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Diversity and Abundance of Crustacean Zooplankton Community in Gilgel Gibe Reservoir, Southwestern Ethiopian Highland

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Authors' contributions

This work was carried out in collaboration between all authors. Author EE designed the study, performed the statistical analysis, wrote the protocol and the first draft of the manuscript. Authors MW and ST managed the analyses of the study. Author MW managed the literature searches and publication of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study was conducted to assess spatio-temporal dynamics of diversity and abundance of crustacean zooplankton in Gilgel Gibe Reservoir.
Place and Duration of Study: The reservoir is located in Omo-Gibe catchment in southwestern Ethiopian highland. Samples were collected fortnightly at three major localities representing riverine, transition and lacustrine zones from March to August 2013.
Methodology: Water samples for zooplankton were collected with plankton net and fish were sampled using gillnets. Zooplankton identification and counting were made in laboratory. Chlorophyll-a concentration and major physico-chemical parameters (dissolved oxygen, pH, water temperature, and electric conductivity) were measured *in situ* using standard meters. Water transparency was measured using Secchi disc. Data were analyzed using two-way analysis of variance (ANOVA). The habitat patterns of crustacean zooplankton were assessed using two way

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cluster analysis, and association between abundance of crustacean zooplankton and the measured environmental variables was explored using canonical correspondence analysis (CCA).

Results: Forty-nine species and two subspecies of crustacean zooplankton in three major categories were identified. The abundance of crustacean zooplankton varied spatio-temporally (P = 0.01). The crustacean zooplankton diversity was higher during the dry season while abundance was higher during wet season. While most of the crustacean zooplankton species (63%) were distributed virtually across all the sampling sites of the reservoir, a few species turned to be habitat specialists occurring only at a particular site. The dynamics of cyclopoids largely related to chlorophyll-a, water temperature, and electric conductivity while the dynamics of calanoids largely associated with Secchi depth, and partly with amount of dissolved oxygen and water pH. The dynamics of cladocerans remained unaccounted for by environmental variables measured during study period. Fish predation appeared to have largely structured the large sized cladoceran zooplankton as these were the most frequent and highest contributors to *Oreochromis niloticus* and *Labeobarbus intermedius* diets, the two dominant fish species in the reservoir.

Conclusion: This indicates that dynamics of the crustacean zooplankton community of the reservoir is regulated by various factors including primary productivity, major physico-chemical parameters and fish predation.

Keywords: Abundance; composition; crustacean zooplankton; diversity; Gilgel Gibe Reservoir.

1. INTRODUCTION

Ethiopia, a Horn of Africa nation, is endowed with a variety of aquatic ecosystems including rivers, lakes, wetlands and reservoirs that are of great scientific interest, habitats of aquatic organisms, recreational value and economic importance [1,2]. A large number of reservoirs have been constructed in Ethiopia as part of an effort to expand hydropower and agricultural dams. Many reservoirs are characterized by pronounced phytoplankton blooms and a substantial fraction of these show intensive blooms of potentially toxic cyanobacteria that affect composition and abundance of aquatic inhabitants including zooplankton [3]. Moreover, reservoirs are subject to high temporal variability, with frequent reorganization of the relative abundance and species composition of aquatic organisms such as zooplankton and fish as a result of interactions between physical (light and temperature) and chemical (nutrients, conductivity, pH, dissolved oxygen, phosphate, nitrate, cations, anions and sediments) variables. Zooplankton constitutes an important component of freshwater ecosystems. Due to their intermediate position in food webs, they play a key role in the transfer of energy and nutrients as well as regulating contaminants transfer, recycling of nutrients and pollutions from lower trophic levels to higher trophic levels. However, these important ecosystem activities of zooplankton are influenced by biological factors through food web interactions [4]. Fishes are economically important, but their effects on aquatic organisms, food web structure and ecosystem is very high. It was suggested by that stocked fish was the cause for larger size zooplankton disappearance. Gilgel Gibe Reservoir, located in southwestern Ethiopian highland, has not so far been studied for its crustacean zooplankton and their dynamics [5]. The present study was, therefore, undertaken with the objective of assessing species composition and abundance of crustacean zooplankton in relation to primary productivity, fish predation and physico-chemical factors in Gilgel Gibe Reservoir.

2. MATERIALS AND METHODS

2.1 Study Area and Sampling Sites

The study was conducted at Gilgel Gibe Reservoir, a hydropower dam created on Gilgel Gibe River, a tributary of the major Omo-Gibe River, in Southwestern Ethiopia (Fig. 1). It lies at geographic coordinates of 07°42'53"–07°55'580" N and 37°11'53"–37°20'330" E. With a total surface area of 51 km^2 and max volume of 900 million m^3, the reservoir has minimum and maximum water levels of 1653 m (dry season) and 1671 m (wet season) above sea level (asl), respectively (Ethiopian Electric Power Corporation, 1997). The dam area is located at an altitude of 1640 m asl, has a sub-humid, warm to hot climate. It receives between 700 and 1650 mm of rain annually and has a mean annual temperature of 21.3℃. The reservoir was sampled at three major sites: Asendabo site, Yedi site, and the Deneba site. Asendabo site is located at Gilgel Gibe River entry to the reservoir, and thus represents shallow part of the reservoir largely with lotic features (i.e. riverine zone). Deneba site is close to the dam and hence represents deeper part of the reservoir with largely lentic nature (i.e. lacustrine zone), while Yedi represents part of the reservoir that is of intermediate characteristics. Site selection was based on the habitat type, presumption of high fish abundance and accessibility.

2.2 Sampling and *in situ* Measurements

Field survey was conducted from March to August 2013. Samples were collected fortnightly for zooplankton and subsequently analyzed in laboratory. Water samples for zooplankton were collected with plankton net of 55 µm mesh and 6 cm in mouth diameter. The plankton net was lowered below water surface up to a depth of 0.55 m to ensure collection of sufficient zooplankton sample. The water samples for zooplankton were preserved using 4% formalin solution in 300 ml plastic sample jars. Fish specimens were collected every month using gillnets of 16–24 cm stretched mesh sizes, and identified on site using relevant keys [6,7]. A total of 95 gut samples from two fish species, *Oreochromis niloticus* (Linnaeus, 1758) (Cichlidae: Perciformes) and *Labeobarbus intermedius* (Rüppell, 1835) (Cyprinidae: Cypriniformes), were collected from all the three sampling sites. Dissolved oxygen (DO) (mg/L), pH, water temperature (℃) and electric conductivity (µS/cm) were measured *in situ* using Hanna multiprobe meter (HQ40d; 2081 Hutton Drive, Suite 111 Carrollton, TX 75006). Chlorophyll-a and water transparency were measured using Aquafluor fluorometer (TRB8000-010; 1995 N. 1st Street San Jose, CA 95112) and Secchi disc, respectively.

2.3 Sample Analysis

Subsamples of 70 ml were taken from a homogenized sample with a pipette of 4 mm in diameter and transferred into a counting chamber for identification and counting of crustacean zooplankton under a dissecting microscope. Identification was done using relevant identification and taxonomic keys [8,9]. Fish specimens were dissected and gut contents were removed into plastic jars containing 4% formalin solution. In laboratory, fish gut contents were washed with distilled water and filtered with 56 µm mesh size net and transferred into flasks containing 4% formalin solution [10]. Subsamples were then processed in the same way as for water samples.

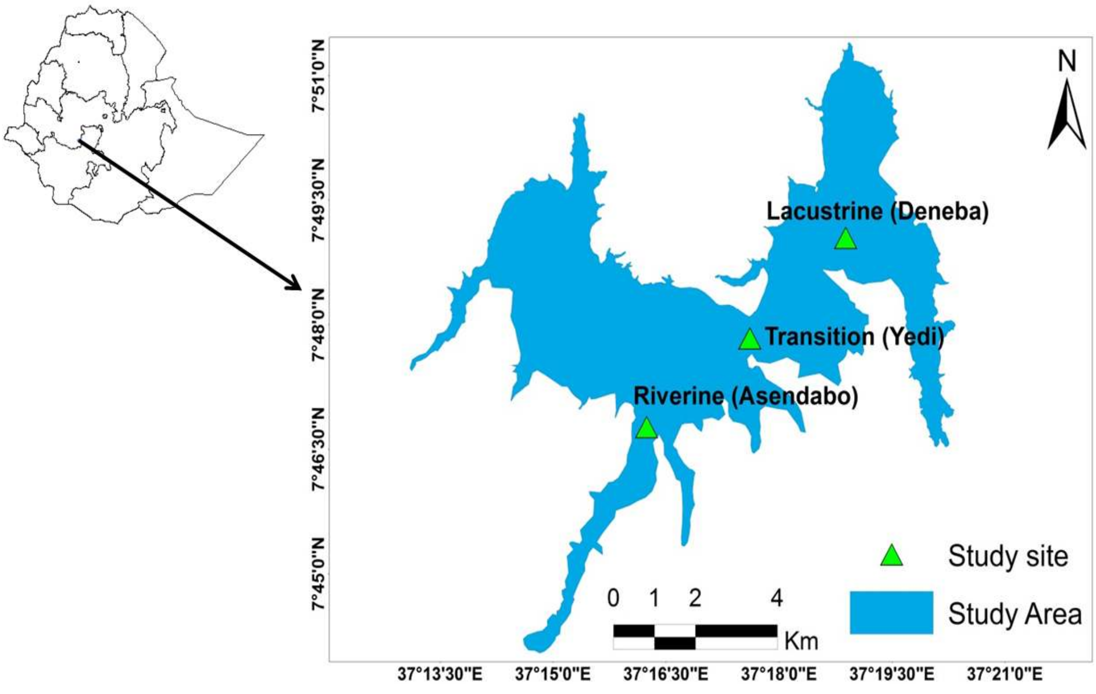

Fig. 1. Geographical location of study area

2.4 Data Analysis

2.4.1 Zooplankton diversity

The Shannon-Weaver diversity index (H') was used as a measure of crustacean zooplankton diversity of the reservoir [11] as:

$$H' = -\sum_{i=1}^{S} \mathrm{Pi} * \ln \mathrm{Pi}$$

where, Pi = proportion of individuals of a particular species in a sample; ln = natural logarithm; S = species richness

2.4.2 Zooplankton abundance

The abundances of crustacean zooplankton in water samples were expressed as number of individuals per cubic meter (ind./m^3) [12] as:

$$\text{Abundance (ind./m}^3) = (N*V_s)/V_f$$

Where, N = Number of crustacean zooplankton per ml of concentrated sample; V_s = volume of concentrated sample (ml); V_f = volume of water filtered (ml).

The crustacean zooplankton prey items in diets of fishes were assessed using Percentage composition by number (%N) and Frequency of occurrence (%O) [13] as follows:

$$\%O = (F_i/n_s)*100,$$
$$\%N = (N_i/n_p)*100,$$

Where, F_i = number of stomachs containing a particular crustacean zooplankton prey taxon; n_s = total number of stomachs with any zooplankton prey; N_i = total number of crustacean zooplankton prey items of a particular taxon; n_p = total number of all zooplankton prey items identified.

2.4.3 Statistical analyses

Two-Way analysis of variance (ANOVA) in SPSS (version 16) was used to infer significant variations in physico-chemical variables and abundance of crustacean zooplankton across season and sampling localities. Hierarchical cluster analysis was performed, in PC ORD for Windows version 5.31, to explore the pattern of crustacean zooplankton distribution across the three major sampling sites [14]. Canonical correspondence analysis (CCA) was performed in PAST (version 3.08) to measure the strength of correlation of zooplankton abundance to the physico-chemical variables and chlorophyll-*a* [15].

3. RESULTS AND DISCUSSION

3.1 Physico-chemical Parameters and Chlorophyll-a

Summary of the spatio-temporal mean values of physico-chemical and chlorophyll-a concentration is provided in Table 1.

Water transparency was higher at lacustrine zone (Deneba site) during dry season followed by transition zone (Yedi site) during same season, while lowest transparency was recorded at riverine zone (Asendabo site), and variation was statistically significant (P = 0.02). Low transparency of water was recorded in reservoir during wet season. This observation could be attributable to external loading of particulate materials through runoff, turbidity by inflow river, and increased primary productivity [16].

Water temperature was relatively higher in dry season and lower in the wet season at all sites. The variability in water temperature could affect physical, chemical and biological processes in reservoir as, for instance, solubility of oxygen increases with a decrease in water temperature [17]. The metabolic rate of aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter [18]. The highest maximum mean value for DOwas recorded at transition zone (Yedi site) during the season while least value was recorded at riverine zone (Asendabo site) during the same season (P = 0.01). The lowest amount of DO at riverine zone could be ascribed to high decomposition rate which is often evident in such portions of a reservoir due to high allochthonous influx of organic matter [16,18]. The highest DO was recorded during wet season which could relate to low water temperature, conductivity, and low decomposing activity during rainy season [19].

Electric conductivity was generally higher at riverine zone (P = 0.02). This could be explained in terms of increased disturbances in inlet due to agriculture-induced sedimentation from catchment area [20-22]. High photosynthetic activity due to increased production of phytoplankton may support an increase in pH. The pH value was generally higher during dry

Table 1. The spatio-temporal mean values of physico-chemical parameters and chlorophyll-a concentration of Gilgel Gibe Reservoir during study period (March to August 2013)

Parameters	Sampling sites and seasons					
	Asendabo (Riverine zone)		Yedi (Transition zone)		Deneba (Lacustrine zone)	
	Dry	Wet	Dry	Wet	Dry	Wet
Water transparency (m)	0.20 ± 0.03	0.12 ± 0.03	0.36 ± 0.04	0.22 ± 0.07	0.39 ± 0.11	0.25 ± 0.11
Water temperature (℃)	31.08±0.96	24.03±2.52	25.29±1.43	23.88±3.39	25.73±2.63	23.05±2.95
Dissolved oxygen (mg/L)	5.67±0.54	4.90±1.95	5.86±0.67	6.25±0.25	5.46±0.64	5.77±0.42
Conductivity (µS/cm)	93.25±5.94	95.85±12.15	88.96±2.29	88.84±10.33	88.39±3.28	88.53±8.25
pH	7.79±.18	7.20±0.42	7.99± 0.67	7.39±0.64	7.853± 0.35	7.22±0.47
Chlorophyll-a (µg/L)	19.89±9.56	28.06±24.27	8.50±1.60	15.27±2.30	9.05±1.51	13.65±2.25

season but variation was not statistically significant (P = 0.07). The chlorophyll-a concentration was much higher at riverine zone (Asendabo) site during both seasons (P = 0.02). This spatio-temporal variation in chlorophyll-*a* concentration should be explained in terms of the high organic input via runoff and inflow river from catchment [16-18,23].

3.2 Fish Predation

Three major crustacean zooplankton categories, viz. cladocerans, calanoids and cyclopoids, were identified from the gut samples. Of these prey items, ten species came from the crustacean zooplankton (Table 2). Cladoceran zooplankton were most frequent and consumed prey items in diets of both *O. niloticus* (87.5%O_i, 55%N_i) and *L. intermedius* (99.56%Oi, 68.49%Ni). The predominance of cladocerans species in diet of majority of zooplanktivorous fish species is a common phenomenon largely due to large size of these preys [24,25]. Cyclopoids were least preferred and the least consumed prey items in both fish species (Figs. 2 and 3).

3.3 Zooplankton Diversity and Abundance

A total of 49 species and two subspecies of crustacean zooplankton, belonging to three major taxonomic groups, were identified from reservoir zooplankton net samples and fish stomach (Table 2). The qualitative composition of crustacean zooplankton community in the reservoir was relatively dominated by cyclopoids (18 species and subspecies, 35.29%), followed by cladocerans (17 species, 33.33%), and calanoids (16 species, 31.37%). However, in terms of numeric abundance calanoids dominated community (51.3%), followed by cyclopoids (25.3%) and cladocerans (23.4%).

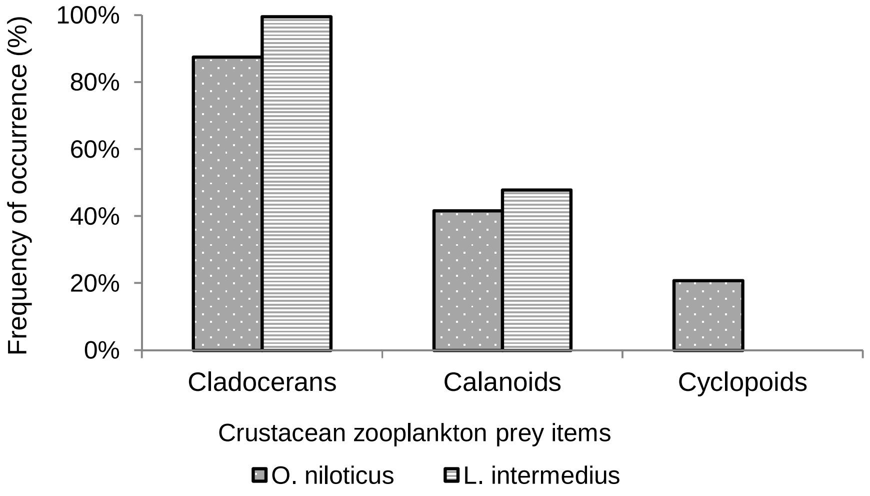

Fig. 2. Frequency of occurrence of the prey items identified in the gut of fishes in Gilgel Gibe Reservoir (March to August 2013)

3.4 Spatio-temporal Dynamics of Crustacean Zooplankton Diversity and Abundance

The temporal patterns of the Shannon-Weaver diversity index and species richness of crustacean zooplankton community for reservoir are given in Figs. 4 and 5, respectively. The diversity index and species richness were generally higher during dry months (March to May) and lower during wetter months (July and August). The lowest species diversity was recorded in August and the highest in April. Spatially, the lacustrine zone (Deneba site) had relatively the lowest crustacean zooplankton species richness while riverine (Asendabo site) had highest richness, though variation was trivial. Seasonal variation in abundance of crustacean zooplankton community was reasonably high ranging from 0.26×10^8 to 2.3×10^8 ind./m^3. In contrast to species diversity, lowest abundance was recorded in March (dry season), and peak abundance was recorded in August (wet season) (Fig. 6). Cladocerans were most diverse at lacustrine zone (Deneba site) during both seasons, whereas they were more numerous (mean = 62.20 ind./m^3) at transition zone (Yedi site) during wet season. These spatio-temporal variations in crustacean zooplankton distribution were statistically significant (P = 0.01).

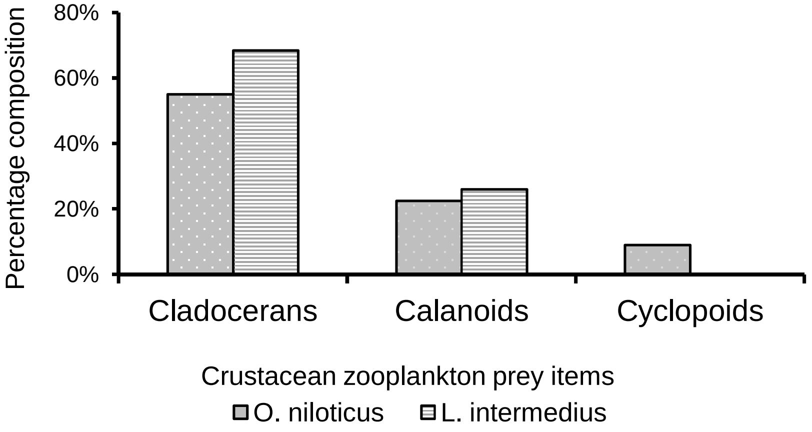

Fig. 3. Percentage composition of the prey items identified in the gut of fishes in Gilgel Gibe Reservoir (March to August 2013)

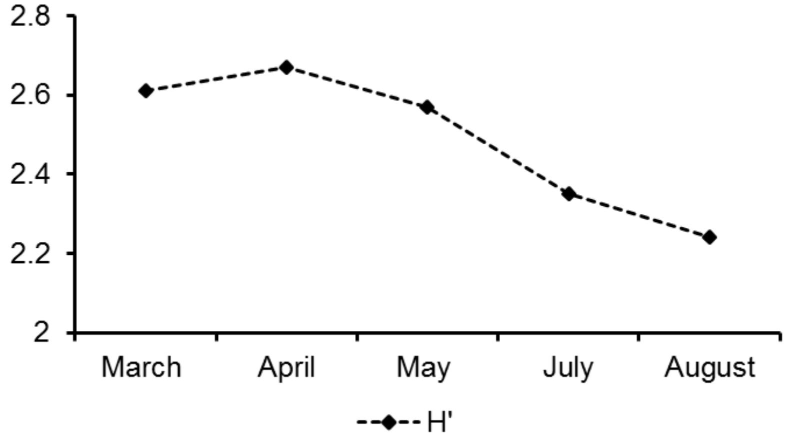

Fig. 4. Temporal pattern of Shannon-Weaver diversity index for crustacean zooplankton of Gilgel Gibe Reservoir during study period (March to August 2013)

Key: H' = Shannon-Weaver diversity index

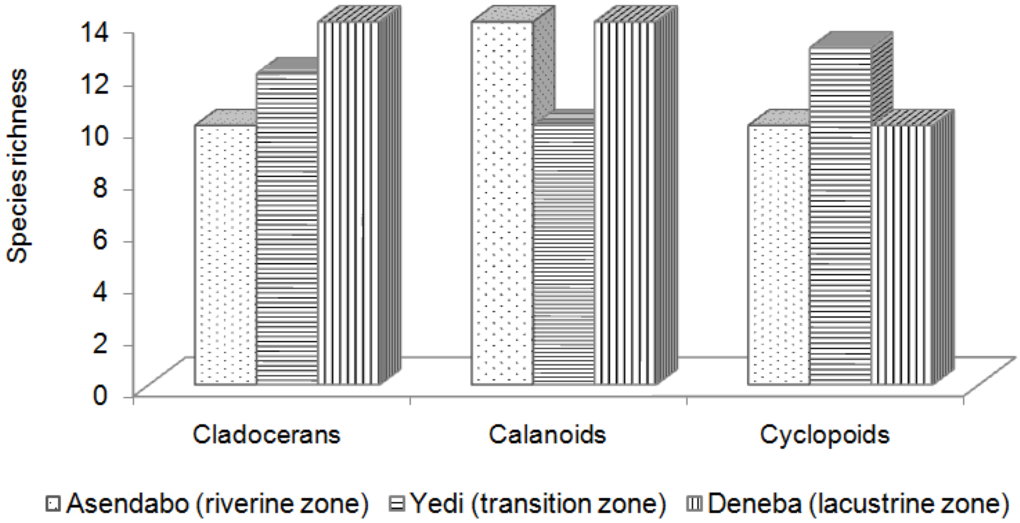

Fig. 5. The spatial pattern of species richness of crustacean zooplankton community of Gilgel Gibe Reservoir during study period (March to August 2013)

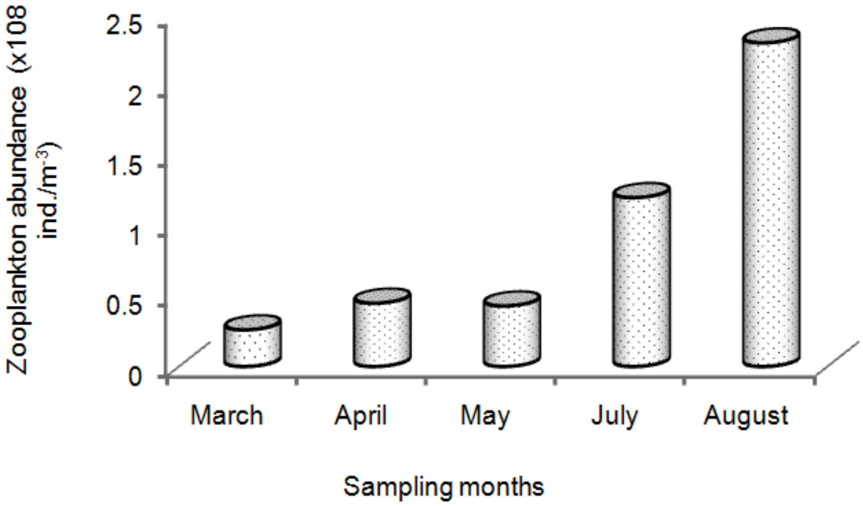

Fig. 6. Temporal fluctuation of crustacean zooplankton abundance in Gilgel Gibe Reservoir (March to August 2013)

Two-way cluster dendogram for distribution pattern of the crustacean zooplankton across the three major sampling localities of Gilgel Gibe reservoir during the study period is given in Fig. 7. The cluster dendogram depicts that out of the 49 species and two subspecies of crustacean zooplankton sampled during the study period, 32 species (63%) occurred at all the three or at least two of the sampling localities (Fig. 7). A few species from each major taxon, however, demonstrated habitat specialization. Four copepod species, i.e. three calanoid species (*Boeckella brasiliensis, Diaptomus cadcus* and *Diaptomus sicilis*) and one cyclopoid species (*Mesocycops edax*), occurred only at Asendabo site (the riverine habitat). Eight crustacean zooplankton species occurred only at the lacustrine habitat (Deneba site). These include two cladoceran species (*Bosmina berhmi* and *Diaphnosoma dubium*), three calanoid species

Table 2. Crustacean zooplankton identified from the reservoir zooplankton net samples and fish stomach in Gilgel Gibe Reservoir (March to August 2013); x = presence; Species codes are formed by taking the first two letters of generic and specific names, and by adding a third letter when overlaps happen

Group	Species	Species Code	Zooplankton net			Fish stomach
			Asendabo site	Yedi site	Deneba site	
Cladocerans	*Bosmina berhmi* Lieder 1962	BoBe			x	
17 spp	*Bosmina meridionalis* Sars 1904	BoMe		x		
	Bosminopsis deitersi Richard 1895	BoDe	x	x	x	
	Ceriodaphnia cornuta Sars 1885	CeCo	x	x	x	
	Daphnia cephalata King 1853	DaCe		x		
	Daphnia dubia Herrick 1883	DaDu	x		x	
	Daphnia pulex Leydig 1860	DaPu	x	x	x	x
	Daphnia retrocurva Forbes 1882	DaRe	x	x	x	x
	Diaphanosoma birgei Korínek 1981	DiBi	x	x	x	x
	Diaphanosoma dubium Manujlova 1964	DiDu			x	
	Holopedium amazonicum Stingelin 1904	HoAm	x	x	x	
	Holopedium gibberum Zaddach 1855	HoGi	x	x	x	x
	Leptodora kindti (Focke 1844)	LeKi		x		
	Moina belli Gurney 1904	MoBe	x		x	
	Moina micrura Kurz 1875	MoMi	x	x	x	
	Moina rostrata McNair 1980	MoRo	x	x	x	
	Scapholeberis spinifera (Nicolet 1849)	ScSp		x	x	
Calanoids	*Acanthodiaptomus denticornis* (Wierzejski, 1887)	AcDe			x	
16 spp	*Boeckella brasiliensis* (Lübbock, 1855)	BoBr	x			
	Boeckella dilatata Sars, 1904	BoDi	x		x	x
	Canthocamptus staphylinoides Pearse, 1905	CaSt	x	x	x	
	Diaptomus caducus Light	DiCa	x			
	Diaptomus kenai Wilson	DiKe	x	x	x	x
	Diaptomus leptopus Forbes, 1893	DiLe	x	x	x	
	Diaptomus nudus Marsh, 1904	DiNu	x	x	x	x
	Diaptomus sicilis Forbes	DiSi	x			
	Diaptomus siciloides Lilljeborg, 1889	DiSio			x	
	Epischura nevadensis Lilljeborg in Guerne and Richard, 1889	EpNe	x	x	x	x
	Eurytemora affinis (Poppe, 1880)	EuAf	x	x	x	
	Eudiaptomus gracilis (G. O. Sars, 1862)	EuGr	x	x	x	
	Heterocope septentrionalis Juday and Muttkowski, 1915	HeSe	x	x	x	
	Senecella calanoids Juday, 1923	SeCa	x	x	x	
	Skistodiaptomus oregonensis (Lilljeborg in Guerne and Richard, 1889)	SkOr			x	

Group	**Species**	**Species Code**	**Zooplankton net**			**Fish stomach**
			Asendabo site	**Yedi site**	**Deneba site**	
Cyclopoids	*Acanthocyclops vernalis* (Fischer, 1853)	AcVe	x	x	x	
16 spp +2 subspp	*Afrocyclops gibsoni* (Brady, 1904)	AfGi	x	x		
	Afrocyclops gibsoni abbreviatus Kiefer, 1933	AfGia	x		x	
	Cyclops bicuspidatus odessanus Shmankevich, 1875	CyBi			x	
	Cyclops vicinus Ulyanin, 1875	CyVi	x	x	x	
	Eucyclops agiloides (Sars, 1909)	EuAg	x		x	
	Halicyclops magniceps (Lilljeborg, 1853)	HaMa		x		
	Macrocyclops albidus (Jurine, 1820)	MaAl	x	x	x	x
	Macrocyclops ater (Herrick, 1882)	MaAt	x	x	x	
	Mesocyclops edax (S. A. Forbes, 1890)	MeEd	x			
	Metacyclops gracilis (Lilljeborg, 1853)	MeGr			x	
	Megacyclops viridis (Jurine, 1820)	MeVi			x	
	Microcyclops varicans (G. O. Sars, 1863)	MiVa	x		x	
	Paracyclops fimbriatus (Fischer, 1853)	PaFi		x		
	Thermocyclops emini (Mrázek, 1898)	ThEm		x		
	Thermocyclops kawamurai Kikuchi K., 1940	ThKa		x		
	Thermocyclops tenuis (Marsh, 1909)	ThTe	x	x	x	x
	Tropocyclops prasinus (Fischer, 1860)	TrPr	x	x		

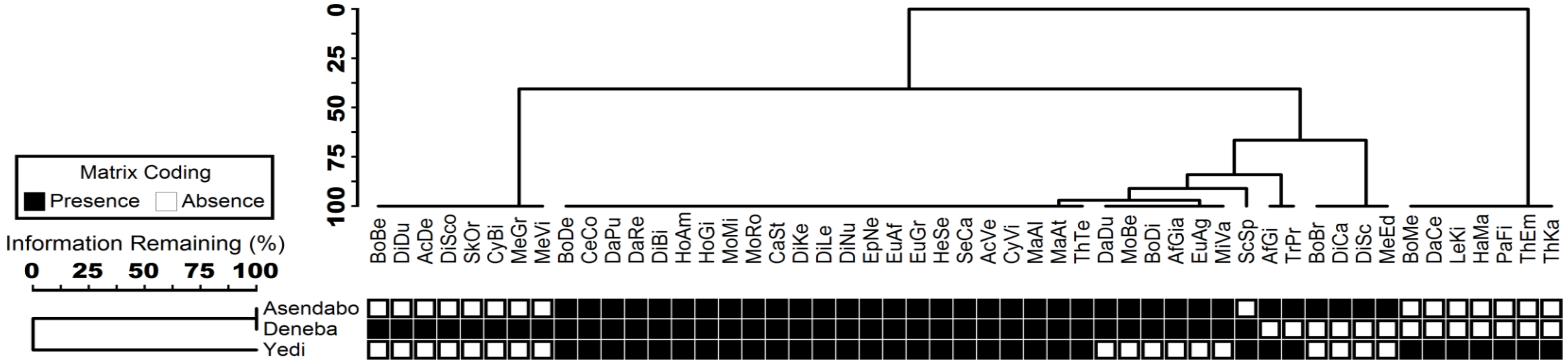

Fig. 7. Two-way cluster dendogram for the crustacean zooplankton distribution in Gilgel Gibe Reservoir (March to August 2013)

See Table 2 for the species codes

(*Acanthodiaptomus, Diaptomus siciloides* and *Skistodiaptomus oregonensis*) and three cyclopoid species (*Cyclops bicuspidatus, Metacyclops gracilis* and *Megacyclops virdis*). The transition zone habitat had three cladoceran species (*Bosmina meridionalis, Daphnia cepahala*, and L*eptodora kenditi*) and four cyclopoid species (*Halicyclops magniceps, Paracyclops fibriatus, Thermocyclops emini* and *Thermocyclops kawamurai*) specialists.

The CCA plot for the correlation between abundance of the three major crustacean zooplankton taxa and measured environmental variables is given in Fig. 8. More than 67% of variation in abundance of crustacean zooplankton in reservoir was explainable by water temperature, conductivity, chlorophyll-*a*, pH and DO.

Cladocerans were most diverse at the lacustrine zone (Deneba site) during both seasons, whereas they were more numerous (mean = 62.20 ind./m^3) at transition zone (Yedi site) during wet season. The occurrence of cladocerans sparsely in reservoir, particularly at riverine zone (Asendabo site) was apparently related to fish predation as high water transparency there could contribute to high predation pressure [3,4,26,27]. *Daphnia pulex* and *Daphnia retrocurva, Diaphnosoma birgei, Holopedium amazonicum,* and *Holopedium gibberum* species were highly preyed by *O. niloticus and L. intermedius* throughout the study period. The relatively higher abundance of cladocerans at transition zone (Yedi site) remained unaccounted for by environmental variables measured and analyzed during present study (Fig. 8). Copepods were the most dominant crustacean zooplankton throughout reservoir. Particularly, calanoid species such as *Diaptomus nudus, Diaptomus kenai* and *Diaptomus leptopus* were dominant throughout study period and appeared commonly at all sites, a trend also noticed by other investigators elsewhere [17,25]. Calanoid s were most diverse at transition zone (Yedi site) during both seasons. The calanoids also had highest numeric abundance (mean = 126.07 ind./m^3) at transition zone. The calanoid abundance at transition zone (Yedi site) and lacustrine zone (Deneba site) correlated with Secchi depth and partly with pH and DO. The relative abundance of calanoids was generally low in dry season and high in wet season [28]. Cyclopoids were most diverse at riverine zone (Asendabo site) during wet season, whereas they had highest abundance (mean = 122.80 ind./m^3) at lacustrine zone (Deneba site) during wet season. The abundance of cyclopoids at riverine zone (Asendabo site) was positively associated with chlorophyll-a, water temperature and electric conductivity, and negatively with Secchi depth (extent of water clarity). The occurrence of cyclopoids generally relates to availability of food (diatoms and calanoids), habitat preference, tolerance of organic pollution, high water volume, and predation by fish [26,27,29,30].

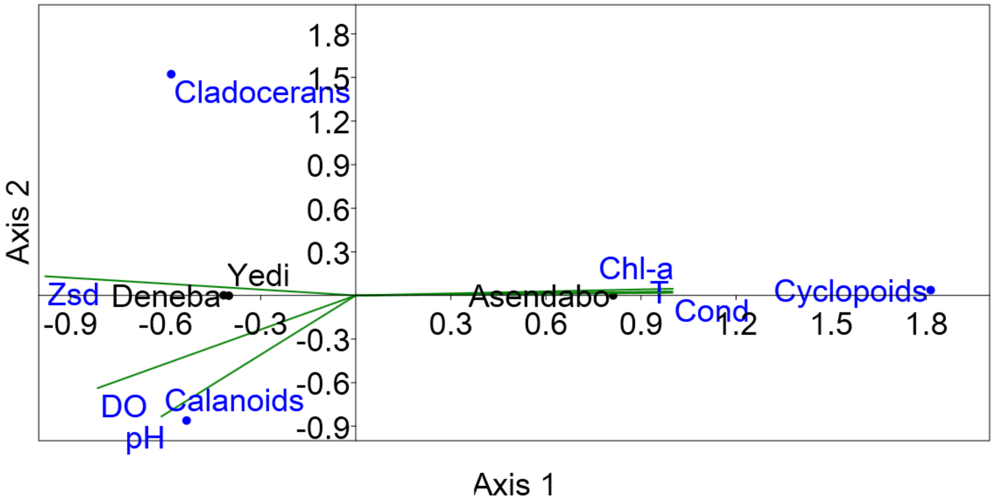

Fig. 8. CCA plot of the association between the environmental variables and crustacean zooplankton distribution in Gilgel Gibe Reservoir (March to August 2013)

Key: Chl-a = chlorophyll-a, Cond = electric conductivity, DO = dissolved oxygen, T = water temperature, Zsd = Secchi depth.

4. CONCLUSION

The physico-chemical parameters and chlorophyll-a concentration varied both spatially and temporally in Gilgel Gibe Reservoir. The three major freshwater crustacean zooplankton taxa were represented in the reservoir. The crustacean zooplankton demonstrated spatio-temporal dynamics in both their species diversity and abundance. Overall, crustacean zooplankton diversity was higher during dry season, while abundance was higher during wet season. The environmental variables were found to have largely explained spatial dynamics (> 67% variability) of crustacean zooplankton. While most of the crustacean zooplankton species (63%) were distributed virtually across all the sampling sites of the reservoir, a few species turned to be habitat specialists occurring only at a particular site. The dynamics of cyclopoids largely related to chlorophyll-a, water temperature, and electric conductivity, while dynamics of calanoids largely associated with Secchi depth, and partly with amount of dissolved oxygen and water pH. The dynamics of cladocerans remained unaccounted for by environmental variables measured during the study period. Fish predation appeared to have largely structured large-sized cladoceran zooplankton.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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