

Full Length Research Paper

A limnological survey on characterizing the high altitude water bodies for enhanced future fisheries productivity in Kigezi satellite Lakes

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A limnological survey was conducted in six Lakes: Mulehe, Mutanda, Kayumbu, Chahafi, Bunyonyi and Nakasanda, of South-Western Uganda (SWU) in September 2014. The baseline survey aimed at characterizing the high altitude water bodies for enhanced future fisheries productivity. The results indicated that Lake Nakasanda had the highest temperature (24°C). Although other physic-chemical conditions of the water bodies varied, they were within acceptable ranges for fish productivity with no extreme cases reported. Chlorophyll-a was recorded highest in Lakes Nakasanda ($16.8 \pm 3.4 \mu\text{gL}^{-1}$) and Bunyonyi ($14.2 \pm 9.5 \mu\text{gL}^{-1}$). Rotifers were the most dominant zooplankton taxa with a total of 16 species and Lake Mulehe had the highest abundance ($2,089,423 \pm 4,511$ individuals m^{-2}) while the least abundance were recorded in Lakes Nakasanda ($471,608 \pm 35,505$ individuals m^{-2}) and Chahafi ($473,354 \pm 15,279$ individuals m^{-2}). Among the macro-invertebrates, Diptera was the most abundant with Lake Mutanda recording the highest species richness of 8. The recorded absence or fewer individuals of some zooplankton and macro-invertebrate species/groups in certain aquatic ecosystems were attributed to the water quality. The variation in water quality, results from human activities and this may impart negative implications on fish productivity if not remedied.

Key words: Minor Lakes, physic-chemical parameters, Chlorophyll-a, zooplankton, macro-invertebrates.

INTRODUCTION

The great Lakes of Africa are in a state of environmental siege, and some endemic aquatic fauna are facing extinction due to anthropogenic activities (Hecky,

1993). While Ugandan major bodies; Victoria, Albert, Kyoga, Edward and George are fronted for numerous investigations (Ayieko et al., 2010; Budeba and Cowx, 2007; Hecky et al., 2010), less focus has been on minor/satellite Lakes estimated to be 160 (Kizito et al., 1993). This is particularly the case with the six Kigezi highland minor Lakes, namely: Bunyonyi, Mutanda,

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Mulehe, Kayumbu, Chahafi and Nakasanda which are of special limnological consideration. These Lakes are situated at an altitude of or greater than 1,700 m above sea level (masl) (Hughes and Hughes, 1992; Kamanyi et al., 2006; Tibihika et al., 2015). Kamanyi et al. (2006) revealed that, the high altitude contributes to the low water temperatures (15-24°C), confirming to Green, (1976) who reported temperatures of about 20°C throughout the year. Lake (L) Bunyonyi is the largest of the studied Lakes with an area of 56 km²; maximum depth of 40 m lying at 1,973 masl (Beadle, 1966; Green, 2009). Bunyonyi is fed by river Kabirita at its Southern end from Rwanda and remains stratified for many years without mixing (Hughes and Hughes, 1992) thus having anoxic bottom waters. It drains into Lake Mutanda via river Ruhezamyenda (Per. com). Much of the information on limnology for Bunyonyi was last reported by Worthington, (1932) and Worthington and Ricardo, (1936). The information revealed phytoplankton being sparse with *Botryococcus* and a few diatoms while the juvenile *Caridina nilotica* formed about 0.4% of the mid-lake invertebrate. Thereafter, little has been updated on this finding since then. Lake Mutanda is the second largest with an area of 29 km² (9 km long and 2.5 km wide) and deepest (maximum depth 56 m) among Kigezi Lakes (Green, 2009). It is located at 1,792 masl (Hughes and Hughes, 1992; Kamanyi et al., 2006; Green, 2009). Mutanda discharges its water via River Kako from the southwestern through Tshengere Swamp in the Democratic Republic of Congo (DRC) and joins River Rutshuru that flows into L. Edward and River Nile (Hughes and Hughes, 1992; Green, 2009). However, Kisoro District Local Government (KDLG) report of 2007/2008 indicated that L. Mutanda drains into River Mkarara which expands to L. Edward. In addition to River Ruhezamyenda which drains from L. Bunyonyi to L. Mutanda, River Mucha (approximately 2 km long) drains from L. Mulehe to L. Mutanda (KDLG, 2007/2008). According to Green, (1965a) the phytoplankton of L. Mutanda contained desmids *Staurostrum* and *Closterium*, with *Pediastrum* and *Coelastrum* though Green, (2009) reported *Microcystis* as dominating.

Mulehe also known as lake Muanga (Hughes and Hughes, 1992) is the third largest of the studied Lakes and is situated at an altitude of 1800 masl, east of Mutanda (Figure 1). It is very shallow with a maximum depth of 7.5 m, 3 km length and width of 1 km (Hughes and Hughes, 1992; Green, 2009; KDLG, 2007/2008). The lake was reported to be dominated with *Melosira*, *Synedra*, *Oscillatoria* and *Coelastrum* in 1962 while *Microcystis* and *Ceratium* dominated in 1990 (Green, 2009).

Lakes Kayumbu (2.2 km²) and Chahafi (1 km²) are small minor Lakes situated at 1890 masl close to each other and near the border with the Republic of Rwanda (Kamanyi et al., 2006; KDLG, 2007/2008). The limnology of these two Lakes are poorly documented apart from a

few studies by Magumba, (2000), who indicated dissolved oxygen of both Lakes to be ranging in between 1-11 mg/l and 1.3-7 mg/l, respectively.

Lake Nakasanda/Garubunda in Rukungiri has about the same size as Kayumbu and Chahafi (Per. Com). The Limnological conditions for this Lake to date remain undocumented.

In most of the reports, the Kigezi minor Lakes are known to be poor in fisheries. It is important to note that, fish productivity is directly correlated to the physics, chemistry and biology (limnology) of water bodies. However, for positive interventions like restocking to improve fisheries productivity, the limnological aspects of the water bodies should be well understood. More so these six water bodies studied are interconnected henceforth documenting their baseline limnological status prior to restocking, recommendation to management is paramount. This study therefore aimed at limnological characterization of the Kigezi Lakes to understand and document the productive and nonproductive water bodies among them for purposes of fish restocking in those productive Lakes and promoting cage aquaculture in the nonproductive ones. This will in turn contribute to increased fish productivity for enhanced food security, nutrition and better livelihoods of the Kigezi communities. Currently, the level of malnutrition and unemployment in the region is high; hence, the potential of these natural water bodies needs to be exploited to help improve on the livelihoods. It must also be realized that the current study in the Kigezi satellite Lakes is a baseline and thus provides a benchmark for the future intensive work in the region water bodies.

MATERIALS AND METHODS

Study area

The study was conducted in three districts of Kisoro, Kabale and Rukungiri; former Kigezi/South-Western Uganda. The survey covered six Lakes: Mutanda, Mulehe, Chahafi, and Kayumbu found in Kisoro while Bunyonyi and Nakasanda/Garubunda - situated in Kabale and Rukungiri respectively (Figure 1 and Table 1). All Lakes were sampled only once during the wet season in September 2014, using locally made dug-out canoes (Plate 1).

Physico-chemical parameters

Water samples were collected from sub-surface (0.5 m) using a 2 L Van Dorn sampler, placed in 250 mL plastic sample bottles (Plate 1) and transported in a cool-box to National Fisheries Resources Research Institute (NaFIRRI) laboratories for further analysis. Dissolved oxygen (DO) in mgL⁻¹, Temperature (°C), pH and Conductivity (µS cm⁻¹) were measured *in situ* using Multiprobe (Hach HQ40d). Light transparency was measured using a black and white Secchi disc with a diameter of 25 cm. In the Laboratory, Ammonia-nitrogen and Nitrate-nitrogen, Ortho-phosphate, total phosphorus (TP), total nitrogen (TN) and Soluble Reactive Silica (SRSi) were determined using standard methods (APHA, 1995; Stainton et al., 1977).

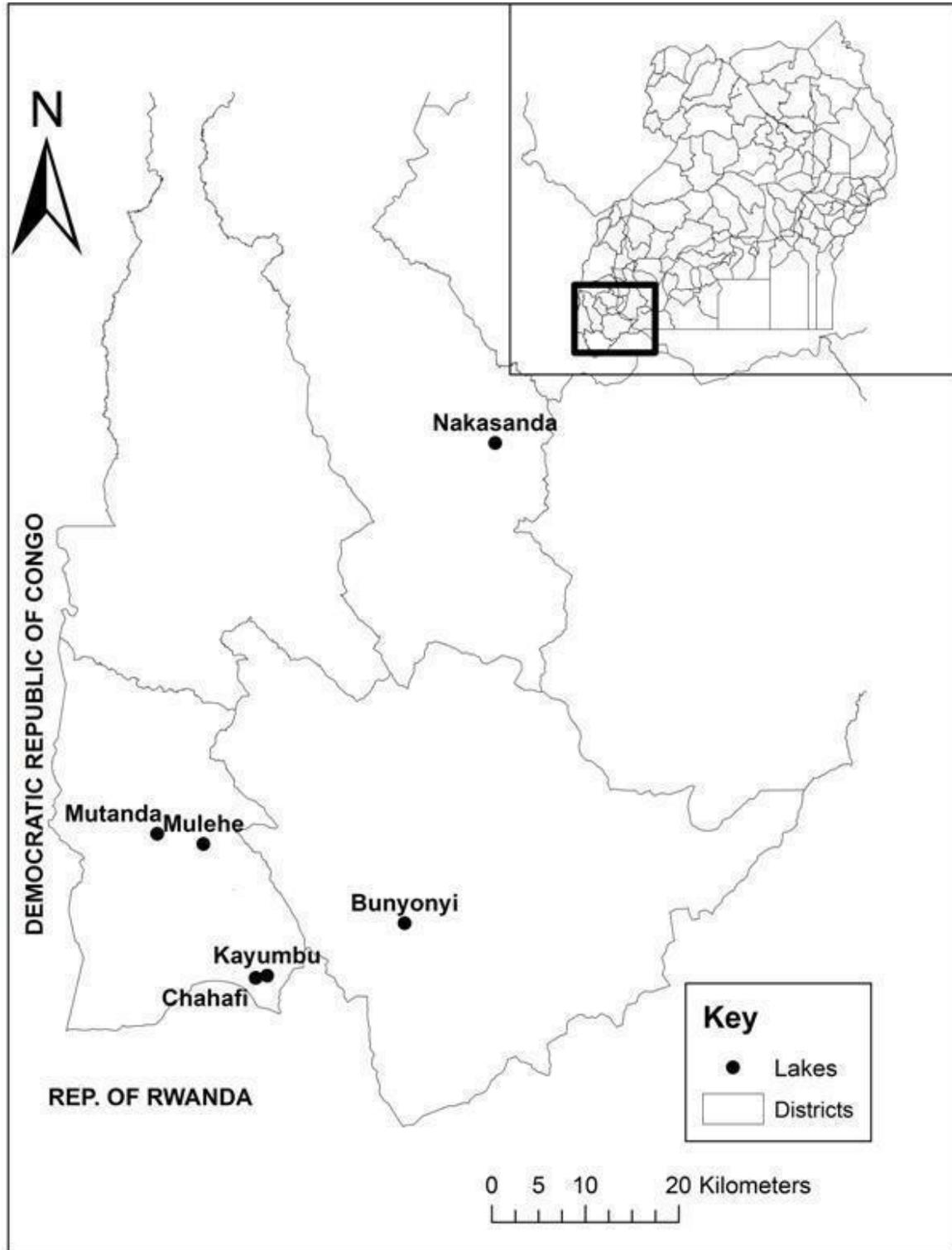


Figure 1. Locations of the studied Lakes in South-Western Uganda.

Phytoplankton biomass

At each sampling site, 100 ml of water for assessing baseline status of phytoplankton biomass was drawn from 0.5 m depth and 1 m

above the bottom sediment. This was then immediately filtered through a 0.45 μm pore size Whatman GF/C filter (Plate 2). Filter was stored in silica gel in the dark while being transported back to the laboratory. In the laboratory, chlorophyll-a pigment was

Table 1. Basic data on South-Western Ugandan Lakes (UTM= Universal Transverse Mercator and 35= zone).

Lakes	DISTRICTS	Coordinates (UTM 35)		Maximum depth (m)	Area (km ²)	Altitude (masl)
		Easting	Northing			
Mulehe	Kisoro	802689	9864515	6	4.1	1,800
Mutanda	Kisoro	795942	9863236	56	29	1,792
Kayumbu	Kisoro	810030	9851368	5	2.2	1,890
Chahafi	Kisoro	809200	9850728	5	1	1,890
Bunyonyi	Kabale	825459	9858076	45	56	1,973
Nakasanda	Rukungiri	833678	9908181	3	-	1,616

masl: Meters above sea level.



Plate 1. A technician taking water samples on Lake Chahafi in a dug-out canoe.



Plate 2. Filtering phytoplankton using 0.45 µm pore size Whatman GF/C filter.

extracted from the filter using 10 mL of 90% Methanol at 4°C for 12 h. The following day, the extract was equilibrated to room temperature and absorbance reading taken at 665 nm and 750 nm and Chlorophyll-a concentration ($\mu\text{g L}^{-1}$) was computed taking into consideration the coefficient of Methanol extract (Stainton et al., 1977).

Zooplankton species composition and distribution

Integrated samples were taken using conical plankton (Nansen type) net of nitex mesh size 60 μm and mouth diameter 0.25 m, towed vertically through a water column from 0.5 m above the sediments to surface. Three hauls were taken to make a composite sample, concentrated through a 53 μm and preserved with 4% sugar-formalin solution to stop morphological ballooning of cladocerans. In the laboratory, samples were washed over a 53 μm sieve to remove the fixative, diluted depending on the concentration of each sample. Sub-samples of 2, 5 and 10 mls were taken to increase capturing and recording of rare species, with a wide bore automatic pipette from a well agitated sample that ensured homogeneous distribution of organisms. Each sub-sample was introduced on a counting chamber, examined under an inverted microscope (HUND WETZLAR) at both X100 and X40 magnification for taxonomic analysis and counting to determine the species composition and abundance respectively. Species identification was done using published keys (Rutner-Kolisko, 1974; Brooks, 1957; Pennak, 1953; Sars, 1895).

Macro-invertebrates species composition and distribution

The total depth (m) at each site was measured using an echosounder of 400Hz, and triplicate sediment samples were collected using a ponar grab of jaw area 238 cm^2 (APHA, 1992), mixed in a basin before washing out sediment using washing (filtering) bag of 400 μm mesh size. Individual composites were then concentrated, transferred in sample containers and preserved with 5% formalin solution before transported to the Laboratory for further analysis. Sorting of organisms from remaining sediments and organic materials was done with the help of a hand lens and pair of forceps (APHA, 1992; Ferraro and Cole, 1992; Ochieng, 2006; Ochieng et al., 2008). The individual taxa were identified to the lowest possible taxonomic levels using a dissecting compound microscope at X40 magnification with the help of published identification manuals (Mandal-Barth, 1954; Pennak, 1953; De Moor et al., 2003). The data was processed in MS Excel and analyzed using SPSS version 17. The mean numbers of macro-invertebrate taxa were calculated from the counts obtained from the composite samples and rounded off to the nearest whole numbers to determine taxa richness and abundance (Individuals numbers per square meter).

RESULTS

Water temperature, dissolved oxygen, pH and conductivity

All the Lakes in the region had lower water temperature readings of around 22°C during the day except L. Nakasanda (Figure 2f) from Rukungiri District with 24°C. Lakes Mulehe, Kayumbu, Mutanda and Nakasanda, recorded generally slight temperature variations with depth contrary to Lakes Chahafi and Bunyonyi. For instance, L. Chahafi recorded a decline in temperature

from 22 to 18°C despite its shallow depth (Figure 2c). Water dissolved oxygen (DO; 9 mg l^{-1}) and pH (≈ 9.5) in L. Nakasanda were higher than in Lakes Mulehe, Kayumbu, Chahafi, Mutanda and Bunyonyi. whose, DO and pH was almost uniform, at 7 mg l^{-1} and 8 mg l^{-1} , respectively (Figure 2a, b, c, d, e, f). Despite a slight fall in DO levels for Lakes Mulehe, Kayumbu, Chahafi, Mutanda and Nakasanda at depth 6, 5, 5, 40 and 3 m, respectively, the DO in L. Bunyonyi was near zero at a depth of 40 m (Figure 2a, b, c, d, e, f). The pH in all the Lakes was recorded almost uniform with an increase in depth. On the contrary, water conductivity was recorded low in Lakes Nakasanda and Kayumbu with 149 and $160 \mu\text{sm cm}^{-1}$ respectively compared to Lakes Mutanda, Mulehe, Chahafi and Bunyonyi (Figure 2g). L. Bunyonyi had the highest conductivity level ($278 \mu\text{sm cm}^{-1}$) which was relatively uniform with depth and followed by L. Mutanda ($260 \mu\text{sm cm}^{-1}$). L. Mutanda had a drastic fall in conductivity from 260 to $250 \mu\text{sm cm}^{-1}$ at a depth of 45 m (Figure 2g). Generally, conductivity levels for the rest of the Lakes were all uniform with depth.

Water nutrients and chlorophyll-a ($\mu\text{g l}^{-1}$)

L. Nakasanda at 166.8 ± 28.5 had the highest total nitrogen (TN) followed by L. Bunyonyi (103.6 ± 8.4). Total nitrogen in the other Lakes did not vary from each other in the range 85-98, Table 2). Similarly, ammonia (NH_4), Nitrite (NO_2), total phosphorus (TP), soluble reactive phosphorus (SRP) and chlorophyll-a were higher in Lakes Nakasanda and Bunyonyi compared to the other four Lakes studied. Ammonia levels in L. Bunyonyi (400.4 ± 34) were specifically higher than even L. Nakasanda (62.3 ± 4.2) (Table 2). Contrarily, soluble reactive silica (SRSi) was least in L. Bunyonyi (35.6 ± 5.3) and significantly higher in L. Chahafi (501.8 ± 10) followed by L. Mulehe (466.5 ± 8.9). The other Lakes: Kayumbu, Mutanda and Nakasanda had values in a range between 250-380 (Table 2).

Zooplankton taxa

Zooplankton species showed great variability among the studied Lakes, where three broad taxonomic groups; Copepoda, Cladocera and Rotifera were identified. Three species of copepods were recorded; *Mesocyclops* sp, *Thermocyclops decipiens*, *Thermocyclops neglectus* and the young stages (copepodite and Nauplius larvae). *Mesocyclops* sp. was only recorded in two Lakes: Kayumbu and Mutanda, while *T. decipiens* was recorded in four Lakes: Kayumbu, Mulehe, Mutanda and Nakasanda. *Mesocyclops* sp. and *T. decipiens* were more abundant in Kayumbu and Mutanda, respectively (Table 3). *T. neglectus*, cyclopoid copepodite and Nauplius larvae were recorded in all Lakes with the latter

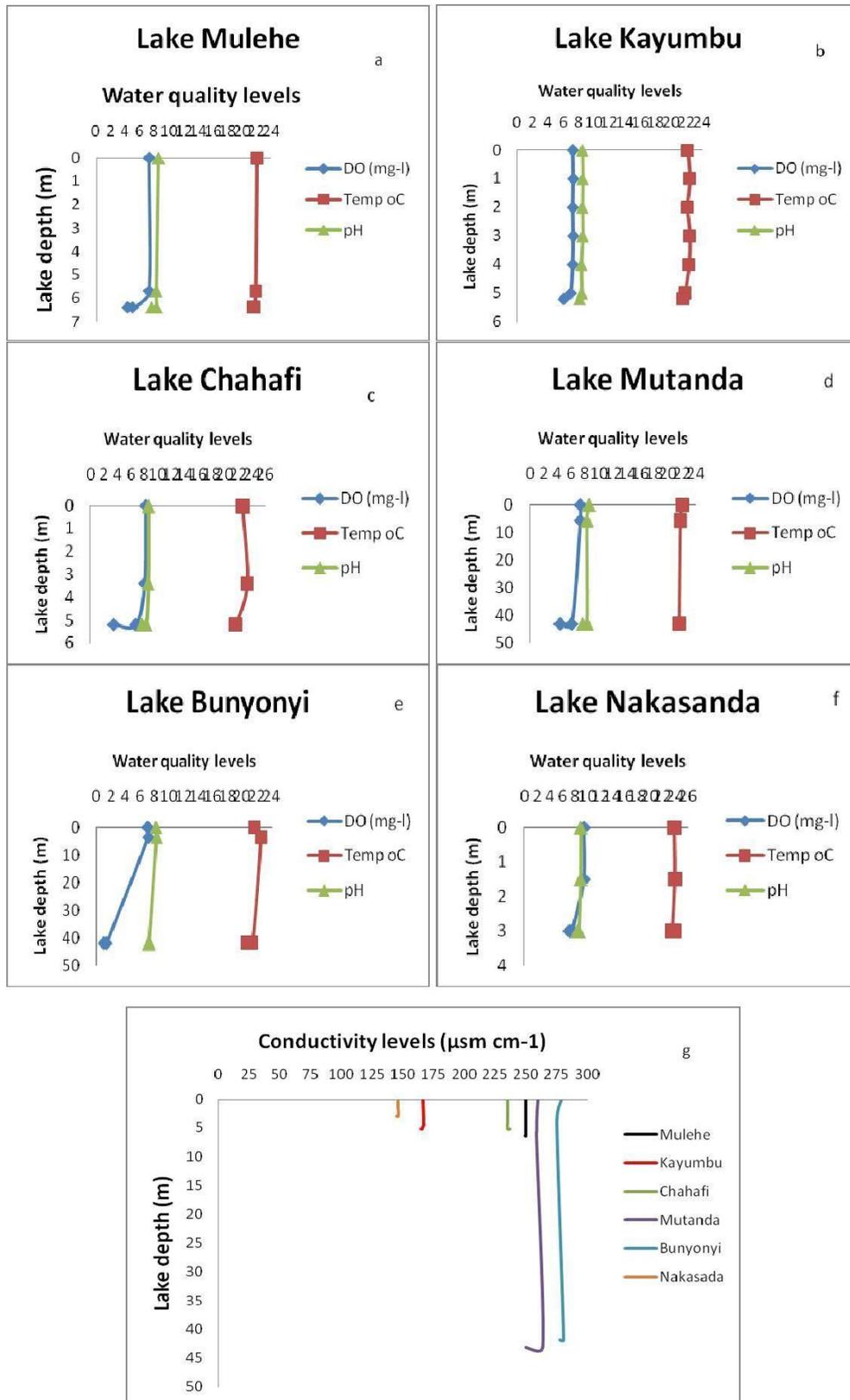


Figure 2. Physico-chemical parameters (Oxygen, temperature, pH and conductivity) of the Kigezi minor Lakes. a) Lake Mulehe b) Lake Kayumbu c) Lake Chahafi d) Lake Mutanda e) Lake Bunyonyi f) Lake Nakasanda and g) Conductivity levels of all Kigezi minor Lakes.

Table 2. Nutrients and phytoplankton (chlorophyll-a) of the Kigezi minor Lakes (μg^{-1}): TP = total Phosphorus; SRP = Soluble Reactive Phosphorus; SRSi = Soluble Reactive Silica; NO_2 = Nitrite, NO_3 = Nitrate, NH_4 = Ammonia and TN = total Nitrogen. Data presented as mean \pm Std Error and comparisons are made vertically between Lakes.

Lake	TN	NH_4	NO_2	NO_3	SRSi	TP	SRP	Chl-a
Mulehe	85.1 \pm 11.3	58.8 \pm 5.7	30.5 \pm 0.9	43.0 \pm 4.4	466.5 \pm 8.9	85.0 \pm 7.2	16.0 \pm 0.7	11.6 \pm 0.8
Kayumbu	93.3 \pm 12.6	56.8 \pm 9.9	29.0 \pm 1.2	44.8 \pm 0.8	288.3 \pm 5.9	76.5 \pm 3.6	17.5 \pm 1.3	5.6 \pm 0.76
Chahafi	98.3 \pm 29.8	45.0 \pm 4.8	31.0 \pm 1.4	43.8 \pm 0.3	501.8 \pm 10	85.0 \pm 3.4	16.8 \pm 0.5	3.7 \pm 1.2
Mutanda	80.0 \pm 14.4	53.6 \pm 11	29.0 \pm 1.3	39.6 \pm 1.7	263.4 \pm 6.6	94.9 \pm 5.4	16.6 \pm 0.4	3.3 \pm 1.7
Bunyonyi	103.6 \pm 8.4	400.4 \pm 34	32.9 \pm 0.7	33.8 \pm 2.1	35.6 \pm 5.3	100.8 \pm 7.9	18.3 \pm 0.3	14.2 \pm 9.5
Nakasanda	166.8 \pm 28.5	62.3 \pm 4.2	38.5 \pm 2.5	90.6 \pm 9.9	379.8 \pm 6	150.5 \pm 3.2	20.0 \pm 0.6	16.8 \pm 3.4

being the most abundant. Considering copepods Kayumbu and Mutanda were most species rich. Lake Mulehe had the highest copepod abundance of 1,191,753 \pm 204,301 followed by Bunyonyi (971,494 \pm 78,917), Mutanda (881,288 \pm 467,910), Chahafi (325,222 \pm 46,710), Nakasanda (356,241 \pm 38,586) and Kayumbu (230,590 \pm 73,436) (Table 3).

Three species of Cladocera; *Ceriodaphnia cornuta*, *Ceriodaphnia dubia*, and *Moina micrura*, were recorded in five Lakes (Bunyonyi, Mulehe, Mutanda, Chahafi and Kayumbu) out of the six studied (Table 3). *C. cornuta* was abundant in Kayumbu with 43,994 \pm 2,959 individuals m^{-2} (ind.) followed by Mulehe (37,834 \pm 16,298 ind. m^{-2}) and Mutanda (2,571 \pm 534 ind. m^{-2}). *M. micrura*, was abundant in Kayumbu (31,091 \pm 18,674 ind. m^{-2}) followed by Mulehe (13,679 \pm 4,948 ind. m^{-2}) and Bunyonyi (437 \pm 437 ind. m^{-2}). While *C. dubia* was found more abundant in Mulehe (174,325 \pm 45,691 ind. m^{-2}) followed by Kayumbu (126,305 \pm 12,223 ind. m^{-2}) and Chahafi (1,310 \pm 1,310 ind. m^{-2}) (Table 3). Comparing abundance of Cladocera, Mulehe had the highest (225,837 \pm 24,447 ind. m^{-2}) followed by Kayumbu (201,390 \pm 3,492 ind. m^{-2}), Bunyonyi (16,298 \pm 4,657 ind. m^{-2}), Mutanda (12,029 \pm 3,880 ind. m^{-2}) and Chahafi (7,130 \pm 1,601 ind. m^{-2}) (Table 3).

Rotifera was the most diverse group in all studied Lakes, with Chahafi contributed 14 species richness followed by L. Kayumbu (11 species), Mulehe (10 species), Bunyonyi and Mutanda (9 species) and Nakasanda (7 species) (Table 3). The widely distributed rotifer species included; *Brachionus angularis*, *Filinia opoliensis* and *Keratella tropica*, recorded in all Lakes while *Brachionus bidentata* was only identified in Nakasanda (Table 3). Although *B. angularis*, *F. opoliensis* and *K. tropica* appeared in all the Lakes, the abundance varied in some Lakes: with *B. angularis* more abundant in Kayumbu (83,428 \pm 3,105 ind. m^{-2}) followed by Mulehe (79,741 \pm 1,164 ind. m^{-2}), Nakasanda (30,291 \pm 1,285 ind. m^{-2}) and Bunyonyi (5,966 \pm 5,966 ind. m^{-2}). *F. opoliensis* recorded higher abundance in Kayumbu (48,601 \pm 23,573 ind. m^{-2}) followed by Bunyonyi (10,671 \pm 1,358 ind. m^{-2}), Mutanda (8,489 \pm 2,377 ind. m^{-2}), Kayumbu (5,530 \pm 292 ind. m^{-2}), Chahafi (2,910 \pm 1,746 ind. m^{-2}) and Nakasanda (825 \pm 340 ind. m^{-2}) while *K. tropica*

was recorded highest in Bunyonyi (201,342 \pm 24,107 ind. m^{-2}) followed by Mulehe (43,945 \pm 9,022 ind. m^{-2}), Chahafi (43,509 \pm 146 ind. m^{-2}), Mutanda (11,423 \pm 5,214 ind. m^{-2}), Kayumbu (4,705 \pm 1,504 ind. m^{-2}) and Nakasanda (2,813 \pm 97 ind. m^{-2}) (Table 3). Generally, Lake Mulehe recorded the highest total number of rotifers (671,834 \pm 224,236 ind. m^{-2}) followed by Kayumbu (431,446 \pm 106,370 ind. m^{-2}), Mutanda (385,913 \pm 28,145 ind. m^{-2}), Bunyonyi (240,291 \pm 33,662 ind. m^{-2}), Chahafi (141,003 \pm 33,032 ind. m^{-2}) and Nakasanda (115,368 \pm 3,080 ind. m^{-2}). However, Lake Mulehe contributed the highest zooplankton abundance (2,089,423 \pm 4,511 ind. m^{-2}), followed by Mutanda (1,279,230 \pm 443,645 ind. m^{-2}), Bunyonyi (1,228,082 \pm 117,235 ind. m^{-2}), Kayumbu (863,427 \pm 176,314 ind. m^{-2}), Chahafi (473,354 \pm 15,279 ind. m^{-2}) and Nakasanda (471,608 \pm 35,505 ind. m^{-2}) (Table 3).

Macro-invertebrates

Three orders of macro-invertebrates were identified, namely; Odonata, Diptera and Oligochaeta (Table 4). Of these invertebrates, Diptera contributed the highest species (five) followed by Oligochaeta (three) and one Odonata (Table 4). Dipteran species; *Chironomus sp.*, *Procladius sp.*, *Tanytus sp.*, *Chironomineae* and *Chaoborus sp.* were the most dominant among these Lakes. Lake Mulehe emerged with the highest abundance of *Chironomus sp.* (2,902 ind. m^{-2}), *Procladius sp.* (543 ind. m^{-2}), and *Tanytus sp.* (216 ind. m^{-2}) compared to other Lakes (Table 4). On the other hand *Chaoborus sp.* was more abundant in Kayumbu with 1,587 ind. m^{-2} followed by Mulehe (571 ind. m^{-2}) and recorded lowest in Mutanda, the exception among the Diptera species distribution was *Chironomineae sp.* in Mutanda (Table 4). *Libellulidae sp.* (the only species contributed under Odonata order) was recorded in Mutanda (Table 4). In this table, we observed that Oligochaeta contributed three species; *Tubifex sp.*, *Hirudinea sp.*, and *Oligochaetes* and were (Oligochaeta) not crosscutting and less abundant compared to Diptera.

Table 3. Zooplankton species composition, distribution and abundance (Mean \pm standard deviation; Individuals m^{-2}) of the studied Lakes, September 2014.

Lakes:	Bunyonyi	Chahafi	Kayumbu	Mulehe	Mutanda	Nakasanda
Copepoda						
<i>Mesocyclops</i> sp.	0	0	1.164 \pm 1164	0	970 \pm 970	0
<i>Thermocyclops decipiens</i>	0	0	14.455 \pm 2426	77.995 \pm 10.477	93.711 \pm 93.711	18.044 \pm 485
<i>Thermocyclops neglectus</i>	58.496 \pm 113	41.326 \pm 14843	50.455 \pm 50455	48.310 \pm 34.341	19.523 \pm 19.523	2.571 \pm 146
Young stages of copepods						
Cyclopoid copepodite	356.507 \pm 50.930	91.382 \pm 32.886	141.099 \pm 80.275	428.827 \pm 98.803	297.769 \pm 169.426	168.747 \pm 8.489
Nauplius larvae	556.491 \pm 16.637	192.516 \pm 1.019	68.828 \pm 10.623	636.620 \pm 129.361	469.316 \pm 223.326	166.880 \pm 30.728
Total Copepoda	971.494 \pm 78.917	325.222 \pm 4.6710	230.590 \pm 73.436	1.191.753 \pm 204.301	881.288 \pm 467.910	356.241 \pm 38.586
Cladocera						
<i>Ceriodaphnia cornuta</i>	13.679 \pm 3.784	4.366 \pm 1.747	43.994 \pm 2.959	37.834 \pm 16.298	2.571 \pm 534	0
<i>Ceriodaphnia dubia</i>	2.183 \pm 1.310	1.310 \pm 1.310	126.305 \pm 12.223	174.325 \pm 45.691	0	0
<i>Moina micrura</i>	437 \pm 437	1.455 \pm 1.455	31.091 \pm 18.674	13.679 \pm 4.948	9.459 \pm 3.347	0
Total Cladocera	16.298 \pm 4.657	7.130 \pm 1.601	201.390 \pm 3.492	225.837 \pm 24.447	12.029 \pm 3.880	0
Rotifera						
<i>Ascomorpha</i> sp.	9.362 \pm 7.325	4.220 \pm 1.892	33.565 \pm 33.565	76.540 \pm 45.691	0	33.614 \pm 1.019
<i>Asplanchna</i> sp.	1.552 \pm 776	873 \pm 873	0	23573 \pm 23573	11.278 \pm 6.185	8.295 \pm 534
<i>Brachionus angularis</i>	5.966 \pm 5.966	11.350 \pm 4.074	83.428 \pm 3.105	79.741 \pm 1.164	6.573 \pm 3.517	30.291 \pm 1.285
<i>Brachionus bidentata</i>	0	0	0	0	0	146 \pm 146
<i>Brachionus calyciflorus</i>	3.880 \pm 1.552	2.619 \pm 291	7.761 \pm 1.552	4.657 \pm 4.657	0	0
<i>Brachionus falcatus</i>	0	728 \pm 146	2.183 \pm 146	0	0	0
<i>Filinia longiseta</i>	0	1.601 \pm 146	0	58.205 \pm 10.477	0	39.386 \pm 2.717
<i>Filinia opoliensis</i>	10.671 \pm 1.358	2.910 \pm 1.746	5.530 \pm 292	48.601 \pm 23.573	8.489 \pm 2.377	825 \pm 340
<i>Hexathra</i> sp.	1.358 \pm 1.358	2.037 \pm 2.037	125.287 \pm 78.432	0	0	0
<i>Keratella cochlearis</i>	0	291 \pm 291	3.298.5 \pm 3.299	35.796.5 \pm 16.589	17.777 \pm 4.972	0
<i>Keratella tropica</i>	201.342 \pm 24.107	43.509 \pm 146	4.705 \pm 1.504	43.945 \pm 9.022	11.423 \pm 5.214	2.813 \pm 97
<i>Lecane bulla</i>	0	1.019 \pm 1.019	2.619 \pm 2.619	0	29.111 \pm 29.111	0
<i>Lecane luna</i>	1.552 \pm 1.552	20.372 \pm 11.350	108.116 \pm 8.003	184.802 \pm 43.363	0	0
<i>Polyarthra vulgaris</i> .	4.608 \pm 3.153	48.165 \pm 15.279	54.956 \pm 1.795	115.974 \pm 69.410	231.136 \pm 21.985	0
<i>Synchaeta</i> sp.	0	1.310 \pm 1.310	0	0	70.817 \pm 16.104	0
<i>Trichocerca cylindrica</i>	0	0	0	0	25.514 \pm 5.142	0
Total Rotifera	240.291 \pm 33.662	141.003 \pm 33.032	431.446 \pm 106.370	671.834 \pm 22.4236	385.913 \pm 28.145	115.368 \pm 3.080
Total abundance	1.228.082 \pm 11.7235	473.354 \pm 15.279	863.427 \pm 176.314	2.089.423 \pm 4.511	1.279.230 \pm 443.645	471.608 \pm 35.505

Table 4. Macro-invertebrates taxa richness, distribution and abundance (Individuals m⁻²) along the studied Lakes, September 2014.

Macro-invertebrates		Lakes				
Orders	Genus	Mulehe	Mutanda	Bunyonyi	Kayumbu	Chahafi
Odonata	<i>Libellulidae</i>	0	2	0	0	0
Sub total		0	2	0	0	0
	<i>Chironomus sp.</i>	2902	92	22	5	9
	<i>Procladius sp.</i>	543	10	4	5	5
Diptera	<i>Tanypus sp.</i>	216	16	2	51	9
	<i>Chironominea</i>	0	46	0	0	0
	<i>Chaoborus sp.</i>	571	86	422	1587	140
Sub total		4,232	250	450	1,648	163
	<i>Tubifex sp</i>	0	6	0	0	0
Oligochaeta	<i>Hirudinea</i>	3	0	0	0	0
	<i>Oligochaetes</i>	0	18	0	0	23
Sub total		3	24	0	0	23
Total abundance		4,235	276	450	1,648	186
Number of taxa (Richness)		5	8	4	4	5

Tubifex sp. was only recorded in Mutanda (6) and *Hirudinea sp.* in Mulehe (3). The exception was recorded from two Lakes: Mutanda (18) and Chahafi (23), Table 4. Generally, Mulehe recorded the highest mean density macro-invertebrate (4,235 ind. m⁻²) followed by Kayumbu (1,648 ind. m⁻²), Bunyonyi (450 ind. m⁻²), Mutanda (276 ind. m⁻²) and Chahafi (186 ind. m⁻²). Although Mutanda contributed lowest in total densities, it had the highest species richness (8 species) followed by Mulehe and Chahafi (5 species) and then Bunyonyi and Kayumbu (4 species), Table 4.

DISCUSSION

Water bodies possess unique physical, chemical and biological characteristics which may change over time due to anthropogenic activities. Holistic parameters like the physical, chemical and biological, may influence the survival and productivity of fish and other aquatic organisms. Therefore, understanding these characteristics would be paramount and imperatively employed to describe and measure the quality of water bodies for fish productivity. This corroborates the relevance of our work.

The water temperature, dissolved oxygen, pH and conductivity parameters of the minor Lakes of South-Western Uganda varied between the Lakes. The variation was more significant for temperature where L. Nakasanda had the highest (24°C) contrary to the other Lakes (averaging 22°C). The high recorded temperature

was expected due to varying altitudes. L. Nakasanda is at 1616 m above sea level (masl) compared to Mulehe, Mutanda, Chahafi, Kayumbu and Bunyonyi which are above 1700 masl. Similarly, the higher dissolved oxygen levels (9 mgL⁻¹) for Nakasanda compared to the lower DO levels (7 mgL⁻¹) of the other Lakes were expected because of its shallow depth. Shallow Lakes can easily be mixed by the wind. Although most of the Lakes indicated a decline in DO with depth, it was more significant for L. Bunyonyi where at a depth of 40 m the DO was near to zero. Our results corroborate with those of Hughes and Hughes (1992) who recorded 8 mg⁻¹ DO in L. Bunyonyi and anoxic near the lake bottom. Contrarily, our results do not agree with those of Beadle (1966) who reported that L. Bunyonyi is completely anoxic beyond a depth of 15 m. This contrast in results may be attributed to different time frames for the studies. Beadle's work was during the dry season in June 1963 while the current study was conducted in the wet season of September 2014. Therefore, the results of Beadle, 1966 could be explained by thermal stratification of L. Bunyonyi during the dry spell of June in Uganda. Details of the Ugandan climate are described by Hughes and Hughes, 1992. Lake Nakasanda again was discovered to have the highest pH (9.9) contrary to the other Lakes where the pH was about 8. Lakes with pH higher than 7, are considered alkaline. Alkaline water bodies (high water pH) are dependent on the function of formation and nature of soils surrounding the water source or bedrock (Linntech, 2013). The alkalinity of water bodies is escalated by carbonate rich soils (carbonates and bi-carbonates) such

as limestone. Details of alkaline Lakes were reported by Matagi, 2004 and Grant, 2006. Although the current study report L. Nakasanda with a pH value of more than 8, majority of the studied Lakes bear pH values not lethal to fish and hence conducive for fish growth and productivity. pH values ranging in between 6.5 to 9.0 were recommended for fish growth by Wurts and Durborow (1992), Baldisserotto (2011) and Heydarnejad (2012).

Conductivity is a measure of the water's ability to conduct electric current. It is useful for estimating the concentration of the total dissolved solids in an aquatic environment (IEPA, 1998). Lakes with high alkalinity often have high conductivity and vice versa (Beadle, 1966; Kizito et al., 1993; IEPA, 1998). Our results are contrary to this explanation; for instance L. Nakasanda which had a higher pH (basic or alkaline water) would be expected to have a significantly higher conductivity. Conductivity is influenced by cations and anions which is an indicator of available inorganic ions in aquatic environments and plays a major role in determining the availability of aquatic organisms (Gupta and Mrinal, 2013). The low conductivity levels in Lakes Nakasanda and Kayumbu might be explained by low concentrations of inorganic ions (e.g. Ca^{++} , Mg^{++} , Na^+ and K^+). However, we have little information on the contribution of inorganic ions in the satellite Lakes. Therefore, further studies are required to assess the availability and variations of inorganic ions in the Lakes of South-Western Uganda.

Nutrients (TP, TN, NH_4 , SRP, SRSi, NO_2 and NO_3) in Lakes serve the same basic function as in gardens: they help plants grow. In water bodies such as Lakes, Phosphorus and Nitrogen are the major nutrients of primary concern (IEPA, 1998). In aquatic environments, additional phosphorus loadings will escalate the growth of algae and other aquatic plants and hence primary productivity. In the current study, the nutrients; TN, NH_4 , NO_2 , TP and SRP were recorded higher in Lakes Nakasanda and Bunyonyi which also corresponded to higher levels of chlorophyll-a in the same Lakes. Particularly, NH_4 was extremely higher in Lake Bunyonyi compared to the other Lakes. On the contrary, L. Bunyonyi was found with low levels of SRSi. The high levels of chlorophyll-a in Lakes Nakasanda and Bunyonyi corresponding to higher levels of TP and TN were expected. Nutrient concentrations in Lakes are a function of external and internal sources. External source of nutrients is from run-offs of storms and waste water. Run-off from storms could pick large amounts of phosphorus and nitrogen from agricultural fields, septic systems and load them in aquatic habitats (CCME, 2010). Internal sources of nutrients particularly phosphorus originates within Lakes and is typically linked to sediments. For example, plants may take up nutrients from the lake sediment with their roots and release them in the water column. Also sediment suspension to release nutrients may occur with the help of wind/wave action especially in shallow Lakes (CCME, 2010). Contrarily, in

protected and thermally stratified Lakes with anoxic hypolimnion, chemical reactions may occur in which nutrients bound to iron complexes in the sediment becomes soluble and is released in the water column (CCME, 2010). This phenomenon may explain the presence nutrients recorded in the current study for the case of L. Bunyonyi as it is thermally stratified almost throughout the year (Beadle, 1966). Similarly, nutrients like ammonia (NH_4) concentration in any aquatic habitat may be released from decomposing organic material under anoxic conditions and may be elevated in the hypolimnion (Leslie et al., 2000). This scenario explains the presence of high concentrations of ammonia in L. Bunyonyi.

Zooplankton communities for these Lakes were last studied by Green (1976) and also gave a brief highlight in 2009. These micro-organisms play an important role in aquatic ecosystems by linking primary and secondary producers in the food chain (Hutchinson, 1967; Lind, 1985; Wetzel, 1975). The current study reports the presence a higher variability of zooplankton in the Kigezi water bodies. Our results differed from the previous studies by Green (1965a, 1976, 2009) who reported only one copepod species; *Thermocyclops oblongatus*. Green, 1965a reported that *T. oblongatus* dominated Lakes Bunyonyi, Mutanda and Mulehe, however, this copepod species was not reported in the current study. Disparity in sampling methods and seasons may be an explanation. Except *C. dubia* which was absent in L. Mutanda, and Nakasanda, all the other cladoceran species appeared in all the Lakes. *C. cornuta* and *M. micrura* were more abundant in L. Kayumbu while *C. dubia* in L. Mulehe. Like the copepod above, L. Mulehe had the highest cladoceran individuals unlike other Lakes. On the other hand rotifers were the most numerous zooplankton taxa in the current study. Our results are in agreement with those of Green (1976, 2009). The only discrepancy in our results from those of Green, 1976, is the Lakes studied and period. Green, 1976, studied only three Lakes: Mutanda, Bunyonyi and Mulehe. Although the current study recorded similar results like those of Green, 1976, the reported results differ in species' abundance and distribution among the Lakes. For instance Green, 1976 reported *C. cornuta* and *M. micrura* most abundant in L. Mulehe, while in the current study, *the same species* were more abundant in L. Kayumbu. Similarly, Green, 1976 reported *C. dubia* only in Lake Bunyonyi contrary to our results. Furthermore, although our findings reported nine species of rotifer (*Brachionus calyciflorus*, *Brachionus falcatus*, *Filinia longiseta*, *F. opoliensis*, *Hexathra* sp., *K. tropica*, *Lecane bulla*, *Synchaeta* sp., and *Trichocerca cylindrica*) similar to those of Green, 1976, other discrepancies exist. For instance, the seven rotifer species (*Anuraeopsis fissa*, *Brachionus caudatus*, *Brachionus quadridentatus*, *Polyarthra dolichoptera*, *Trichocerca chattoni*, *Trichocerca pusilla*, and *Trichocerca similis*) reported by



Plate 3. Lake Bunyonyi and developments thereon (Author's picture).

Green (1976), have not been encountered in the current study.

The explanation for the reported mismatch of some zooplankton taxa from the current study and previous ones might be complex, ranging from sampling season variations and attributes from the environmental effect. The sampling season is crucial and considered as one of the greatest concerns while surveying zooplankton. For instance the wet and dry sampling season may influence the abundance and composition of zooplankton taxa. Semyalo and Nattabi (2009) found the total zooplankton abundance in Lake Victoria significantly lower in the dry than in the wet season. The forces behind the distribution and abundance of zooplankton taxa are a function of many factors including temperature, food availability and predation pressure (Beklioglu et al., 2008). While the current study was carried out during one season, we do not have concrete data to validate and compare the optimal abundance and composition of the zooplankton taxa in South Western Ugandan satellite Lakes. Future studies should encompass this. On the other hand, the structural composition and abundance of zooplankton taxa in South Western Ugandan satellite Lakes are assumed to have changed probably due to the anthropogenic effect on the catchment areas around the Lakes. According to the current state and physical observation around the Lakes, there is little left as all the lands near the Lakes' shores are either tilled or under several hotels (Plates 3 and 4). Chemicals from the tilled land and sewer systems from the hotels around the Lakes could be polluting the water bodies in the region.

Green (1976) elaborates that the Lakes in the region (Kigezi) have undergone changes since 1931 to 1962

which have contributed to a reduction in zooplankton taxa. The changes were attributed to eutrophication, pollution and grazing pressure by large numbers of zooplanktivorous fish. According to Waya and Chande (2004), some zooplankton species may disappear or crash when exposed to pollutants including chemicals and high quantity of nutrients which cause eutrophication. Other than ideal environment and probably abundant zooplankton food items, the high contribution of zooplankton from L. Mulehe could be linked to low zooplanktivorous organisms in the higher trophic levels. This was emphasized by Katunzi (2001) who found high zooplankton species and composition in L. Kitumi and Kyarano and attributed this to low fishery (zooplanktivorous fish) production. The high contribution of rotifers in the current study might be attributed to resistant traits of rotifers to harsh conditions. Mavuti and Litterick (1991) argue that rotifers can flourish in turbid waters and are more tolerant to pollution and eutrophication than most of other zooplankton taxa.

Benthic macro-invertebrates are animals big enough to be seen with the naked eyes, have no backbones, live at least their entire lives in or on the bottom (benthos) of the water bodies (Rashid and Pandit, 2014). Despite macro-invertebrates serving as food for higher trophic levels, their presence or absence in any aquatic habitat is a function of ecosystem quality, (Elias et al., 2014; Likens, 2010). Consequently, a wider scope of fresh water ecosystems offers a high diversity of macro-invertebrates. Variations in the distribution and plentiful macro-invertebrates in an aquatic site are characterized by either the absence of sensitive taxa or presence of a few taxa of macro-invertebrates that are tolerant to



Plate 4. Construction of a new hotel on Lake Mutanda (Author's picture).

changes in the environment/pollution (Elias et al., 2014). Furthermore, Kaul and Pandit (1981) stipulate that the presence of macro-invertebrate species indicates the suitability of the environment for its growth and development, and the absence of any species does not necessarily indicate the unsuitability of the environment, but, the absence of an entire group/order of species indicates adverse environmental conditions for instance pollution.

Indeed, the strong correlation between the orders and the species of macro-invertebrates from the minor/satellite Lakes of South-Western Uganda as revealed in our work appears to support Kaul and Pandit (1981) elaboration. Order *odonata* seemingly disappeared from most of the satellite Lakes apart from L. Mutanda. In the same trend, *Tubifex* and *Hirudinea* species under the order *Oligochaeta* only appeared in Lakes Mutanda and Mulehe, respectively. This is unlike order *Diptera* whose species were numerous and almost diverse in most of the regional water bodies. The complete absence of the herein mentioned species/orders from some minor Lakes is most likely related to the water quality variations. The water quality variation is attributed to the differences of in-stream and catchment degradation along the Lakes resulting from anthropogenic activities, like, urbanization, agriculture and industrialization. On the contrary, diversification of Dipteran species among almost all the minor Lakes may be an indicator that they are tolerant to harsh conditions/pollution. Revelation of the *Diptera* order of insects as most dominant in freshwater bodies was also

observed by Covich et al. (1999). On the other hand, our results do not concur with Green (1976), whose findings did not report *Chaoborus* species in the Lakes: Mutanda, Bunyonyi and Mulehe. Therefore, the presence of *Chaoborus* species under *Diptera* order in our work suggests that *Chaoborus* might have developed resistant traits over time to harsh conditions/pollution in South-Western Ugandan Lakes. The disappearance of certain orders/species from given aquatic ecosystems is a powerful indicator of water quality assessment for bio-monitoring tool (Elias, et al., 2014). Further and routine studies on aquatic macro-invertebrates should be conducted to monitor the water quality in Kigezi and the entire country.

Conclusion

The results of the current study reveal that L. Nakansanda has the highest temperature (24°C) compared to the Lakes with an average temperature of 22°C. Dissolved oxygen, pH values and the other water nutrients were within the best ranges for fish production except for L. Bunyonyi whose deeper waters were anoxic. High chlorophyll-a in the Lakes was attributed to influx of high levels of nutrients. Zooplankton species were dominated by Rotifers and disappearance of certain taxonomic groups may be related to anthropogenic activities. Our work reveals that, Dipteran species of macro-invertebrates are the most diverse in the Kigezi water bodies. The disappearance or absence of certain

macro-invertebrates from the water bodies was linked to water quality. Further studies on the inorganic ions composition, seasonal limnological sampling for (dry, wet, day and night) and routine assessments of macro-invertebrates as a bio-monitoring tool for water quality in the Kigezi Lakes are recommended.

Conflict of Interests

The authors have not declared any conflict of interests.

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