Zooplankton diversity of a sub-tropical reservoir of Mizoram, Northeast India

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Abstract. This study on zooplankton diversity from the state of Mizoram of northeast India, based on plankton samples collected from Khawiva reservoir during November 2005-October 2007, recorded a total of 46 species. Zooplankton indicated monthly richness ranging between 19-36 and 25-34 species; registered 52.8-88.9 and 60.0-89.3% community similarities (*vide* Sørensen's index); and comprised between 31.2±12.7 and 46.7±11.3% of net plankton abundance during two years, respectively. Copepoda and Rotifera, together, influenced zooplankton abundance. Rhizopoda and Cladocera showed limited importance while Nematoda and Ciliata recorded poor densities. *Mesocyclops* spp. > *Keratella tropica* are important taxa. Our results are characterized by moderate species diversity, high evenness and low dominance except in some months. Richness, abundance and species diversity followed no definite patterns of monthly variations. Individual abiotic parameters exerted limited influence on zooplankton richness and abundance, and on abundance of its constituent groups. The canonical correspondence analysis with fifteen abiotic parameters explained high cumulative variance (84.8%) of zooplankton assemblages along axis 1 and 2 with importance of water temperature, rainfall, free carbon dioxide, conductivity and phosphate. Sladecek's $Q_{B/T}$ quotient and Shannon's diversity index reflected mesotrophic nature of Khawiva reservoir.

Keywords. Richness, diversity, ecology, hydal reservoir, trophic status.

INTRODUCTION

Reservoirs, an important component of inland aquatic resources of India, are known for their rich biogenic production potential (Sugunan 1997) which can be significantly augmented based on information on diversity of fish-food organisms. The limnological studies in India began in the early part of the last century and culminated in several works on ecology and plankton in diverse aquatic biotopes (Gopal & Zutshi 1998, Jana 1998). Our knowledge of zooplankton diversity and their role biological productivity in reservoirs of this country is yet limited. This generalization holds true to reservoirs of northeast India in particular. The related studies from this region are restricted to a preliminary report from the tropical Gumti reservoir of Tripura state (Bhattacharya & Saha 1986, 1990) while zooplankton are analyzed in detail till date only from three sub-tropical reservoirs of the state of Meghalaya (Sharma 1995, Sharma & Lyngskor 2003, Sharma & Lyngdoh 2004).

The present two-year study on zooplankton diversity, the first such contribution from Mizoram state of northeast India, deserves special ecological importance due to the stated lacunae. The monthly qualitative and quantitative net plankton collections of a subtropical hydal reservoir are analyzed with reference to composition, species richness, abundance, community similarities, species diversity, dominance and evenness of zooplankton. Individual and cumulative influence of abiotic factors on richness and abundance of zooplankton and on abundance of its constituent groups are analyzed. Comments are made on trophic status of the reservoir *vide* Sladecek's quotient and Shannon's diversity index.

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MATERIALS AND METHODS

This study is part of a limnological survey of Khawiva reservoir (22^o 35'N; 93^o 47'E) undertaken from November 2005 – October 2007. This small reservoir is located at a distance of 12 km from Lunglei town in Lunglei district, south Mizoram (Fig. 1, A–C). It was commissioned in 1986 for generating hydal power and is fed by Khawiva River. The reservoir is devoid of aquatic macrophytes and it is surrounded by forest with *Phyllanthus* sp., *Cyperus* sp., *Eupatorium* sp., *Farmaria* sp., and *Centella* sp.

Water samples were collected monthly at two sampling stations of Khawiva reservoir. Water temperature, specific conductivity and pH were recorded by the field probes; dissolved oxygen was estimated by Winkler's method while other abiotic parameters were analyzed following APHA (1992). Monthly qualitative and quantitative net plankton samples were collected, at both sampling stations, by nylobolt plankton net (# 55 µm) and were preserved in 5% formalin; the former were collected by towing plankton net and the later by filtering 25 l water each. The qualitative samples were screened and zooplankton taxa were identified following identified following Koste (1978), Michael & Sharma (1988), Sharma (1998) and Sharma & Sharma (1999a, 1999b, 2000, 2008). Quantitative samples were analyzed with a Sedgewick-Rafter counting cell for abundance (ind.l^{-1}) of zooplankton and its constituent groups; their average monthly densities at two sampling stations were taken for detailed analysis.

The community similarities (Sørensen's index), species diversity (Shannon's index), dominance (Berger-Parker's index) and evenness (Pileou's index) were calculated following Ludwig & Reynolds (1988) and Magurran (1988). ANOVA (two-way) was used to ascertain the significance of temporal variations of biotic parameters. The hierarchical cluster analysis, based on the community similarities, was done using SPSS (version 11.0). Ecological relationships between abiotic and biotic parameters were determined by Pearson's correlation coefficients during the study period (r); their P values were calculated and significance was ascertained after use of Bonferroni correction. The canonical correspondence analysis (XLSTAT version 2012) was done to observe cumulative influence of fifteen abiotic parameters (rainfall, water temperature, specific conductivity, pH, dissolved oxygen, free CO_2, alkalinity, hardness, chloride, sulphate, phosphate, nitrate, silicate, dissolved organic matter and total dissolved solids) on zooplankton communities. Comments on trophic status of the reservoir were based on $Q_{B/T}$ quotient following Sladecek (1983) and Shannon's diversity index.

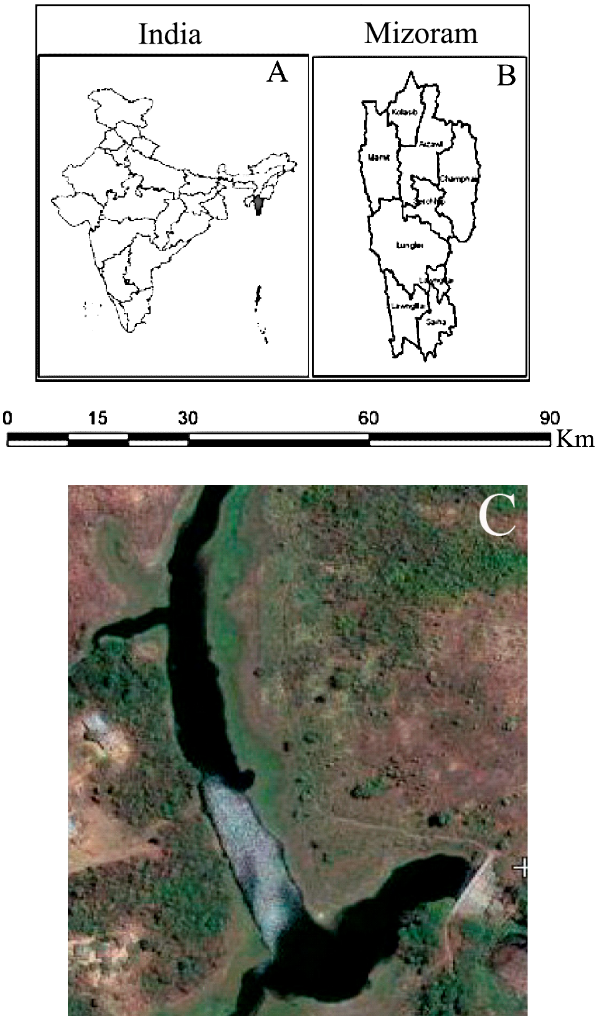

Figure 1. A = Map of India showing Mizoram state;
B = District map of Mizoram showing Lunglei District
C = Khawiva reservoir (Google photo)

RESULTS

The annual variations in abiotic parameters (annual ranges and average ± SD) of Khawiva reservoir as well as during the study period are indicated in Table 1. The details of occurrence and abundance of zooplankton taxa are included in Appendices I and II and their annual variations (ranges and average ± SD) are summarized in Table 2. A total of 46 species of zooplankton are recorded in this study. Their monthly richness ranged between 19–36 and 25–34 species and community similarities (Sørensen's index) varied between 46.6–80.4% and 37.0–95.9% (Tables 2–3) during two years, respectively. The monthly variations in species richness are shown in Fig. 2 while annual variations in the hierarchical cluster analysis, based on Sørensen's community similarities, are shown in Figs. 3-4, respectively.

The monthly variations in zooplankton abundance are shown in Fig. 5. They (159 ± 59 ind. l^{-1} and 242 ± 90 ind. l^{-1}) comprised between 31.2 ± 12.7 % and 46.7 ± 11.3 % of net plankton abundance during two years, respectively (Table 2). Copepoda and Rotifera abundance ranged between 51 ± 59 ind. l^{-1}, 116 ± 87 ind. l^{-1} and 75± 17 ind. l^{-1}, 86 ± 19 ind. l^{-1} during two years, respecttively. The monthly variations in quantitative variations of these groups are shown in Figs. 6–7. Cladocera (17 ± 8 ind. l^{-1}) and Rhizopoda (18 ± 10 ind. l^{-1}) indicated relatively low abundance while Nematoda and Ciliata (2 ± 2 ind. l^{-1}, 2 ± 1 ind. l^{-1}) showed poor densities during the study period. The zooplankton species diversity (Table 1) ranged between 2.618 ± 0.274 during first year and between 2.360 ± 0.546 during second year; the monthly variations of species diversity are shown in Fig. 8. The dominance varied between 0.285 ± 0.127 and 0.245 ± 0.127 while evenness ranged between 0.756 ± 0.107 and 0.764 ± 0.130 during two years, respectively (Table 1). The canonical correspondence analysis (CCA) ordination biplot of fifteen abiotic parameters and zooplankton assemblages, during the study period, is shown in Fig. 9.

Table 1. Temporal variations (range, average and SD) of abiotic parameters

	Nov. 2005-Oct. 2006			Nov. 2006-Oct. 2007			Study Period		
Parameters ↓	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**
Rainfall mm	0-901.8	268.7	283.4	0–901.8	272.4	320.7	0–901.8	270.5	302.6
Water temperature ^0C	14.5–28.0	22.4	4.0	14.0–27.0	21.7	3.9	14.0–28.0	22.1	4.0
Specific conductivity µS cm^{-1}	20.0–62.0	42.8	13.5	28.0–50.0	38.3	7.2	20.0–62.0	40.5	11.0
pH	6.34–7.18	6.81	0.24	5.86–6.83	6.48	0.29	5.86–7.18	6.64	0.31
Dissolved Oxygen mg l^{-1}	5.6–10.4	8.1	1.5	4.8–9.6	7.2	1.6	4.8–10.4	7.7	1.6
Free Carbon dioxide mg l^{-1}	8.0–16.0	12.8	2.6	6.0–14.0	10.2	2.8	6.0–16.0	11.5	3.0
Alkalinity mg l^{-1}	24.0–40.0	32.3	5.5	26.0–34.0	30.8	3.6	24.0–40.0	31.6	4.7
Hardness mg l^{-1}	18.0–46.0	30.3	9.5	22.0–38.0	29.7	6.2	18.0–38.0	30.0	8.0
Chloride mg l^{-1}	1.0–12.0	9.2	3.6	4.0–11.0	6.6	2.8	1.0–11.0	7.9	3.5
Sulphate mg l^{-1}	0.714–2.584	1.055	0.640	0.285–4.638	2.725	1.601	0.285–4.638	1.890	1.478
Phosphate mg l^{-1}	0.017–0.445	0.079	0.115	0.017–0.221	0.100	0.061	0.017–0.445	0.089	0.093
Nitrate mg l^{-1}	0.074–0.392	0.199	0.105	0.074–0.238	0.171	0.065	0.074–0.392	0.185	0.088
Silicate mg l^{-1}	0.037–1.384	0.482	0.456	0.037–0.664	0.353	0.221	0.037–1.384	0.417	0.364
DOM mg l^{-1}	0.016–2.236	0.413	0.797	0.025–0.452	0.192	0.138	0.016–2.236	0.302	0.582
Total Dissolved Solids mg l^{-1}	0.018–0.296	0.191	0.221	0.075–0.347	0.183	0.081	0.018–0.347	0.187	0.166

Table 2. Temporal variations (range, average ± SD) of Zooplankton

	Nov. 2005-Oct. 2006	Nov. 2006-Oct. 2007	Study Period
RICHNESS	Phytoplankton > Zooplankton		
Zooplankton	46 species: 19–36 28±4	45 species: 25–34 29±3	46 species: 29–36 28±4
% similarity	52.8–88.9	60.0–89.3	
Rotifera	27 species: 11–22 16±3	27 species: 11–20 17±3	27 species: 11–22 16±3
ABUNDANCE	Phytoplankton > Zooplankton		
Zooplankton ind.l^{-1}	114–322 159±59	127–483 242±90	114–483 201± 87
% composition	10.8–58.7 31.2±12.7	22.4–60.9 46.7±11.3	20.8–60.9 38.9 ±14.3
Species diversity	2.049–2.969 2.618±0.274	1.339–3.152 2.360±0.546	1.339–3.152 2.489±0.412
Dominance	0.144–0.590 0.285±0.127	0.080–0.649 0.245±0.127	0.080–0.649 0.336±0.134
Evenness	0.545–0.919 0.756±0.107	0.472–0.921 0.764±0. 130	0.472–0.921 0.746±0.122
Different groups	Copepoda > Rotifera > Rhizopoda > Cladocera		
Rotifera ind.l^{-1}	43–103 75±17	60–130 86±19	43–130 81±19
% composition	23.6–74.8 50.0±15.6	20.7–64.6 40.6±12.9	20.7–74.8 45.3±15.1
Copepoda ind.l^{-1}	15–172 51±49	43–365 116±87	15–365 84±78
% composition	11.3–59.3 28.0±14.1	14.2–75.6 43.2± 15.6	11.3–75.6 35.6±16.7
Rhizopoda ind.l^{-1}	1–49 16±11	8–31 19±8	1–49 18±10
% composition	0.8–15.7 9.8±4.4	1.9–21.2 9.1±5.3	0.8–21.2 9.5±4.9
Cladocera ind.l^{-1}	7–24 14±5	8–31 19± 10	0–192 17±8
% composition	4.8–14.4 9.1±3.0	1.7–14.8 8.6± 3.6	01.7–14.8 8.8±3.3
Nematoda ind.l^{-1}	1–7 2±2	1=2 1±2	1–7 2±2
Ciliata ind.l^{-1}	0–1 0±0	0–1 0±0	0–1 0±0
Important taxa			
Mesocyclops spp. ind.l^{-1}	10–151 42±45	11–333 101±79	10–333 71 ± 71
Keratella tropica ind.l^{-1}	5–61 23±18	8–109 28± 28	5–109 26 ± 24
Nauplii ind.l^{-1}	3–25 10±7	2–32 16± 10	2–32 13 ± 9
Chydorus sphaericus ind.l^{-1}	3–14 7±3	2–34 10± 9	2–34 9 ± 7

Table 3. Percentage similarities of Zooplankton (First year)

Months	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.
Nov.	-	70.8	66.7	67.9	52.8	64.3	62.5	64.1	82.1	83.9	76.7	75.5
Dec.		-	81.2	78.3	63.3	85.7	61.8	78.7	75.8	75.4	86.6	73.3
Jan.			-	80.8	73.1	76.4	63.8	64.2	62.1	75.4	81.4	69.2
Feb.				-	70.8	66.7	55.5	61.2	63.0	70.2	69.1	75.0
March					-	78.4	60.5	57.1	55.6	56.1	65.6	62.5
April						-	78.3	65.4	63.2	73.3	75.9	58.8
May							-	81.8	65.3	65.4	64.0	55.8
June								-	80.6	72.4	75.0	57.1
July									-	88.9	78.7	77.8
Aug.										-	77.6	77.8
Sept.											-	72.7
Oct.												-

Table 4. Percentage similarities of Zooplankton (Second year)

Months	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.
Nov.	-	84.4	73.0	78.0	78.0	81.4	78.1	60.0	76.8	72.7	81.8	77.6
Dec.		-	71.2	72.7	72.7	83.6	70.0	67.9	77.4	77.4	80.6	79.4
Jan.			-	77.8	70.4	70.4	74.6	69.1	68.8	75.4	75.4	74.2
Feb.				-	84.0	68.0	76.4	62.7	63.2	73.7	73.7	72.4
March					-	72.0	72.7	62.7	70.2	77.2	77.2	75.9
April						-	72.7	66.7	73.7	77.2	80.7	72.4
May							-	78.6	67.7	67.7	77.4	76.2
June								-	86.2	72.4	65.5	89.0
July									-	78.1	81.2	89.3
Aug.										-	78.1	87.5
Sept.											-	80.0
Oct.												-

DISCUSSION

Abiotic parameters

The slightly acidic-circum neutral, soft and well oxygenated waters of sub-tropical Khawiva reservoir are characterized by low ionic concentrations which, in turn, warranted its inclusion under 'Class I' category of trophic classification *vide* Talling & Talling (1965). This study showed low free CO_2, low chloride content as well as low concentrations of nutrients and other abiotic factors. ANOVA recorded significant annual variations of only pH ($F_{1, 23} = 7.553$, $P = 0.019$) and sulphate ($F_{1, 23} = 9.465$, $P = 0.011$) while specific conductivity ($F_{11, 23} = 3.589$, $P = 0.022$) registered significant monthly variations.

Richness and community similarities

The zooplankton of Khawiva reservoir is fairly more speciose than the reports from other subtropical ecosystems of India i.e., from Uttrakhand (Negi & Pant 1983, Sharma & Pant 1985), Kashmir (Vass & Zutshi 1983, Yousuf & Qadri 1985, Yousuf *et al.* 1986) and Karnataka (Patil & Gouder 1985) as well as from the neighboring countries of Nepal (Nakanishi *et al.* 1988) and Myanmar (J. Green, personal communication). Referring to northeast India, the richness is high than that from the tropical Gumti reservoir, Tripura (Bhattacharya & Saha 1990) and from subtropical water bodies of Meghalaya (Alfred & Thapa 1985, Sharma 1995, Das *et al.* 1996, Sharma & Lyngskor 2003, Sharma & Lyngdoh 2004, Sharma & Wanswett 2006). The qualitative importance of Rotifera concurred with the stated works although Khawiva rotifers are more species-rich than various reports from northeast region. The stated comparisons hypothesized relatively more environmental heterogeneity of the sampled reservoir.

Our results indicated a narrow range of zooplankton richness which followed no definite monthly pattern during the study; the former aspect is affirmed by its insignificant annual and monthly variations. The occurrence of nearly all species during both years and limited monthly richness differences reflected homogeneity in zooplankton composition in spite of the fact that only six and eight species indicated perennial nature during two years respectively. In general, the monthly richness during the second year is relatively higher than that of during first year except in December, April and August. Peak richness observed during December (winter) and November (autumn) respectively, during two years coincided with the periods of low water temperatures while lowest species number is reported during pre-monsoon *i.e.*, in the months of May (first year) and April (second year) respectively.

The annual community similarities ranges, suggesting high similarity in zooplankton composite-on, are attributed to common occurrence of various cosmopolitan and cosmotropical species. These remarks are re-affirmed by the fact that

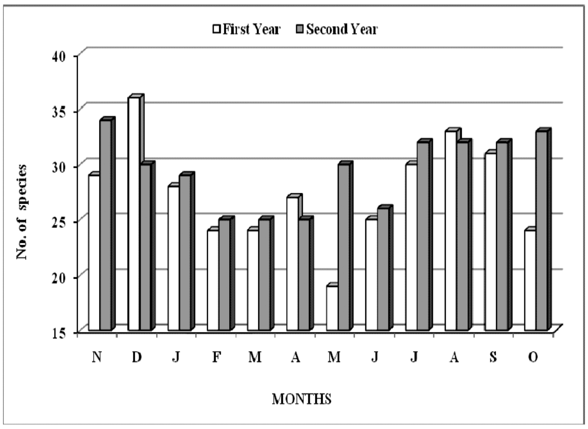

Figure 2. Monthly variations of zooplankton species richness

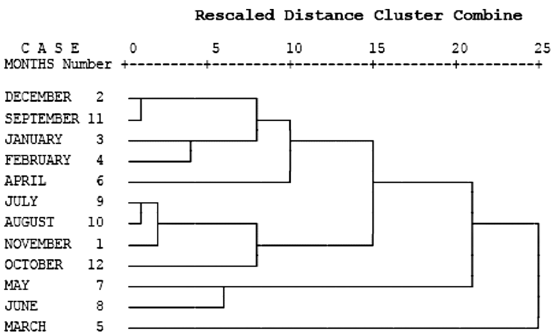

Figure 3. Hierarchical cluster analysis of Zooplankton (First year)

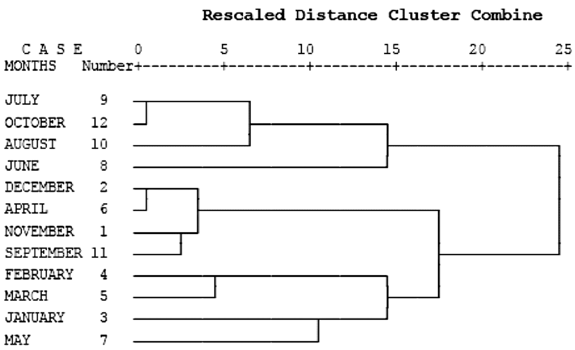

Figure 4. Hierarchical cluster analysis of Zooplankton (Second year)

Sørensen's similarity varied between > 60-80% in majority of instances (72.7 %) during first year while 80.3% instances affirmed > 60-80 similarity in the following year. Hierarchical cluster analysis showed differences in monthly groupings between two years which, in turn, is primarily influenced by the occurrence or absence of different members of the species-rich Rotifera and Rhizopoda. High zooplankton affinities between July–August and December-September collections during first year and between July–October and December–April communities during second year exhibited more homogeneity in their species composition. The divergence exhibited by March and June communities during first year and, January, February and May collections in the following year is due to variations in the richness of rotifers and cladocerans.

Abundance

The zooplankton formed sub-dominant quantitative component of net plankton during the study and thus concurred with the reports from certain water bodies of Kashmir (Kaul & Pandit 1982), Bihar (Baruah *et al.* 1993, Sanjer & Sharma 1995), Assam (Yadava *et al.* 1987) and West Bengal (Sugunan 1989). This generalization differed from their dominance observed from flood-plain lakes of northeast India (Sharma & Hussain 2001, Sharma 2011a, 2011b, Sharma & Sharma 2011, Sharma & Sharma 2012). Our results recorded relatively high zooplankton abundance with wider variations during second year than the preceding year and registered significant annual density variations ($F_{1,\ 23} = 5.271$, $P = 0.042$). The abundance is high than the reports from certain other reservoirs of northeast India (Bhattacharya & Saha 1990, Sharma 1995, Sharma & Lyngskor 2003, Sharma & Lyngdoh 2004), Nepal (Nakanishi *et al.* 1988) and Myanmar (J. Green, personal communication) with broadly similar abiotic parameters. However, it is lower than the reports from various sub-tropical ecosystems of Kashmir (Zutshi *et al.* 1980, Vass & Zutshi 1983, Vass *et al.* 1988, 1989).

This study showed oscillating monthly zooplankton density variations with peaks during December and March respectively, during two years. The former feature concurred with the reports of Sharma (1995), Sharma & Lyngskor (2003) and Sharma & Lyngdoh (2004) while it differed from bimodal patterns noticed by Yousuf & Qadri (1985) and Das *et al.* (1996). Khawiva zooplankton lacked quantitative importance of any individual constituent group. Copepoda and Rotifera, together, influenced their density variations and mainly contributed to annual peaks during the study period. This pattern differed from the stated orders of significance of Rotifera > Cladocera in Malse (Sharma 1995), Copepoda > Cladocera in Nongmahir (Sharma and Lyngskor 2003) and Rotifera > Cladocera in Umiam (Sharma & Lyngdoh 2004) reservoirs of Meghalaya.

The copepods, represented exclusively by the cyclopoids, indicated relatively high abundance during second year and recorded annual peaks during December and March respectively. The importance of the group corresponded with the results of Negi & Pant (1983), Das *et al.* (1996), Sharma & Hussain (2001) and while it differed from its sub-dominance observed by Yadava *et al.* (1987) and Alfred & Thapa (1995).

The quantitative significance of the copepods reflected the prevalence of stable environmental conditions for these 'k-strategists' as suggested by Allen (1976) and Schmidt-Araya & Zuniga (1992). The occurrence of nauplii throughout the study indicated periods of active reproduction. This generalization affirmed the results of Sharma & Hussain (2001), Sharma & Lyngskor (2003) and Sharma & Lyngdoh (2004). *Mesocyclops* spp. with its sporadic abundance on several occasions deserved mention in this study.

Rotifera recorded relatively wide density variations with broad range during second year. This group registered significant monthly ($F_{11,23}$=3.522, P=0.022) but insignificant annual quantitative variations. The rotifer abundance is high than the reports from various sub-tropical ecosystems of northeast India (Sharma 1995, Das *et al.* 1996, Sharma & Lyngskor 2003, Sharma & Lyngdoh 2004)

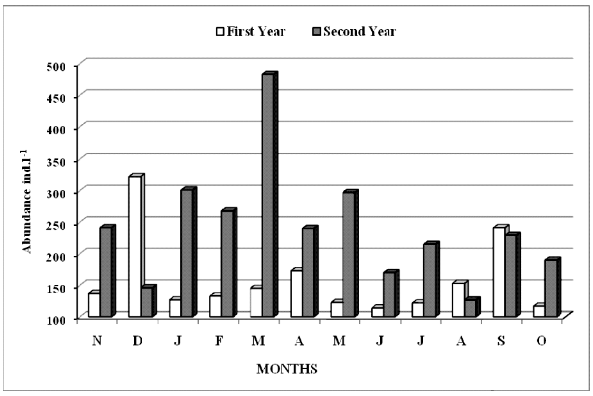

Figure 5. Monthly variations of zooplankton abundance (ind. l^{-1})

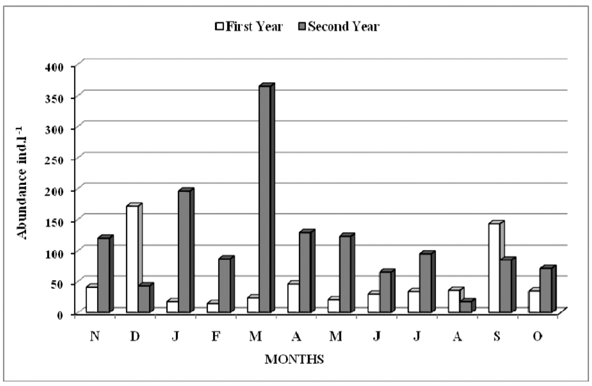

Figure 6. Monthly variations in abundance (ind. l^{-1}) of Copepoda

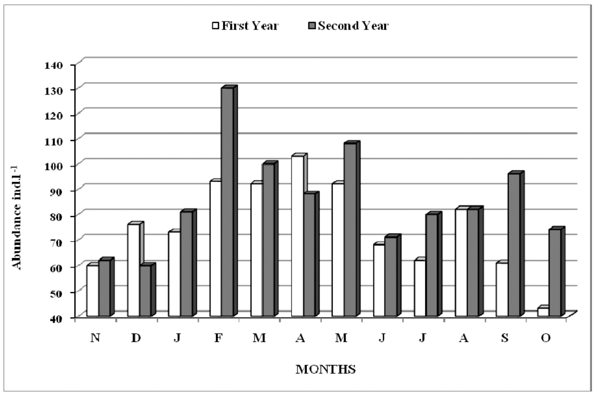

Figure 7. Monthly variations in abundance (ind. l^{-1}) of Rotifera

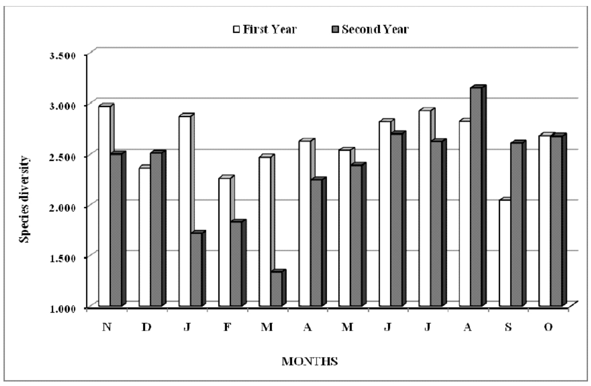

Figure 8. Monthly variations in Species diversity of Zooplankton

with broadly similar abiotic conditions. They followed oscillating monthly density variations and relatively high abundance from February through March; their peak abundance is observed during April and February respectively, during two years. *Keratella tropica* significantly influenced Rotifera abundance (r = 0.664, P=0.0004) during the study in general and contributed to its peaks in particular. This brachionid showed importance during December through March in particular and is positively correlated with hardness (r = 0.588, P=0.0025).

Rhizopoda and Cladocera showed limited quantitative role and comprised between 9.5±4.9 % and 8.8±3.3 % of zooplankton. Of the members of these groups, only *Chydorus sphaericus* showed certain importance. Among other groups, Nematoda and Ciliata indicated poor densities.

Species diversity, evenness and dominance

The species diversity is influenced by richness and equitability or relative abundance of species (Sager & Hasler 1969). Zooplankton species diversity followed oscillating monthly patterns and registered insignificant annual and monthly variations. It showed relatively wide variations (1.339–3.152) during second year rather than the preceding year (2.049–2.969). The peak and lowest diversity values are observed during August and March respectively, during the second year. The annual differences are affirmed by the ranges of density variations during two years and that the periods of high abundance concurred with low diversity in general. The latter feature is endorsed by inverse correlation of species diversity with abundance of zooplankton (r= -0.812, P < 0.0001) and Copepoda (r= -0.802, P < 0.0001). The diversity is also inversely influenced by abundance of *Mesocyclops* spp. (r= -0.803, P < 0.0001) and *Keratella tropica* (r= -0.642, P < 0.0004). The salient features of high species diversity with relatively lower densities of majority of species of our study may be ascribed to fine niche portioning amongst zooplankton species in combination with high micro- and macro-scale habitat heterogeneity as hypothesized by Segers (2008) and affirmed by Sharma (2011a, 2011b) and Sharma & Sharma (2011, 2012).

Our results showed notable variations of zooplankton evenness (0.472-0.921); equitable occurrence and low densities of majority of species resulted in high evenness. It is positively correlated with species diversity (r = 0.961, P < 0.0001) and is inversely correlated with their abundance (r = - 0.886, P < 0.0001) as well as abundance of Copepoda (r= -0.863, P < 0.0001), *Mesocyclops* spp. (r= -0.865, P < 0.0001) and *Keratella tropica* (r= -0.642, P < 0.0004). This is particularly true during period of annual evenness maxima in November and August respectively, during two years. On the other hand, low evenness is observed in the month of September during first year and again from January through March during second year.

Modde & Drewes (1990) asserted dominance to be the most effective approaches to describe the responses of biotic communities to environmental changes. This index is always higher in community dominated by a fewer number of species and lower where dominance is shared by a large number of species (Whittaker 1965), or the total population of the community is uniformly distributed among different species (Osborne *et al.* 1976). Interestingly, this study showed wide variations in dominance index (0.080–0.649). Following MacArthur's (1965) explanation, it is hypothesized that the habitat of Khawiva reservoir has resources for utilization by fewer and majority of species and thus providing variable conditions from low to high amount of niche overlap.

Trophic status

Sladecek (1983) proposed $Q_{B/T}$ quotient, an analogue of phytoplankton indices and based on ratios of *Brachionus* and *Trichocerca* species, to establish trophic status of lentic or lotic water bodies or even individual plankton samples. Sharma & Dudani (1992), Sharma (2001), Sharma & Lyngskor (2003) and Sharma & Lyngdoh (2004) ascertained its reliability under Indian conditions. The monthly $Q_{B/T}$ quotient values for

Khawiva reservoir varied from 1.0–2.0 during the study period and thus affirmed its 'mesotrophic' nature following Sladecek's classification. Wilham & Dorris (1968) and Staub *et al.* (1970) suggested the utility of the species diversity index in assessing water quality. According to Whittaker (1965), the index is actually not a real assessment of the species diversity in a community but it represented the relative importance value of the species taken into account. Trivedi (1981) and Datta (2001) emphasized the importance of species diversity in assessing the water quality. Our diversity results re-affirmed 'mesotrophic' status of Khawiva reservoir following Datta (loc cit.).

Ecological correlations

Individual abiotic factors exerted limited influence on richness and abundance of zooplankton and on abundance of its constituent groups during the study period. The richness is inversely correlated with specific conductivity (r = -0.649, P=0.0006) and hardness (r = -0.581, P=0.0029). The zooplankton and Copepoda abundance are not significantly influenced by any individual abiotic parameter. The density of Rotifera is positively correlated with hardness (r = 0.567, P= 0.0039) while that of Rhizopoda and Cladocera is inversely correlated with specific conductivity (r = -0.563, P = 0.0042) and alkalinity (r = -0.564, P=0.0041), respectively. The canonical correspondence analysis with fifteen abiotic factors explained high (84.8%) cumulative variance of zooplankton assemblages along axis 1 and 2 during the study period with importance of water temperature, rainfall, free carbon dioxide, conductivity and phosphate. The abundance of zooplankton, Rotifera and nauplii are influenced by water temperature and free carbon dioxide; zooplankton richness is influenced by rainfall; *Keratella tropica* is influenced by low specific conductivity; and Copepoda and *Mesocyclops* spp. densities are influenced phosphate.

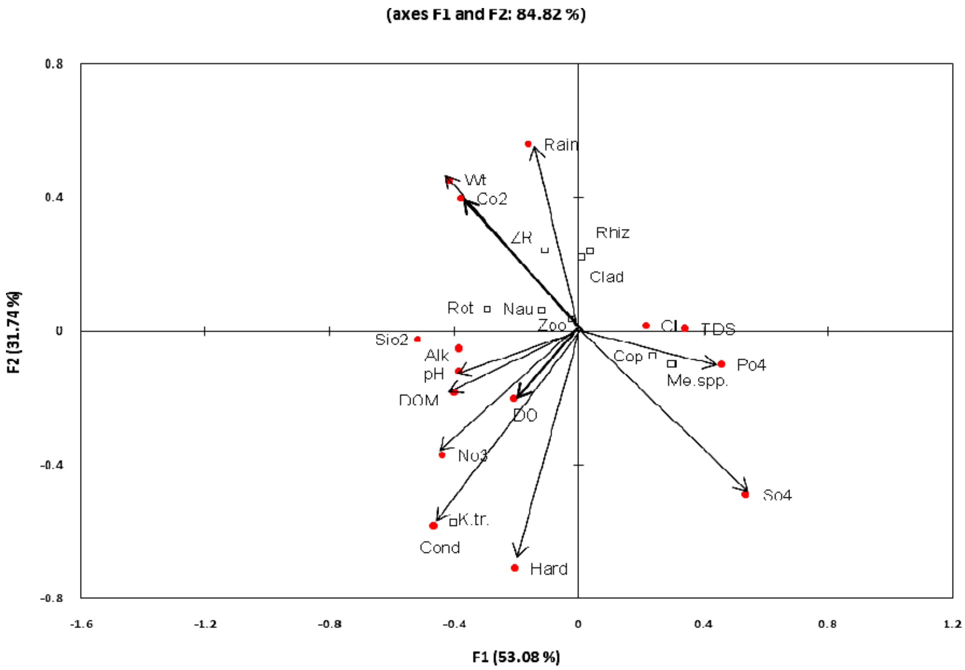

Figure 9. CCA ordination biplot of Zooplankton and abiotic factors

Abbreviations. *Abiotic***.** Alk (alkalinity), Co2 (free carbon dioxide), Cl (Chloride), Cond (conductivity), DO (dissolved oxygen), DOM (dissolved oxygen matter), pH (hydrogen-ion concentration), No3 (nitrate), PO_4 (phosphate), Rain (rainfall), Sio2 (silicate), So4 (sulphate), TDS (Total dissolved solids), Trans (transparency), Wt (water temperature).
*Biotic***.** ZR (Zooplankton richness), Rot (Rotifera), Clad (Cladocera), Cop (Copepoda), Rhiz (Rhizopoda), K tr. (*Keratella tropica*), Me spp. (*Mesocyclops* spp.), Nau (Nauplii)

CONCLUSION

The fairly species-rich zooplankton of Khawiva reservoir formed sub-dominant quantitative component of net plankton. Copepoda and Rotifera influenced their abundance; while *Mesocyclops* spp. and *Keratella tropica* are important taxa. Richness and abundance and species diversity of zooplankton and abundance of its constituent groups followed no definite patterns of monthly variations. This study indicated moderate average species diversity, high evenness and low dominance of zooplankton. Our results indicated limited influence of individual abiotic factors and CCA with fifteen abiotic parameters explained high cumulative variance of zooplankton assemblages. Sladecek's $Q_{B/T}$ quotient and Shannon's diversity index affirmed mesotrophic nature of Khawiva reservoir.

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Appendix 1. Monthly variations in abundance of Zooplankton (First Year)

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct
ROTIFERA												
Brachionus angularis Gosse	0	2	2	4	5	9	2	1	10	23	6	0
B. quadridentatus (Hermann)	4	1	2	3	0	5	30	7	2	3	1	3
Keratella tropica (Apstein)	5	17	29	61	49	42	11	5	9	15	21	10
Plationus patulus (Muller)	5	2	0	0	5	5	9	7	2	0	5	3
Colurella uncinata (Gosse)	1	1	1	1	0	1	0	0	0	1	1	0
C. sulcata (Stenroos)	0	2	1	0	0	1	0	0	0	1	1	0
Lepadella patella (Muller)	2	0	0	0	0	0	0	1	2	0	1	0
Euchlanis dilatata Ehrenberg	3	5	1	0	0	0	7	8	5	4	1	1
Lecane bulla (Gosse)	7	5	7	3	2	1	3	3	1	1	1	2
L. closterocerca (Schmarda)	1	0	0	0	0	0	0	0	1	1	0	1
L. hamata (Stokes)	0	3	2	1	1	0	0	0	0	0	1	3
L. leontina (Turner)	7	5	0	5	3	4	6	9	7	2	1	4
L. lunaris (Ehrenberg)	2	3	0	0	0	0	0	3	2	3	2	3
L. pertica (Harring & Myers)	0	0	0	0	0	0	0	0	2	2	1	0
L quadridentatus (Ehrenberg)	0	3	2	0	4	2	0	0	0	0	0	3
Cephalodella forficula (Ehrenberg)	0	0	0	0	0	0	0	0	0	1	0	0
C. gibba (Ehrenberg)	1	0	1	1	1	0	0	1	0	1	0	0
Monommata grandis Tessin	2	1	0	0	0	1	1	1	1	1	0	0
Polyarthra vulgaris Carlin	5	7	7	3	0	0	0	0	5	3	9	5
Dicranophorus sp.	0	1	1	1	0	1	0	0	0	1	0	0
Testudinella emarginula (Stenroos)	5	7	3	5	9	6	7	0	0	5	4	0
T patina (Hermann)	3	5	7	5	11	15	9	7	5	7	1	3
Trichotria tetractis (Ehrenberg)	0	1	0	0	0	3	3	13	5	2	1	0
Trichocerca similis (Wierz.)	5	3	2	0	0	4	3	1	0	1	1	0
Philodina citrina Ehrenberg	0	1	5	0	2	2	1	1	1	2	2	0
P. roseola Ehrenberg	0	1	0	0	0	1	0	0	0	0	0	0
Rotaria neptunia (Ehrenberg)	2	0	0	0	0	0	0	0	2	2	0	2
RHIZOPODA												
Arcella megastoma Ehrenberg	6	14	7	3	0	0	0	1	1	1	2	3
A. discoides Ehrenberg	0	4	3	2	0	0	0	2	3	0	5	3
A. hemispherica (Bernard)	2	3	0	0	0	0	0	2	2	0	0	0
A. vulgaris Ehrenberg	5	15	3	2	2	1	1	2	1	1	1	1
Assulina muscorum Greet	0	0	1	0	1	1	0	0	0	0	0	0
Centropyxis aculeata (Ehrenberg)	2	2	1	1	2	3	0	0	3	6	7	11
Difflugia urceolata Carter	2	10	5	3	5	6	0	1	1	4	1	2
Euglypha ciliata Ehrenberg	0	1	0	0	4	1	0	0	0	0	1	0
E. tuberculata Dujardin	0	0	0	0	1	0	0	0	0	0	0	0
CLADOCERA												
Coronatella anodonta (Daday)	0	3	5	2	1	0	0	0	0	0	0	2
Bosmina longirostris (Muller)	7	5	5	7	3	2	0	0	3	2	5	1
Karualona karua (King)	0	3	0	0	0	2	3	1	0	0	0	0
Ephemeroporus barroisi (Richard)	5	4	0	0	0	0	0	3	3	5	0	0
Chydorus faviformis Birge	1	0	0	0	0	0	0	0	1	1	2	0
C. sphaericus (Muller)	5	9	5	3	3	7	5	3	7	14	9	10
COPEPODA												
Mesocyclops spp.	31	151	13	10	17	21	14	20	28	33	128	32
Nauplii	10	21	5	5	7	25	7	10	6	3	15	3
CILIATA												
Epistylis	0	0	0	1	0	0	0	0	0	0	1	0
NEMATODA	1	1	1	1	7	1	1	1	1	1	3	6
Rotifera ind.l^{-1}	**60**	**76**	**73**	**93**	**92**	**103**	**92**	**68**	**62**	**82**	**61**	**43**
Rhizopoda ind.l^{-1}	**17**	**49**	**20**	**11**	**15**	**12**	**1**	**8**	**11**	**12**	**17**	**20**
Cladocera ind.l^{-1}	**18**	**24**	**15**	**12**	**7**	**11**	**8**	**7**	**14**	**22**	**16**	**13**
Copepoda ind.l^{-1}	**41**	**172**	**18**	**15**	**24**	**46**	**21**	**30**	**34**	**36**	**143**	**35**
Nematode ind.l^{-1}	**1**	**1**	**1**	**1**	**7**	**1**	**1**	**1**	**1**	**1**	**3**	**6**
Ciliata ind.l^{-1}	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
ZOOPLANKTON ind.l^{-1}	**137**	**322**	**127**	**133**	**145**	**173**	**123**	**114**	**122**	**153**	**241**	**117**

Appendix 2. Monthly variations in abundance of Zooplankton (Second Year)

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct
ROTIFERA												
B. quadridentatus (Hermann)	5	1	0	0	9	15	30	9	3	2	0	1
Keratella tropica (Apstein)	9	33	48	109	50	17	16	13	9	8	18	11
Plationus patulus (Muller)	7	0	1	0	0	4	5	3	7	2	1	5
Colurella uncinata (Gosse)	2	0	1	1	1	0	1	0	0	0	0	0
C. sulcata (Stenroos)	2	0	0	0	0	0	0	0	3	2	0	2
Lepadella patella (Muller)	1	0	0	1	1	0	0	0	0	1	0	2
Euchlanis dilatata Ehrenberg	2	3	1	0	1	0	0	2	3	3	1	1
Lecane bulla (Gosse)	1	5	2	1	2	8	3	3	7	4	3	5
L. closterocerca (Schmarda)	3	0	0	0	0	0	0	3	2	3	2	3
L. hamata (Stokes)	1	1	2	0	0	2	0	4	2	3	0	3
L. leontina (Turner)	5	2	9	3	5	2	2	0	7	5	4	5
L. lunaris (Ehrenberg)	3	1	1	1	2	1	1	0	0	3	2	2
L. pertica (Harring & Myers)	0	0	0	0	0	0	0	2	3	2	0	1
L. quadridentatus (Ehrenberg)	2	0	1	0	2	2	3	1	2	0	1	2
Cephalodella forficula Ehrenberg)	0	0	0	0	0	0	0	0	0	0	1	0
C. gibba (Ehrenberg)	1	0	0	0	0	0	1	0	0	0	0	0
Monommata grandis	0	0	0	0	0	0	2	3	2	2	1	2
Polyarthra vulgaris Carlin	3	1	1	1	5	3	3	2	1	4	3	3
Dicranophorus sp.	0	0	1	0	0	0	1	0	0	0	0	0
Testudinella emarginula (Stenroos)	3	2	0	2	3	10	23	9	7	9	5	7
T. patina (Hermann)	3	5	7	3	9	11	7	5	4	7	5	5
Trichotria tetractis (Ehrenberg	0	1	0	0	0	1	5	9	3	0	2	5
Trichocerca similis (Wierz.)	2	1	0	0	1	2	0	0	3	2	1	0
Philodina citrina Ehrenberg	0	0	1	1	2	0	1	1	0	1	1	1
P. roseola Ehrenberg	0	0	0	0	0	0	0	0	2	0	1	0
Rotaria neptunia (Ehrenberg)	2	1	0	0	0	1	0	0	0	0	1	0
RHIZOPODA												
Arcella megastoma Ehrenberg	7	11	5	7	1	3	6	0	2	1	3	1
A. discoides Ehrenberg	2	1	0	3	5	3	4	0	3	3	5	2
A. hemispherica (Bernard)	2	2	1	0	0	3	2	0	0	2	2	0
A. vulgaris Ehrenberg	7	9	1	3	1	1	7	1	5	1	1	1
Assulina muscorum Greet	1	0	1	1	0	0	0	0	0	1	0	0
Centropyxis aculeata (Ehrenberg)	5	1	1	1	1	1	1	4	1	2	9	20
Difflugia urceolata Carter	6	5	1	4	1	0	0	0	5	5	7	3
Euglypha ciliata Ehrenberg	0	0	0	0	0	0	0	3	2	0	0	0
E. tuberculata Dujardin	0	2	1	0	0	0	0	0	0	0	1	1
CLADOCERA												
Coronatella anodonta (Daday)	3	3	1	1	0	0	2	3	2	0	2	1
Bosmina longirostris(Muller)	3	2	1	4	0	3	4	8	5	3	5	5
Karualona karua (King)	6	1	2	1	3	2	0	0	0	2	3	0
Ephemeroporus barroisi (Richard)	0	3	2	0	0	0	0	3	5	2	0	3
Chydorus faviformis Birge	0	0	1	1	0	0	4	2	0	0	0	0
C. sphaericus (Muller)	15	2	6	24	5	7	34	5	9	5	5	7
COPEPODA												
Mesocyclops spp.	105	41	165	81	333	100	110	52	85	11	59	66
Nauplii	15	2	31	6	32	29	13	13	10	7	26	5
CILIATA												
Epistylis	1	0	0	0	0	0	1	0	0	0	0	0
NEMATODA	1	1	0	1	1	0	1	5	1	0	5	1
Rotifera ind.l^{-1}	**62**	**60**	**81**	**130**	**100**	**88**	**108**	**71**	**80**	**82**	**96**	**74**
Rhizopoda ind.l^{-1}	**30**	**31**	**11**	**19**	**9**	**11**	**20**	**8**	**18**	**15**	**28**	**28**
Cladocera ind.l^{-1}	**27**	**11**	**13**	**31**	**8**	**12**	**44**	**21**	**21**	**12**	**15**	**16**
Copepoda ind.l^{-1}	**120**	**43**	**196**	**87**	**365**	**129**	**123**	**65**	**95**	**18**	**85**	**71**
Nematode ind.l^{-1}	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**5**	**1**	**0**	**5**	**1**
Ciliata ind.l^{-1}	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
ZOOPLANKTON ind.l^{-1}	**241**	**146**	**301**	**268**	**483**	**240**	**297**	**170**	**215**	**127**	**229**	**190**