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Research Paper

Abundance, Species Composition and Spatial Distribution of Planktonic Rotifers and Crustaceans in Lake Ziway (Rift Valley, Ethiopia)

key words: zooplankton, Rotifera, Cladocera, Copepoda, tropical lake

Abstract

Species composition, abundance, and spatial distribution of rotifer and crustacean zooplankton were studied in Lake Ziway from late April to early July 2004. A total of 49 rotifer species was recorded, with *Anuraeopsis fissa, Brachionus angularis, Filinia novaezealandiae,* and *Trichocerca ruttneri* being numerically dominant. Variation in abundance was extremely high, ranging from 2 to 1000+ individuals per litre. There was no significant difference in the distribution of rotifer species between inshore and offshore regions. Crustacean species richness was low, with only five cladoceran and three copepod species occurring in the open water. *Moina micrura* and *Diaphanosoma excisum* dominated the cladoceran community, whereas *Thermocyclops decipiens* was the dominant copepod. Although numerically dominant (75%), rotifers accounted for less than 30% of mean total zooplankton biomass. Peak abundance of crustaceans was observed in May and June, following the onset of the rainy season and increased phytoplankton production. Variation in the spatial distribution of crustacean species was neither observed horizontally between inshore and offshore areas nor vertically in the highly turbid and wind exposed deeper part of the lake. On the other hand, *Moina micrura* varied significantly in size between inshore and offshore areas. Adult *M. micrura* dominated offshore, whereas juveniles were more abundant inshore, suggesting a predominantly littoral selective predation on large and adult crustaceans by fish.

1. Introduction

The earliest studies on the zooplankton of the Ethiopian Rift Valley Lakes and highland crater lakes date back into the 1930s (*e.g.*, BRYCE, 1931). There is a growing body of information on zooplankton of Ethiopian lakes, particularly from the Ethiopian Rift Valley (CANNICCI and ALMAGIA, 1947; WODAJO and BELAY, 1984; GREEN, 1986; MENGESTOU *et al.*, 1991). It is well established that smaller plankton organisms, particularly rotifers and protists predominate tropical zooplankton and that species associations in tropical waters are largely governed by temperature and salinity gradients (GREEN, 1993, 1994; FERNANDO, 1994). GREEN and MENGESTOU (1991) found that the zooplankton of Ethiopian lakes is a mixture of species found throughout Africa, and that high rotifer diversity in the plankton

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is caused predominantly by the family Brachionidae. In Lake Awassa cyclopoids dominate the crustacean zooplankton in terms of numbers and biomass, while cladocerans are less abundant (MENGESTOU, 1989; MENGESTOU *et al.*, 1991). GREEN (1986) found that Ethiopian crater lakes are dominated by rotifers and only a few species of copepods. FERNANDO (1980a) and MAVUTI (1990) showed that no distinctive pelagic zooplankton occur in tropical lakes and reservoirs, and littoral species such as *Alona diaphana* can form dominant components in the pelagic zone (FERNANDO *et al.*, 1990). In the tropics, pelagic species occur predominantly in the littoral, whereas in temperate regions there appear to be some truly planktonic species (FERNANDO, 1980b; FREY, 1990). Littoral zooplankton may sometimes invade the pelagic both in the tropics and in temperate regions (FERNANDO *et al.*, 1990). Tropical lakes are generally characterized by little seasonal variation in water temperature, which may cause little or no seasonal variation in species number, biomass, and production of zooplankton (BURGIS, 1971, 1978). However, marked seasonal variation in the abundance of tropical zooplankton was reported in other investigations. Rainfall and wind are frequently markedly seasonal in the tropics and lead to changes in plankton populations (LEWIS, 1979; TWOMBLY, 1983). CARMOUZE *et al*. (1983) and HART (1985) reported the influence of hydrological changes on zooplankton populations. Occasionally, zooplankton biomass began to rise during the rainy season and reached highest densities in the dry season (MENGESTOU and FERNANDO, 1991; ISUMBISHU *et al*., 2006). Nutrient remobilisation and increased algal production following mixing, stimulated the major annual abundance peak in zooplankton standing stock in Lake Valencia, Venezuela (INFANTE, 1982) or Lake Kivu (ISUMBISHU *et al*., 2006). Similarly, MENGESTOU *et al*. (1991) found that zooplankton biomass increased following the mixing cycle in the Ethiopian Rift Valley lake Awassa.

Earlier studies on the zooplankton of Lake Ziway focused mainly on copepods (VAN DE VELDE, 1984; DEFAYE, 1988). FERNANDO *et al.* (1990) documented the horizontal distribution of *Alona diaphana* in lakes Awassa and Ziway. Although rotifers have a key role in aquatic ecosystems, very little information is available on this group from Ethiopian inland waters (WODAJO and BELAY, 1984; GREEN, 1986; BELAY, 1988; MENGESTOU *et al*., 1991). Therefore, the purpose of the present study was to examine abundance and species composition of rotifers and crustaceans in Lake Ziway and compare results with earlier reports.

2. Methods

2.1. Study Site

Lake Ziway (Zwai or Zwei) is a shallow freshwater lake situated in the most northern section of the Ethiopian Rift Valley (8°01′ N and 38°47′ E) at an altitude of 1636 m above sea level. The lake has a surface area of 442 km^2, a maximum depth of 7 m and an average depth of 2.5 m. It is of tectonic origin (DI PAOLA, 1972), with sandy or rocky shores (SCHRÖDER, 1984). The lake is fed by the two rivers Meki and Katar in the northern part and drains into Lake Abijata through Bulbula River in the south. The latter usually falls dry during the dry season. There are five main islands in the lake: Gelila, Debre Sina, Tulu Gudo, Tsedecha and Fundro (Fig. 1). The lake region is characterised by a semiarid to subhumid type of climate with mean annual precipitation and mean annual temperature varying between 650 mm and 25 °C close to the lake and 1200 mm and 15 °C on the humid plateaux escarpment, respectively (LEGESSE *et al*., 2001). During the unusually dry study period in 2004, 25 mm and 150 mm monthly rainfall were recorded in March and April, respectively, while May and June were dry (courtesy of the 'National Meteorological Services Agency of Ethiopia'). According to WODAJO and BELAY (1984) major rain falls between June and mid September, with a shorter wet period between March and May. Maximum and minimum temperatures were 31 °C and 16 °C, respectively. The weather in the lake region is fre-

Table 1. Chemical features of Lake Ziway (after KEBEDE *et al.*, 1994).

Parameter	Units	Value
Conductivity	µS cm^{-1}	410
Salinity	g l^{-1}	0.4
pH		8.5
Alkalinity	meq l^{-1}	4
TP	µg l^{-1}	219
Na^+	meq l^{-1}	2.87
Ca^{2+}	meq l^{-1}	0.56
Mg^{2+}	meq l^{-1}	0.64
$HCO_3^- + CO_3^{2-}$	meq l^{-1}	4
Cl^-	meq l^{-1}	0.32
SO_4^{2-}	g l^{-1}	0.32
$NO_3^+ + NO_2$–N	µg l^{-1}	3.9
NH_4^+–N	µg l^{-1}	36.3

quently windy to stormy (SCHRÖDER, 1984). Due to the large surface area relative to the shallow depth and the absence of strong shelter even slight winds can cause complete mixing of the lake. We frequently observed strong wind-induced water currents, especially in the afternoon. This supports the observation by WOOD *et al*. (1978) that no strong thermal stratification ever develops in Lake Ziway. The lake is highly turbid, with a Secchi depth of only 20–35 cm. Details on the chemical characteristics of the eutrophic lake were reported by KEBEDE *et al*. (1994) (Table 1).

The phytoplankton community of Lake Ziway is dominated by Cyanobacteria, diatoms and green algae, *i.e*., *Anabaena circinalis*, *A. flosaquae, Cylindrospermopsis* sp., *Lyngbya* sp., *Merismopedia glauca, Microcystis* sp., *Cymbella* sp., *Navicula* spp., *Fragilaria* sp., *Melosira* sp., *Synedra* sp., *Actinastrum* spp., *Botryococcus* sp., *Cosmarium* spp. Generally, Cyanobacteria predominate the algal biomass. SCHRÖDER (1984) reported that about 80% of the phytoplankton biomass is contributed by *Microcystis*-species. Numbers of crustacean species are low and rotifers are dominant.

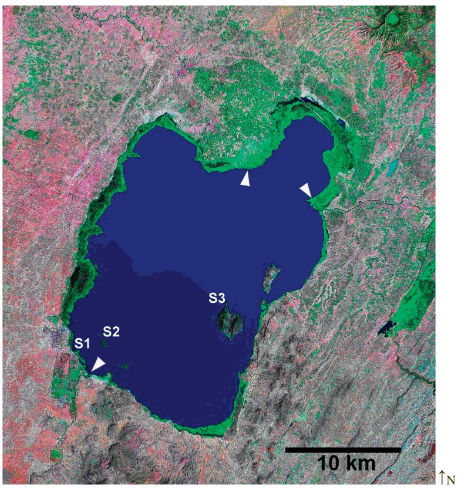

Figure 1. Satellite image of Lake Ziway with sampling stations. White arrowheads indicate positions of inflowing rivers in the north (Meki, Katar), and outflowing River Bulbula in the south.

The commercially important fish species of Lake Ziway are *Oreochromis niloticus*, *Tilapia zilli, Clarias gariepinus*, and *Cyprinus carpio. Barbus ethiopicus* and *Garra makinsis* are endemic to the lake (GOLUBTSOV *et al*., 2002). Extensive areas of emergent (reed) and submerged (*Potamogeton* spp.) littoral vegetation occur nearshore.

2.2. Sampling

Biweekly water samples were collected from late April to early July to cover both the end of the dry period and the onset of the rainy season (statistically). Samples were usually taken around noon from three open water stations using a 5 litre Schindler sampler: S1: 1 km off the shore, sampling depth 0.5 m, beyond the outer margin of dense macrophyte growth; S2: 6 km off the shore, sampling depths 0.5 and 2 m; S3: 12 km off the shore, sampling depths 0.5, 2, 4 and 6 m (Fig. 1). Water samples were filtered through plankton gauze of 30 µm mesh size and preserved in 4% formaldehyde solution. Sub-samples were analyzed in counting chambers at 100–400 × magnification. Rotifers were identified alive. Identification is based on JOSE DE PAGGI (2002), FERNANDO (2002), JEJE (1988), KOROVCHINSKY (1992), KOSTE (1978), NOGRADY *et al*. (1995), SEGERS (1995), and SANOAMUANG (2002). For qualitative zooplankton analysis samples were collected by means of vertical net hauls from 0.5 to 0 m (S1), 2 to 0 m (S2) and 6 to 0 m (S3) with tow nets of 30 µm (for rotifers) and 100 µm (for crustaceans) mesh sizes, opening diameter 30 cm. Developmental stages of all copepod species were grouped together as copepodite and naupliar stages, while for cladocerans all stages were counted as one age class. Total counts were made and individual densities expressed as numbers per litre. Fresh weight of rotifers was calculated from length measurements and biovolume approximations. Biovolumes of rotifers were computed from linear dimensions applied to simple geometric formulae appropriate to body shape, assuming a density of 1.0 (volume of 10^6 $\mu m^3 = 1$ µg fresh weight) (RUTTNER-KOLISKO, 1977) (Table 5). We used different conversion factors for body weight calculations. For crustaceans and most rotifers dry weight was assumed to be 10% of the wet weight, but 3.9% was assumed for *Asplanchna* (DUMONT *et al*., 1975). Biomass of crustaceans was calculated based on body size (total body length, excluding caudal setae) and applying length-weight relationships (DUMONT *et al*., 1975). 35 individuals from each sample were selected randomly and body lengths measured. Fisher's PLSD test was used to test for differences in size distributions of specimens from inshore and offshore areas of Lake Ziway.

3. Results

A total of 48 species of rotifers, belonging to 19 genera, and 8 crustacean species (8 genera) were identified (Tables 2 and 3). Among them, 21 species of rotifers were counted, of which seven dominated in high densities. *Anuraeopsis fissa*, *Brachionus angularis*, *Filinia novaezealandiae* and *Trichocerca ruttneri* were the most abundant species, contributing on average 24, 23, 10 and 10% to the rotifer community, respectively, and 8–21% to the total zooplankton biomass. Highest densities of >1000 ind. l^{-1} were reached by *A. fissa* (Fig. 2b). The abundance patterns of *B. angularis, F. novaezealandiae* and *T. ruttneri* (Fig. 2c, d, e) revealed one peak each during the first week of June, while the abundance peak of *A. fissa* occurred during the first week of May. The opposed abundance patterns of *A. fissa* and *B. angularis* could reflect competition for resources. *B. angularis* occurred in lower numbers when *A. fissa* reached maximum densities, then *B. angularis* increased in numbers fast when *A. fissa* declined sharply (Fig. 2b, c). The two species alternately dominated the rotifer community at all stations throughout the study period. Other rotifers were rare, *Asplanchna brightwellii*, *Ascomorpha* sp., *Brachionus falcatus*, *Keratella tropica*, and *Polyarthra indica* reached densities of only two to five individuals per litre.

Table 2. Rotifer records (+) from Lake Ziway (1931–2004). References: (1) BRYCE (1931), (2) CANNICCI and ALMAGIA (1947), (3) BELAY (1988), (4) GREEN *et al.* (1991), (5) present study. Major biogeographical regions: Af: Afrotropical, Au: Australian, Na: Nearctic, Nt: Neotropical, O: Oriental, P: Palearctic; additional regions: Ant: Antarctica, Pac: Pacific. Cos: cosmopolite (recorded from all six major regions). World records after DE RIDDER (1986, 1991), DE RIDDER and SEGERS (1997); tropicopolitan: largely restricted to tropical and subtropical latitudes, but occasionally found in suitable habitats in temperate regions.

Species	References					Biogeography	Comment
	(1)	(2)	(3)	(4)	(5)		
Anuraeopsis coelata DE BEAUCHAMP, 1932	+	–	–	+	+	tropicopolitan (Cos)	
A. fissa (GOSSE, 1851)	–	–	–	+	+	Cos (+Pac)	
Ascomorpha saltans BARTSCH, 1870	–	–	–	+	–	Cos	
Ascomorpha sp.	–	–	–	–	+	Af	probably undescribed species
Asplanchna brightwellii GOSSE, 1850	+	–	–	–	+	Cos (+Pac)	
A. sieboldii (LEYDIG, 1854)	–	+	–	+	–	Cos	these records may actually be *A. brightwellii*
Brachionus angularis (GOSSE, 1851)	+	+	+	+	+	Cos	
B. bennini LEISSLING, 1924	–	–	–	–	+	Cos	
B. bidentatus ANDERSON, 1889	–	–	–	–	+	Cos (+Ant)	
B. calyciflorus PALLAS, 1766	+	+	+	+	+	Cos (+Ant)	
B. caudatus BARROIS & DADAY, 1894	+	–	+	+	+	Cos	
B. dimidiatus BRYCE, 1931	+	–	–	–	–	Cos	type localities: Lakes Abijata, Shala, Ziway (as *B. calyciflorus* var. *dimidiatus*)
B. falcatus ZACHARIAS, 1898	–	+	+	–	+	Cos	
B. forficula WIERZEJSKI, 1891	–	+	–	–	–	Cos (introduced in Na)	
B. plicatilis MÜLLER, 1786	+	–	–	–	–	Cos (+Pac)	doubtful record
B. quadridentatus HERMANN, 1783	–	–	–	–	+	Cos (+Ant, Pac)	
B. rubens EHRENBERG, 1838	–	–	–	+	–	Cos	
Conochilus sp.	–	–	–	+	–		
Cephalodella catellina (MÜLLER, 1786)	–	–	–	–	+	Cos (+Ant)	
C. forficata (EHRENBERG, 1832)	–	–	–	–	+	Cos (+Ant, Pac)	
C. gibba (EHRENBERG, 1830)	–	–	–	–	+	Cos (+Ant, Pac)	
Collotheca ornata (EHRENBERG, 1832)	–	–	–	–	+	Cos (+Ant, Pac)	
C. pelagica (ROUSSELET, 1893)	–	–	–	–	+	Cos	
Colurella obtusa (GOSSE, 1886)	–	–	–	–	+	Cos (+Ant, Pac)	

+ *navicula* ?

= *intuta* Myers, 1924

C. uncinata (Müller, 1773)	–	–	–	–	+	Cos	
Diplois daviesiae Gosse, 1886	+	–	–	–	–	?	questionable taxon, reliable records are missing
Eosphora najas Ehrenberg, 1830	–	–	–	–	+	Cos (+Ant)	
Epiphanes brachionus var. *spinosus* (Rousselet, 1893)	–	–	–	–	+	P, E, O, Nt	
Euchlanis dilatata Ehrenberg, 1832	+	–	–	–	–	Cos (+Ant, Pac)	
E. oropha Gosse, 1887	+	–	–	–	+	Cos (+Ant)	(1) as *Euchlanis parva* Rousselet (syn.)
Filinia longiseta (Ehrenberg, 1834)	+	+	–	–	+	Cos	
F. novaezealandiae Shiel & Sanoamuang, 1993	–	–	+*	+*	+	tropicopolitan (Af, Au, Nt, O, Pac)	*records of *Filinia terminalis* Plate (3, 4) probably refer to this species
F. opoliensis (Zacharias, 1898)	–	–	–	–	+	Cos	
Hexarthra intermedia brasiliensis (Hauer, 1953)	–	–	–	–	+	Af, Nt, O	
H. mira (Hudson, 1871)	+	–	+	+	–	Cos (+Pac)	
Keratella tropica (Apstein, 1907)	+	+	+	+	+	tropicopolitan (Cos) (+Pac)	
Lecane aculeata (Jakubski, 1912)	+	–	–	–	+	tropicopolitan (Cos) (+Pac))	
L. acus (Harring, 1913)	+	–	–	–	–	Cos	doubtful record (acidophilic species)
L. bulla (Gosse, 1851)	–	–	+	+	+	Cos (+Pac)	
L. closterocerca (Schmarda, 1859)	+	–	–	–	+	Cos (+Ant, Pac)	
L. curvicornis (Murray, 1913)	+	–	–	–	–	Cos	(1) as *Lecane zwaiensis* n. sp.
L. flexilis (Gosse, 1886)	+	–	–	–	–	Cos (+Ant, Pac)	
L. furcata (Murray, 1913)	+	–	–	–	+	Cos	(1) as *Monostyla elachis* Harring & Myers
L. hamata (Stokes, 1896)	–	–	–	–	+	Cos (+Pac)	
L. leontina (Turner, 1892)	–	–	–	–	+	Cos	
L. luna (Müller, 1776)	+	–	+	+	+	Cos (+Pac)	
L. lunaris (Ehrenberg, 1832)	+	–	–	+	–	Cos (+Ant, Pac)	
L. papuana (Murray, 1913)	–	–	–	+	+	tropicopolitan (Cos (+Pac))	
L. pyriformis (Daday, 1905)	–	–	–	–	+	Cos (+Pac)	
L. undulata Hauer, 1938	–	–	–	–	+	tropicopolitan (Cos)	
L. ungulata (Gosse, 1887)	+	–	–	–	–	Cos	
Lepadella apsicora Myers, 1934	–	–	–	–	+	tropicopolitan (Af, Au, Na, Nt, O)	
L. ehrenbergii (Perty, 1850)	–	–	–	–	+	Cos	

Table 2. *(Continued)*

Species	References (1)	(2)	(3)	(4)	(5)	Biogeography	Comment
L. patella (MÜLLER, 1773)	–	–	–	–	+	Cos (+Ant, Pac)	
L. triptera (EHRENBERG, 1832)	–	–	–	–	+	Cos (+Ant, Pac)	
Mytilina mucronata (MÜLLER, 1773)	+	–	–	–	–	Cos (+Ant)	
M. ventralis (EHRENBERG, 1830)	+	–	–	+	–	Cos (+Pac)	
Plationus patulus (MÜLLER, 1786)	+	–	–	–	+	Cos	(1) as *Brachionus patulus* MÜLLER
Polyarthra indica SEGERS & BABU, 1999	–	–	–	–	+	Af, O, Pac	
P. vulgaris CARLIN, 1943	+	–	–	–	+	Cos (+Pac)	(1) as *Polyarthra trigla* EHRENBERG
Pompholyx complanata (GOSSE, 1851)	–	–	–	–	+	Cos	
Proalides cf. *wulferti* SUDZUKI, 1959	–	–	–	–	+	E, P, Pac	
Scaridium longicaudum (MÜLLER, 1786)	+	–	–	–	–	Cos (+Ant)	
Trichocerca gracilis (TESSIN, 1890)	–	–	+	+	+	Cos	
T. pusilla (JENNINGS, 1903)	+	–	+	+	+	Cos (+Pac)	
T. ruttneri DONNER, 1953	–	–	+	+	+	Cos	
T. tenuior (GOSSE, 1886)	–	–	–	+	–	Cos (+Pac)	
Trichocerca sp.	–	–	–	+	–		
Wolga sp.	–	–	–	–	+		

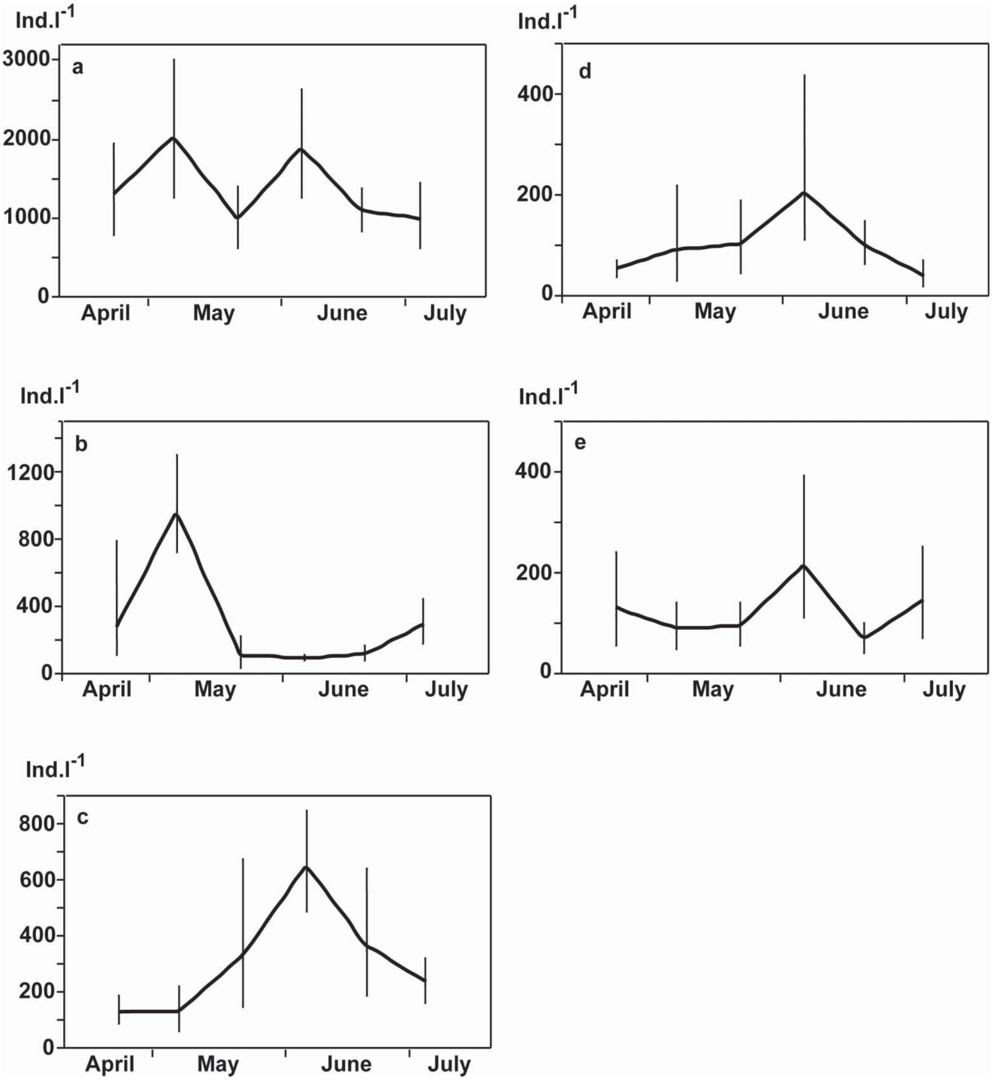

Figure 2. Abundance development of total rotifers and dominant rotifer species in Lake Ziway. a – total rotifers; b – *Anuraeopsis fissa*; c – *Brachionus angularis*; d – *Filinia novaezealandiae*; e – *Trichocerca ruttneri*. Mean values (three stations and different depths) and standard deviation based on log-transformed data.

A total of five cladocerans and three cyclopoid copepod species were identified (Table 3). *Moina micrura* and *Diaphanosoma excisum* were numerically dominant among the Cladocera, and on average contributed 6.6 and 2.7% of the total crustacean biomass, respectively. *Alona* sp. and *Daphnia barbata* were very rare, whereas *Ceriodaphnia cornuta* was common (Table 3). *Alona* sp. occurred only at two sampling occasions, whereas *D. barbata* was found throughout the sampling period with low abundance (up to 0.6 ind. l^{-1}). Among adult cyclopoids, *Thermocyclops decipiens* dominated with a 5% share

Table 3. Crustacean species and their relative contribution to crustacean abundance at single sampling stations and mean during investigation period.

Species	S1	S2	S3	Mean
Alona sp.	0.0	0.2	0.0	0.1
Ceriodaphnia cornuta SARS, 1886	0.6	2.9	1.3	1.5
Daphnia barbata WELTNER, 1897	0.0	0.0	0.1	0.1
Diaphanosoma excisum SARS, 1885	4.5	2.1	1.6	2.7
Moina micrura KURZ, 1874	6.6	7.4	6.0	6.6
Mesocyclops aequatorialis KIEFER, 1929	0.8	1.2	1.6	1.2
Thermocyclops decipiens KIEFER, 1929	5.4	5.3	5.2	5.3
Afrocyclops gibsoni (BRADY, 1904)	<0.1	<0.1	<0.1	<0.1
Cyclopoid nauplii	79.3	78.2	80.9	79.5
Cyclopoid copepodites	2.7	2.8	3.3	2.9

of the crustacean biomass, whereas *Mesocyclops aequatorialis* contributed only 1.2%. The major component, representing 80% of total crustacean numbers, were cyclopoid nauplii (Table 3). *Afrocyclops gibsoni* was rare, with only two individuals found in April. Calanoid and harpacticoid copepods were totally absent. *M. micrura* and *D. excisum* showed variations in their spatio-temporal abundance. *M. micrura* occurred in highest numbers in April, followed by a steady decline until it increased again to reach a second peak during the first week of June, and then declined again (Fig. 3b). *D. excisum* (Fig. 3c) and the less abundant

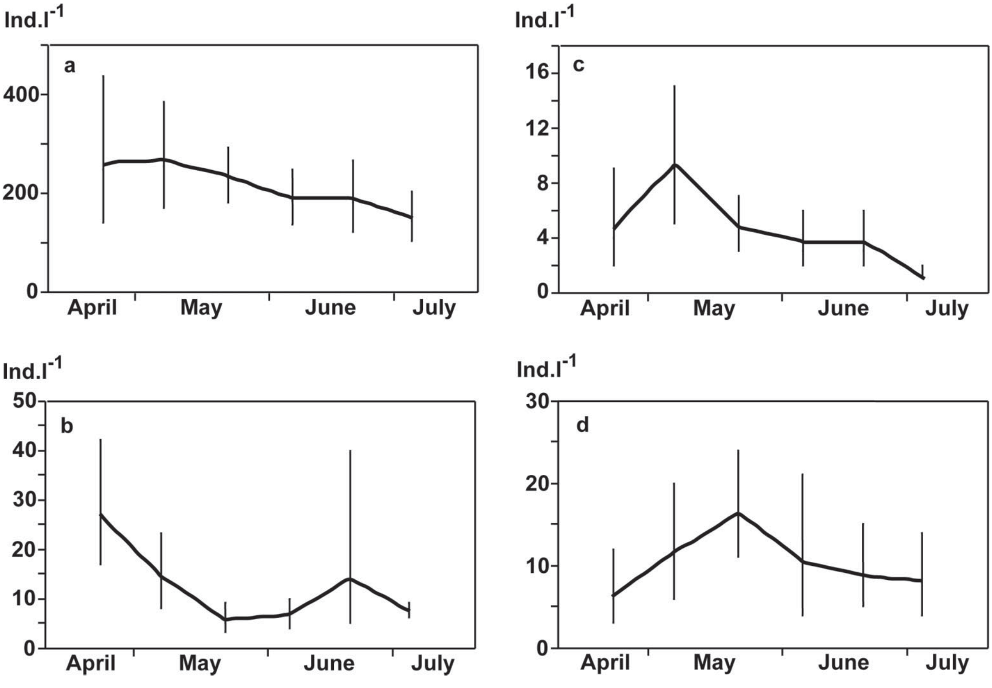

Figure 3. Abundance development of total Crustacea and dominant crustacean species in Lake Ziway. a – total Crustacea; b – *Moina micrura*; c – *Diaphanosoma excisum*; d – *Thermocyclops decipiens*. Mean values (three stations and different depths) and standard deviation based on log-transformed data.

Table 4. Length measurements of the dominant Crustacea; inshore (in: S1) and offshore (off: S2 + S3). ANOVA, Fisher's PLSD (Protected Least Significant Difference); *n* – number of measurements, SD – standard deviation, *P*-value – level of significance.

	Diaphanosoma excisum		*Moina micrura*		*Thermocyclops decipiens*	
	in	off	in	off	in	off
n	210	416	209	420	210	417
mean leng, µm	666	722	520	565	744	792
±SD, µm	91	104	66	63	65	55
P-value	<0.0001		<0.0001		<0.0001	

C. cornuta had only one peak each at the beginning of May and then declined. The abundance of the three cladocerans showed a similar pattern in all stations.

The spatial distribution of adult and juvenile *M. micrura* varied between stations. Adults were prevailing in the open water, whereas juveniles dominated inshore (Fig. 4a, b). With the exception of *C. cornuta* ($P = 0.153$), body sizes of crustaceans varied significantly between inshore and offshore samples (Table 4). The mean lengths of the specimens inshore were significantly smaller than in the offshore areas for *D. excisum, M. micrura*, and *T. decipiens*.

Rotifers accounted for 75% of total zooplankton numbers and 27% (dw) of total zooplankton biomass. The mean total biomass of rotifers for the investigation period was 36.3 µg l^{-1} dry weight, while that of crustaceans was 97.2 µg l^{-1}. The contribution of cladocer-

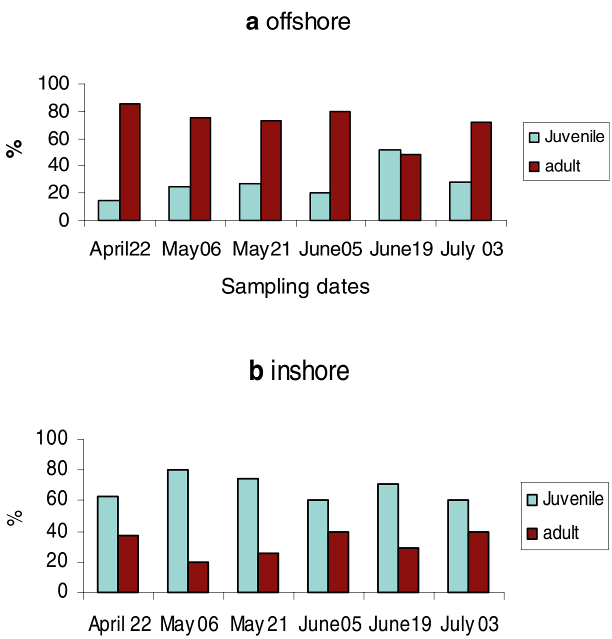

Figure 4. Contribution of juvenile instars and adults of *Moina micrura* to the standing stock of inshore (S1) and offshore (S2, S3) regions of Lake Ziway.

Table 5. Mean individual biomass of planktonic rotifers and crustaceans.

Species/stages	Mean length (µm)	Mean abundance (ind./l)	Dry weight (µg/ind.)	Fresh weight (µg/ind.)
Anuraeopsis coelata	95	87.4	0.003	0.026
Anuraeopsis fissa	80	329.6	0.002	0.015
Ascomorpha sp.	110	3.2	0.016	0.160
Asplanchna brightwellii	850	1.9	5.509	141.20
Brachionus angularis	86	316.4	0.080	0.076
Brachionus calyciflorus	227	19.3	0.141	1.410
Brachionus caudatus	153	35.2	0.043	0.426
Brachionus falcatus	138	2.6	0.032	0.315
Collotheca ornata	320	30.0	0.062	0.617
Filinia longiseta	160	21.2	0.053	0.532
Filinia novaezealandiae	110	130.5	0.017	0.173
Filinia opoliensis	180	6.6	0.076	0.758
Hexarthera intermedia brasiliensis	126	9.6	0.026	0.262
Keratella tropica	95	4.0	0.019	0.186
Polyarthra indica	90	2.7	0.020	0.204
Polyarthra vulgaris	140	5.4	0.077	0.768
Pompholyx complanata	82	27.9	0.008	0.082
Proalides cf. *wulferti*	125	74.8	0.008	0.082
Trichocerca gracilis	190	71.6	0.042	0.417
Trichocerca pusilla	105	58.2	0.011	0.106
Trichocerca ruttneri	220	134.5	0.112	1.121
Moina micrura (all stages)	549	14.5	1.576	15.76
Diaphanosoma excisum (all stages)	702	5.9	1.784	17.84
Ceriodaphnia cornuta (all stages)	356	3.4	0.991	9.91
Daphnia barbata (all stages)	988	0.1	4.537	45.37
Alona sp. (all stages)	425	0.1	0.597	5.97
Thermocyclops decipiens (adult)	822	11.5	1.679	16.79
Mesocyclops aequatorialis (adult)	1010	2.6	3.640	36.40
Cyclopoid copepodites (pooled)	689	6.4	1.435	14.48
Nauplii (pooled)	193	173.4	0.125	1.25

ans and copepods to the total zooplankton biomass was 28% and 45% (dw), respectively. Mean individual length and weight estimates are given for the most important zooplankton species in Table 5.

4. Discussion

Rotifers form the major zooplankton component in Lake Ziway, both numerically and in terms of species richness. Only eight crustacean species were identified from all stations, as opposed to 49 rotifer species. Similarly, low crustacean diversities and high rotifer abundances were reported from other Rift Valley Lakes. WODAJO and BELAY (1984) reported four crustacean species for Lake Abijata and five for Lake Langano. Four cladoceran species from Lake Awassa and three from Lake Ziway were identified by FERNANDO *et al*. (1990), and the zooplankton community of Lake George (Uganda) is dominated by only two species of cyclopoid copepods (BURGIS, 1971). The species composition in Lake Ziway agrees well with earlier reports from Ethiopian Rift Valley lakes. FERNANDO (1980b) concluded that zooplankton in the tropics is less diverse than in temperate zones, with smaller planktonic species, particularly rotifers and protists, predominating. Most rotifer species that have been identified from Lake Ziway in previous studies were also recorded by us. Differences between current species composition and species richness, as compared to earlier reports, may have resulted from different methodological approaches and collecting intensity, as well as from misidentifications. In this study we used 30 μm mesh gauze that can quantitatively retrieve also the smallest rotifers. In previous studies (*e.g.* GREEN and MENGESTOU, 1991) larger mesh sizes (55 or 64 μm) were used, and 20 species from 12 samples were recorded. We found a total of 48 rotifer species in 60 samples, which probably also reflects a larger sampling effort. More than 50% of the species were identified from samples taken from the littoral area, and not all can be considered strictly planktonic. *Hexarthra mira*, as reported by earlier workers, was not found in the present study, but the similar *Hexarthra intermedia brasiliensis* could be identified instead. The earlier record of the cold stenothermic species *Filinia terminalis* (GREEN and MENGESTOU, 1991) most likely represents the closely related *Filinia novaezealandiae*, a recently described species that typically occurs in tropical waters (SANOAMUANG, 2002). Similarly, *Ascomorpha saltans* as reported by GREEN and MENGESTOU (1991), may actually represent a closely related, yet undescribed species that was found in low numbers throughout our study period. Previous reports of *Asplanchna sieboldii* in Lake Ziway must be treated with caution, as the taxonomy of the *A. brightwellii-sieboldii*-group has been particularly confused in the past, and both taxa were also treated under the umbrella name of *A. brightwellii sensu lato* (DE BEAUCHAMP, 1951; GILBERT, 1968). A highly doubtful record concerns the halobiont *Brachionus plicatilis*, that has been identified from material collected by the Hugh Scott Expedition in 1927 (BRYCE, 1931). The same expedition also collected from nearby salt lakes, so that a contamination of samples seems more likely than an actual record of this species from the freshwater Lake Ziway. The same could also be true for *Brachionus dimidiatus*, a species that is largely restricted to soda lakes, and has not been confirmed for Lake Ziway by any of the later studies (Table 2). It should be noted in this context, that Lake Ziway is listed as a type locality for this species (others are the soda lakes Abijata and Shala) (BRYCE, 1931).

When comparing the current rotifer species composition in Lake Ziway with previous records, a good agreement of rotifer communities, with little changes of long-term species numbers over the past decades, becomes apparent. A number of species, particularly of families Brachionidae (*Anuraeopsis coelata*, *Brachionus angularis*, *B. calyciflorus*, *B. caudatus*, *Keratella tropica*, and *Plationus patulus*), and Lecanidae (*Lecane aculeata*, *L. closterocerca*, *Lecane furcata* and *L. luna*), have already been reported in 1927 (BRYCE, 1931). From a biogeographical perspective, wide-ranging rotifers are dominant, with the large majority being cosmopolites, in many cases with their range even including the Antarctic and/or Pacific region, some are tropicopolitan (Table 2). With a good proportion of warm temperate-centered taxa, associations show some similarities to those of temperate regions. One cause for this might be climate modification by high altitude, even though Ethiopia lies entirely within the tropics. Among the species with a more restricted range, *Polyarthra indica*, like *Filinia novaezealandiae*, seems to be an example of a rotifer that has been mistaken for a well known species in the past, but after its description turns out to be a widely distributed species. Since its description from India in 1999, this species has been recorded twice from Africa (SCHABETSBERGER *et al.*, 2004; this study) and from the South Pacific (SCHABETSBERGER and JERSABEK, unpubl.). It can be speculated that the range of *P. indica* is actually much wider, perhaps tropicopolitan.

Among the crustaceans, *Moina micrura* (7%) and *Thermocyclops decipiens* (5%) dominated (Table 4). Two more cladoceran species, *Ceriodaphnia cornuta* and *Daphnia barbata,* which were not recorded previously (BELAY, 1988; FERNANDO *et al.*, 1990), were identified. *Alona diaphana*, which was dominant in the littoral and commonly found in the open water by FERNANDO *et al.* (1990), was rare in the present study. *Diaphanosoma mongolianum*, as identified from Lake Zwai (= Ziway) by KOROVCHINSKY (1987), was not found in our samples. Whether this species has been replaced by *D. excisum* or both species co-occur, or whether there is a temporal separation of the two species in Lake Ziway, cannot be said from our 3-months study. Contrary to the cladocerans, copepod species composition in Lake Ziway seems to fluctuate less with time. All species of cyclopoid copepods reported in the present study, *i.e.*, *T. decipiens*, *Mesocyclops aequatorialis*, and *Afrocyclops gibsoni*, were also recorded by VAN DE VELDE (1984), DEFAYE (1988) and BELAY (1988).

The dominant cladoceran species, *M. micrura,* reached densities of up to 30 ind. l^{-1}, followed by *Diaphanosoma excisum* (13 ind. l^{-1}). Similarly, maximum densities of up to 18 ind. l^{-1} for *D. excisum* were reported by MENGESTOU *et al*. (1991) from Lake Awassa. Much lower densities of only 5 ind. l^{-1} were reported from Lake Lanao by LEWIS (1979). Various factors might be responsible for low abundances of cladocerans. It is well known that blue-green algae have a negative influence on filter feeders by affecting ingestion rates and energy balance of large and small cladocerans (*e.g*., PORTER and MC DONOUGH, 1984; GLIWICZ, 1980; 1990). Suspended clay particles (GILBERT, 1990), and toxic substances released by Cyanobacteria, can reduce filtration rates of *Daphnia* by 50% or more (GLIWICZ and LAMPERT, 1990). The phytoplankton of Lake Ziway is dominated by blue-green algae (*Anabaena circinalis*, *A*. *flosaquae*, *Lyngbya* sp., *Microcystis* sp.) and diatoms (GETACHEW, pers. com.). The low abundances of cladocerans in Lake Ziway might thus be caused by the dominance of Cyanobacteria.

Low abundances of large-bodied cladocerans may also be caused by size selective fish predation (BROOKS and DODSON, 1965). The low abundance of large-sized zooplankton in many tropical lakes and reservoirs may thus be an indication of strong fish predation (DUNCAN, 1984; NILSSEN, 1984; FERNANDO, 1994). In Lake Kivu, the small average size of the cladoceran *Diaphanosoma excisum*, which is twice as small as in Lake Malawi, is a strong indication of the significant impact of the planktivorous fish *Limnothrissa miodon* (ISUMBISHU *et al*., 2006). Also, the presence of a helmet in *D. barbata* and a horn in *C. cornuta* possibly indicated high predation pressure (*cf*. ZARET, 1980).

Copepod densities were high, reaching up to 220 ind. l^{-1}. Similar values of up to 180 ind. l^{-1} were reported from Lake Awassa (MENGESTOU *et al*., 1991). Throughout the investigation period, nauplii dominated in the copepod populations. This could indicate a high mortality in the copepodid and adult stages, although some proportion of the nauplii may actually belong to benthic species (with planktonic larvae). Similar results were presented for Lake George, Uganda (BURGIS, 1969) or Lake Kivu (ISUMBISHU *et al*., 2006).

The species distribution of crustaceans in Lake Ziway shows little or no pattern. Species found in the littoral were also common in the open water. Such horizontally homogenous distributions are common in the tropics (FREY, 1990). Samples from different depths in the open water showed that crustaceans distributed evenly throughout the whole water column. On the other hand, the mean lengths of the specimens inshore were significantly smaller than in the offshore areas for *D. barbata, D. excisum, M. micrura*, and *T. decipiens*. Size/stage structure of *M. micrura* varied significantly between inshore and offshore areas. Adult *M. micrura* dominated offshore, whereas juveniles predominated inshore (Fig. 4a, b). This might reflect the increased predation by zooplanktivorous fish. Highest densities of juvenile fish occurred in inshore areas with dense vegetation, probably to avoid predation by piscivorous fish. Here they feed predominantly on zooplankton, and according to ABEBE and TEFERRA (1992) even small rotifers were found in the guts of juvenile tilapias. *Oreochromis niloticus* (less than 60 mm total length) fed on chironomid larvae, copepods, and rotifers in Lake Ziway (TADESSE, 1988). Similarily, size measurements of copepods in Lake Kivu reveal much larger individuals offshore than in the littoral area (ISUMBISHU *et al*., 2004). These examples suggest a predominantely littoral selective predation on large and adult crustaceans by fish.

During the period of investigation, the mean biomass of zooplankton in Lake Ziway was 133.5 mg dw m^{-3}. This is low compared to the results obtained from Lake George (368 mg dw m^{-3}) by BURGIS (1974), and from Chad (333 mg dw m^{-3}) by CARMOUZE *et al*. (1983), but it is in the range obtained from Lake Kivu (188 mg dw m^{-3}) before the introduction of the clupeid *L. miodon* (REYNTJENS in DE IONGH *et al*., 1995). On the other hand, this value is 3 times higher than the mean biomass reported by MENGESTOU *et al*. (1991) from Lake Awassa (44.85 mg dw m^{-3}), a biomass comparable to the values found in Lake Kivu after the introduction of the planktivore *L. miodon* (ISUMBISHU *et al*., 2006), and it is even higher than the maximum biomass (114 mg dw m^{-3}) reported from Lake Awassa after the rainy season.

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