SPATIO-TEMPORAL DISTRIBUTION OF CRUSTACEANS IN A SHALLOW LAKE, LAKE ZIWAY

Adamneh Dagne[1*] and Alois Herzig[2]

Abstract

This study presents spatio-temporal variations of crustacean community in relation to turbidity and predation in one of the Ethiopian Rift Valley lakes, Lake Ziway, based upon one year biweekly sampling data. Abundance of cladocerans correlated best with secchi depth ($P<0.0001$) and weakly and negatively with Chlorophyll a ($p=0.0067$). Copepods responded to Chlorophyll positively ($p=0.0003$) but not to secchi depth. Three major peaks in total crustacean biomass were recorded inshore but a single maximum (less than half of the inshore value) offshore. Abundance and biomass were highest inshore, where a macrophyte belt along the shore of the lake provides shelter and enables the crustaceans to avoid predation. Mean annual biomass of zooplankton was 82.5 mg m^{-3}. Dominant crustaceans: Moinamicrura, Thermocyclopsdecipiens and Mesocyclopsaequatorialis, contributed 90.8 % of the total annual zooplankton biomass. Temporal variation in crustacean biomass was associated with water transparency. Minimum total cladoceran biomass was recorded during the wet season. On the other hand predation by catfish and Chaoborus on larger sized copepods leads them to show diel migration in such a turbid shallow lake and to a shift in zooplankton community structure where small sized Thermocyclops and pre-adult copepods were dominant throughout the sampling period.

Keywords: Cladocerans, copepods, biomass, turbidity, predation

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Introduction

Sediment loading comprises one of the most significant and wide spread forms of aquatic pollution (Kirk, 1991; Waters, 1995). Although the delivery of sediments to lakeswas reduced in some regions owing to the introduction of sediment control programs and improved soil conservation practices, excessive sediment loading remains one of the primary forms of anthropogenic disturbance of aquatic ecosystems in both tropical and temperate regions (Waters, 1995; USEPA, 2000). In addition to affecting natural lake systems, the retention of eroded sediments in reservoirs is a major environmental, social and economic concern globally as high sedimentation rates reduce hydropower efficiency and viability, increase costs of dam maintenance and water treatment and have important consequences for water supply, fisheries and tourism.One of most important physical effects of turbidity on aquatic ecosystems is decreased transmission of light through the water column. The absorption and scattering of light by suspended particles reduces the compensation depth, below which light intensity is insufficient to sustain photosynthesis, thus diminishing the volume of water supporting primary production.

Consequences of suspended sediments to zooplankton biology and ecology might be the alteration of ecological conditions (water temperature, underwater light climate), resources (quantity and quality of phytoplankton), as well as ecological interactions (particularly regarding zooplankton feeding behaviour, and vulnerability to visual planktivores) relevant to zooplankton (Hart, 1986; Hart, 1988)which affect community structure. Compositional shifts in zooplankton dominance with changing turbidity levels reveal differential susceptibilities to resource depression (Hart, 1988).

Depression of feeding rate with rising turbidity by interference in food gathering capabilities is indicated by Hart (1988).

Experimental studies have consistently revealed the relation of *Daphnia* filtering rates with rising suspended sediment concentrations (Arruda et al., 1983; Hart, 1988) and a general negative-relationship between zooplankton and turbidity, particularly among cladocerans and copepods but less constantly among rotifers. Increased turbidity has thereby been shown to enhance the dominance of rotifers over cladocerans in lakes as the former are generally more selective feeders and can avoid increasing large volumes of sediments which reduce the carbon ingestion rate of indiscriminate filter-feeding cladocerans (Kirk, 1991).

The objective of this study was to examine the spatio-temporal crustacean community structure of Lake Ziway in relation to turbidity and predation.

Materials and Methods

Study area

Lake Ziway (7°55’N and 38°43’E) is a turbid freshwater lake situated in the most northern section of the Central Ethiopian Rift Valley. It lies 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, an average depth of 2,5 m; and a volume of 1,1 km^3(UNEP, 2006). According to Schröder (1984), Lake Ziway has a maximum length and width of 32 and 20 km, respectively. The lake is mainly fed by two rivers from the highlands,Meki North West and Katar North East and drains into Lake Abijata through Bulbula River in the southwest (Fig. 1). The latter usually falls dry during the dry season.

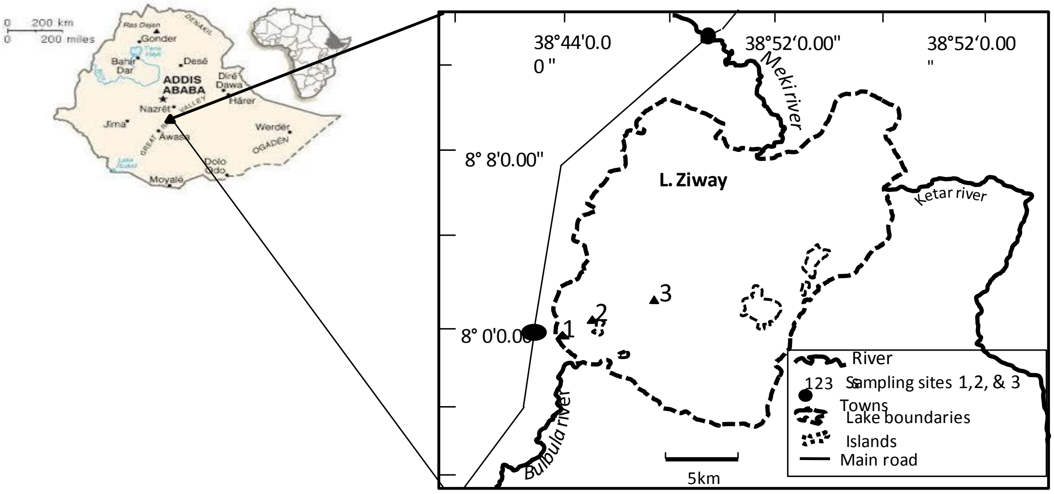


Fig. 1. Location of sampling sites (in numbers) on the study area, Lake Ziway

The weather in the lake region is frequently windy to stormy (Schröder, 1984). Slight wind can cause complete mixing of the lake as the lake is shallow and wind exposed. Strong wind-induced water currents, especially in the afternoon, isa common phenomenon in Lake Ziway.Wood *etal*. (1978) has also indicated such occurrence, and in addition, he found no strong thermal stratification in the lake. The lake is highly turbid, with a secchi depth of less than 30 cm due to re-suspended sediment particles and algae. The water budget of Lake Ziway is regulated by superficial inflows and outflow, evaporation and precipitation is mainly from the distant uplands, as precipitation in the lake area is inadequate to maintain the lake level.An earlier report indicates thatLake Ziway receives 0,42 and 0,44 km^3 via Rivers Katar and Meki, respectively, and losses through Bulbula River are about 0,21 km^3 and additional loss through evaporation of 0,2 km^3 yr^{-1} in 100 km^2 lake area (Wood and Talling, 1988). However, a more recent estimate had indicated much reduced inflows from those rivers into Lake Ziway. According to Tenalem (2004), the annual inflows fromMeki and

Ketar rivers into Lake Ziway are 264,5 and 392 million m^3, respectively. He also indicated that the inflow into the lake has an annual deficit of 74 million m^3 over the overall water loss from the lake. An increasing water demand and uncontrolled water abstractions from the inflowing rivers as well as lake water for irrigation, outflow through River Bulbula, domestic use and loss through evaporation are the cause for the deficit.

Methodology

Field Sampling and Measurement of Environmental Variables

The study was based on biweekly sampling between October 2008 and September 2009. Quantitative (using a 10L Schindler sampler) and qualitative plankton samples (plankton nets of 30 and 100 µm mesh size) were taken from the water column at each 0.5 m depth both from the inshore and offshore stations. Samples were preserved with formalin (5% final solution) and total count was done in the laboratory. Turbidity of the lake water was directly determined after every sampling in the laboratory with turbidity meter LP 2000 HANNA instrument calibrated at 0,0 FTU.

In addition to the routine sampling, repeated vertical sampling (n=10) from surface water and each 0.5 m depth was performed at hourly intervals with Schindler sampler (10 L) and horizontal tows with 100 µm mesh size plankton net. Sampling started at 17:00 PM and ended at 8:00 AMon the next day. Fish gut samples were collected from fish species caught by the commercial fishermen (usually gillnets and long lines seated for overnight) and from live fish caught by beach seining and hooks. Total length of the fish was measured to the nearest 0.1 cm before dissecting to examine prey preference with size.

To determine biomass of crustaceans, body lengths of individuals from *Ceriodaphniacornuta, Moinamicrura, Mesocyclopsaequatorialis* and *Thermocyclopsdecipiens, Cyclopoidcopepodides* and nauplii were measured with a calibrated ocular micrometer from the tip of the head to the base of the tail spines for cladocerans and from the tip of the head to both the base of the furcal rami and base of caudal spines for copepods. After the length measurement, group of individuals usually 20 for adults of *M. micrura, M. aequatorialis* and *T. decipiens,* 50 individuals for larger *C. cornuta,* small *M. micrura,* small *T. decipiens*and copepodides and 100 individuals for small *C. cornuta*and nauplii were grouped per size and transferred into small glass vials and further washed with distilled water for a minimum of half an hour before transferred into a pre-dried hand-made aluminum pans. Weighing pans with zooplankton were placed in a crucible and then into a drying oven at 100 ^{0}C for overnight. In the subsequent day, the crucible containing samples were cooled in desiccators and then pans with dried samples were weighed on a Mettler Toledo XS 205 Dual Range electronic microbalance. Since the balance has an accuracy of 10 μg, animals were weighed in batches to get more accurate biomass estimates than weighing of individuals. Dried group weights were then computed by subtracting the dried weights of each aluminum pans from the weight of dried aluminum pans plus specimens on it and then divided by the number of individuals within the group to get dry weight (μg) per individual. Species specific length-weight regressions were calculated by formula:

$$\ln W = \ln a + b \ln L$$

Where W is dry weight as μg ind^{-1} and L is body length (μm), a is intercept and b is slope of the regression line.

Crustaceans biomass were then estimated from mean sizes of species at each sampling date and converted into size specific dry weight and then multiplied by mean abundance of each species for the sampling date.

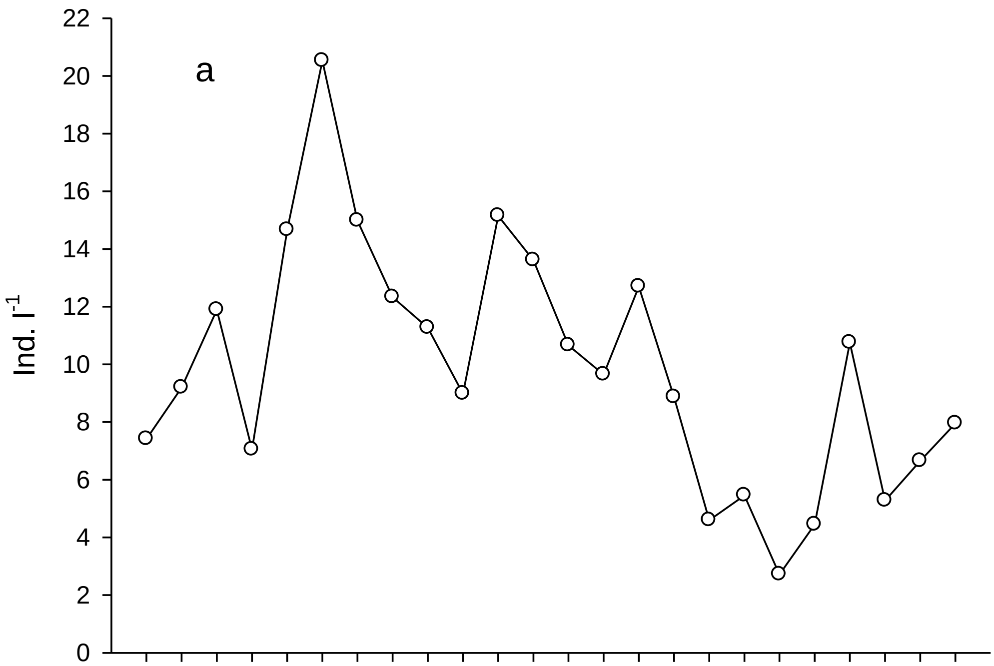
Results

Lake Ziway was very turbid throughout the study period with a single peak during the rainy season. Turbidity measurements varied between 49.4 and 299 FTU (mean 80.2; n = 81). The turbidity during the dry period was nearly uniform and then started to progressively increase from the month of March. It sharply increased to its maximum toward the end of July which was about 8 times higher than the minimum turbidity measured in mid April. The water transparencyincreased from around 23 cm Secchi depth at the beginning of the study period until it doubles to its peak in mid April and then continuously declined to as low as less than 15 cm in July after the rainfall. The mean for the study period was 29.3 cm.

Plankton composition

Phytoplankton of Lake Ziway consists of diatoms, green algae and blue-green algae. A total of 42 phytoplankton genera were identified during the study period, of which *Microcystis*species were dominant throughout the sampling period atall stations. *Synedra* and *Fragilaria* were co-dominant with *Microcystis* during the dry period. *Anabaena* and *Oscillatoria*Spp.were co-dominant with *Microcystis* throughout the rainy season. A total of 59 species comprised the zooplankton community in Lake Ziway. The highest species richness occurred in rotifers and they also contributed 43% of the total zooplankton abundance. On the other hand, cladocerans comprised only less than 5% and cyclopoid copepods 53% of the total zooplankton abundance.

Total cladoceran biomass and population density had shown contrasting differences between the relatively less turbid periods and the time of very low water transparency. Between January and April when Secchi depth ranged between 34,3 and 41,7 cm, the total cladoceran density and biomass were 3 and 2,1, respectively, which is higher than when the water transparency declined (between June and September). In contrast, an increase in the total copepods density (1,4 fold) and biomass (1,3 fold) were observed during the high turbid conditions from June to September (Fig. 2).



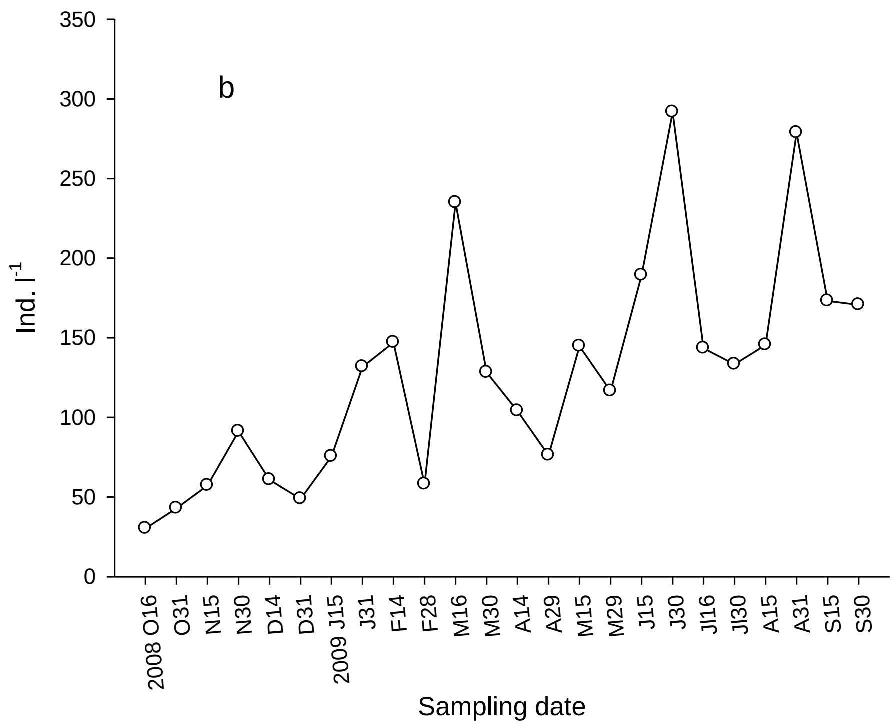


Fig. 2. Temporal abundance patterns of crustaceans: cladocerans (a) and copepods (b); Seasons: dry (Dec.- Apr.), pre-rainy (May – Jun.), rainy (July – Aug.), and post-rainy (Sept. – Nov.)

To evaluate the relationship of zooplankton density with selected abiotic and biotic parameters, correlation analysis was performed. Water temperature, dissolved oxygen, pH and conductivity had shown no significant correlation with density. Rotifera, Cladocera and Copepoda were found to correlate either with water transparency or Chlorophyll-a and/or with both. Total zooplankton density was not significantly correlated with either of the two, but was significantly correlated with the densities of Rotifera and Copepoda, reflecting the contribution of both to total the zooplankton ($p<0, 0001$ in both cases). Density of Rotifera showed weak negative correlation with Chlorophyll and with Cladocera ($p = 0,007$ and $p = 0,0067$, respectively) and somehow with Secchi depth. The abundance of Cladocera correlated best with Secchi depth (p< 0.0001) and weakly and negatively with Chlorophyll (p = 0.0067). Copepoda responded to Chlorophyll positively (p = 0.0003) but not to Secchi depth.Spearman rank correlation coefficients of zooplankton groups and selected environmental variables also revealed thesignificanceofturbidity for cladocerans as compared to either copepods and/or rotifers (Table 1).

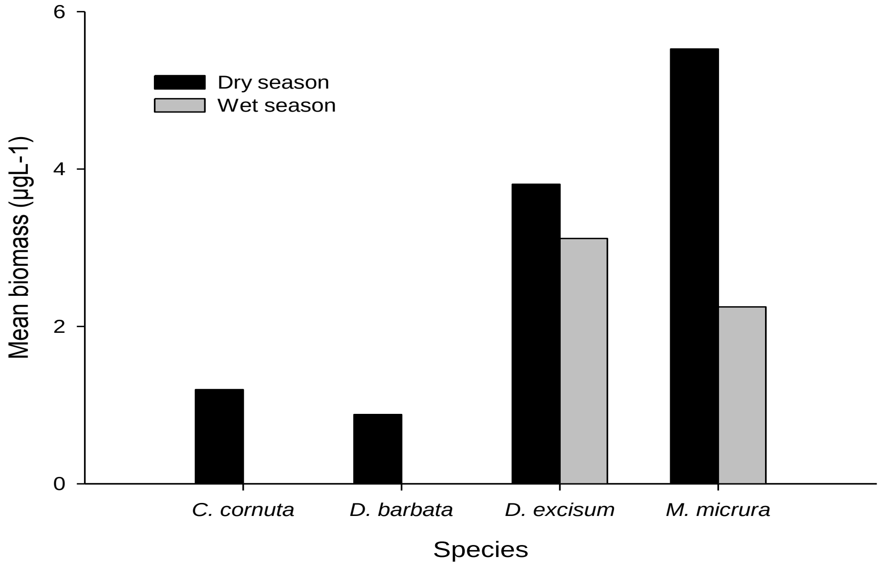
Table 1.**Spearman rank correlation coefficients for density of total zooplankton and zooplankton groups and selected environmental variables (the highest significant coefficients are shown in bold)**

Independent variable	Dependent variable		
	Cladocera	Copepoda	Rotifera
Secchi depth	**0,465*****	–	0,237*
Chlorophyll	0,382*	0,**531****	-0,**392****
Cladocera	– –	0,322**	
Copepoda	– –	–	
Rotifera	0,322*	–	–

*p<0,01; **p<0,001; ***p<0,0001; sample size is 24 for each parameter

The impact of turbidity was clearly observed in cladoceran biomass (Fig. 3 upper).Higher biomass of cladocerans was recorded during the dry period when compared to the wet period.Some of the cladocerans,i.e., *C. cornuta* and *D. barbata* were not found in the samples taken during the wet period.Thereverse trend had shown for copepods (Fig. 3 lower).

(a)



(b)

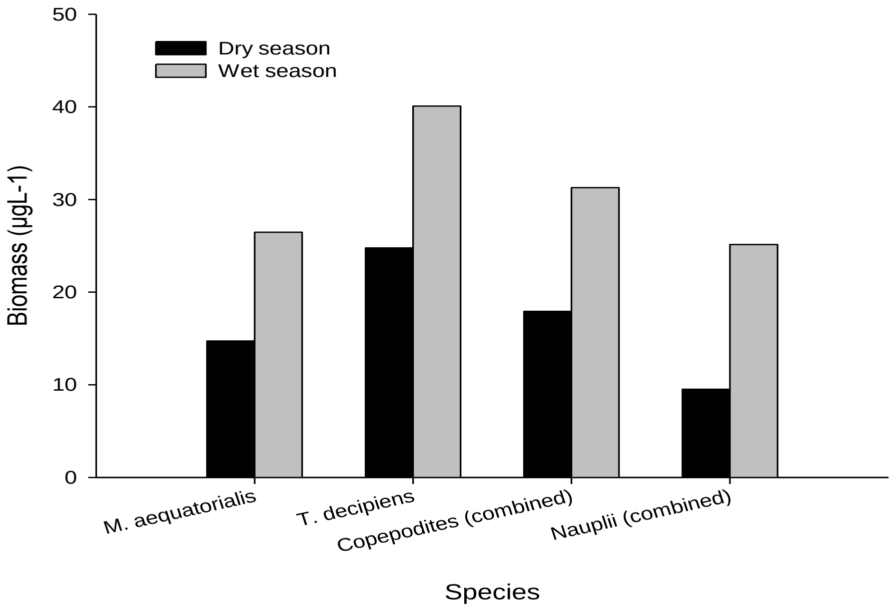


Fig. 3. Seasonal variation of crustacean biomass:cladocerans (a), copepods & development stages (b)

Crustacean biomass varied spatially and temporally. Three major peaks were recorded inshore but a single peak (less than half of the inshorevalue) offshore (Fig 4). In 71% of the sampling dates, inshore crustacean biomass was higher than the offshore. *Thermocyclopsdecipiens*contributed 58%,4% and 26% of those biomass peaks at the end of June, mid-March and end of August, respectively. The overall mean total zooplankton biomass for Lake Ziway was 91 mg m^{-3}.(Fig.4).

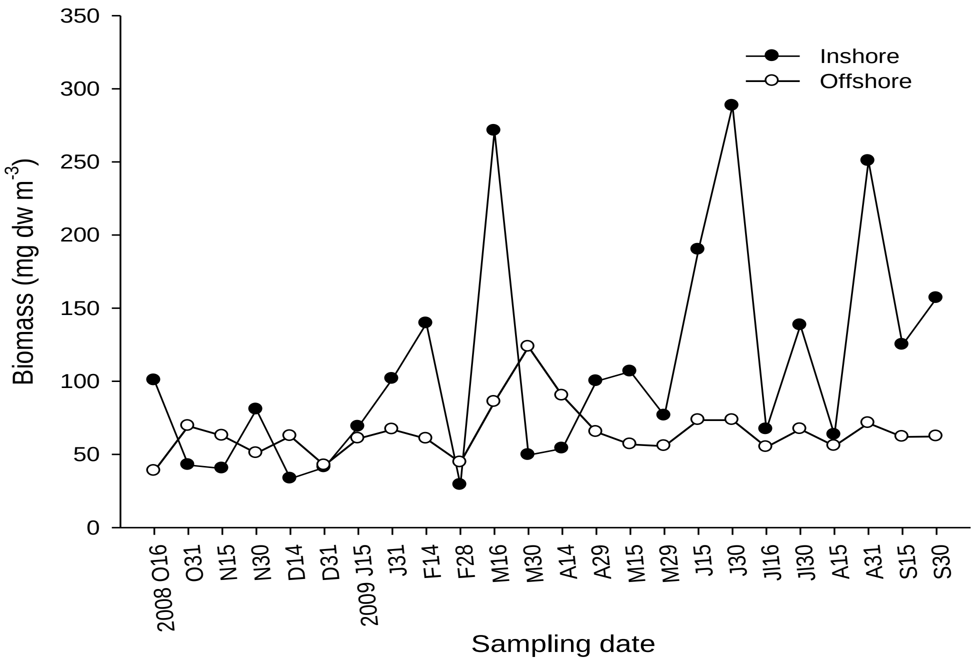
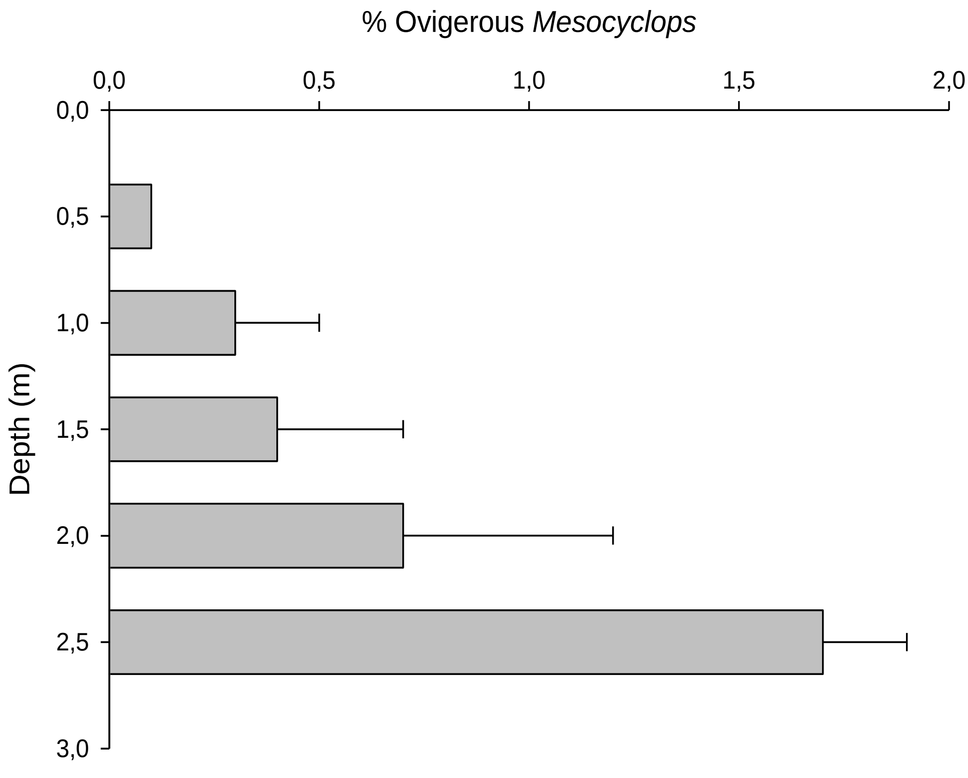


Fig. 4.Spatio-temporal variation of crustacean biomass

Besides turbidity, predation pressure mainly on large sized and vigorous copepods with large clutch size was observed. It leads to a spatio-temporal variation in sucha turbid lake with mean Secchi depth 29 cm (Fig 5). To get informationon the possible predation impact of the fish species which may have caused such marked diel vertical migration, the gut contents of six fishspecieswere analyzed: *Oreochromisniloticus, Tilapia zillii*, *Clariasgariepinus*, *Carassiuscarassius*, *Barbus* sp. and *Gara* sp. were examined (n= 50). *C. gariepinus* fed mainly on copepods, *C. carassius* to a lesser extent, while copepods were not found in the guts of other fish species. In 10% of the *C. gariepinus*guts examined more than 1000 copepods per gut (maximum more than 2000 copepods) were recorded (Fig. 6). To examine Zooplanktivory by the juveniles of *C.gariepinus*, attempts to catch the juveniles were not successful as it was difficult to catch in the wild. However, proportion of the prey in different length classes of *C. gariepinus* varies. Moreover, copepods were not found in the guts of *O. niloticus* juveniles.

(a)



(b)

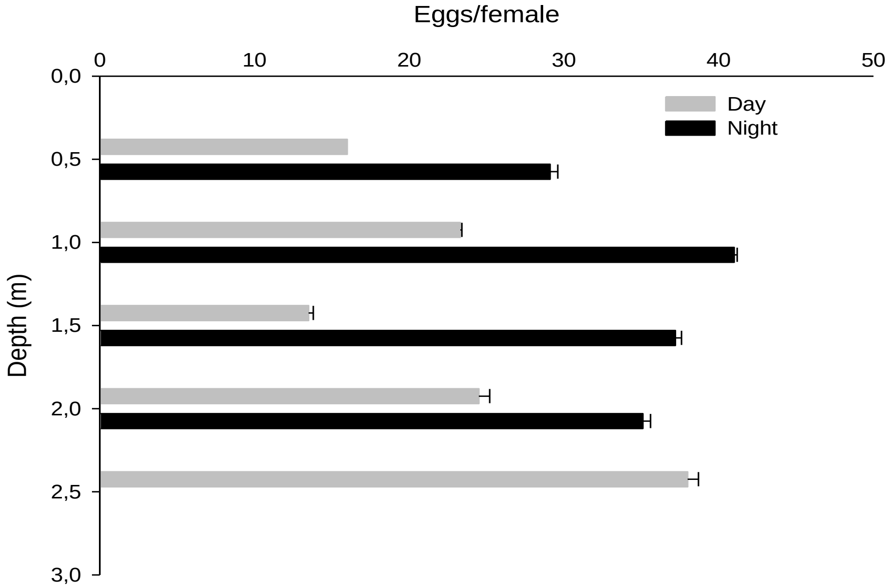


Fig.5. Vertical distribution of ovigerous copepods during day time (a) and diel variation in the clutch size of *Mesocyclopsaequatorialis* at offshore station-lower (b)

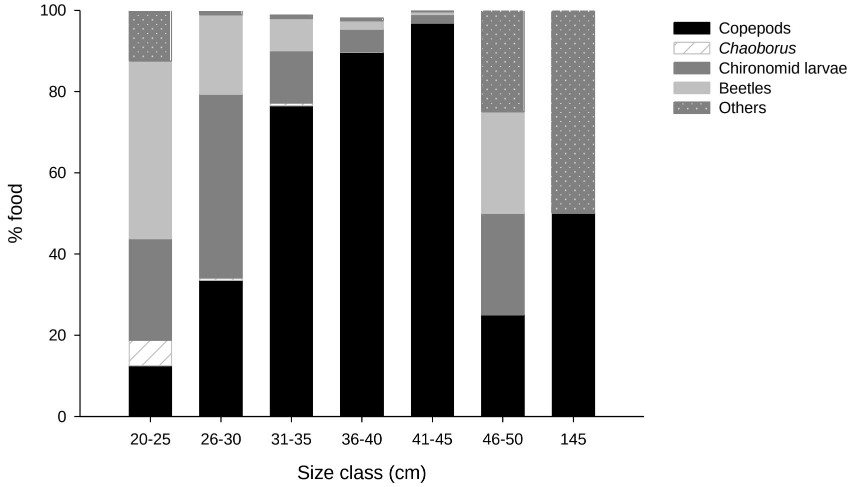


Fig. 6.Percent occurrence of different food items in the guts of *C. gariepinus*

Discussion

The brown color of the lake throughout the study period is the result of the influence of wind induced turbulences that keep sediment particles suspended in the water column. Frequent wind-induced turbulence together with sediment laden inputs from surface run-off and river inflows during the main rainy season have substantial impact on the turbidity and on the water transparency of the lake. The high turbidity (maximum up to 342 FTU) was the major cause for the decline in most abiotic and biotic components of the lake during the rainy season. The lowest records of Secchi depth, dissolved oxygen and sharp decline in Chlorophyll-a concentration were recorded during the time of high turbidity. The increase in turbidity following rainfall is clearly a basic limnological feature of the lake.

Plankton community composition

Besides the information on physico-chemical variables, information on the phytoplankton community is essential to evaluate the fluctuation in composition and abundance of the herbivorous plankton organisms. The phytoplankton community was dominated by large colonial forms like *Microcystis*species and filamentous *Anabaena* and *Oscillatoria* species. Earlier studies on phytoplankton of Lake Ziway also documented the dominance of blue green algae, mainly large filamentous and colonial forms (Schröder, 1984; Wood and Talling, 1988; Elizabeth and Willen, 1998; Adamneh*et al*., 2008). Absence of large filter feeders from the lake could contribute to their dominance in such turbid environment. However, the response of phytoplankton is not only the result of grazing pressure and nutrient availability. The change in the light climate due to suspended sediments, self-shading, wind, seasonal hydrological events can lead to temporal changes in the composition of phytoplankton. According to Tilman*et al*. (1986), blue greens are able to grow under low light intensities or more turbulent conditions (Allanson*et al*., 1990; Scheffer, 1998).

In shallow lakes like Lake Ziway, continuous stirring of the bottom sediments by benthic feeding fish (e.g., catfish and *Gara* sp.) and the turbulences could ensure the availability of nutrients in the water column and help the blue greens to dominate. Dominance of blue greens with increasing nutrient concentration is also reported by Elser (1999). Internal recycling of phosphorous via *Tilapia* excretion is also reported to contribute to the external total phosphorous load in a reservoir in Brazil (Starling *et al*., 2002) which may be the case in Lake Ziway too.

Cladocerans abundance varied significantly between dry and wet seasons, the former being the maximum and the latter the minimum. Unlike the cladocerans, rotifers and copepods did not show significant variation in their abundances which could reveal the differential impact of turbidity and food quality among zooplankton groups. Disappearance of *Daphnia barbata* and *Ceriodaphniacornuta* at low water transparency but an increase of *Moinamicrura* and *Diaphanosomaexcisum* is a good evidence for the differences in the susceptibility of the species. Generally, cladocerans seem to be affected by the high turbidity of the lake and the food quality.It has been indicated in several studies that the formation of large colonies or filaments, which were dominant in Lake Ziway too, limits their exploitation by zooplankton through physical constraint on ingestion, nutritional inadequacy and toxicity (Gilbert, 1990; Haney *et al*., 1994). Though chlorophyll-a increased during the wet period, it does not favour the development of cladocerans and hence low production because of low food quality. This agrees well with the results from other tropical lakes: the absence of daphnids in years with a high level of inorganic turbidity in Lake le Roux in South Africa (Hart, 1986), the negative impact of turbidity on daphnids abundance in Lake Tana (Eshete*et al*., 2004) and interference of resuspended sediments in *Daphnia* grazing in Lake Waihola, New Zealand (Levine *et al*., 2005).

The number of egg carrying females, clutch size and body size of *M. aequatorialis*varied markedly between day and night samples. In most cases ovigerous females with larger clutch were found in the lower part of the water column from day samples but in the upper part of the water column and even near the surface from night samples (Fig. 5). Body lengths measured from the day samples revealed that smaller sized *M. aequatorialis,* usually males and copepodid stages were common while adult and egg carrying females being very rare. The mean body size of adult *M. aequatorialis*from night samples was much larger (1212.4 μm, n=179) compared to the mean body size from day samples (890 μm, n=385) which reflects that large sized *M. aequatorialis*were nearly absent from day samples. The high occurrence of copepods in the guts of different length classes of *C. gariepinus* revealed the importance of plankton in the diets of this benthic and opportunistic feeding fish (Fig 6).

Conclusion

Crustacean community distribution of Lake Ziway was governed by seasons (i.e. turbidity following rainy season) and predation. Cladocerans were mainly affected by turbidity whereas large sized and egg carrying copepods were affected by predation. Generally, predation by catfish and Chaoborus on larger sized copepods leads them to show diel migration in such a turbid shallow lake and to a shift in zooplankton community structure where small sized Thermocyclops and pre-adult copepods were dominant.

Acknowledgments

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