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Zooplankton diversity of Loktak Lake, Manipur, India

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Abstract: Zooplankton communities of Loktak Lake showed rich and speciose biocoenosis (162 and 142 species), high monthly richness (91 ± 13 and 80 ± 10 species) and by higher similarities (51.1–82.0 and 51.8–78.3 %) and peak richness during winter and autumn over two years of study. Zooplankton (267 ± 41 n/l) formed a significant quantitative component (56.0 ± 6.3 %) of net plankton and showed annual peak abundance during winter. Rotifera > Cladocera are dominant quantitative groups while Copepoda > Rhizopoda are sub-dominant groups. We observed significant annual and monthly variations of zooplankton richness and abundance. This study showed limited influence of individual abiotic factors on zooplankton, with richness showing a significant inverse correlation with water hardness and chloride, and abundance inversely correlated with nitrate. Multiple regressions indicated higher cumulative effects of 15 abiotic factors on richness and abundance. Our results exhibited no definite periodicity of richness and abundance of zooplankton and their constituent groups during two annual cycles. Zooplankton is characterized by highest species diversity (4.172 ± 0.237), higher evenness and lower dominance.

Keywords: Abundance, community similarities, diversity indices, ecology, Ramsar site, richness.

INTRODUCTION

Zooplankton are integral components of aquatic food webs and contribute significantly to aquatic productivity in freshwater ecosystems. They have been studied from various inland aquatic environs of India, but a review of the limnological literature indicates limited information on their composition, ecology and role in aquatic productivity in the floodplain lakes in particular (Sharma & Sharma 2008). The related contributions from the floodplain lakes of northeastern India (Sharma & Hussain 2001; Sharma 2005; Sharma & Sharma 2008) are as yet restricted to the beels of the Brahmaputra river basin of Assam.

The present study on synecology of zooplankton of Loktak Lake assumes special limnological significance in view of a lack of investigations in the floodplain lakes (pats) of Manipur. The observations are made on temporal variations in richness, community similarities, abundance, species diversity, dominance and evenness of zooplankton of this important floodplain lake, a Ramsar site of India. In addition, the influence of abiotic parameters on richness and abundance of zooplankton are analyzed.

MATERIALS AND METHODS

This study is a part of a limnological survey undertaken (November 2002–October 2004) in Loktak Lake (93^{0}46'–93^{0}55'E & 24^{0}25'–

24^{0}42'N) located in Bishnupur/Imphal districts of Manipur of India. Various common aquatic plants of this Ramsar site included *Eichhornia crassipes, Hydrilla verticellata, Euryale ferox, Vallisnaria spiralis, Utricularia flexuosa, Trapa natans, Lemna trisula, Pistia striates, Salvinia* sp. *Nymphaea* spp., *Nymphoides* spp., *Nelumbo mucifera, Potamageton* spp. and *Azolla pinnata.*

The observations were undertaken at one sampling site at Sendra (93^{0}47'45.61''E & 24^{0}30'56.75''N). Water samples were collected at regular monthly intervals and were analyzed for various abiotic factors following APHA (1992); water temperature, specific conductivity, pH and dissolved oxygen were recorded by the field probes. Qualitative (by towing) and quantitative plankton samples (by filtering 25l water each) were collected monthly by nylobolt plankton net (mesh size 50µm) and were preserved in 5% formalin. The former were screened for various species and quantitative samples were analyzed for their abundance. Zooplankton species were identified following the works of Koste (1978), Michael & Sharma (1988), Sharma (1998) and Sharma & Sharma (1999a, 1990b, 2000, 2008). Community similarities (Sorensen'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). Significance of temporal variations of biotic parameters was ascertained by ANOVA (two-way). The hierarchical cluster analysis, based on zooplankton community similarities, was done using SPSS (version 11.0). Ecological correlations between abiotic and biotic parameters were determined by simple correlation coefficients (r); their P values were calculated vide http://faculty.vassar.edu/lowry/tabs.html. and significance was ascertained after use of Bonferroni correction ($p < 0.0033$). Multiple regression (R^2) was used to ascertain cumulative effect of 15 abiotic factors i.e., water temperature (X_1), rainfall (X_2), pH (X_3), specific conductivity (X_4), dissolved oxygen (X_5), free carbon dioxide (X_6), alkalinity (X_7), hardness (X_8), phosphate (X_9), nitrate (X_{10}), sulphate (X_{11}), silicate (X_{12}), chloride (X_{13}), dissolved organic matter (X_{14}) and total dissolved solids (X_{15}) on biotic factors.

RESULTS AND DISCUSSION

Abiotic parameters

Mean water temperature affirms sub-tropical range of Loktak Lake. Slightly acidic and soft waters of this Ramsar site are characterized by low specific conductivity (Table 1) depicting low ionic

Table 1. Abiotic factors of Loktak Lake

		2002–03	2003–04	Study period
Parameters		Mean±SD	Mean±SD	Mean±SD
Water Temperature	^{0}C	21.4±4.0	22.2±4.1	21.8±4.2
Rainfall	mm	112.1±116.8	164.4±183.7	138.2±154.8
pH		6.38±0.23	6.25±0.39	6.31±0.32
Specific Conductivity	µS/cm	98.9±19.7	87.9±11.1	93.3±17.1
Dissolved oxygen	mg/l	6.2±1.1	5.3±0.7	5.7±1.1
Free Carbon dioxide	mg/l	9.5±2.1	8.9±2.0	9.2±2.0
Alkalinity	mg/l	16.0±4.4	22.1±8.1	19.1±7.1
Hardness	mg/l	38.1±8.2	38.4±7.2	38.3±7.8
Phosphate	mg/l	0.23±0.12	0.21±0.04	0.22±0.10
Nitrate	mg/l	0.34±0.04	0.30±0.03	0.32±0.04
Sulphate	mg/l	0.86±0.12	0.87±0.12	0.86±0.12
Silica	mg/l	10.4±1.2	9.7±1.6	10.1± 1.4
Chloride	mg/l	14.9±3.1	16.6±2.7	15.8±3.0
Dissolved organic matter	mg/l	1.38±0.40	1.29±0.39	1.34±0.39
Total dissolved solids	mg/l	0.46±0.22	0.43±0.17	0.44±0.19

concentrations. Our results also indicate moderate dissolved oxygen, low free CO_2, low concentrations of micro-nutrients and other abiotic factors.

Zooplankton richness and community similarities

Among 189 species of Zooplankton documented from Loktak Lake (Sharma unpublished), 169 species observed at the sampled site reflect speciose and diverse nature of their biocoenosis. Zooplankton comprise dominant qualitative component of net plankton (237 species) and significantly influence temporal variations of the latter ($r = 0.960$, $p < 0.0001$). Overall zooplankton richness is the highest known till date from any floodplain lake or any individual aquatic ecosystem of India and, hence, reflects greater environmental heterogeneity of this Ramsar site. The richness is, however, notably higher than an unpublished report of 55 species (including undetermined and doubtful species) from this lake (Singh 1991). Besides, it is distinctly higher than the records from other Indian floodplain lakes i.e., 51 species (Khan 1987) and 26 species (Yousuf et al. 1986) from Kashmir; 19 species (Baruah et al. 1993) and 31 species (Sanjer & Sharma 1995) from Bihar; 49 species (Sharma & Hussain 2001) from Assam, and 71 species (Khan 2003) from West Bengal. Qualitative dominance of zooplankton in net plankton communities of Loktak Lake concurs with the findings of Sharma & Sharma (2008) but differs from higher phytoplankton richness observed by Baruah et al. (1993), Sinha et al. (1994) and Sharma & Hussain (2001). In general, zooplankton biocoenosis exhibits typical 'tropical character' and greater richness of cosmopolitan species while cosmotropical and pantropical species are well represented.

Monthly zooplankton richness varies between 69–121 (85±13) species during the study period (Table 2); it registers significant annual ($F_{1, 23.} = 26.712$, $p < 0.005$) and monthly variations ($F_{11, 23.} = 10.752$, $p < 0.005$). Richness ranges between 91±13 and 85±13 species during two years and shows annual maxima during winter (December 2002) and autumn (November 2003) respectively. Qualitative diversity is higher

Table 2. Temporal variations of Zooplankton of Loktak Lake

	2002-03	2003-2004	Study period
Qualitative			
Net Plankton Monthly richness	237 species 119–177 138 ± 18	213 species 117–150 129 ± 12	237 species 117–177 134 ± 16
Zooplankton Monthly richness	169 species 76–121 91 ± 13	142 species 69–98 80 ± 10	169 species 69–121 85 ± 13
Rotifera	47–79 57 ± 10	41–60 48 ± 6	41–79 53 ± 9
Cladocera	19–31 23 ± 5	17–30 22 ± 4	17–31 22 ± 4
Rhizopoda	5–9 7 ± 1	4–8 6 ± 1	4–9 6 ± 1
Quantitative			
Zooplankton (n/l)	204–319 246 ± 35	256–314 287 ± 34	204–319 267 ± 41
% composition	39.4–62.0 54.9 ± 6.6	45.2-65.2 57.1 ± 5.8	39.4-65.2 56.0 ± 6.3
Diversity	3.750–4.639 4.186 ±.0.278	3.912–4.519 4.158 ± 0.185	3.750–4.639 4.172 ± 0.237
Dominance	0.044–0.170 0.087 ± 0.019	0.044–0.101 0.071 ± 0.019	0.044–0.170 0.079 ± 0.033
Evenness	0.853–0.992 0.929 ± 0.040	0.903–0.988 0.950 ± 0.024	0.853–0.992 0.939 ± 0.035
Rotifera (n/l)	84–157 113 ± 23	115–188 136 ± 22	84–188 125 ± 25
Cladocera (n/l)	42–108 66 ± 20	69–103 79 ± 9	42–108 72 ± 18
Copepoda (n/l)	19–87 48 ± 21	26–64 44 ± 11	19–87 45 ± 16
Rhizopoda (n/l)	11–22 18 ± 4	15–36 27 ± 6	11–36 22 ± 7
Ostracoda (n/l)	0–3 1 ± 1	0–2 1 ± 1	0–3 1 ± 1
Gastrotricha (n/l)	0–1	0–2	0–1
Conchostraca (n/l)	0–1	0–1	0–1

throughout first year except during July. In general, this study records (Figs. 1 & 2) relatively lower number of species from February–July during first year while this trend is noticed from January–August in the succeeding year. Individual abiotic factors exert limited influence on zooplankton richness; it registers only significant negative correlations with hardness ($r = -0.650$, $p = 0.0011$) and chloride ($r = -0.723$, $p = 0.0002$). On the other hand, multiple regression (Table 3) indicates higher cumulative effect of 15 abiotic factors on richness ($R^2 = 0.863$).

The collections examined from the selected study site indicate Rotifera (104 species) > Cladocera (41 species) > Rhizopoda (17 species). The faunal diversity of Rotifera and Cladocera of Loktak Lake is explained separately by Sharma (2009a), and Sharma & Sharma (2009a) respectively. Monthly richness (Figs. 1 & 2) of Rotifera ranges between 41–79 (53±9) species during the study period with annual ranges of 57±10 and 48±6 species respectively (Table 2). Cladocera monthly richness ranges between 17–31 (22±4) species and annual mean richness between 23±5 and 22±4 species respectively while Rhizopoda record lower mean annual richness (7±1 and 6±1 species). The qualitative dominance of the rotifers concurs with the reports of Sharma (2000a, 2000b, 2005), Sharma & Sharma (2001, 2005, 2008) and Khan (2002, 2003). Further, zooplankton or their constituent groups follow no definite pattern of periodicity of richness in this Ramsar site.

Zooplankton communities indicate (Tables 4 & 5) only marginally different i.e., 51.1–82.0 % and 51.8–78.2 % annual similarity ranges (vide Sorenson's index). Peak similarities are observed between December–October and February–September while minima are noticed between April–August and

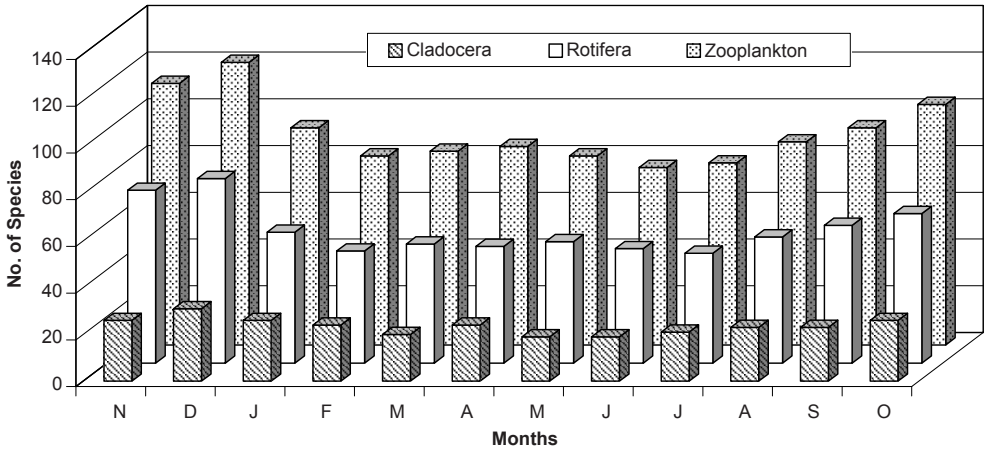

Figure 1. Monthly variations in richness of zooplankton, Rotifera and Cladocera (2002–03)

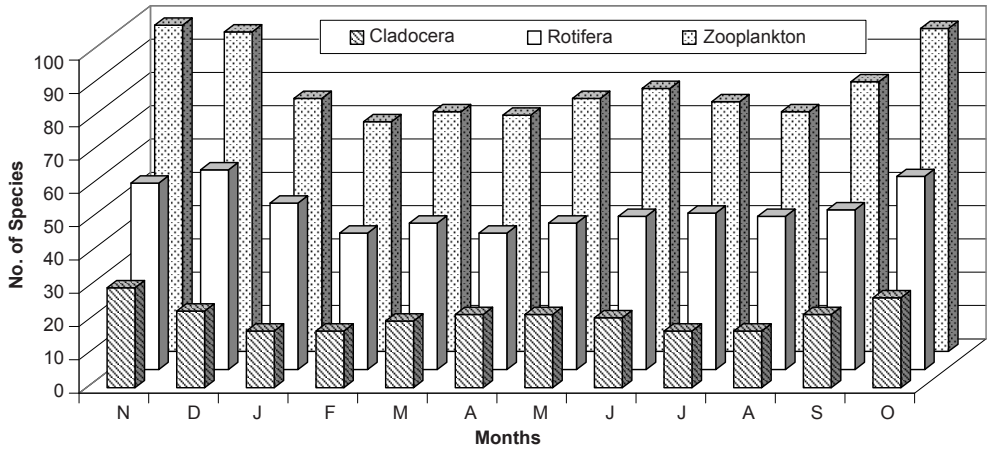

Figure 2. Monthly variations in richness of zooplankton, Rotifera and Cladocera (2003–04)

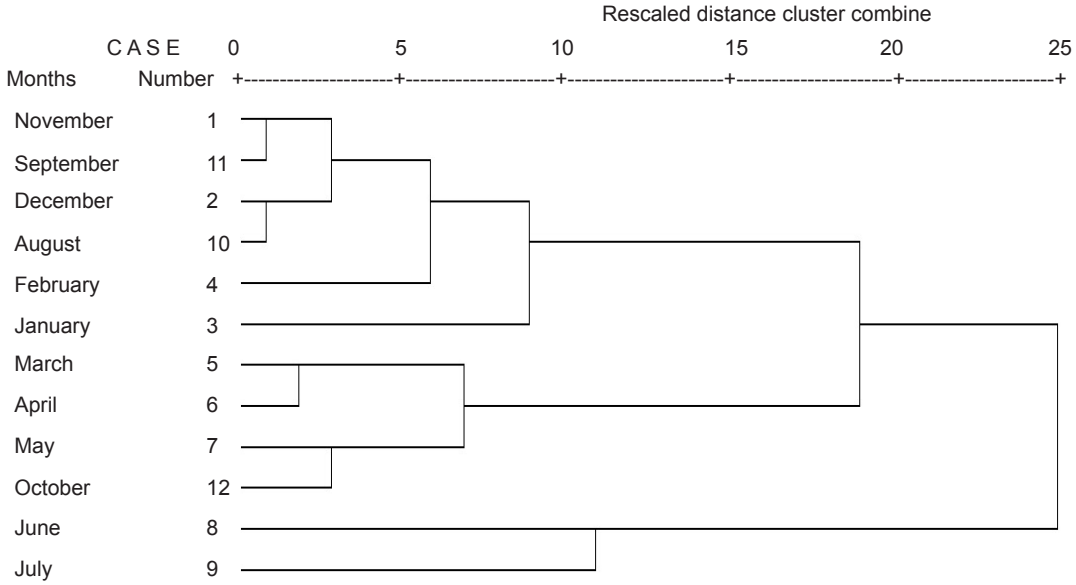

Figure 3. Hierarchical cluster analysis of zooplankton (2002–03)

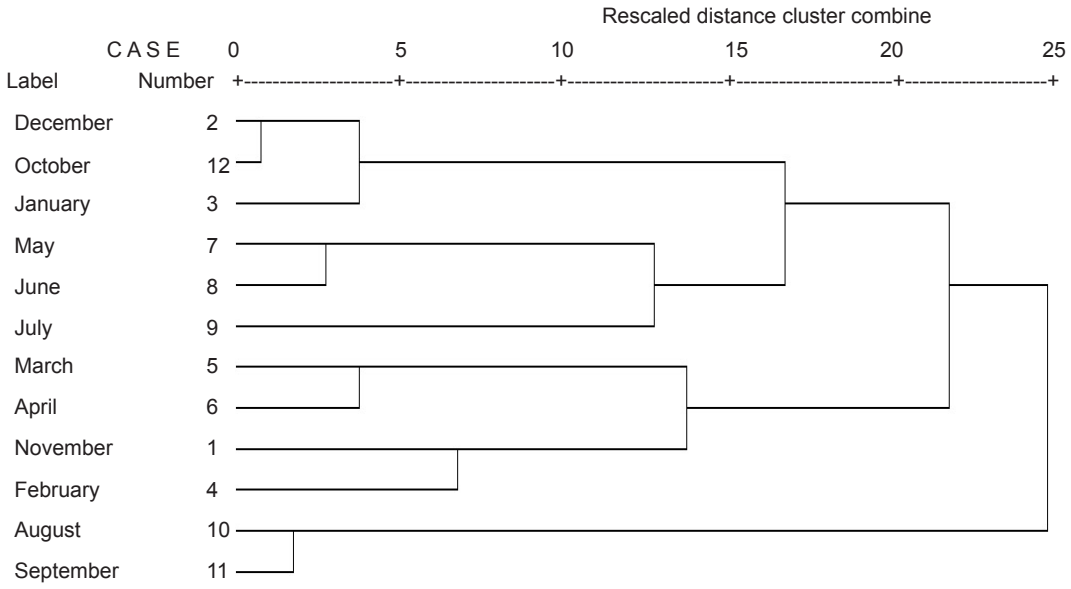

Figure 4. Hierarchical cluster analysis of zooplankton (2003–04)

May–July communities during two years respectively. Similarity matrices exhibit broadly concurrent maximum instances (50.0% and 48.3%) of 60–70 % similarity in both years but show different patterns of cluster analysis (Figs. 3 & 4). The hierarchical cluster analysis shows (Fig. 3) closeness in zooplankton composition between December–October, May–June, March–April and August–September; the last group, however, shows distinct divergence from rest of the monthly collections during 2002–03. In the following year (Fig. 4), greater zooplankton similarity is noticed between November–September, December–August, March–April and May–October while June–July communities indicate diverse composition.

Zooplankton abundance

Abundance of zooplankton (Table 2) ranges between 204–319 (267±41) n/l and indicates significant annual ($F_{1, 23}$ = 32.096, $p < 0.005$) and monthly variations ($F_{11, 23}$ = 7.132, $p < 0.005$). The density is apparently higher than the reports of Yadava et al. (1987), Baruah et al. (1993) and Sharma & Hussain (2001) and it is,

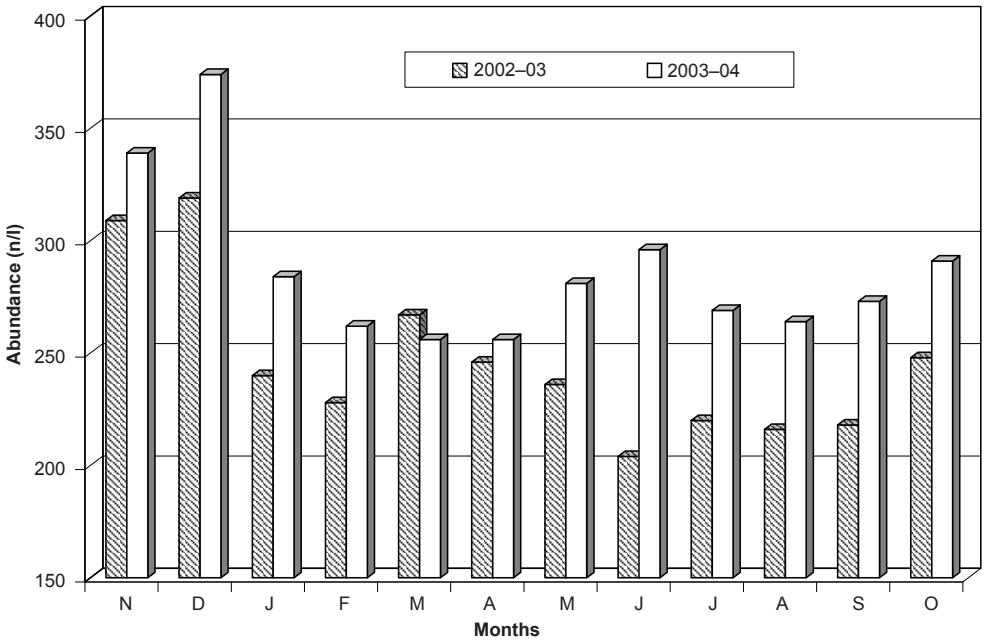

Figure 5. Monthly variations in abundance of zooplankton

Table 3. Multiple regressions between abiotic parameters and zooplankton

Zooplankton richness
Y = 80.424 - 0.218 (X_1) + 0.004 (X_2) + 22.829 (X_3) + 0.422 (X_4) - 3.756 (X_5) + 3.116 (X_6) -1.191 (X_7) - 0.717 (X_8) + 48.906 (X_9) -106.975 (X_{10}) - 67.274 (X_{11}) - 3.785 (X_{12}) - 0.613 (X_{13}) -0.108 (X_{14}) - 3.252 (X_{15}) **R^2 = 0.863**
Zooplankton abundance
Y = 420.371 + 0.823 (X_1) + 0.065 (X_2) - 0.126 (X_3) + 0.790 (X_4) - 16.838 (X_5) + 14.226 (X_6) -0.020 (X_7) - 2.208 (X_8) + 36.539 (X_9) - 463.853 (X_{10}) - 25.335 (X_{11}) - 9.550 (X_{12}) + 3.727 (X_{13}) + 49.283 (X_{14}) – 149.027 (X_{15}) **R^2 = 0.851**

water temperature (X_1), rainfall (X_2), pH (X_3), specific conductivity (X_4), dissolved oxygen (X_5), free carbon dioxide (X_6), alkalinity (X_7), hardness (X_8), phosphate (X_9), nitrate (X_{10}), sulphate (X_{11}), silicate (X_{12}), chloride (X_{13}), dissolved organic matter (X_{14}) and total dissolved solids (X_{15})

however, lower than the results of Khan (1987), Sanjer & Sharma (1995) and Khan (2002). The abundance shows (Fig. 5) broadly trimodal annual patterns with peaks during winter (December 2002 and December 2003). The stated patterns differ from bimodal periodicity noticed by Yadava et al. (1987) and Sanjer & Sharma (1995) while these concur with the findings of Sharma & Hussain (2001). Abundance is noticed to be relatively higher (287±34 n/l) throughout the second year except only during March.

Zooplankton comprise main quantitative component (39.4 - 65.2, 56.0±6.3) % of net plankton (480±74 n/l) and contribute significantly to their temporal variations (r = 0.652, p = 0.0012). The quantitative dominance of zooplankton of Loktak Lake, in turn, concurs with the results of Sharma & Hussain (2001). This salient feature is in contrast to higher phytoplankton abundance reported from the floodplain lakes and wetlands from different parts of India i.e., Kashmir (Kaul & Pandit 1982), Bihar (Baruah et al. 1993; Sanjer & Sharma 1995), West Bengal (Sugunan 1989) and Assam (Yadava et al. 1987). Abundance records only significant inverse correlation with nitrate (r = -0.697, p = 0.0003) showing very limited influence of individual abiotic while multiple regression indicates (Table 3) higher cumulative effect of 15 abiotic factors on zooplankton abundance (R^2 = 0.851).

Amongst different groups (Figs. 6 & 7), Rotifera form (46.6±4.1%)) an important quantitative component of zooplankton and contribute significantly (r = 0.974) to their abundance; Cladocera (27.1±5.0 %) and Copepoda (17.4±7.2 %) also contribute to their abundance while Rhizopoda (Table 2) comprise between 8.3±2.0 %. Other groups of zooplankton, namely, Ostracoda, Gastrotricha and Conchostraca indicate very poor abundance (Table 2). The

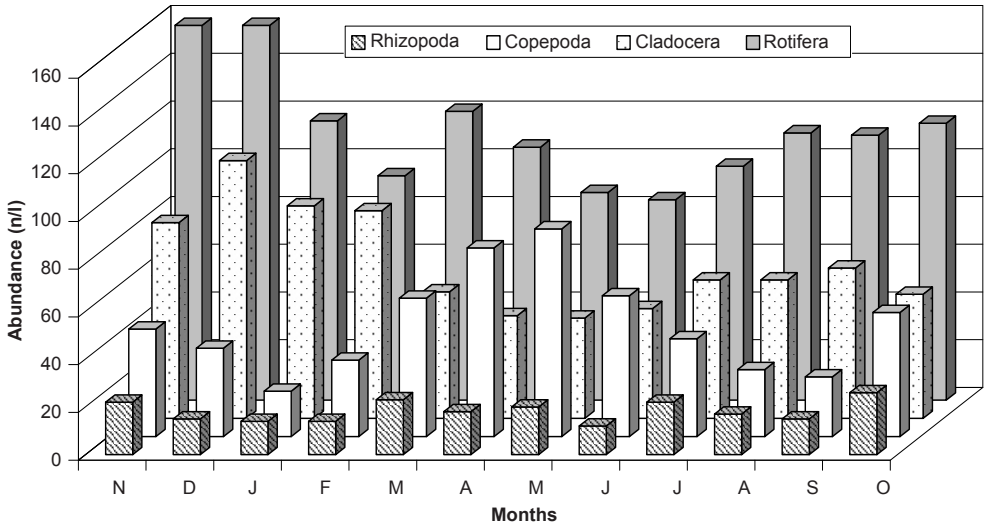

Figure 6. Monthly variations in abundance of different groups of zooplankton (2002–03)

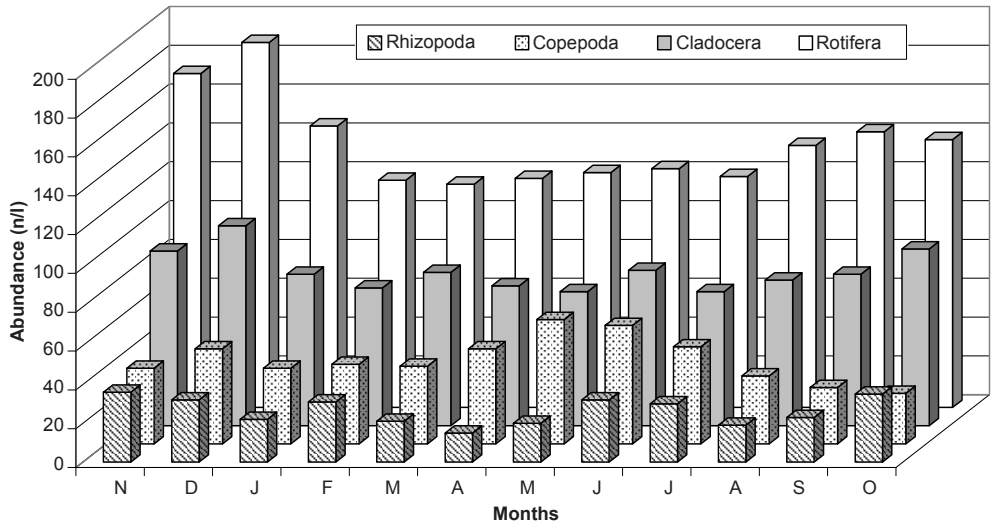

Figure 7. Monthly variations in abundance of different groups of zooplankton (2003–04)

synecology of Rotifera and micro-crustaceans are dealt with separately by Sharma (2009b) and Sharma & Sharma (2009b) respectively. In general, zooplankton and their constituent groups follow no definite pattern of quantitative periodicity in Loktak Lake.

Species diversity, evenness and dominance

Zooplankton show the highest species diversity (3.750–4.639, 4.172±0.237) so far known from any floodplain lake or aquatic ecosystem of northeastern India and elsewhere from this country (Sharma unpublished). This salient feature affirms higher environmental heterogeneity of Loktak Lake. It registers significant monthly ($F_{11, 23} = 3.762$, $p < 0.01$), shows (Table 2) relatively higher values (4.186±0.278) during the second year and exhibits broadly bimodal but different annual patterns (Fig. 8) with peaks during winter (December 2002) and post-monsoon (October 2004) and minima during summer (May). In general, higher species diversity (< 4.0) is observed during November-February, July and September–October during both years and again during May and June (2nd year) and August (1st year). The notable feature of higher species diversity with relatively lower densities of majority of species noticed in this 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

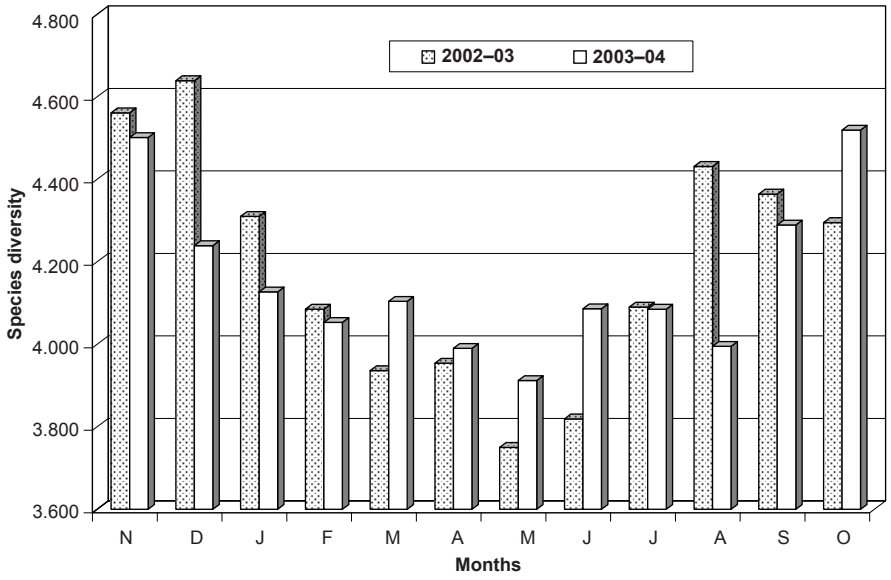

Figure 8. Monthly variations in species diversity of zooplankton

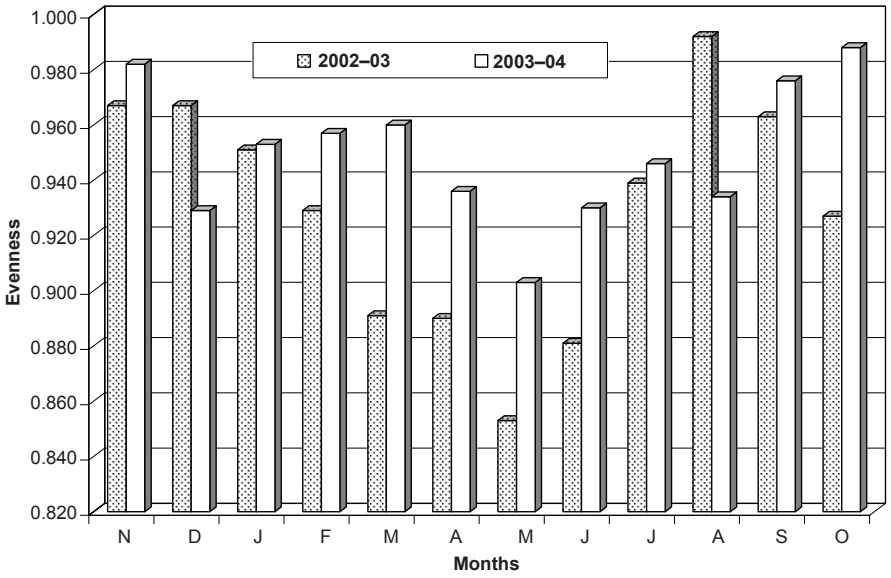

Figure 9. Monthly variations in evenness of zooplankton

(2008).

This study depicts (Table 2) higher evenness (0.813–0.992, 0.939±0.032) of zooplankton; this feature affirms equitable abundance of various species and concurs with the results of Sharma & Hussain (2001) and Sharma & Sharma (2008). It follows (Fig. 9) bimodal and multimodal annual patterns with peaks during August and October during the two years respectively while minima are noticed during summer (May). Zooplankton show (Table 2) lower dominance (0.044–0.170, 0.079±0.033) indicating lack of quantitative importance of individual species. This feature again concurs with the results of Sharma & Hussain (2001) and Sharma & Sharma (2008). It registers only significant monthly variations ($F_{11, 23}$ = 3.896, $p < 0.01$), and follows (Fig. 10) different annual patterns with maxima during April and May during two years respectively.

To sum up, zooplankton form important qualitative and quantitative components of net plankton, exhibit highly speciose character with richest diversity and quantitative dominance of Rotifera > Cladocera,

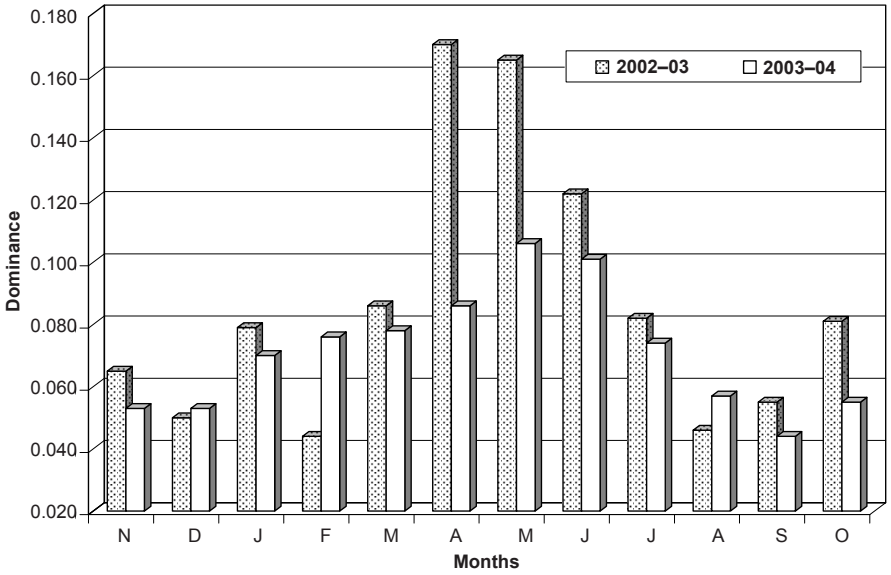

Figure 10. Monthly variations in dominance of zooplankton

Table 4. Percentage similarities between Zooplankton communities (2002-03)

	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct
Nov	-	76.7	70.2	61.8	62.1	64.3	75.4	67.9	63.2	75.0	76.7	71.2
Dec		-	75.4	70.6	59.3	61.5	66.7	65.4	71.7	76.9	75.0	72.7
Jan			-	70.8	58.8	53.1	55.6	69.4	72.0	73.5	75.5	65.4
Feb				-	77.5	63.8	65.4	63.8	58.3	76.6	78.3	72.0
Mar					-	76.0	72.7	56.0	58.8	64.0	70.4	71.7
Apr						-	75.5	54.2	57.1	52.5	65.4	74.5
May							-	67.9	51.8	67.9	73.7	75.0
Jun								-	69.4	62.5	61.5	70.6
Jul									-	65.3	56.6	57.7
Aug										-	76.9	70.6
Sep											-	72.3
Oct												-

Table 5. Percentage similarities between Zooplankton communities (2003-04)

	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct
Nov	-	66.7	61.0	76.4	75.0	67.9	71.4	77.2	67.9	74.1	80.0	75.4
Dec		-	81.4	61.8	57.1	60.4	67.9	66.7	67.9	70.4	58.2	82.0
Jan			-	70.4	65.5	65.4	61.8	60.7	69.1	67.9	55.6	73.7
Feb				-	70.6	70.8	58.8	69.2	64.0	65.3	64.0	67.9
Mar					-	77.5	57.7	60.4	62.7	60.0	62.7	66.7
Apr						-	65.3	52.0	54.2	51.1	54.2	59.3
May							-	79.2	62.7	52.0	54.9	66.7
Jun								-	73.1	54.9	61.5	75.9
Jul									-	65.3	56.0	64.3
Aug										-	81.6	72.7
Sep											-	64.3
Oct												-

and indicate no definite periodicity of richness or abundance of zooplankton or their constituent groups. zooplankton are characterized by highest species diversity, higher evenness and lower dominance, and exhibit lower densities of majority of species. This study registers limited influence of individual abiotic factors but records higher cumulative influence of 15 abiotic factors on richness and abundance. The present observations limited to one sampling station, though provide useful information on composition, production and ecology of zooplankton yet may not reflect full view of heterogeneity of this interesting Ramsar site. Further studies in different parts (pats) of Loktak basin are, hence, desired and have been initiated.

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