Spatial-temporal variability of phytoplankton abundance and species composition in Lake Victoria, Kenya: implication for water quality management

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Abstract

Study of phytoplankton abundance and species composition in Lake Victoria, Kenya showed a marked difference between the main lake and the semi-closed Nyanza (Winam) Gulf. Phytoplankton biomass and species composition showed both spatial and seasonal variation. In the main lake the highest chlorophyll concentration was during the short stratification season (August to September) but in the gulf it was after the short and long rainy seasons. Deep mixing depth (aprox. 30 m) in the main lake imposes light limitation to algal growth leading to the observed lower chlorophyll in the main lake, despite the higher soluble reactive phosphorus (SRP) in the main lake compared to the gulf. Blue green algae were the most abundant algal species, contributing between 45 and 65% of total abundance. *Cylindriospermopsis africana,* a nitrogen fixing and potentially highly toxic species was present in the gulf during the dry season but was absent during the wet season and in the main lake the nitrogen fixing *Anabaena sporoides* was present in high numbers during mixing period, which can be attributed to low availability of dissolved inorganic nitrogen during lake mixing. Rusinga channel, the transition area between the Nyanza Gulf and the main lake, had high diatom abundance and showed a different phytoplankton species composition compared to the other lake zones. The current dominance of cyanobacteria (blue-green algae) in the lake, and especially bloom forming and potentially toxic species calls for urgent management of pollution loading into the lake in order to stem further degradation of water quality and help in the restoration of Lake Ecosystem.

Key words*:* Nyanza Gulf, Phytoplankton, Water quality

Introduction

Phytoplankton productivity and species composition in a water body are mainly influenced by nutrient availability (mainly phosphorus, nitrogen and silica (for diatoms)), environmental factors such as temperature and light and the morphology of the water body (Kalff, 2002). Availability of light for phytoplankton growth in a lake is determined by water transparency, mixing depth and incident light intensity. Nutrients are normally present in very variable quantities from one water body to another and even within the same system may vary in space (especially during stratification) or seasonally according to rainfall, temperature, wind and the nature of the phytoplankton community (Maitland, 1990).

In lake Victoria, the influence of nutrient and light availability on phytoplankton abundance and species composition has be been reported and associated with the changes in phytoplankton assemblage that have occurred in the last 4 decades (Mugidde *et al.,* 2003). The shift from dominance by diatoms to that of blue green in the open waters of Lake Victoria has been associated with reduction of silica concentration in the water column due to increased burial of diatoms in the sediments, associated with increased productivity in the lake (Verschuren *et al.,* 2002). Increased nutrient loading into the lake, associated with increased human population in the lake catchment and resultant land degradation has been blamed for increased eutrophication and changes in phytoplankton productivity and assemblage in Lake Victoria (Botsma & Hecky, 1993; Hecky, 1993). The dominance of blue green algae and associated algal blooms in the lake (Ochumba & Kibaara, 1989; Krienitz *et al.,,* 2002) will continue to affect the lake water quality since some blue green species have been found to produce cyanobacterial toxins (Krienitz *et al.,* 2002).

Materials and methods

Study area

The Kenyan waters of Lake Victoria lie just south of the equator between 0^0 6' S/0^0 32'S and 34^0 13'E/ 34^0 52'E at an altitude of 1134 m asl and cover an area of 3600 Km^2 (approximately 6% of the whole lake) of which 1400 Km^2 comprises the Nyanza (Winam) Gulf (Figure 1). It has a catchment area of 3600 Km^2, which is drained, by 5 major rivers (Nzoia, Kuja, Nyando, Yala and Sondu) through which it contributes approximately 30% of total riverine inflow into Lake Victoria. The catchment falls in some of the most agriculturally productive areas in the country with extensive use of agro-chemicals and has several major urban centers including Kisumu.

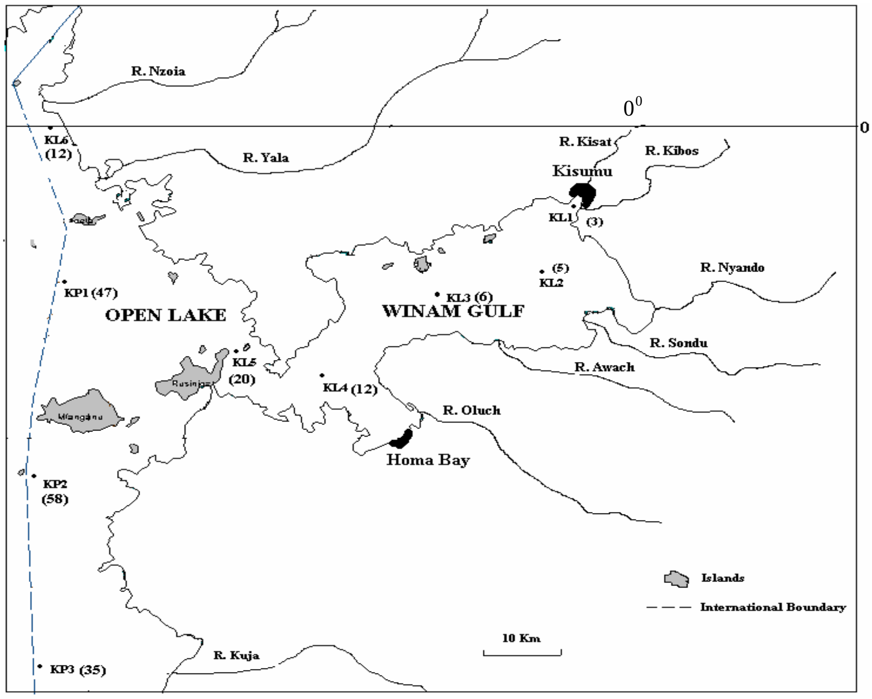

Figure 1. Location of the sampling stations in the Gulf (KL1-5) and in the open lake (KP1-3; KL6). Values in the parenthesis indicate the station depth.

Samples for analysis of phytoplankton biomass (chlorophyll) and species composition and nutrients were collected between 2000 and 2004 in stations within the main Lake Victoria and the Nyanza Gulf. The stations are part of the lake-wide LVEMP water quality monitoring network, chosen to fall within spatial transects covering both littoral and pelagic stations. Pelagic stations are the deep (>20 m) and offshore (>5 km from shoreline) whereas the littoral stations are those less than 20m deep and less than 5km from the shoreline.

Sampling and laboratory analysis

Water samples were collected at different depths using the 2-litre Van don sampler for the analysis of phytoplankton biomass (chlorophyll) and species composition and nutrients. Phytoplankton samples were fixed in the field with Lugol's iodine solution and analysis was done in the laboratory using standard inverted microscope techniques. Chlorophyll *a* was extracted using 95% ethanol and analyzed according to Wetzel and Likens (1990). Treatment and analysis of total and dissolved nutrients (Total phosphorus (TP), Orthophosphate (PO_4-P), Total nitrogen (TN), Nitrate (NO_3-N), Ammonium nitrogen (NH_4-N) and Silica (SiO_2-Si)) were carried out using spectrophotometric methods as described in APHA (1995). In the field, light penetration was estimated with a 25 cm diameter white Secchi disc and a Conductivity–Temperature–Depth (CTD) Probe with additional sensors (Hydrolab Survey 4a) was used to measure temperature, pH, dissolved oxygen, turbidity and conductivity at different depths down the water column.

Results

Observations in the field showed spatial and temporal variability of occurrence of algal blooms in the Nyanza Gulf and in the main Lake Victoria with heavy blooms observed in the eastern and southeastern zones near Kisumu City and rivers mouths in the gulf and near the mouths of major rivers in the main lake (Nzoia, Yala and Kuja). Heavy algal blooms in the gulf were found to occur after the rainy season (May to July), after the settling of inorganic turbidity associated with the rainy season. Physical observations and satellite imagery has shown the area north of Rusinga Channel, in the main lake, to have occasional algal blooms.

Phytoplankton biomass (chlorophyll a) showed a reducing trend along the gulf into the main lake with a highest average value of 21.1µg/l (KL2) and a lowest value of 6.9µg/l (KP3). KL6, a littoral station in the main lake, had an average value of 18.18 (Figure 2a). A comparison of 4 seasons, Jan-March (dry and long stratification); April-July (cool and mixing season); August-September (short stratification) and November-December (short mixing and onset of stratification) showed the maximum biomass in the gulf and the in the main lake to be during August-October (29.6µg/l and 15.8µg/l respectively) but in KL6, the littoral station in the main lake, it was during November-December (31.4 µg/l) (Figure 2b).

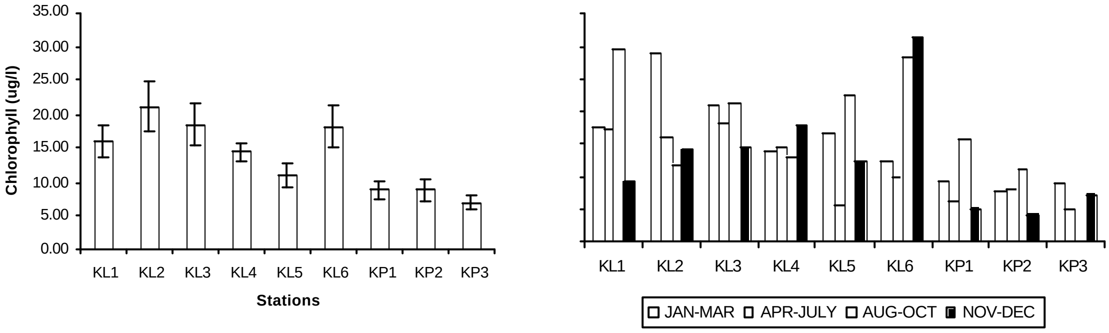

Figure 2. Spatial and seasonal variation (a and b respectively) of chlorophyll in the lake.

Species composition and abundance

Phytoplankton species composition varied within stations and between seasons. In both littoral and pelagic areas, cyanobacteria was the most abundant, contributing between 45 and 65% of the total phytoplankton abundance and diatoms contributed between 20 and 40% of total abundance, with the main lake having higher relative diatom abundance than the gulf (Figure 3 a and b). *Cyndrospermopsis africana* was present both in the littoral and pelagic stations but occurred in higher densities in March 2004 compared to other months sampled. Among the diatoms, *Nitzschia acicularis* was dominant in the main lake, whereas in the gulf *Aulacoseira nyassensis* dominated. *Anabaena sp* was more common in the main lake and *Microcystis aeruginosa* was more common in the gulf. Phytoplankton abundance was higher in the gulf than in the main lake and followed a similar spatial pattern with phytoplankton biomass (chlorophyll) (Figure 2a).

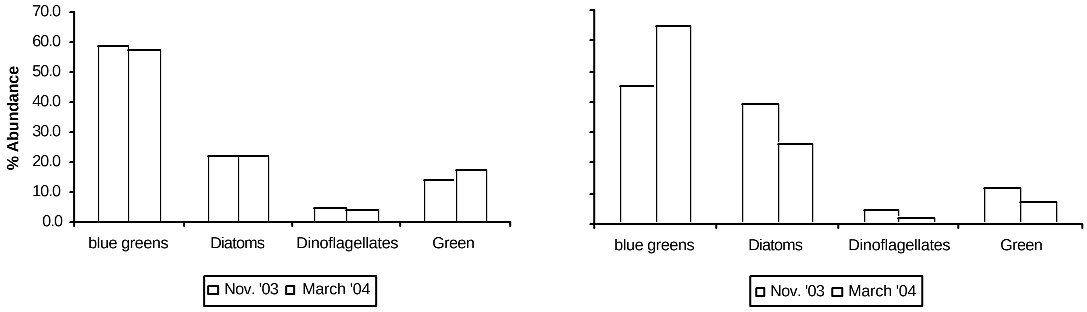

Figure 3. Relative abundance of different phytoplankton groups in the (a) gulf stations and (b) pelagic stations.

Productivity

Primary productivity rate in the lake ranged between 217 and 646 mg O_2 m^{-3} h^{-1} and showed seasonal variation within and between stations (Figure 4a).Photosynthetic efficiency as indicated by average productivity per unit biomass was low in the gulf station KL3 and in the main lake station (KP1) and ranged between 11 and 53 mg O_2 mg $Chll^{-1}$ h^{-1} (Figure 4b).

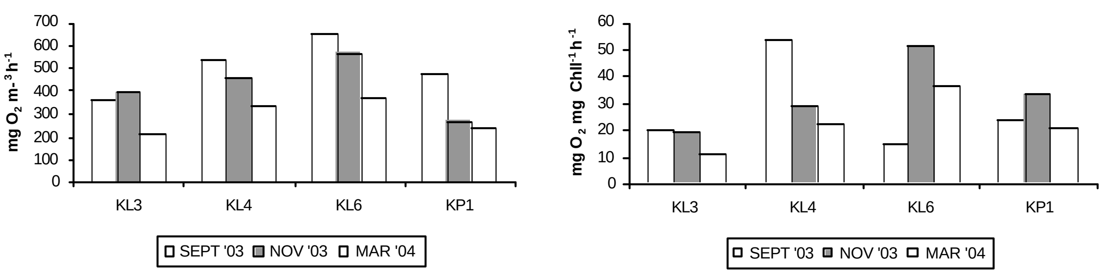

Figure 4. Primary productivity rate (a) and photosynthetic efficiency (b) in littoral and pelagic stations during September 2003, November 2003 and Mach 2004.

Nutrient concentrations varied spatially between the gulf and the main lake. PO_4-P concentration ranged between 19.4 and 56.5 µg/l and was higher in the main lake than in the gulf but SiO_2-Si was higher in the gulf than in the main lake with values ranging between 0.6 and 4.97 mg/l. The TN:TP ratio (molar) in the gulf stations was more than 50 whereas in main lake stations it was between 40 and 50. Water transparency (measured as Secchi depth) reduced from and an average value of 2m in the main lake to an average value of 0.5 m and showed a strong negative logarithmic relationship with the chlorophyll.

Discussion

Talling (1966) reported phytoplankton biomass (chlorophyll) values of 1.2-5.5µg/l in the pelagic waters which is less than the values measured during the present study (Figure 2) in the pelagic stations, confirming the reported changes in phytoplankton biomass in the past four decades (Kling *et al.,* 2001; Hecky, 1993). The dominance of cyanobecteria in lake, during the present study, is consistent with observations made by other scientists (e.g. Ochumba & Kibaara, 1989; Lung'aiya *et al.,* 2000) and in line with the reported changes of phytoplankton assemblage from diatom dominated to blue green dominated population (Hecky, 1993; Lehman & Branstrator, 1994; Kling *et al.*, 2001).

In the main lake, where the mixing depth is greater than the photic zone (Gikuma-Njuru & Hecky, 2005), phytoplankton growth is normally light limited (Mugidde, 2003), which may account for low algal biomass in this part of the lake despite the high dissolved nutrient concentration. In the gulf, phytoplankton may be light limited due to self shading and high inorganic turbidity associated with riverine inflows (Gikuma-Njuru & Hecky, 2005). As the water depth increases from approximately 2m in the eastern part of the gulf to more than 40 m in the main lake, the resultant changing light and nutrient regimes will result in spatial variability of phytoplankton assemblage since different species will respond differently to this changing environment.

The ratio between N and P can be used to indicate the phytoplankton nutrient status in a water body. According to Guildford and Hecky (2000), for TN:TP ratio <20 phytoplankton is normally nitrogen limited and in cases where the ratio is >50 phytoplankton will most likely be phosphorus limited. The TN:TP ratio in the lake shows that the Nyanza Gulf is consistently phosphorus limited whereas the main lake can be either nitrogen or phosphorus depending on the prevailing physico-chemical and nutrient status. Under nitrogen limited conditions, phytoplankton species with the ability to fix inorganic dinitrogen from the atmosphere, normally has an advantage over the other species and therefore dominate (Guildford et al., 2003; Mugidde *et al.,* 2003). This is in line with current status where of the nitrogen fixing *Anabaena sp* occur in the main lake and *Microcystis sp*, non nitrogen fixing blue green, is more common in the gulf. Since the gulf as a whole is P limited, continued P input to this semi-closed part of the lake will result in increased algal blooms and increased eutrophication and therefore negatively affecting the water quality.

The dominance of cyanobacteria in the lake present water quality challenges, as this algal group is bloom forming and has species which are known to produce phycotoxins, which can both cause fish kills and compromise drinking water quality (Hummert *et al.,* 2001; Kling *et al.,* 2001; Krienitz *et al.,* 2002). The occurrence, in mid 2004, of a large algal bloom in Kisumu Bay, which lead to the closure of the Prisons Department water treatment works for a number of days, is a good example of negative impact of algal blooms on water quality. Although this occurrence was thought to be as a result of reduced lake levels, due to long dry spell at the time, continued nutrient enrichment of the lake will probably increase the frequency and severity of such occurrences especially in the littoral hotspot areas (LVEMP, 2002).

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