENCES

ANZECC (1992) Australian water quality guidelines for fresh and marine waters, Australian and New Zealand Environment and Conservation Council 1992.

APHA (1985) Standard Methods for the Examination of Water and Wastewater, 16th edn. American Public Health Association, (APHA), American Water Works Association (AWWA) and American Pollution Control Federation (WPCF), Washington DC, USA.

Ballot A., Pflugmacher S., Wiegand C., Kotut K. & Krienitz L. (2003) Cyanobacterial toxins in Lake Baringo, Kenya. *Limnologica*. **33**, 2–9.

Ballot A., Kotut K., Novelo E. & Krienitz L. (2009) Changes of phytoplankton communities in Lakes Naivasha and Oloidien, examples of degradation and salinization of lakes in the Kenyan Rift Valley. *Hydrobiologia* **632**(1), 359–63.

Barton C. E., Solomon D. K., Bowman J. R., Cerling T. E. & Sayer M. D. (1987) Chloride budgets in transient lakes: Lakes Baringo, Naivasha and Turkana. *Limnol. Oceanogr.* **32**, 745–51.

Beadle L. C. (1932) Scientific results of the Cambridge Expedition to the East African Lakes, 1930-1.—4. The waters of some East African Lakes in relation to their fauna and flora. *J. Linn. Soc. London, Zool.* **38**, 157–211. doi:10.1111/j.1096-3642.1932.tb00699.x.

Betcht R., Mwango F. & Munro F. A. (2005) Groundwater links between the Kenyan rift valley lakes. In: Proceedings,11th World Lake Conference, Nairobi, Kenya. 31 October to 4 November 2005, Volume II, Ministry of Water and Irrigation, International Lakes Environment Committee, ILEC (eds. E. O. Odada, D. O. Olago, W. Ochola, M. Ntiba, S. Wandiga, N. Gichuki & H. Oyieke) pp. 7–14. Nairobi, Kenya.

Brian V. T. (2001) Large freshwater lakes in Australia: A review of their limnology and threats to their future. *Lakes Reserv.: Res. Manag.* **6**(2), 183–96.

Chapman D. (1992) Water Quality Assessments. A Guide to the use of Biota, Sediments and Water in Environmental Monitoring, 1st edn. (ed. D. Chapman) UNESCO, WHO, UNEP, Chapman & Hall, London.

Dunkley P. N., Smith M., Allen D. J. & Darling W. G. (1993) The geothermal activity and geology of the northern sector of the Kenya rift valley. British Geological Survey Research Report SC/93/1, Keyworth Nottingham, United Kingdom.

EMCA (2006) National Environmental Management Authority, Environmental Management and Coordination Act, (Water Quality) Regulations 2006, Nairobi, Kenya.

Gregory J. W. (1894) Contributions to the physical geography of British East Africa. *Geogr. J.* **4**, 289–315.

Gregory J. W. (1921) The rfit valleys and geology of East Africa. Seeley Service London.

Guildford S. J. & Hecky R. E. (2000) Total Nitrogen, total phosphorus and nutrient limitation in lakes and oceans. *Limnol. Oceanogr.* **6**, 1213–23.

Guildford S. J., Hecky R. E., Taylor W. E., Mugidde R. & Bootsma H. A. (2003) Nutrient enrichment experiments in tropical Great Lakes Malawi/Nyasa and Victoria. *J. Intern. Great Lakes Res.* **29**(2), 89–106.

Hart B. T., Freeman P. & McKelvie I. D. (1992) Whole–stream phosphorus release studies: Variation in uptake length with initial phosphorus concentration. *Hydrobiologia* **235–236**(1), 573–84.

Hecky R. E., Bugenyi F. W. B., Ochumba P. *et al.* (1994) The deoxygenation of Lake Victoria. *Limnol. Oceanogr.* **39**, 1476–81.

Hickley P., Muchiri M., Boar R. *et al.* (2004) Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya. *Ecohydrol. Hydrobiol.* **4**(4), 503–17.

Hubble D. S. & Harper D. M. (2002) Impact of light regimen and self-shading by algal cells on primary productivity in the water column of a shallow tropical lake (Lake Naivasha, Kenya). *Lakes Reserv.: Res. Manag* **6** (2), 143–50.

Kallqvist T. (1987). Primary production and phytoplankton in Lake Baringo and Lake Naivasha, Kenya. Norwegian Institute for Water Research report: 59 pp.

Kiage L. M. & Kam-biu L. (2009) Paleoenvironmental changes in the Lake Baringo basin, Kenya, East Africa sSince AD 1650: Evidence from the paleorecord. *Prof. Geogr.* **61**(4), 438–58.

Kishe M. A. (2004) Physical and chemical characteristics of water in selected locations in Lake Victoria Tanzania. *Tanz. J. Sci.* **30**(2), 65–72.

Kotut K., Ballot A. & Krienitz L. (2006) Toxic cyanobacteria and their toxins in standing waters of Kenya: Implications for water resource use. *J. Water Health* **4**(2), 233–45.

Lwenya C. & Yongo E. (2010) Human aspects of siltation of Lake Baringo: Causes, Impacts and Interventions. *Aquat. Eco. Health Manag.* **13**(4), 437–41.

Mergeay J., Declerck S., Verschuren D. & de Meester L. (2005) Daphnia community analysis in shallow Kenyan lakes and ponds using dormant eggs in surface sediments. *Freshwater Biol.* **51**(93), 399–411.

Metcalf J. S., Morrison L. F., Krienitz L. *et al.* (2006) Analysis of the cyanotoxins anatoxin-a and microcystins in Lesser Flamingo feathers. *Toxicol. Env. Chem.* **88**, 159–67.

Mugidde R., Hecky R. E., Hendzel L. L. & Taylor W. D. (2003) Pelagic nitrogen fixation in Lake Victoria (East Africa). *J. Great Lakes Res.* **29**(2), 76–83.

Mugidde R., Gichuki J., Rutagemwa D., Ndawula L. & Matovu A. (2005) Status of water quality and its implication on fishery production. *In: LVFO 2005. The state of the fisheries resources of Lake Victoria and their management: Proceedings, Entebbe Regional Stakeholders Conference, 24–25 February 2005, Entebbe, Uganda. ISBN: 9970-713-10-2.*

Muli J. R., Getabu A., Gichuki J., Wakwabi E. & Abila R. (2007) Lake Baringo Research Expedition (LABRE), KMFRI/LABRE/Technical Report 2, xxi+107 pp.

Muyodi F. J., Hecky R. E., Kitamirike J. M. & Odong R. (2009) Trends in health risks from water related diseases and cyanotoxins in Ugandan portion of Lake Victoria basin. *Lakes Reserv.: Res. Manage.* **14**, 247–57.

Ngaira J. K. (2005) Implications of climate change on the management of Rift Valley lakes in Kenya: The case of lake Baringo. In: Proceedings, 11th World Lake Conference, Ministry of Water and Irrigation Kenya and International Lakes Environment Committee, (ILEC), Volume II, Nairobi Kenya, 31 October to 4 November 2005. (eds E. O. Odada, D. O. Olago, W. Ochola, M. Ntiba, S. Wandiga, N. Gichuki & H. Oyieke) pp. 133–8. Nairobi, Kenya.

Odada E. O., Onyando J. O. & Obudho P. A. (2006) Lake Baringo: Addressing threatened biodiversity and livelihoods. *Lakes Reserv.: Res. Manag.* **11**(4), 287–99.

Odhiambo W. & Gichuki J. (2000) Seasonal dynamics of the phytoplankton community in relation to environment in Lake Baringo, Kenya (impact on the Lake's resource management). *Afr. J. Trop. Hydrobiol. Fish.* **9** (1/2):1–16.

Oduor S. O. & Schagerl M. (2007) Temporal trends of ion contents and nutrients in three Kenyan Rift Valley saline–alkaline lakes and their influence on phytoplankton biomass. *Hydrobiologia* **584**(1), 59–68.

Oduor S. O., Schagerl M. & Mathooko J. M. (2003) On the limnology of Lake Baringo (Kenya): I. temporal physico-chemical dynamics. *Hydrobiologia* **506–509**, 121–7.

Omondi R. (2011) Spatial and temporal variations of zooplankton in relation to some environmental factors in Lake Baringo, Kenya. *Egerton J. Sci. Technol.* **11**, 29–50.

Onyando J. O. (2003) Soil Erosion hazard assessment of River Perkerra Catchment. 36 Consultancy Report submitted to UNOPS.

Onyando J. O., Kisoyan P. & Chemelil M. C. (2005) Estimation of potential soil erosion for river Perkerra Catchment in Kenya. *Water Resour. Manage* **19**(2), 133–43.

Owen R. B., Renaut R. W. & Jones B. (2008) Geothermal diatoms: A comparative study of floras in hot spring systems of Iceland, New Zealand, and Kenya. *Hydrobiologia* **610**(1), 175–92.

Oyoo-Okoth E., Muchiri M., Ngugi C. C. *et al.* (2011) Zooplankton partitioning in a tropical alkaline–saline endorheic Lake Nakuru, Kenya: Spatial and temporal trends in relation to the environment. *Lakes Reserv.: Res Manage.* **16**(1), 35–47. doi:10.1111/j.1440-1770.2011.00461.x.

Patterson G. & Kiplagat K. W. (1995) The influence of the diel climatic cycle on the depth-time distribution of phytoplankton and photosynthesis in a shallow equatorial lake (Lake Baringo, Kenya). *Hydrobiologia* **304**(1), 1–8.

Schagerl M. & Oduor S. O. (2003) On the limnology of Lake Baringo (Kenya): II. Pelagic primary production and algal composition of Lake Baringo, Kenya. *Hydrobiologia* **506–509**, 297–303.

Sitoki L., Gichuki J., Ezekiel C., Wanda F., Mkumbo O. C. & Marshall B. E. (2010) The environment of Lake Victoria (East Africa): Current status and historical changes. *Inter. Rev. Hydrobiol.* **95**(3), 209–23.

Sitoki L., Kurmayer R. & Rott E. (2012) Spatial variation of phytoplankton composition, biovolume, and resulting microcystin concentrations in the Nyanza Gulf (Lake Victoria, Kenya). *Hydrobiologia* **691**(1), 109–22. doi:10.1007/s10750-012-1062-8.

Tarits C., Renaut R. W., Tiercelin J. J., Le Hérissé A., Cotten J. & Cabon J. Y. (2006) Geochemical evidence of hydrothermal recharge in Lake Baringo, central Kenya Rift Valley. *Hydrol. Process.* **20**(9), 2027–55.

Tarras-Wahlberg H., Everard M. & Harper D. M. (2002) Geochemical and physical characteristics of river and lake sediments at Naivasha, Kenya. *Hydrobiologia* **488** (1–3), 27–41.

UK (1984) Water quality standards arising from European Community Directives, Technical report TR 204, Water Research Centre, Marlow 1984.

Vollenweider R. A. (1968) Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Report DAS/CSI/68.27, Organization for Economic Cooperation and Development, Paris, 192 pp.; Annex, 21 pp.; Bibliography, 61 pp.

Wetzel R. G. (1983) Limnology, 2nd edn. Saunders College Publishing, Philadelphia.

Wetzel R. G. & Likens G. E. (1991) Limnological Analyses, 3rd edn. Springer Verlag, Berlin, 429 pp.

WHO (1993) Guidelines for Drinking Water Quality, 2nd edn. Vol. 2, WHO, Geneva, Switzerland.

Yasindi A. W. & Taylor W. D. (2005) The abundance, biomass and composition of pelagic ciliates in East African lakes of different salinity and trophy. In: Volume II (eds E. O. Odada, D. O. Olago, W. Ochola, M. Ntiba, S. Wandiga, N. Gichuki & H. Oyieke) pp. 374–8. Proceedings, 11th World Lake Conference, Ministry of Water and Irrigation of Kenya and International Lakes Environment Committee (ILEC), Nairobi Kenya, 31 Oct–4 Nov 2005.