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Comparative limnology, species diversity and biomass relationship of zooplankton and phytoplankton in five freshwater lakes in Kenya

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Abstract

Comparative studies on the limnology, species diversity and standing stock biomass of phytoplankton and zooplankton in five freshwater lakes, Naivasha and Oloidien, Ruiru, Masinga and Nairobi reservoirs, were undertaken. Phytoplankton chlorophyll *a*, dissolved oxygen and temperature were also measured. *Thermocyclops oblongatus* (Copepoda) was dominant in all the lakes. *Ceriodaphnia cornuta* and *Diaphanosoma excisum* (Cladocera) dominated in lakes Naivasha and Oloiden, whereas in Ruiru, Masinga and Nairobi reservoirs, *Brachionus angularis* and *Hexarthra mira* (Rotifera) were the dominant zooplankters. Phytoplankton biomass as chlorophyll *a* was lowest in Ruiru dam $5.64 \pm 4.0\ \mu g\ l^{-1}$ and highest in the eutrophic Nairobi dam $71.5 \pm 12.02\ \mu g\ l^{-1}$. The endorheic lakes Naivasha and Oloidien showed medium values of $24.5 \pm 4.0\ \mu g\ l^{-1}$.

Introduction

The interactions between zooplankton and phytoplankton form an important basis of the food chain in natural and man made lakes. These interactions may govern aquatic productivity usually realised in terms of the amount of fish harvested from aquatic ecosystems. The species diversity and standing stock biomass of zooplankton and phytoplankton vary in water bodies depending on their different limnological and trophic conditions. The five bodies that are considered in this study are the main Lake Naivasha, Oloidien Bay and three reservoirs, Ruiru, Masinga and Nairobi dams (Fig. 1).

Lake Naivasha is an endorheic freshwater lake that lies in the Eastern Rift Valley in Kenya at 0° 45′ S, 36° 25′ E and an altitude of 1890 m above sea level. It has a mean area of $142 \pm 20\ km^2$ and it is the second largest freshwater lake in Kenya. Previous studies by Mavuti (1983, 1990), and Harper *et al.* (1990), give detailed documentation of the geography, ecology, fisheries, and management of the lake. The lake is made up of four morphometrically distinct water bodies (Naivasha Main Lake, Oloidien Bay, Crescent Island Crater Lake and Lake Sonachi) which are a result of tectonic faulting and volcanic activity associated with the formation of the Rift Valley. The Naivasha Main Lake has remained fresh (250–350 $\mu s\ cm^{-1}$) due to the presence of underground seepage routes, ion exchanges with the sediment and dilution of lake waters by rain and river inputs (Gaudet, 1976; 1978, and Gaudet & Melack, 1981). The main rivers that drain into the lake are the Gilgil, Malewa and Karati.

Oloidien Bay, one of the four Lake Naivasha

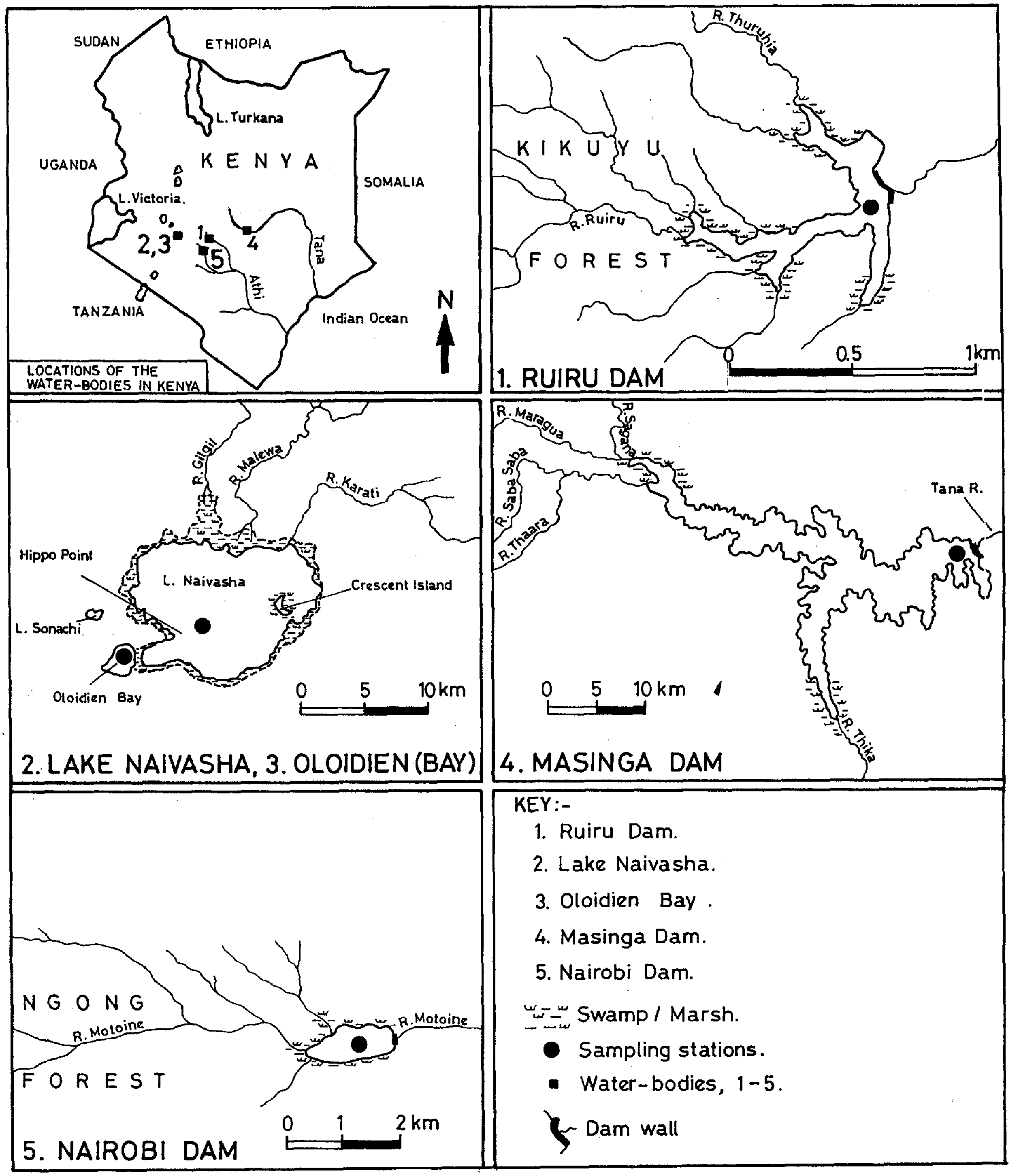

Fig. 1. General location and the sampling stations of the five water-bodies in Kenya.

water bodies lies to the south-west of the main lake and has an area of 5.5 km^2. Oloidien Lake was originally, and until 1955, a bay of Lake Naivasha only at high water levels. A boat canal was built in the 1960's to connect it to the main lake but the canal has now been blocked by *Cyperus papyrus* vegetation. Consequently there is a lack of water inflow from the main lake and this has resulted in highly saline conditions in Oloidien Bay. The water is highly saline and has conductivities between 900 and 1000 $\mu s\ cm^{-1}$ as compared to that of the main Lake Naivasha between 250 and 350 $\mu s\ cm^{-1}$.

The other three water bodies studied were man-made lakes: the Masinga, Nairobi and Ruiru dams (Fig. 1) were created for water supply to the urban population of Nairobi. Nairobi dam presents an example of a peri-urban reservoir located in the south western suburbs of Nairobi city. It lies at 1° 19′ S, 36° 48′ E and an altitude of 1600 m above sea level. It was built in 1945 on the Motoine river which rises in the Dagoretti forest, flows through the Ngong forest, enters the reservoir and flows out to join the Nairobi Athi river system. Over the years unplanned settlements along the reservoir banks and catchment in the form of housing estates and slums have led to an increased spill over of untreated sewage and other domestic pollutants into the dam. Though the use of the dam for water supplies has ceased, recreational activities such as sailing are still carried out. The reservoir contains an introduced fish community comprising of *Oreochromis* spp., *Clarias* spp. *Haplochromis* spp., *Barbus* spp., *Labeo* spp. and *Poecilia* spp.

The Ruiru dam is located in Githunguri, Kiambu district, on the confluence of Ruiru and Ngeteti rivers at an altitude of 2000 m above sea level in a highland rural agricultural zone. It was built by the Nairobi City Council in 1949 for domestic and industrial water supply. This reservoir is a protected area and access is only through special arrangements with the City Council of Nairobi. Around the dam there exists a 10 m buffer zone of uncultivated land which prevents excessive sediment run off into the dam. Tea plantations form the basis of the rural agricultural community surrounding the dam and catchment. The reservoir is still one of the main sources of domestic water supply for the city of Nairobi. A few fish species *Oreochromis* spp. and *Micropterus salmoides* have been introduced.

The Masinga dam was constructed on the Tana River in 1981 by the Tana and Athi River Development Authority for hydroelectric power generation. The reservoir is about 110 km^2 with fluctuating water level. The dam also acts as a storage reservoir for four other lower dams, which form a cascade of the Seven-Forks dam system named after the seven tributaries of the Tana river. The lower dams include Kamburu, Gitaru, Kindaruma, and Kiambere. Masinga dam lies at an altitude of 1000 m above sea level. The Eastern sub-catchment has a geological composition of ancient basement rocks which produce thin, infertile and erodable soils. These factors coupled with the high temperatures in the region limit irrigation and other agricultural activities. The rates of soil erosion are high due to the sparse vegetation cover, thus siltation rates into the dam are high. The South Western sub-catchment comprise the fertile and agricultural red soils on the Aberdares and Mount Kenya which are drained by the Thika, Mathioya and Tana Rivers. 90% of the water that flows into the Masinga dam comes from this sub-catchment. The fish community in this dam consists of *Oreochromis* spp., *Clarias* spp., *Barbus* spp., *Labeo,* spp., a variety of Carps and the eel *Anguilla* spp. These fish form the mainstay of the commercial fishery in this dam.

Materials and methods

In each water body one permanent sampling station was established in the middle of the lake. Three sampling visits were undertaken to each water body as follows: (a) Naivasha and Oloidien lakes, 8th Nov, 28th Dec 1990, 11 Jan 1991, (b) Nairobi Dam, 3rd Nov, 11th Dec 1990 & 18th Jan 1991, (c) Masinga Dam, 18th Nov to 15th Dec 1990 and 12th Jan 1991, (d) Ruiru Dam, 14th Nov, 2nd Dec 1990 and 20th Jan 1991.

Additionally two sampling visits were made for Masinga in 5th May and 12th June 1991. At each sampling station temperature, oxygen, conductivity and Secchi disc transparency were measured. Temperature and conductivity were obtained using a salinity-conductivity-temperature (SCT) meter and transparency using a standard secchi disc. Water samples for dissolved oxygen determination were obtained using a Macvuti volume sampler. The samples were fixed in the field and titrated using the standard Winkler titrimetric method later in the laboratory.

Integrated water samples for chlorophyll *a* determination were obtained using the Macvuti volume sampler (Litterick & Mavuti 1985), from 0–3 m depth. The total chlorophyll *a* content of the water was estimated by the standard methanol extraction method. Plankton samples were concentrated by the filtration of the water from the 4 litre Macvuti sampler using a plankton strainer of 60 μm mesh. In addition, a plankton net of 0.066 m^2 mouth opening, a length of 1 m and 60 μm mesh size was used to obtain qualitative vertical haul samples from a standard 4 m depth in each lake. The zooplankton was transferred to plankton bottles and preserved in 5% neutral formalin. The phytoplankton samples were preserved in Lugols solution. In the laboratory, the zooplankton was identified to species level using keys by Penak (1975) and Mavuti (1983). The zooplankton counts were made using a 1 ml Sedgwick rafter cell under a compound microscope. Zooplankton biomass was estimated from the individual species densities, according to Edmonson & Winberg (1971) and mean individual biomass values (Table 1) see Mavuti (1983 & 1990). The individual dry weight was obtained from a mean of 100 animals for each category *i.e.* species and developmental stages. Animals were dried at 60–63 °C in micro-trays in an oven for 24 hrs after which their weights were obtained by difference using a Kahn milli-electrobalance.

Phytoplankton species were identified using various keys: Lind (1968), Boney (1975) and Davis (1975). Chlorophyll *a* was used as an estimator of phytoplankton biomass.

Table 1. The mean dry weights of individual stages of the common zooplankton species in Lake Naivasha. (Adopted from Mavuti, 1983).

Species/Stage	μg dwt ind^{-1}
1. *Thermocyclops oblongatus*	
Nauplius	0.01 ± 0.01
Copepodite	0.614 ± 0.04
Adult	1.783 ± 0.62
2. *Mesocyclops equitorialis*	
Adult	3.13 ± 1.41
3. *Diaphanasoma excisum* + *Moina* sp.	
Adult	1.72 ± 0.60
4. *Simocephalus vetulus*	
Adult	3.78 ± 0.35
5. *Ceriodaphnia* sp.	
Adult	0.52 ± 0.38
6. *Daphnia laevis* & *Daphnia pulex*	
Adult	2.90 ± 0.21
7. *Brachionus caudatus*	
Adult	0.18 ± 0.04
8. *Brachionus calyciflorus*	
Adult	0.31 ± 0.13
9. *Brachionus angularis*	
Adult	0.07 ± 0.01

Results and discussion

Limnological characteristics

The basic limnological conditions of the five water bodies between Nov 1990 and Jan 1991 are illustrated in Table 2. Conductivity, was highest in Oloidien Bay which may be attributed to its long time separation and lack of water exchange from the main Lake Naivasha in addition to its endorheic nature. Nairobi Dam also had a relatively high conductivity when compared with the other two dams and this is due to the high sewage and waste water input. The low conductivity value of Ruiru Dam is a reflection of the chemical conditions of the Ruiru river which drains the nutrient-poor Tea farmlands and forested catchment. No fertilizers are used in the tea farms because of the low chemical requirements of tea in terms of pesticides and fertilizers. Thus the run-off into the dam does not have a high chemical/nutrient content.

Table 2. Physicochemical characteristics of the five water bodies Main Lake Naivasha (MLN), Oloidien Bay (OBY), Nairobi Dam (NRD), Ruiru Dam (RRD) and Masinga Dam (MSD).

	MLN	OBY	NRD	RRD	MSD
Altitude (m)	1890	1890	1700	2200	1000
Area (km^2)	145	5.5	0.3	40.49	160
Volume (m^3)	6.8×10^8	3.1×10^7	–	2.48×10^{10}	–
Maximum depth (m)	7.3	6.1	15.0	30	50
Mean depth (m)	6.1	4	7	15	15
Conductivity ($\mu S\ cm^{-1}$)	300–320	1300	500	45	120
Dissolved oxygen ($mg\ l^{-1}$)	7.48 ± 2.19	8.15 ± 0.44	5.34 ± 1.81	6.59 ± 0.12	9.64 ± 0.11
Temp. (surface temp. °C)	24.36 ± 1.95	25.00 ± 2.83	23.75 ± 0.5	21.60 ± 0.57	24.83 ± 1.041
Secchi disc transparency (m)	0.90	0.60	0.58	3.90	0.48
No. samples	14	8	14	12	12

Nairobi Dam exhibited the lowest values in dissolved oxygen concentration. This was due to the high biochemical oxygen demand and creation of anoxic conditions from the sewage. In this dam there was no oxygen present below 3 m depth but hydrogen sulphide was present. Secchi disc transparency was lowest in Masinga Dam. This is attributed to the high sedimentation rates into the dam from the western catchments. The water appeared turbid especially during the rainy season when the surface run-off, river inputs and rates of erosion are high. Ruiru Dam had the highest light penetration levels.

Species composition and structure of the plankton community

Tables 3 and 4 list the species of phyto- and zooplankton that were identified from the five water

Table 3. The phytoplankton species composition of the 5 water bodies: The relative abundance values shown by: – absent, + present but rare scale based on × 10 magnification: 1+ 1 cell in a microscopic field; 2+ 5 cells in a microscopic field; 3+ 10 cels in a microscopic field; 4+ 15 cells in a microscopic field; 5+ over 25 in a microscopic field most abundant.

Species	Main Lake Naivasha	Oloidien Bay	Nairobi Dam	Ruiru Dam	Masinga Dam
Synedra sp.	5+	–	–	–	–
Ceratium sp.	4+	+	1+	2+	+
Closterium sp.	2+	2+	4+	–	+
Melosira sp.	3+	–	+	–	+
Microcystis sp.	3+	5+	+	–	+
Botryococcus braunii	2+	–	–	–	+
Pediastrum sp.	1+	–	+	–	+
Cosmarium sp.	1+	+	–	–	–
Euglena sp.	+	–	2+	4+	–
Dinobryon sertularia	+	–	–	3+	–
Micrasterias cruxmelitensis	–	–	–	+	–
Euastrum sp.	–	–	–	+	–
Peridinium	+	–	–	+	+
Kirchneriella obesa	–	–	–	+	–
Ankistrodesmus sp.	+	–	–	+	–
Nitzschia sp.	1+	–	–	–	5+
No. of species	13	4	6	8	8

bodies. In general the abundance in number of species is greatest in the natural Lake Naivasha and Oloidien Bay, however, in Oloidien Bay the plankton is limited to the species which are tolerant of the existing high salinity levels (1000 ms m^{-1}). The man-made lakes show a lower plankton species richness which could be attributed to the semi-lotic nature and fast flow through rates of these ecosystems since they have been developed from lotic riverine ecosystems.

The phytoplankton

In general, phytoplankton belonging to the Chlorophyta was found to dominate in all water bodies. Lake Naivasha showed a high number of species with the dominant one being *Closterium* sp, *Botryococcus braunii*, *Pediastrum* sp. and *Cosmarium* sp.

The Chlorophyta found on Oloidien Bay and Nairobi Dam are *Closterium* sp. and *Cosmarium* sp., *Ankistrodesmus* sp., *Kirchneriella obesa.*, *Micrasterias crux-melitensis* and *Euastrum* sp. occurred in Ruiru dam whereas in Masinga Dam had *Closterium* sp., *Botryococcus braunii* and *Pediastrum* sp. were the dominant algae.

In Lake Naivasha Bacillariophyta were also dominant. The species here included *Synedra* sp., *Melosira* sp. and a few *Nitzschia* sp. In the other water bodies, this group was limited to *Melosira* sp. and *Synedra* sp. in Nairobi and Masinga Dams. *Nitzchia* sp. was found to be most abundant in Masinga Dam. Ruiru Dam was the only water body in this study that contained any Chrysophyta represented by *Dinobryon setularia*. Euglenophyta were abundant in Lake Naivasha, Nairobi and Ruiru dams. *Microcystis* (Cyanophyta) was found abundantly in Oloidien Bay and Lake Naivasha only, but a few specimens were also found in Nairobi Dam.

The zooplankton

The Copepoda were the most abundant group of zooplankton in all the water bodies, followed by the Cladocera and Rotifera in that order (Table 4). *Thermocyclops oblongatus* and *Mesocyclops equatorialis* (Copepoda) dominated in all the water bodies with *Tropodiaptomus* sp. also occurring intermittently.

The dominant Cladocera in Lake Naivasha are were *Diaphanasoma excisum* followed by *Simocephalus vetulus*. In comparison to the other water bodies Lake Naivasha had a wider diversity with the greatest number of species occurring although in relatively low numbers. In Oloidien Bay and Masinga Dam the dominant Cladocera were *Diaphanosoma excisum* and the smaller *Ceriodaphnia cornuta*. The dams also showed a low diversity of Cladocera species. *Moina micrura*, *Daphnia pulex* and *Ceriodaphnia cornuta* were the only species seen in Nairobi Dam. Daphnids were virtually absent from Masinga dam and *D. barbata* has been recorded only once in June 1991. In Ruiru Dam the Cladocera community is limited to *Daphnia laevis* and *Daphnia pulex* with neither *Diaphanosoma* nor *Moina* species occurring.

The common Rotifers in all five waters bodies were *Hexathra* sp., *Polyarthra* sp., *Trichocherca* sp. and *Branchionus angularis*. *B. angularis* tended to be dominant in the sewage ladden waters of Nairobi Dam and the more saline Oloidien Bay. *B. angularis* rarely occurred in Lake Naivasha and Ruiru dam.

Plankton abundance

Concentrations of chlorophyll *a* from the five waterbodies are given in Table 5 along with density and biomass values of the zooplankton species. The relative abundances of the plankton are shown in Tables 3 and 4 for phytoplankton and zooplankton respectively.

Chlorophyll *a* values are lowest in Ruiru and Masinga Dams. This could be attributed to the low nutrient inputs into these two reservoirs. In contrast Nairobi Dam which receives a high nutrient load has higher levels of phytoplankton.

Eutrophic Oloidien Bay has chlorophyll *a* levels that exceed those in the main lake Naivasha.

Table 4. The zooplankton species composition of the 5 water bodies: The relative abundance values are shown by: – absent, + present but are scale based on × 10 magnitification: 1 + 1 individual animal in a microscopic field; 2 + 5 individual animals in a microscopic field; 3 + 10 individual animals in a microscopic field; 4 + 15 individual animals in a microscopic field; 5 + over 25 individual animals in a microscopic field most abundant.

Species	Main Lake Naivasha	Oloidien Bay	Nairobi Dam	Ruiru Dam	Masinga Dam
COPEPODA:					
Thermocyclops sp.	2 +	1 +	4 +	2 +	+
Mesocyclops sp.	1 +	+	3 +	2 +	1 +
Tropodiaptomus sp.	+	+	+	+	+
CLADOCERA:					
Diaphanosoma sp.	2 +	2 +	+	+	1 +
Simocephalus sp.	1 +	–	–	–	–
Ceriodaphnia sp.	+	2 +	+	–	+
Chydorus sp.	+	–	–	–	–
Moina micrura	+	–	2 +	–	–
Daphnia laevis	+	–	–	2 +	–
Daphnia pulex	+	–	1 +	1 +	–
ROTIFERA:					
B. caudatus	1 +	1 +	+	+	+
B. angularis	+	2 +	3 +	+	+
B. calyciflorus	1 +	1 +	+	+	
B. falcatus	+	+	1 +	+	+
Keratella tropica	+	+	+	+	+
Filinia spp.	+	+	+	+	+
Hexarthra sp.	+	+	1 +	1 +	+
Polyarthra sp.	+	+	+	+	1 +
Trichocerca sp.	+	+	+	+	+
Euchlanis sp.	+	+	–	–	–
Asplanchna sp.	+	+	+	+	+
Platyias sp.	+	–	–	–	–
Epiphanes sp.	+	–	+	–	–
Total No. species	23	16	18	16	15

Though the phytoplankton diversity is low, the high chlorophyll concentrations in Oloidien could be due to the blue green algae *Microcystis* sp.

The variation in chlorophyll *a* values is also reflected in zooplankton densities and biomass. The dams which have lower chlorophyll *a* levels,

Table 5. Chlorophyll *a* concentrations and standing stock density and biomass of zooplankton in the five water bodies.

Waterbody	Chl. *a* mg m^{-3}	Density NO m^{-3}	Biomass mg m^{-3}	*n*
Ruiru Dam	4.6 ± 1.6	66.0 ± 10.0	56 ± 3.6	12
Nairobi Dam	71.5 ± 10.2	180.0 ± 12.0	112 ± 7.0	11
Masinga Dam	5.1 ± 1.3	54.0 ± 5.0	50 ± 10.0	12
Oloidien Bay	29.0 ± 3.1	372.0 ± 16.0	341.0 ± 20.0	18
Main Lake Naivasha	24.7 ± 3.4	240.0 ± 18.0	242 ± 12.0	14

as compared to the natural lakes Naivasha and Oloidien Bay, also have lower zooplankton densities.

Conclusions

From the foregoing results it would appear that salinity and conductivity play a major role in the determination of phytoplankton and zooplankton species richness and abundance. This is discerned from the low numbers in species richness and abundance observed from the dams Oloidien and Nairobi dam. Ruiru Dam which has the lowest conductivity contains some phytoplankton species that are not present in the other water bodies. As the nutrient content increases in Nairobi Dam due to sewage input and Oloidien Bay due to evaporation and naturally acquired salts, the abundance of, *Microcystis* sp. increase and the species abundance is limited to only a few tolerant plankton species. Thus the existing limnological parameters play a larger role in determining the species abundance and diversity in these tropical freshwater bodies whilst altitude may be important in determining the occurrence and abundance of daphniids (H. Dumont, 1991, pers. comm).

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