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Planktonic and Fisheries biodiversity of Alkaline Saline crater lakes of Western Uganda

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ABSTRACT Eight (8) selected saline crater lakes in Western Uganda were sampled for fish biodiversity. Water samples collected from each of these lakes were analysed for zoo- and phyto-planktonic composition and abundance. In situ, physico-chemical parameters including average depth, salinity, temperature, conductivity, Dissolved Oxygen and pH were taken at each sample collection point. The Mean ± SD of the different parameters ranged between 0.2±0.0 m and 2.3±0.3 m for average depth,0.0±0.0 mgl^{-1} and 205.0±15.3 mgl^{-1} for salinity, 27.9±0.3°C and 34.4±2.4°C for temperature, 18.6±0.1 mscm-1 and 106.3±3.5 mscm-1 for conductivity, 1.7±0.4 mgl^{-1} and 6.0±1.0 mgl^{-1} for Dissolved Oxygen and 9.6±0.1 and 11.5±1.0 for pH. With the exception of the Lakes Bagusa, where *Anabaena circinalis* Rabenhorst ex Bornet et Flahaulwas found to dominate the algal biomass, and Bunyampaka and Nyamunuka where no *Spirulina platensis* (Nordstedt) Gomont was found, the rest of the studied lakes had *S. platensis* dominating their algal biomass. All lakes showed very low zooplankton abundances and biodiversity, with Lake Kikorongo (the one with the highest zooplankton biodiversity) having *Brachionus calyciflorus* Pallas, 1766 as the most abundant, only ranging between 50 to 100 individuals/litre. None of the lakes had fish at the time of sampling.

KEY WORDS Zooplankton; Phytoplankton; Fish; saline; alkaline; lakes.

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INTRODUCTION

Minute free-floating organisms found in various water bodies can be referred to as planktons and have been reported to be the main food for fish (Lind, 1965). Planktons have been reported to play pivotal roles in the biosphere in terms of both primary and secondary production (Boero et al., 2008). Plant-like minute organisms continuously drifting in the water are referred to as phytoplankton while the minute animal-like organisms, unable to synthesize food are referred to as zooplankton. Planktons are not only food organisms for fish fry, fingerlings and adult fish but also influence key abiotic features in aquatic systems (Joshi, 2009).

Saline systems have been reported to have a generally low biodiversity (Hammer, 1986), with diatoms being more dominant among algal biomass in alkaline saline systems (Stenger-Kovács et al., 2014). Rotifera, Cladocera, Copepoda and Anostraca species generally are the dominant zooplankton in saline systems with their biodiversity decreasing with increasing salinity (Hammer, 1993). In particular, East African saline lakes have been reported to show more rotifers in their zooplankton assemblages than either Copepods or Cladocerans, with the dominant species of Rotifera, Copepoda and Cladocera reported to change with the salinity gradient (Green, 1993). Alkaline saline crater lakes are considered very productive environments (Harper et al., 2003; Grant, 2006), with prokaryotic photosynthetic primary production suggested to be the driving force behind nutrient recycling in these systems (Jones & Grant, 1999). Community evenness decreases with increasing nutrient concentration, with the few favored species being dominant (Harper et al., 2003). Abundance of certain species like *Dunaliella* sp. dominate the saline waters of Utah lake in the USA (Larson & Belovsky, 2013), while '*Spirulina*' *Arthrospira fusiformis* (Voronikhin) Komárek et J.W.G.Lund has been reported to be dominant in lake Bogoria which is a hypersaline lake in Kenya, east Africa (Harper et al., 2003; Matagi, 2004) with no macro-zooplankton and lesser flamingo, *Phoeniconaias minor* (E. Geoffroy Saint-Hilaire, 1798), as the only grazers (Harper et al., 2003).

Several fish species more especially amphihaline species have been described to have physiological mechanisms which enable them to migrate between freshwater and sea water, with many other species with ability to tolerate, adapt or even acclimate to salinity, alkalinity and ionic compositions levels outside the conventional freshwater and seawater conditions (Brauner et al., 2013). Whereas both native and exotic species were found in waters with salinities less than 30 mgl^{-1} in a study of fish distribution in inland saline waters in Victoria, Australia, no inland fish species were found at salinities above 30 mgl^{-1} (Chessman & Williams, 1974). Flamingo lakes with salinity levels below 20 mgl^{-1} are reported to have fish species of commercial value (Hadgembes, 2006). Several species were said to tolerate salinities as high as 15,000 mgl^{-1} with only the nine-spined stickle back resisting at salinities of 20,000 mgl^{-1} (Rawson & Moore, 1944). *Oreochromis alcalicus alcalicus* (Hilgendorf, 1905), *O. alcalicus grahami* (Trewavas, 1983), and *O. amphimelas* (Hilgendorf, 1905), have been reported to be endemic in lakes Magadi and Natron which are among the East African saline lakes (Matagi, 2004).

A number of environmental factors including salinity and nutrients in hypersaline systems may be potential factors which do affect biodiversity in saline environments (Larson & Belovsky, 2013). Saline lakes show limited species complement in micro-organisms contrary to the considerable biodiversity in micro-organisms (Harper et al., 2003). Larson & Belovsky (2013) reported salinity and nutrient concentration in hypersaline lakes as among the strong determinants of phytoplankton diversity, with species richness decreasing with increasing salinity and increasing with increasing nutrient concentration. Despite the inverse proportionality between saline and aquatic biodiversity, the relationship between salts is still not well understood (Derry et al., 2003; Ríos-Escalante, 2013). Contrary to the numerous fish and planktonic biodiversity studies in fresh water systems, very little of such studies has been conducted in these unique saline systems (Jones & Grant, 1999; Larson & Belovsky, 2013). The aim of this study is, therefore, to investigate fish and planktonic biodiversity in selected saline crater lakes of western Uganda as a way of providing more information on fish and planktonic biodiversity in saline systems.

MATERIAL AND METHODS

Study area

Lakes considered in this study are small unique water bodies found in Katwe–Kikorongo volcanic field in western Uganda. Lake Katwe (029.87033˚E, 00.13217˚S), is the largest among these lakes with an average area of 2.5 km^2 (Nixon et al., 1971). Other lakes considered in this study were Katwe Munyanyange (029.88591˚E, 00.13513˚S), Nyamunuka (029.98743˚E, 00.09344˚S), Bagusa (030.17958˚E, 00.09793˚S), Murumuri (029.99186˚E, 00.07323˚S), Maseche (030.19019˚E, 00.09355˚S), Bunyampaka (030.12819˚E, 00.03765˚S) and Kikorongo (030.01228˚E, 00.01190˚S). Among the studied lakes, Bagusa and Kikorongo were at the lowest and highest altitude, 884 m and 939 m, respectively, above sea level (a. s. l). The majority of these lakes are alkaline and saline in nature with dominant anions being carbonates and sulphates (Nkambo et al., 2015). These lakes exhibit considerable temporal variations in volume and surface area, with their total depth ranging between <1–6 m (Kirabira et al., 2013).

Zooplankton and phytoplankton diversity

Data collection in this study was done between the 26th of February and 3rd of March, 2014, a period towards the end of the dry season in this region. A Global Positioning System (GPS) unit (GARMIN 12XL) was used to take GPS coordinates and the Altitude / elevation above sea level of the different sampling points.

Zooplankton samples were obtained by filtering four liters of water collected from every set geo-referenced sampling point through a 50 µm mesh zooplankton net. The samples obtained after filtration were preserved in 95% ethanol and carried to the National Fisheries Resources Research Institute (NaFIRRI) laboratory, Jinja, for identification to the lowest possible taxonomic level and counted under an inverted microscope. Using a Van Dorn water sampler, water samples for phytoplankton analysis were collected at a depth of 0.5 m in lakes whose average depth was more than 1 m. For the very shallow lakes (depth < 0.5 m), surface water samples were collected for zoo and phytoplankton analysis. 500 ml of the collected water samples were preserved using Lugol's solution in pre-rinsed Nalgene bottles which were kept in a cooler box containing dry ice and later transferred to the National Fisheries Resource Research Institute (NaFIRRI) laboratory in Jinja. In the laboratory, phytoplanktons in the collected water samples were identified to the lowest possible taxonomic level and the wet biomass of each of the identified group determined.

Selected physical and chemical parameters (depth, temperature (T°C), dissolved oxygen concentration (DO), pH, Conductivity (Cond) and salinity) were also measured in-situ at the lake surface and bottom. Where lakes were too shallow, physico-chemical measurements were taken at the lakes surface. Water temperature, dissolved oxygen concentration and conductivity were measured using a YSI oxygen/temperature/conductivity meter (Model YSI 550A), pH was determined using an OAKTON pH Tester 30, while salinity was measured with a refractometer. The depth was determined using a portable depth finder (Hondex PS-7).

Fish diversity

All the study lakes, deeper than 0.5 m were sampled for fish by setting gill nets and seine nets in the evening at 5 pm and removing them in the following morning at 7 am. In addition we also asked to the people belonging to the communities around each of the studied lakes whether they have ever seen or got any fish from these lakes.

RESULTS

Physico-chemical parameters

Lakes Munyanyange, Nyamunuka, Murumuri, and Bunyampaka were found to be very shallow (depth<0.5 m) at the time of sampling, whereas, lake Kikorongo was the deepest. The highest measured dissolved oxygen (DO) was 6.0±1.0 mgl^{-1} in Lake Kikorongo while Munyanyange and Murumuri had the lowest and second lowest DO (1.7±0.4 and 1.7±0.5 mgl^{-1}, respectively). All the sampled lakes were found to be alkaline with pH ranging between 9.58±0.1 (lake Bunyampaka) and 11.5±1.0 (Nyamunuka). The highest temperatures ranged between 28.9±0.4°C and 34.4±2.4°C. Salinity was between 0 mgl^{-1} (lake Kikorongo) and 205.0±15.3 mgl^{-1} (Nyamunuka) Conductivity ranged between 10.5±0.6 $mscm^{-1}$ (Nyamunuka) and 106.3±3.5 $mscm^{-1}$ (Murumuri) (Table 1).

Phytoplankton diversity

A total of twenty nine (29) phytoplankton species were found in the eight study lakes. Out of them, nineteen (19) belonged to Cyanophyceae, commonly known as Cynobacteria (blue-green algae (BG)) which are predominantly photosynthetic prokaryotes containing a blue pigment in addition to the chlorophyll (WHO, 1999). Six (6) belonged to Chlorophyceae commonly referred to as Chlorophyta (green algae (G)). Four (4) belonged to Bacillariophyceae, commonly referred to as diatoms (D). Lakes Maseche (912,347 μgL^{-1}) and Bagusa (210,290 μgL^{-1}) were found to have the highest and second highest algal biomass. These were followed by lakes Katwe and Murumuri which had algal biomass of 90,653 μgL^{-1} and 86,240 μgL^{-1}, respectively. Lakes Katwe and

Lake	Depth (m)	D.O (mgl^{-1})	pH	Temp. (^oC)	Salinity (mgl^{-1})	Cond ($mscm^{-1}$)
Katwe	2.1±0.7	2.6±0.2	9.9±0.1	27.9±0.3	180±67.8	104.5±6.4
Munyanyange	0.2±0.1	1.7±0.4	10.8±0.4	34.4±2.4	101.0±7.1	59.7±8.2
Nyamunuka	0.2±0.2	2.6±0.3	11.5±1.0	30.5±3.1	205.0±15.3	10.5±0.6
Murumuri	0.2±0.0	1.7±0.5	11.1±1.3	32.0±0.8	162.8±34.2	106.3±3.5
Bunyampaka	0.2±0.1	2.20±0.6	9.6±0.1	30.33±1.5	199.50±16.4	103.90±4.3
Bagusa	1.9±0.5	3.2±0.8	10.5±0.4	32.1±2.0	199.5±16.4	103.9±4.3
Maseche	1.3±0.2	2.9±0.4	10.9±0.4	30.0±0.7	92.3±7.6	71.2±1.3
Kikorongo	2.3±0.3	6.0±1.0	10.4±0.0	28.9±0.4	0.0±0.0	18.6±0.1

Table 1. Mean±SD of the selected measured physico-chemical parameters in the selected studied saline crater lakes.

Bunyampaka showed the highest algal biodiversity while lakes Maseche and Nyamunuka had the lowest biodiversity. Cyanophyceae (BG) dominated the algal composition of all the studied lakes. With the exception of Lake Munanyange, were no Chlorophyceae species (G) were found, the other lakes showed Chlorophyceae and Bacillariophyceae (D) species in relatively small abundances in comparison to Cyanophyceae. With the exception of Lake Bagusa where *Anabaena circinalis* was found to be dominant, and Bunyampaka and Nyamunuka where no *Spirulina platensis* was found, in the rest of the lakes *S. platensis* was dominant (Table 2).

Zooplankton diversity

Lakes Kikorongo, Maseche, and Katwe were found to have zooplanktons belonging to Rotifera. Lakes Maseche and Kikorongo showed also zooplanktons belonging to Copepoda and none of the studied lakes was found to have cladocerans at the time of sampling. Lakes Munyanyange, Maseche, Murumuli, Katwe and Nyamunukahad small cysts which could not be identified. Water samples from lakes Bunyampaka and Bagusa had neither zooplankton nor un-identified cysts (Table 3).

Fish diversity

None of the selected saline crater lakes considered in this study had fish at the time of sampling. With the exception of Lake Kikorongo, in which the African catfish, *Clarias gariepinus* (Burchell, 1822), was observed (sometimes) during the rainy season, none of the other studied lakes was reported to have fish, ever.

DISCUSSION

Phytoplankton diversity

In the present study, blue-green (Cyanobacteria) algae are dominant in all the lakes, with *Spirulina* P.J.F. Turpin ex M. Gomont being the most dominant phytoplankton in the majority of them (Table 2). This is in agreement with earlier studies done in alkaline, saline crater lakes which reported *Spirulina platensis* to be the most dominant (Hecky & Kilham, 1973) in constrast with the reported dominance of algal biomass by diatoms in anthroposaline lakes in Romania and Bolivia (Stenger-Kovács et al., 2014). The dominance of Cyanobacteria in these harsh environments can be attributed to their ability to withstand extreme water conditions like very high temperatures, pH and salinity. Some Cyanobacteria species have got special adaptations like ultraviolet absorbing sheath pigments which increase their fitness in relatively exposed environments; indeed they have been reported to occur in waters that are salty, brackish or fresh, in cold or hot springs and in environments where no other

Taxa Group	Taxa	Bagusa	Buny-ampaka	Munya-nyange	Maseche	Katwe	Kiko-rongo	Nyamu-nuka	Muru-muri
BG	*Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová et Cronberg	15845	2,773	-	8,216	7,343	-	-	7,805
BG	*Aphanocapsa* sp.	522	274	548	-	342	-	365	730
BG	*Spirulina platensis* (Nordstedt) Gomont	12,324	-	25,880	879,909	66,856	43,133	-	69,012
BG	*Anabaena* sp.	15,649	219	-	-	3,286	-	-	-
G	*Stichococcus* sp.	3.912	96	-	-	787	-	-	-
D	Centric diatoms	104	292	37	146	730	-	292	37
BG	*Planktolyngbya circumcreta* (G.S. West) Anagnostidis et Komárek	440	411	1,438	-	-	-	205	411
BG	*Chroococcus* sp.	391	137	-	365	-	23	-	-
BG	*Anabaena circinalis* Rabenhorst ex Bornet et Flahault	157,273	11.867	9,859	5,112	6,207	548	38,085	913
G	*Stichococcus* sp.	3,668	342	274	479	2,465		1,575	1,404
G	*Nephrochlamys rostrata* Nygaard, Komárek, J.Kristiansen et O.M. Skulberg	162	-	-	-	-	1,506	-	-
BG	Tiny blue green	-	101	151	-	-	228	-	-
BG	*Anabaenopsis tanganyikae* (G.S. West) Woloszynska et V.V.Miller	-	55	-	-	-	-	-	-
BG	*Pseudoanabaena* sp.	-	411	411	-	103	-	308	-
BG	*Anacystis limnetica* (Lemmermann) Drouet et Daily	-	183	365	-	274	137	342	297
BG	*Romeria* sp.	-	55	-	-	-	-	-	-
D	*Nitzschia acicularis* (Kützing) W. Smith	-	274	-	-	23	-	137	23
G	*Closterium acerosum* Ehrenberg ex Ralfs	-	-	411	411	205	205	411	-
BG	*Oscillatoria tenuis* C. Agardh ex Gomont	-	-	-	17,253	-	-	-	-
BG	*Aphanocapsa nubila* Komárek et H.J. Kling	-	-	-	456	-	91	-	183
BG	*Coelosphaerium kuetzingianum* Nägeli	-	-	-	-	1,826	-	-	4,747
BG	*Planktolyngbya undulata* Komárek et H. Kling	-	-	-	-	103	-	-	-
G	*Ankistrodesmus falcatus* (Corda) Ralfs	-	-	-	-	103	-	-	-
BG	*Chroococcus dispersus* (Keissler) Lemmermann	-	-	-	-	-	68	-	-
D	*Cyclostephanodiscus* sp.	-	-	-	-	-	37	-	-
D	*Navicula gastrum* (Ehrenberg) Kützing	-	-	-	-	-	856	-	-
BG	*Merismopedia tenussima* Lemmermann	-	-	-	-	-	-	-	292
G	*Monoraphidium contortum* (Thuret) Komárková-Legnerová	-	-	-	-	-		-	22
BG	*Aphanizomenon flosaquae* Ralfs ex Bornet et Flahault	-	-	-	-	-	-	-	365
	Total	**210,290**	**17,488**	**39,372**	**912,347**	**90,653**	**48,065**	**44,698**	**86,240**

Table 2. Mean Wet biomass (µg/l) concentrations of the different phytoplanktons in the selected Alkaline, saline lakes considered in this study. BG = Blue green algae, G = green algae, D = Diatoms.

microalgae occur (WHO, 1999). Allelopathy can be another factor to explain the dominance of *Cyanobacteria* in these lakes. Freshwater Cyanobacteria like *Oscillatoria* sp. have been reported to have exudates which can inhibit green alga *Chlorella vulgaris* Beyerinck [Beijerinck] (Leão et al., 2010). In the same way Cyanobacteria in these saline crater lakes might be influencing the algal biodiversity through allelopathy. Matagi (2004) reported *Spirulina* (*Arthrospira fusiformis*) to be the most successful algae in colonizing alkaline, saline lakes found in the Eastern Rift valley. Lake Lonar, an inland alkaline saline crater lake in India was reported to have its phytoplankton biomass dominated by *Spirulina platensis* (Satyanarayan et al., 2007; Siddiqi, 2007; Yannawar & Bhosle, 2013). Lakes Nakuru, Bogoria and Elmenteita, which are alkaline-saline lakes in Kenya, were characterized by mass growth of Cyanobacteria including *Arthrospira fusiformis* (Harper et al., 2003; Ballot et al., 2004). The Presence of Cyanobacteria in these alkaline-saline lakes is in conformity with the findings of the present study where *Spirulina* dominates the phytoplankton biomass. Jones & Grant (1999) reported *Spirulina* spp. to be among the main contributors to primary production in moderately saline lakes while studies by Hadgembes (2006) documented *Spirulina* to be one of the unique Cyanobacteria occurring in East African saline lakes.

The extreme inhospitable conditions in alkaline, saline crater lakes mean that the biodiversity in these systems is limited to organisms with special adaptations to survive such extreme conditions (Matagi, 2004). Primary production in Flamingo lakes of East Africa was reported to be dominated by *A. fusiformis* with *Ectothiorhodospira* sp. sometimes playing a key role (Jones & Grant, 1999; Matagi, 2004). *Nitzchia* sp. and *Navicula* sp. are some of the other algal species found in these lakes (present study) or in other highly alkaline and saline environments (Matagi, 2004). *Chroococcus* sp. is another species of Cyanobacteria recorded in this

	Munya-yange	**Kiko-rongo**	**Maseche**	**Murumuli**	**Bunyam-paka**	**Katwe**	**Bagusa**	**Nyamu-nuka**
ROTIFERA								
Brachionus calyciflorus Pallas, 1766	-	+++	-	-	-	+	-	-
Brachionus angularis Gosse, 1851	-	-	+	-	-	-	-	-
Lecane luna (Müller, 1776)	-	+	-	-	-	-	-	-
Trichocerca cylindrica (Imhof, 1891)	-	-	-	-	-	-	-	-
Syncheata sp.	-	+	-	+	-	-	-	-
COPEPODA								
nauplii	-	+	-	-	-	-	-	-
cyclopoid copepodite	-	-	+	-	-	-	-	-
CLADOCERA								
Moina micrura Kurz, 1874	-	-	-	-	-	-	-	-
unidentified cysts	+	-	+	+	-	+	-	+

Table 3. Mean zooplankton abundance (Individuals per litre) in the different studied saline crater lakes.
+ = 1 to 10 individuals /l, ++ = 10 to 50 individuals/l, +++ = 50 to 100 individuals/l, - = 0 individuals/l.

study which was reported by Jones & Grant (1999) to play a key role in primary production in soda lakes of East Africa.In studies aimed at reconstructing relationships between diatoms assemblages with salinity, it was observed that salinity might not be the primary cause of the shift in the diatom assemblage but a factor highly related to drivers of species shift (Saros & Fritz, 2000).

In the same way salinity might be playing a key role in determining the Cyanobacteria species occurring in the alkaline saline environments, but other possible drivers should not be overlooked. In a study to determine the extent to which salinity influences community structures in saline systems, salinity was reported to play a less significant role in the determination of composition, species richness and biodiversity (William, 1998). For example, the highest algal biodiversity observed in lakes Katwe and Bunyampaka and the least algal biodiversity (in lakes Maseche and Nyamunuka) might be attributed to the daily anthropogenic disturbances experienced by the first two lakes during the process of salt extraction, while the other two are lakes with no daily anthropogenic disturbance. It should be noted that communities around lakes Katwe and Bunyampaka continuously extract salt from these lakes on a daily basis and such disturbances might be impacting various algal species differently.

Zooplankton diversity

All the studied lakes showed a very low zooplankton biodiversity, with only *Brachionus calyciflorus* in lakes Kikorongo and Katwe; *Brachionus angularis* in Lake Maseche, and *Syncheata* sp. in lakes Kikorongo and Murumuli (the only species of the phylum Rotifera present, see Table 3). *Brachionus plicatilis* (Müller, 1786) and *Paradiaptomas africanus* (Daday, 1910) (= *Lovenula africana*) have already been reported to be characteristic zooplankton in alkaline saline crater lakes (Hecky & Kilham, 1973). Matagi (2004) listed *Lovenula africana* (Daday, 1910), *Brachionus dimidiatus* (Bryce, 1931), *B. plicatilis* (Müller, 1786) and chironomids as the dominant macro-invertebrates in the highly alkaline, hypersaline flamingo lakes of east Africa. All of these were absent in our study. Nauplii in Lake Kikorongo and cyclopoid copepodites in Lake Maseche were the only Copepoda members observed. Other macro-zooplanktons like cladocerans, neckton fauna, and crustacean decapods were conspicuously absent, probably due to the highly alkaline pH. Lake Bogoria in Kenya which is an alkaline, saline lake was reported to have no macro-zooplankton with lesser Flamingo, *Phoeniconaias minor* as the only grazer occasionally visiting these lakes in high numbers (Harper et al., 2003). The absence of crustacean decapods in a limnological study of lake Lonar an alkaline, saline crater lakes in India was attributed to a pH shock (pH > 10–11, alkaline death point) (Siddiqi, 2007). An inverse proportionality between biodiversity and salinity was reported by Derry et al., (2003); Larson & Belovsky (2013), and Ríos-Escalante (2013); this might be the explanation for the slightly high zooplankton biodiversity in Lake Kikorongo since its salinity was found to be very low at the time of sampling (Table 1). In field and laboratory experiments designed to examine the consequences of climate-induced salinity increases on zooplankton abundance and diversity in coastal lakes, severe disturbances in zooplankton community structure and abundance were caused by even very small salinity changes, with even very small increments in salinity capable of leading to biodiversity depletion (Schallenberg et al., 2003). Similarly, the low zooplankton biodiversity in these lakes might be attributed to the high salinity levels (see Table 1).

The unidentified cysts found in some of the lakes might be dormant stages of zooplanktons released as a mean of surviving extreme environmental conditions. These dormant stages return to life on the set of suitable conditions within the lakes. Some zooplanktons, particularly members of the order Anostroca like *Artemia* Leach, 1819, have been reported to release dormant embryos in form of cysts. Indeed, all *Artemia* species and strains reproduce ovoviviparously (by generating live nauplii) under favorable conditions, and oviparously when dormant embryos are released in form of cysts to withstand the harsh unfavorable environmental conditions (Ghomari et al., 2011; Ben Naceur et al., 2012).

Fish diversity

Although some fish species like *Oreochromis alcalicus alcalicus, O. alcalicus grahami*, and *O. amphimelas* were reported to inhabit lakes Magadi and Natron which are both alkaline and saline in nature (Matagi, 2004), no fish were found in these lakes during the study. Hecky & Kilham (1973) also reported cichlid fish like *Alcolapia grahami* (Boulenger, 1912) to occur in some of the alkaline, saline lakes. The absence of fish in the different studied lakes at the time of sampling can be attributed to the extreme environmental conditions like the very high temperatures, salinity and alkalinity. Previously, the complete absence of fish in Lake Lonar was reported to be correlated with extreme environmental physico-chemical parameters (Siddiqi, 2007). Many lakes, being shallow, experience very high variations in volume and surface area with some of these lakes reported to evaporate to dryness during the extreme dry seasons (Nkambo et al., 2015). This makes difficult, if not impossible, for fish to survive during the dry seasons. Moreover, the absence of appropriate food organisms in form of zooplankton (i.e. *Brachionus plicatilis*) could be another probable reason for the absence of fish (see Table 3).

Some of the Cyanobacteria found in these lakes like *Anabaena* sp, *Anabaenopsis* V.V. Miller, 1923 and *Oscillataria* Vaucher ex Gomont, 1892, have been reported to release cyanotoxins with lethal effects on mammals (WHO, 1999; Lyra et al., 2001). Although several research works on cyanotoxins have focused on humans and other livestocks (Leão et al., 2010), it is possible that these cyanotoxins have similar toxic effects on aquatic organisms including fish. *Anabaena* sp. have been reported to release anatoxin-a which is a neurotoxin reported to have lethal effects when tested on *Cyprinus carpio* Linnaeus, 1758 larvae (Oswawald et al., 2007). The presences of toxic Cyanobacteria might be hindering fish occurrence in these lakes considered under this study. With the exception of Lake Kikorongo, which sometimes receives flood waters from the neighboring lake Gorge (Hecky & Kilham, 1973; Mungoma, 1990; Nkambo et al., 2015), the rest of the lakes considered under this study are located in closed basins with no connections to other lakes or rivers. This implies that these lakes have no possibilities of being seeded with fish by inflowing waters from other natural systems. The reported occurrence of the African Catfish, *Clarias gariepinus*, in Lake Kikorongo in the rainy season might be due to flood waters from Lake Gorge. In fact, Nkambo et al., (2015) reported incoming flood waters from Lake Gorge to cause a reduction in the salinity of Lake Kikorongo. A reduction in salinity might make this lake conducive for fish survival during the wet season. It is possible that catfish brought along with floods remain in this lake during the rainy season and die off in the dry season as the water conditions become extremely unbearable.

CONCLUSIONS

Our findings are in agreement with earlier studies by Hecky & Kilham (1973), Matagi (2004), Satyanarayan et al., (2007), Siddiqi (2007) and Yannawar & Bhosle (2013) which reported Cyanobacteria to dominate algal biomass in saline systems, in contrast with earlier studies by Stenger-Kovács et al., (2014), which reported diatoms to dominate the algal biomass in saline lakes in Romania and Bolivia. Lakes considered under this study had very low zooplankton abundance and diversity with Lake Kikorongo, which had the highest zooplankton biodiversity, showing the rotifer *Brachionus calyciflorus*, the most abundant, ranging only between 50 to 100 individuals /litre. None of the study lakes had fish at the time of sampling.

In our opinion, this information on fish and planktonic biodiversity in these alkaline, saline systems is very useful in providing the ecological basis for the management of the lakes. Data on dominant zoo and phytoplanktons in the lakes can be used as bio-indicators in assessing the ecological status, as well as the impact of climate change on these unique systems.

Recommendations

Further comprehensive studies are needed to assess the effect of season variability on fish and planktonic biodiversity. Detailed studies of the daily anthropogenic disturbances on the algal and zooplankton biodiversity in these lakes during the salt extraction process are required to give a better understanding of the changes in planktonic composition, species abundance and biodiversity due to anthropogenic disturbances.

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