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SHORT RESEARCH NOTE

Changes of phytoplankton communities in Lakes Naivasha and Oloidien, examples of degradation and salinization of lakes in the Kenyan Rift Valley

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Abstract Increasing degradation of the water quality, caused by overuse and salinization, leads to considerable changes of the phytoplankton composition in Kenyan Rift Valley lakes. Exemplarily, the phytoplankton communities and biomasses of deteriorating freshwater Lake Naivasha and salinizing Lake Oloidien were studied between 2001 and 2005, accompanied by physico-chemical measurements (pH, total phosphorus and nitrogen, alkalinity, conductivity). Over the last three decades, the ecology of these two water basins has been subjected to dramatic changes, caused by excessive use of water and catchment area by man. In L. Naivasha a shift in the dominance of coccoid cyanobacteria towards dominance of Chlorophyceae (*Botryococcus terribilis*) was observed. Lake Oloidien exhibited a shift in the dominance of coccoid Chlorophyceae towards dominance of cyanobacteria (*Arthrospira fusiformis*, *Anabaenopsis elenkinii*). Phytoplankton findings and chemical data demonstrate that L. Naivasha has developed towards a eutrophic freshwater lake while L. Oloidien has progressed towards a hypereutrophic alkaline-saline lake.

Keywords Lake Naivasha · Lake Oloidien · Eutrophication · Salinization

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Lake Naivasha is the largest freshwater lake in the Kenyan Rift Valley. This shallow body of water remains fresh due to inflow from three river systems (Malewa, Gilgil, and Karati) and underground outflow through seepage (Beadle, 1932; Gaudet & Melack, 1981; Becht & Harper, 2002). Lake Oloidien is a former bay of L. Naivasha with a hydrologically closed basin. Its water level is maintained only by rainfall, evaporation, and subsurface inflow from L. Naivasha through a permeable sill (Verschuren et al., 2000). For geomorphological features of the lakes see Table S1.

The first studies on the Naivasha-basin were conducted by Jenkin (1929) and Beadle (1932). Subsequent studies were done in 1960s (Evans, 1962; Lind, 1968; Richardson, 1968), end of 1970s (Kalff & Watson, 1986), beginning of 1990s shortly after the separation of both lakes (Uku & Mavuti, 1994), and in 1997–1998 (Hubble & Harper, 2002). Over the last three decades, the Naivasha-basin ecology has been subjected to dramatic changes caused by excessive use of water and catchment area by man (Harper, 2006). Consequently, the phytoplankton community exhibited substantial fluctuations whose magnitude needs to be documented to assess further development of protection and restoration strategies for the lake ecosystem.

The aim of this study was, therefore, to investigate (a) changes in salinity/conductivity and nutrient concentrations, and (b) changes in phytoplankton community. This study was carried out from June 2001 to May 2005. Physico-chemical data and methods of measurements are given in Table S2. Phytoplankton methods were applied according to Ballot et al. (2004).

Lakes Naivasha and Oloidien showed clear differences in physico-chemical conditions. Secchi-depth never exceeded 0.62 m, with median values of 0.50 m in L. Naivasha and 0.22 m in L. Oloidien. The pH ranged from 8.0 to 9.4 in L. Naivasha and from 9.3 to 9.9 in L. Oloidien. Conductivity values between 282 and 374 µS cm^{-1} in L. Naivasha and 3,890 and 5,270 µS cm^{-1} in L. Oloidien were measured. Total alkalinity ranged from 2.6 to 5.0 meq l^{-1} in L. Naivasha and from 39 to 65 meq l^{-1} (1,970–3,250 mg $CaCO_3$ l^{-1}) in L. Oloidien. Total phosphorus (TP) concentrations ranged from 0.07–0.20 mg l^{-1} in L. Naivasha and from 0.4–1.0 mg l^{-1} in L. Oloidien. Total nitrogen (TN) concentrations ranged from <0.5–2.4 mg l^{-1} in L. Naivasha and from 0.9–6.3 mg l^{-1} in L. Oloidien.

The phytoplankton community of L. Naivasha was dominated by cyanobacteria, Chlorophyceae, and Bacillariophyceae (Fig. 1a). A list of identified taxa is presented in Table S3. Coccoid cyanobacteria e.g. *Cyanocatena planctonica*, *Chroococcus limneticus*, and *Aphanocapsa* sp. were responsible for 83–98% of the cyanobacterial biomass. Throughout 2002/2003, the Chlorophyceae was the most abundant group. A maximum phytoplankton biomass of 56.6 mg l^{-1} was recorded during a bloom of *Botryococcus terribilis* in September 2002. Other groups that temporarily reached high biomass were Desmidiaceae (*Gonatozygon* sp.) and Bacillariophyceae

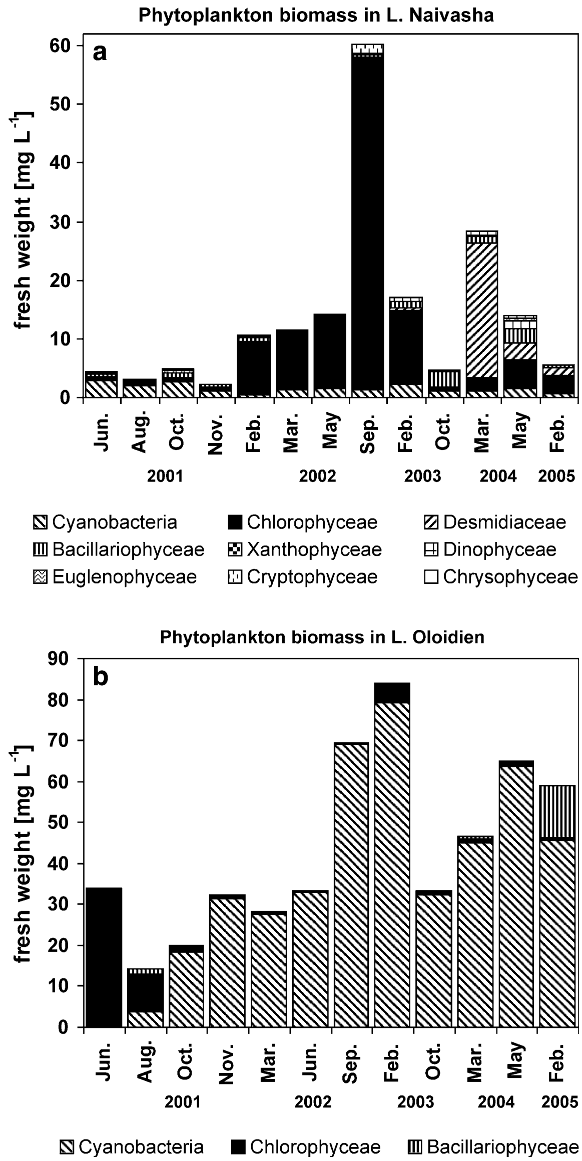

Fig. 1 Biomass (fresh weight in mg l^{-1}) of the main phytoplankton groups in Lakes Naivasha (**a**) and Oloidien (**b**) from June 2001 to February 2005

(*Aulacoseira* sp.). Most samples had low biomass of the cyanobacterium *Microcystis aeruginosa*.

The phytoplankton of L. Oloidien was dominated by cyanobacteria and Chlorophyceae (Fig. 1b). Coccoid Chlorophyceae were dominant in June/August 2001 with a percentage of 98.3 and 63.6% respectively. This group was mainly composed of unidentifiable spherical-ellipsoid taxa. Samples from October 2001 to February 2005 showed mass developments of cyanobacteria comprising between 77.5 and 99.2% of the biomass. The total phytoplankton biomass ranged from 14.4 up to 83.9 mg l^{-1}. Dominant taxa were *Chroococcus minutus,* unidentifiable thin filamentous Oscillatoriales*, Arthrospira fusiformis*, and *Anabaenopsis elenkinii*.

Our study revealed major differences in the two lakes investigated. Lake Naivasha is characterized by constant freshwater conditions. Only slight variations in conductivity have been recorded over the last 40 years. Talling & Talling (1965) recorded a conductivity of 285 µS cm^{-1} in 1961 while Kalff & Watson (1986) recorded a value of 335 µS cm^{-1} in 1979, both within the similar range to that of 282–374 µS cm^{-1} measured in our study. Only during an eight year long drought period between 1983 and 1991 slightly higher conductivity values of up to 480 µS cm^{-1} were recorded by Harper et al. (1993).

In contrast to L. Naivasha, L. Oloidien has changed from freshwater conditions towards an alkaline-saline lake. Conductivity values measured during our study differed considerably from those reported in former studies. In the period 1979/1980 when the two lakes were connected, the conductivity in L. Oloidien was 660 µS cm^{-1}, which was only twice higher than in L. Naivasha (Kalff & Watson, 1986). Over the last 25 years, the conductivity of L. Oloidien has increased almost eightfold, reaching a maximum of 5,270 µS cm^{-1} in 2005.

A progressive increase in nutrient concentrations can be observed in both lakes. Kalff & Watson (1986) measured a mean TP concentration of 0.04 mg l^{-1} in 1979/80. We measured between 0.07 and 0.2 mg l^{-1} TP in L. Naivasha and between 0.4 and 1.0 mg l^{-1} TP in L. Oloidien. These data indicate a shift to higher trophic conditions in both lakes. According to the classification system for warm-water tropical lakes (Salas & Martino, 1991), L. Naivasha can presently be classified as eutrophic while L. Oloidien is hypereutrophic.

Several factors are responsible for increasing nutrient concentrations in both lakes. The water level and volume decrease during dry periods, causing rising nutrient concentrations in L. Naivasha and rising salt and nutrient concentrations in L. Oloidien. At L. Naivasha with a catchment area of around 3,400 km^2, overgrazing and tilling leading to erosion are common phenomena (Everard & Harper, 2002) hence, inflowing rivers contribute to nutrient enrichment. Another factor is the intensive horticultural industry, using water of L. Naivasha for irrigation. The horticultural runoff is a source of nutrients and pesticides (Kitaka et al., 2002; Harper, 2006) deteriorating the water quality. Compared to L. Naivasha, the catchment of L. Oloidien is small without inflowing rivers. The main sources of nutrient input are cattle and goat herds watering at the lake and local women washing clothes using detergents. On the other hand, domestic use of water from L. Oloidien is threatened by unsuitable physico-chemical conditions. Waters with pH values above 9 or alkalinity values above 3,000 mg $CaCO_3$ l^{-1} are solely suitable for livestock-watering with restrictions (Beede, 2005).

Changes in physico-chemical properties of lake ecosystems are closely linked to changes in the phytoplankton composition. In L. Naivasha, we identified 116 phytoplankton taxa. Earlier investigations by Kalff & Watson (1986) and Hubble & Harper (2002) recorded higher numbers of 143 and 173 taxa, respectively. One reason for different numbers of species between our and previous studies is a decrease in the number of diatom species. Hubble & Harper (2002) found 69 diatom taxa, whereas our study recorded only 15 species. Furthermore, the eutrophic condition of L. Naivasha can stimulate the growth of *Microcystis* species. In 2006, dense blooms of *M. aeruginosa* were observed near Elsamere in the southwestern lagoon (Krienitz, unpublished observations).

In L. Oloidien, we found 26 taxa, a considerably lower number than in L. Naivasha. This can be related to the increasing alkalinity and salinity. According to Hammer (1986), alkaline-saline environments are relatively poor in species but with high numbers of individuals. This is supported by Kalff & Watson (1986) who described 94 taxa in 1979/1980 when L. Oloidien was still a freshwater lake. *A. fusiformis* and *A. elenkinii*, which exhibited a progressive increase of biomass in L. Oloidien, are typical cyanobacteria of alkaline-saline lakes (Vareschi, 1982; Melack, 1988; Ballot et al., 2004). In 2004, we observed flocks of Lesser Flamingos (*Phoeniconaias minor*) feeding on the increasing biomass of *A. fusiformis* at L. Oloidien.

Changes in phytoplankton communities of lakes Naivasha and Oloidien can be contextualized to studies on equilibrium phases which reflect degradation-scenarios (Naselli-Flores et al., 2003; Padisák et al., 2003). According to the criterion that only one, two, or three algal species contribute to more than 80% of total phytoplankton biomass to define a period of equilibrium (Sommer et al., 1993), we found several stages of equilibria in our study-sites. In L. Naivasha, in June 2001, *Cyanocatena planktonica*, *Pediastrum simplex*, and *Aulacoseira granulata* together reached 75% of the total biomass and almost fulfilled the equilibrium criterion. In September 2002, *B. terribilis* reached a biomass of more than 90%. In L. Oloidien, equilibrium was indicated by the dominance of unidentified coccoid green algae in June 2001. From March 2002 until 2005 very long lasting steady state phases were established by the cyanobacteria *C. minutus*, *A. elenkinii*, and *A. fusiformis*. Under tropical conditions such equilibria can be longer lasting than in temperate climate (Komárkova & Tavera, 2003; Becker et al., 2008).

The comparison of our results to former studies shows a clear shift in dominating species, in L. Naivasha from cyanobacteria to chlorophyte-dominated periods and in L. Oloidien from freshwater to salt-tolerant taxa. Our study showed that both lakes have deteriorated considerably. Although L. Naivasha has maintained freshwater conditions, it has developed towards a eutrophic lake. The presence of the potential toxic cyanobacterium *M. aeruginosa* is a health risk to the local population and their livestock. Haande et al. (2007) have isolated a toxic *Microcystis*-strain from L. Naivasha. Lake Oloidien is progressing towards a hypereutrophic alkaline-saline lake. The phytoplankton community in L. Oloidien has changed dramatically and is now dominated by cyanobacteria typical for alkaline-saline lakes.

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References

Ballot, A., L. Krienitz, K. Kotut, C. Wiegand, J. S. Metcalf, G. A. Codd & S. Pflugmacher, 2004. Cyanobacteria and cyanobacterial toxins in three alkaline Rift Valley lakes of Kenya-lakes Bogoria, Nakuru and Elmenteita. Journal of Plankton Research 26: 925–935.

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. Journal of the Linnean Society of London Zoology 38: 157–211.

Becht, R. & D. M. Harper, 2002. Towards an understanding of human impact upon the hydrology of Lake Naivasha, Kenya. Hydrobiologia 488: 1–11.

Becker, V., V. L. M. Huszar, L. Naselli-Flores & J. Padisák, 2008. Phytoplankton equilibrium phases during thermal stratification in a deep subtropical reservoir. Freshwater Biology 53: 592–963.

Beede, D. K., 2005. Assessment of water quality and nutrition for dairy cattle. Proceedings of Mid-South ruminant Nutrition Conference, April 27–28. Arlington: 1–19.

Bergner, A. G. N., M. H. Trauth & B. Bookhagen, 2003. Paleoprecipitation estimates for the Lake Naivasha basin (Kenya) during the last 175 k.y. using a lake-balance model. Global and Planetary Change 36: 117–136.

Evans, J. H., 1962. Some records and forms of algae in Central East Africa. Hydrobiologia 20: 59–86.

Everard, M. & D. M. Harper, 2002. Towards the sustainability of the Lake Naivasha Ramsar site and its catchment. Hydrobiologia 488: 191–203.

Gaudet, J. J. & J. M. Melack, 1981. Major ion chemistry in a tropical African lake basin. Freshwater Biology 11: 309–333.

Haande, S., A. Ballot, T. Rohrlack, J. Fastner, C. Wiedner & B. Edvardsen, 2007. Diversity of *M. aeruginosa* isolates (Chroococcales, Cyanobacteria) from East-African water bodies. Archives of Microbiology 188: 15–25.

Hammer, U. T., 1986. Saline ecosystems of the world. Dr. W. Junk Publisher, Dordrecht.

Harper, D. M., 2006. The sacrifice of Lake Naivasha. Swara, East African Wild Life Society 29: 28–37.

Harper, D. M., G. Phillips, A. Chilvers, N. Kitaka & K. Mavuti, 1993. Eutrophication prognosis of Lake Naivasha, Kenya. Verhandlungen der Internationalen Vereinigung für Limnologie 25: 861–865.

Hubble, D. S. & D. M. Harper, 2002. Phytoplankton community structure and succession in the column of Lake Naivasha, Kenya: a shallow tropical lake. Hydrobiologia 488: 89–98.

Jenkin, P., 1929. Biology of lakes in Kenya. Nature 124: 574.

Kalff, J. & S. Watson, 1986. Phytoplankton and its dynamics in two tropical lakes: a tropical and temperate zone comparison. Hydrobiologia 138: 161–176.

Kitaka, N., D. M. Harper & K. M. Mavuti, 2002. Phosphorus inputs to Lake Naivasha, Kenya, from its catchment and the trophic state of the lake. Hydrobiologia 488: 73–80.

Komárkova, J. & R. Tavera, 2003. Steady state of phytoplankton assemblage in the tropical Lake Catemaco (México). Hydrobiologia 502: 187–196.

Lind, E. M., 1968. Notes on the distribution of phytoplankton in some Kenya waters. European Journal of Phycology 3: 481–493.

Melack, J. M., 1988. Primary producer dynamics associated with evaporative concentration in a shallow, equatorial soda lake (Lake Elmenteita, Kenya). Hydrobiologia 158: 1–14.

Naselli-Flores, L., J. Padisák, M. T. Dokulil & I. Chorus, 2003. Equilibrium/steady-state concept in phytoplankton ecology. Hydrobiologia 502: 395–403.

Padisák, J., G. Borics, G. Fehér, I. Grigorszky, I. Oldal, A. Schmidt & Z. Zámbóne-Doma, 2003. Dominant species, functional assemblages and frequency of equilibrium phases in late summer phytoplankton assemblages in Hungarian small shallow lakes. Hydrobiologia 502: 157–168.

Richardson, J. L., 1968. Diatoms and lake typology in East and Central Africa. Internationale Revue der gesamten Hydrobiologie 53: 299–338.

Salas, H. J. & P. Martino, 1991. A simplified phosphorus trophic state model for warm-water tropical lakes. Water Research 25: 341–350.

Sommer, U., J. Padisák, C. S. Reynolds & P. Juhász-Nagy, 1993. Hutchinson's heritage: the diversity disturbance relationships in phytoplankton. Hydrobiologia 249: 1–7.

Talling, J. F. & I. B. Talling, 1965. The chemical composition of African lake water. Internationale Revue der Gesamten Hydrobiologie 50: 421–463.

Uku, J. N. & K. M. Mavuti, 1994. Comparative limnology, species diversity and biomass relationship of zooplankton and phytoplankton in five freshwater lakes in Kenya. Hydrobiologia 272: 251–258.

Vareschi, E., 1982. The ecology of Lake Nakuru (Kenya). III. Abiotic factors and primary production. Oecologia 55: 81–101.

Verschuren, D., 1999. Sedimentation controls on the preservation and time resolution of climate-proxy records from shallow fluctuating lakes. Quaternary Science Reviews 18: 821–837.

Verschuren, D., J. Tibby, K. Sabbe & N. Roberts, 2000. Effects of depth, salinity, and substrate on the invertebrate community of a fluctuating tropical lake. Ecology 81: 164–182.