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Water Quality and Fish Diversity in Lake Kijanebalola, a Forgotten Satellite Lake in the Lake Victoria Basin

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Abstract
This study was carried out in Lake Kijanebalola, a small satellite lake in the Lake Victoria basin, in 2007 and then in 2015. A total of 14 fish species were identified but catches declined drastically between the two sampling periods owing to intensive fishing pressure. Juvenile fish were concentrated in shallow inshore areas. The water quality changed between 2007 and 2015, with significant increases in temperature, oxygen concentrations, pH and BOD, suggesting that the lake had become eutrophic. There was a significant decrease in faecal coliforms in the water suggesting improved sanitation in the lake basin. Recommendations for management of the fishery and catchment area through community involvement and education have been included.

Keywords: Coliforms, Fish species composition, Kijanebalola, Lake Victoria basin, Satellite lake

Introduction
Most fish consumed in Uganda comes from its inland waters, which cover about 20% of the country's surface area. These consist of five major lakes (>200 km^2), Victoria, Albert, Kyoga, Edward and George, and about 160 smaller ones, as well as rivers and wetlands. Lake Kijanebalola is a satellite lake in the Lake Victoria basin, which flows into Lake Victoria via the River Kibale while its inflow is a papyrus swamp connecting it to the Kachera-Nakivali-Mburo lake system (Okaronon, 1977). It is an important freshwater resource for the rapidly growing population in its vicinity but it has received little attention from local and international researchers, and relevant government agencies. People depend on the lake for water, fish, and wetland vegetation, while the ecotone areas are used for grazing and agricultural activities. It is under increasing pressure from human activities such as overfishing, pollution, eutrophication and sedimentation. Because of the ever-decreasing fish catch, fishers have resorted to using illegal fishing methods such as cast-netting, small-meshed gillnets, beach seines and small hooks; these have replaced the traditional papyrus nets and fish traps once used by the local villagers. With overfishing, the size of fish caught has dropped, thus destroying both breeding adults and the young of many species. These human activities have had detrimental impacts on the physico-chemical condition of the lake, as well as its biological productivity (Bugenyi and Balirwa, 1989; Bugenyi and Magumba, 1996; Balirwa, 1998; Muyodi *et al*., 2009). In spite of the drastic decline in its fishery the fishing effort has increased and the lake now has about 1,824 fishermen with 1,306 boats and 68,050 nets of varying mesh sizes, distributed over 27 main fishing grounds.

A survey carried out in April 1977 recorded the following fish: *Astatoreochromis alluaudii*, *Clarias* spp, *Haplochromis* spp, *Protopterus aethiopicus*, *Oreochromis niloticus, Coptodon zillii),* and *Xenoclarias eupogon,* while *Oreochromis leucostictus* had been recorded in 1976 (Okaronon, 1977). The distribution of *O. niloticus* during 1975 and 1976 indicated concentrations of fish at the mouth of the River Kibale and opposite Ntovu fishing village at a point where a papyrus swamp connects the Kachera-

Nakivali-Mburo lake system to Lake Kijanebalola. *Oreochromis esculentus* and *O. niloticus* are introduced fish species in Lake Kijanebalola, and along with *P. aethiopicus* are the two most important commercial species in the lake although the latter was apparently absent in 1957.

The fisheries resources of Lake Kijanebalola were briefly surveyed in April 1977 (Okaronon, 1977), but this information has not been updated since then. This paper therefore updates the information on the fish species composition and environmental quality in the lake, based on data from 2007 to 2015.

Methods

Study area

Lake Kijanebalola is a minor (35 km^2), shallow (average depth 5 m) lake with a shoreline length of 88 km, located at 0º40'S-0º45'S and 31^0 15'E-$31^0$25'E at an altitude of 1367 m in the Rakai District of Uganda (Figure 1). Four major fishing grounds were selected according to their dependency on fishing as the main source of income, access to fishing grounds and the location of these fishing grounds relative to the lake profile, i.e. downstream or upstream. These fishing grounds were Ntovu (inshore depth 3.3 m; midshore 4.5 m and offshore 4.5 m), Nabusozi (inshore depth 1.5 m; midshore 2.0 m and offshore 4.0 m deep) and Malemba (inshore depth 3.0 m; midshore 4.5 m and offshore 6.2 m). Three sampling sites, i.e. inshore (<10 m from the shore), mid-shore (30 m offshore), and offshore (as near as possible to the middle of the lake) were selected and geo-referenced using a Garmin Global Positioning System (Garmin GPS 60).

Fish sampling

Fish samples were collected once every fortnight by gillnetting between December 2006 and June 2007 and again from June to December 2015. At each fishing ground, three fleets of multifilament gillnets were used, each consisting of nine nets ranging from 1-5-inch (25-125 mm) stretched mesh, increasing by 0.5-inch (12.5 mm) increments, were set parallel to the shoreline at the three sampling sites. Nets were set in the evening between 1700 hours and 1800 hours and retrieved the following morning between 0700 hours and 0900 hours. Fish samples were also collected from fishermen who used methods such as fishing baskets, gill nets, and cast nets of different mesh sizes. Immediately after the nets were lifted the catch was sorted, dissected and identified according to Greenwood (1966).

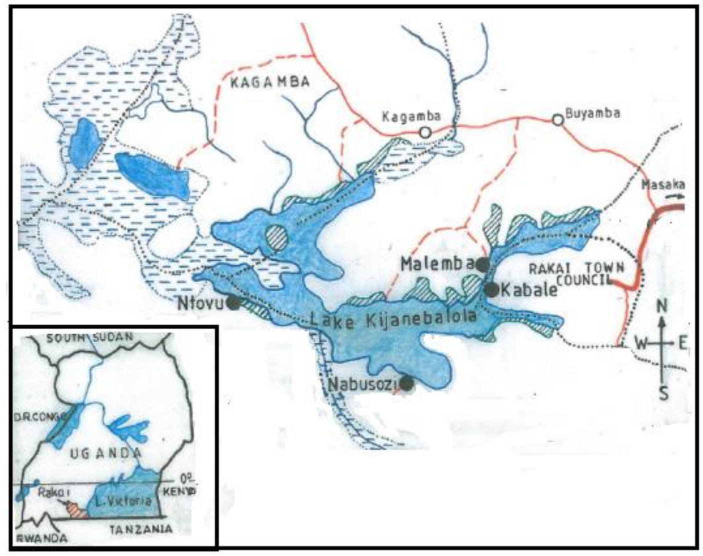

Figure 1. Lake Kijanebalola in the Rakai District of Uganda, showing the location of the sampling sites. The horizontal shading indicates wetlands, the diagonal shading indicates forest reserves.

Environmental conditions

Physico-chemical variables of the water at each fishing ground were determined at the same time as the fish were sampled. Water temperature (˚C) and pH were determined in the field using a portable pH meter, while dissolved oxygen (mg l^{-1}) was determined using the standard Winkler method and a portable DO meter (YSI 85 Dissolved Oxygen and Temperature Meter and Probe). The 5-hour biochemical oxygen demand (BOD_5) was only measured in the 2015 sampling period using standard methods (APHA, 1998).

Water samples were taken at points where people draw water for domestic use. For microbiological examination, they were collected in sterile plastic bottles from approximately 20 cm below the water surface. These samples were held below 6°C during transport until analysis, for a period that did not exceed 6 hours. In the laboratory, they were tested for coliforms using standard methods (APHA, 1998).

Data Analysis

Data were tested by the one-way ANOVA, two-way ANOVA and Chi-square tests using the statistical package for socio-scientists (SPSS version 11.0) and GraphPad Prism Version 7.02 package.

Results

Fish species composition, abundance and distribution

There was some variation in the species that were caught in the 2007 and 2015 sampling periods with a total of 17 species in four families being recorded (Table 1). Twelve of these species were cichlids, four of which were introduced species. *Oreochromis leucostictus*, which had not been recorded 1977 was present in both 2007 and 2015, while *C. rendalli* only appeared in 2017. Only one *Haplochromis* species was collected in 2007 but four different ones were found in 2017. Two unspecialised haplochromine-like species, *Astatoreochromis alluaudi* and *Pseudocrenilabrus multicolor*, were collected only in 2005. Non-cichlids were represented by two *Clarias* spp. and the lungfish *P. aethiopicus* in both years, while *C. liocephalus* and *Labeobarbus altianalis* were added to the list in 2015.

Table 1: Fish species found in Lake Kijanebalola in 2007 and 2015. The symbol * denotes an introduced species.

Family	Species	2007	2015
Cichlidae	*Oreochromis niloticus* *	✓	✓
	Oreochromis leucostictus *	✓	✓
	Oreochromis esculentus	✓	✓
	*Coptodon zillii**	✓	✓
	*Coptodon rendalli**		✓
	Haplochromis nubilus	✓	
	Haplochromis dentex,		✓
	Haplochromis microdon		✓
	Haplochromis sauvagei		✓
	Haplochromis teunisrasi		✓
	Pseudocrenilabrus multicolor	✓	
	Astatoreochromis alluaudi	✓	
Clariidae	*Clarias gariepinus*	✓	✓
	Clarias alluaudi	✓	✓
	Clarias liocephalus		✓
Cyprinidae	*Labeobarbus altianalis*		✓
Lepidosirenidae	*Protopterus aethiopicus*	✓	✓

There was a catastrophic decline in the populations of all fish species in the lake with the total numbers of all fish collected declining by 99.4% between 2007 and 2015 (Table 2). In 2007 the most numerous fish were the haplochromines but by 2015 their catch had collapsed almost completely. Similar declines were also noted in other previously important groups such as the tilapias, *C. gariepinus* and *P. aethiopicus*. *Oreochromis niloticus*, *P. aethiopicus, C. gariepinus* and *Haplochromis* spp. were widely distributed in the inshore, middle and offshore waters of the lake while *O. leucostictus*, *C. zillii* and *C. alluaudi* were concentrated in inshore waters. Juveniles of all fish species were found concentrated in the inshore waters. The distribution of fish species was broadly similar in both sampling periods but of course the numbers of fish were much lower in 2015.

Physico - chemical conditions

The physical environment around the lake changed between the two study periods as the wetland vegetation and forests were significantly reduced by conversion to farming and settlements, as well as an increase in fishing activities. These changes in land use changes have had adverse impacts on the environment of the lake.

Table 2. The number of fish caught at the three fishing grounds in 2007 and 2015. Dashes indicate values of zero.

	Malemba		Nabusozi		Ntovu	
Species	**2007**	**2015**	**2007**	**2015**	**2007**	**2015**
O. niloticus	205	23	32	7	6	8
O. leucostictus	7	8	8	-	8	-
O. esculentus	20	-	331	-	276	-
C. zillii	6	21	8	2	6	9
C. rendalli	0	4	-	-	-	-
Haplochromines	10,270	32	5,980	-	8,000	7
A. alluaudi	3	-	10	-	7	-
C. gariepinus	52	-	41	-	27	-
C. alluaudi	93	-	10	-	30	-
L. altianalis	-	9	-	-	-	-
P. aethiopicus	205	2	32	-	6	-
Total	10,905	99	6,493	13	8,735	27

The average temperature of the lake was around 24°C (Figure 2a) and there was no significant difference between the sites ($F_{1, 422} = 0.074$, $P < 0.05$). By 2015 the average temperature had increased to about 27.5ºC suggesting that the lake had warmed up by almost 4ºC in eight years, a highly significant increase ($p< 0.0001$). There was a slight and insignificant difference in dissolved oxygen concentrations at the three fishing grounds (Figure 2b) where the values ranged from 6.25 to 6.55 mg/l (mean = 6.3 ± 1.0 mg l^{-1}). But dissolved oxygen concentrations had increased by 2015, ranging from 8.5 to 23.5 mg l^{-1} (mean = 14.8 ± 5.4 mg l^{-1}), with an increase in variability between the minimum and maximum concentrations. The differences in oxygen concentrations in 2007 and 2015 were highly significant ($p < 0.001$).

The pH of the lake ranged from 4.0 to 9.0 in 2007 (Figure 2c) but by 2015 it had risen to 6.0 to 8.9. The difference between the two sampling periods was highly significant ($p < 0.0004$). In 2015 the BOD_5 level was 88.9 ± 7.42 mg l^{-1} at Ntovu fishing ground, followed by Nabusozi (61.4 ± 5.68 mg l^{-1}) and Malemba (54.5 ± 14.5 mg l^{-1}).

Discussion

Fish composition and abundance

There were some differences in the composition of the fish stocks in the two sampling periods, but these might be explained by sampling issues. This was particularly important in 2015 when fish populations were greatly diminished, which meant that some scarce species might be overlooked. An example is the apparent disappearance of *Haplochromis nubilis*, which was present in large numbers in 2005 but was not reported in 2015 while the other *Haplochromis* spp. may have been overlooked in 2005. There is some concern that *Xenoclarias eupogon*, which was present in 1977 (Okaronon 1977) was not collected since its status is listed as Critically Endangered (IUCN, 2015). The fishing effort on the lake in 2015 was extremely high, indicated by the density of fishers (52 km^{-2}), boats (37 km^{-2}) and nets (1944 km^{-2}) and this is almost certainly the reason why the fish populations have collapsed.

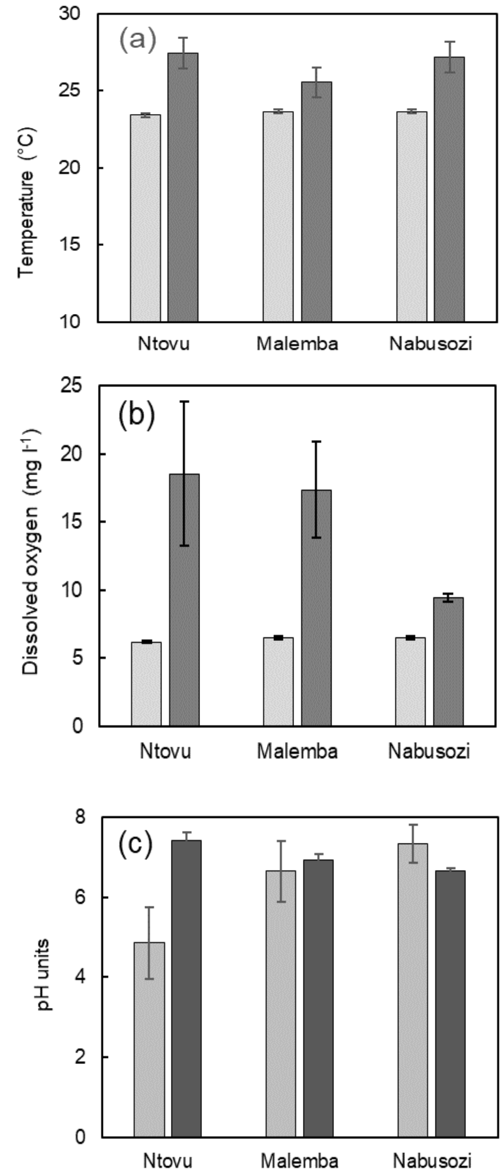

Figure 2. Some water quality chracteristics at the three sampling sites (a) temperature (°C), (b) dissolved oxygen (mg l^{-1}) and (c) pH. Light grey bars = 2007 data, dark grey bars = 2015 data.

Physico-chemical conditions

There was little difference in water quality at the fishing grounds of Lake Kijanebalola in 2007 since the lake is shallow and exposed to wind, which enhances water circulation and mixing (Lewis, 1996). The extremely high dissolved oxygen concentrations recorded in 2015 could be attributed to a dense algal biomass resulting from high nutrient loading to the lake. Although algal biomass was not measured directly, it can be inferred from the high organic content represented by the high biochemical oxygen demand (BOD_5) values and the increase in pH values (Yang *et al*, 2008).

The increase in temperature between 2007 and 2015 is consistent with warming recorded in lakes elsewhere in Africa (Ogutu-Ohwayo *et al*. 2016) and reflects both climate change and destructive human activities (Musinguzi *et al.*, 2015). The rainfall patterns have also changed, becoming shorter and unpredictable, as observed in the cattle corridor areas of Uganda where Lake Kijanebalola is located (Awange, 2008; Nimusiima *et al*. 2013; MWE, 2017). Differences in pH at the fishing grounds could be explained by the fact that Ntovu was always sampled first at 0700 hours before photosynthesis had begun, followed by Malemba at 0830 hours and Nabusozi at 0900 hours.

Microbiological contamination

The World Health Organization (WHO) water quality standards stipulate that there should be no coliforms in water intended directly for drinking or any water entering or treated within the distribution system (WHO, 1982). In 2005 the water in Lake Kijanebalola failed to meet these recommendations, even though much of the population relied on it for drinking water. Since then sanitation has evidently improved and the water now meets both the WHO and national standards for faecal coli in water. However, the BOD_5 levels were above the national standard of 50.0 mg l^{-1} for untreated drinking water, except at the Malemba fishing ground (but this may only reflect a temporary situation, such as a shift in algal blooms). The national permissible limits for pH of untreated surface drinking water are 6.0-8.0 pH units and the lake seem to conform to this requirement.

Lake Kijanebalola is currently under serious pressure from human activities. Fish populations have collapsed while the numbers of boats and nets have increased and the fish being caught are mostly immature. The degradation of the lake basin has resulted in the deterioration of its water quality. Wetlands and adjacent forests have been cleared for cultivation and settlements thus promoting siltation which may have contributed to the increase in water temperature. Siltation and nutrient enrichment favour eutrophication, which is inferred by the high dissolved oxygen concentrations, elevated pH and BOD noted in 2015. If the situation is to be improved then some of the steps that could be taken are outlined below.

Restoration of the fishery will require a reduction in fishing effort. To begin with, there should be no fishing within 30 m from the shoreline in order to protect inshore breeding areas. A minimum mesh size of 4.0 inches (100 mm) is recommended to protect juvenile fish. Closed seasons would allow fish to breed and recruit into the fishery; these could be from March to May (3 months during the breeding season) and then from September to November (3 months) allow for fish growth. These measures would, of course, force many people out of the fishery and deprive them of an income, so a major effort to develop alternative livelihoods, including fish farming, would need to be undertaken. The possibility of restocking the lake should be considered by government, research and development agencies.

Tree planting and afforestation programmes could mitigate siltation and its adverse impacts, while regulating the local climate. Of course, global climate change will contribute to changes in the lake ecosystem and climate change adaptation and mitigation approaches will need to be introduced into the management of the lake basin. Community involvement is an essential component of environmental management and fishers should be educated about the dangers of harvesting immature fish, while the community as a whole should understand the importance of leaving a vegetation zone from the shoreline to their lakeside gardens. This would help to reduce siltation, while the use of watering troughs for livestock and the control of waste disposal into the lake would help to reduce pollution.

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