



Phytoplankton dynamics and cyanobacterial dominance in Murchison Bay of Lake Victoria (Uganda) in relation to environmental conditions

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ABSTRACT

Murchison Bay is a shallow embayment in the north-western part of Lake Victoria, strongly influenced by urban pollution from the Ugandan capital Kampala. Two stations, representing the semi-enclosed innermost part of the bay and the wider outer part of the bay, were sampled in the period from April 2003 to March 2004, in order to assess the phytoplankton community and the nutrient status in the bay. Murchison Bay was highly eutrophic with average concentrations ($n=25$) of total phosphorous $> 90 \mu\text{g L}^{-1}$ and total nitrogen $> 1100 \mu\text{g L}^{-1}$ in the inner part of the bay. The phytoplankton community was dominated by a variety of cyanobacterial species and diatoms. Cyanobacteria were dominant in the whole bay, whereas diatoms were more abundant in the outer part of the bay. Moreover, the proportion of N-fixing species like *Anabaena* sp. was higher in the outer part of the bay, whereas species like *Microcystis* sp. were more abundant in the inner part of the bay. The phytoplankton community, especially in the outer part of the bay, may be influenced by light limitation. Low $\text{NO}_3\text{-N}$ concentrations in the bay may also indicate a possible N-limitation, thus favouring growth of N-fixing cyanobacteria. The open bay is, however, a complex system, and additional environmental factors and loss processes most likely affect the phytoplankton community.

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Introduction

The Lake Victoria ecosystem has undergone substantial changes over the last five decades, including introduction of exotic species, severe eutrophication and climate change (e.g. Hecky, 1993; Verschuren et al., 2002). Expanding urban, agricultural and industrial development has caused historically high nutrient loadings into the lake (Hecky and Bugenyi, 1992; Lipiatou et al., 1996; Verschuren et al., 2002). The overall phytoplankton biomass has increased (e.g. Ochumba and Kibaara, 1989; Ochumba, 1990; Mugidde, 1993; Lung'ayia et al., 2000, 2001), with a fourfold and eightfold increase in the Chlorophyll *a* (Chl-*a*) concentrations in the offshore and inshore areas, respectively, and a notable decrease in water transparency both offshore and inshore (Mugidde, 1993). Whereas rates of primary production have increased near the lake surface, the rates of decomposition have depressed dissolved oxygen concentration to $\leq 1 \text{ mg L}^{-1}$ in the deepest one-third of the water column (Hecky et al., 1994). Lake Victoria is regarded as highly eutrophic and blooms of cyanobacteria have now become common

(Ochumba and Kibaara, 1989; Lung'ayia et al., 2000; Kling et al., 2001). Probably the most known ecological change is the introduction and successful establishment of Nile perch (*Lates niloticus*) which dramatically has altered the indigenous fauna in Lake Victoria (for a review see Goudswaard et al., 2008). The large scale invasion of water hyacinth (*Eichhornia crassipes*) has been another threat by an introduced species to the Lake Victoria ecosystem (Twongo, 1991; Albright et al., 2004). The lake supports one of the largest commercial freshwater fisheries in the world (Simonit and Perrings, 2005), but largely due to failures in controlling the fishing effort, the fish stocks are currently considered overexploited (Simonit and Perrings, 2005). There has been a massive focus on fish and fisheries in Lake Victoria, and the dramatic ecosystem alterations have to a large extent been explained by foodweb changes caused by "top-down" predation by the introduced Nile perch and by overfishing (Goudswaard et al., 2008). It is however, evident that the increased nutrient loading results in a "bottom-up" effect and changes the phytoplankton productivity (Mugidde, 1993) and community structure (Kling et al., 2001), and there is a recent increasing awareness that the ongoing eutrophication is as much a threat to the Lake Victoria ecosystem.

Lake Victoria has attracted scientific interest ever since the late 19th century. The first reported phytoplankton investigation in the lake was accomplished by Schmidle (1902), and since then

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several studies on phytoplankton taxonomy and ecology have been conducted (for a review see Talling, 1987). The phytoplankton community in Lake Victoria before antropogenic eutrophication (1960s) was dominated by diatoms, cyanobacteria and chlorophytes (Talling, 1987). The present composition of the phytoplankton community has to a large extent changed after the significant increase in nutrient loading into Lake Victoria and there is now a strong dominance of cyanobacteria and the diatom *Nitzschia* (Kling et al., 2001). Cyanobacterial blooms in Lake Victoria were reported already at the beginning of the 20th century (Ostenfeld, 1908) and more recent records from Lake Victoria focus on the increasing mass occurrences of cyanobacteria, especially in near shore areas of the lake (e.g. Ochumba and Kibaara, 1989; Hecky and Bugenyi, 1992; Hecky, 1993; Gophen et al., 1995; Lung'ayia et al., 2000; Kling et al., 2001; Krienitz et al., 2002; Sekadende et al., 2005; Okello et al., 2009). Worthington (1930) differentiated two main types of environments within Lake Victoria; the shallow semi-enclosed gulfs and bays that are not deep enough to be persistently stratified, and the open lake waters with stratification and clear seasonality; thus, the physico-chemical environment changes from inshore to offshore waters. Accordingly, there is a differential distribution and abundance of phytoplankton species between the inshore and offshore areas of the lake (Talling, 1987; Lung'ayia et al., 2000; Kling et al., 2001). In tropical areas, where there are only small temperature variations throughout the year, light and nutrient levels may be the main environmental factors influencing the phytoplankton biomass and species composition. In Lake Victoria, changing nutrient conditions, silicon depletion and nitrogen limitation, light limitation, influence of dry and wet season, and food-web changes have been proposed as main factors regulating the phytoplankton populations (Mugidde, 1993; Lung'ayia et al., 2000; Kling et al., 2001; Gikuma-Njurua and Hecky, 2005; Silsbe et al., 2006).

Whereas several studies on phytoplankton have been carried out in other large bays and gulfs of Lake Victoria, there are few reports on phytoplankton biology and ecology from Murchison Bay in the north western part of Lake Victoria. The inner part of Murchison Bay serves as a drinking water supply for Kampala, the capital of Uganda, and is also a recipient of both industrial and municipal wastes, sewage effluents and surface runoff from the city and is shown to be highly eutrophic with a dominance of cyanobacteria (Källqvist et al., 1996; Schröder et al., 1998). The development of cyanobacterial blooms in drinking water supplies calls for special attention due to the ability of many cyanobacterial species to produce toxic compounds (cyanotoxins) which can cause considerable hazards to animal and human health (Krienitz et al., 2003; Bell and Codd, 1994; Kuiper-Goodman et al., 1999). Thus, it is of great importance to understand phytoplankton dynamics and the factors influencing cyanobacterial growth and distribution in water bodies used for drinking water purposes. The aim of this study was therefore to (a) investigate the diversity of the phytoplankton community in Murchison Bay, in particular the cyanobacterial population, and (b) to assess the influence of environmental factors.

Material and methods

Study site

Murchison Bay is an extension of Lake Victoria to the north towards Kampala, and is divided in a semi-enclosed inner part and a wider outer part by narrows about 5 km from the inner shores (Fig. 1). The shallow embayment is 30 km long and the bottom has a gentle slope from the outlet of the Nakivubo channel to about 11 m depth at the Gaba narrows and to about 12 m at the

outer part of the bay. The Inner Murchison Bay (mean depth 3.2 m) covers an area of about 18 km² and has a catchment area of 282 km², both comprising wetland areas and parts of the urban areas of Kampala (> 1 million inhabitants). The most significant drainage of the catchment area is the Nakivubo channel, going through Kampala and the wetland areas surrounding the bay, entering the inner part of the bay from the north. In the past, the Nakivubo channel ended in the outer part of the wetland areas, allowing the water to be drained in the papyrus swamps before entering the bay. In 2001–2003, the Nakivubo channel was enlarged to remove storm water more efficiently from the urban areas. It was widened to about 20 m and stretched through the wetland ending only a couple of hundred meters before Murchison Bay. The water in the channel is a mixture of secondary effluents from the Bugolobi sewage treatment works and heavily polluted untreated wastewater from the city. Moreover, the predominant papyrus wetland has been drained and turned into agricultural areas or developed for commercial, industrial or residential purposes (Kansiime et al., 2005). Due to these major changes in the wetland areas, the retention of nutrients and other pollutants is now moderate to absent, increasing the concerns for the water quality in the bay (Kansiime et al., 2005).

The Lake Victoria region has an equatorial climate with small variations in solar radiation over the year. The lake is situated at an altitude of 1135 m and the mean annual temperatures in areas close to Murchison Bay range from 21.5 to 22.5 °C. As a rule, there are two rainy seasons, the long rains from March to May with a peak in April and the short rains from October to November. There are, however geographical and annual variations.

Sampling

Sampling ($n=25$) of physical, chemical and biological parameters was done at two stations in Murchison Bay every second week in the period April 2003 to March 2004. There had been established four stations in a longitudinal transect from the inner to the outer bay (Haande, 2008), and we have used two of these sampling stations in this study (Fig. 1). Station 2 (St. 2) was in the inner part of the bay (00°15.727'N 32° 38.749'E, max depth 5 m) and station 4 (St. 4) was in the outer part of the bay (00°08.715'N 32° 37.580'E, max depth 11 m). The proximity of Murchison Bay to Kampala allowed the samples to be immediately transported to Makerere University for preservation and analysis. The sampling was carried out between 9 am and 3 pm, starting at station St. 4 and ending at station St. 2. A number of vertical temperature measurements taken at several different sites in Murchison Bay, both fortnightly daytime measurements during the whole sampling period (see Fig. 2) and some day/night samplings (every 6 h), showed that there was no constant thermal stratification in the bay and that the water column was well mixed. Therefore, water samples were taken with a 1 m tube sampler (5 L) of the Van Dorn type (Modified Ramberg Sampler, Norwegian University of Science and Technology, Trondheim, Norway) at the surface (0–1 m) and regarded as representative for the whole water column.

Physical measurements and nutrient analysis

Vertical profiles of water temperature, dissolved oxygen and electrical conductivity were measured with a model 85 oxygen meter (YSI, Yellow Springs, OH, USA) on each sampling date. Data on daily precipitation were from the Makerere Hill in Kampala and were assumed to be representative for the watershed.

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