Zooplankton diversity of two floodplain lakes (pats) of Manipur, northeast India

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Abstract. Plankton samples collected (November, 2002 – October, 2004) from Waithou and Utra pats, two floodplain lakes in Manipur state of northeast India, revealed species rich zooplankton (121 species) with diverse nature of Rotifera (75 species). The individual pats exhibited rich species diversity (110 and 103 species) and high monthly richness (68±7 and 61±8 species) respectively with higher community similarities. Zooplankton formed important quantitative component (56.0±4.3 % and 55.1±5.1 %) of net plankton of the two pats; Rotifera dominantly contributed to their abundance while Cladocera > Copepoda were sub-dominant groups. The richness and abundance showed significant variations between pats and between months and followed oscillating annual patterns in each pat except for peaks during winter. Zooplankton indicated higher species diversity and evenness, lower dominance, lack of quantitative importance of individual species, low densities and equitable abundance of the majority of species in both pats. The richness correlated inversely only with nitrate in Waithou pat and abundance positively correlated with alkalinity only in Utra Pat. Canonical correspondence analysis (CCA) with abiotic factors explained 55.6 % and 61.8% cumulative variance of zooplankton assemblages of Waithou and Utra pats respectively along axis 1 and 2.

INTRODUCTION

Zooplankton invariably forms an integral component of freshwater communities and contributes significantly to biological productivity. These fish-food organisms have been studied from various inland ecosystems of this country but information on their ecology in the Indian floodplain lakes in particular is yet limited (Sharma & Sharma, 2008). The related contributions from northeast India are by Sharma and Hussain (2001), Sharma (2011), Sharma and Sharma (2011). The present study, on diversity of zooplankton of two floodplain lakes (commonly called 'pats') of Manipur, assumes limnological importance in view of the stated lacunae. The observations are made on monthly variations of richness and abundance of zooplankton and their constituent groups with special reference to their community similarities, species diversity, dominance, evenness and ecology.

MATERIALS AND METHODS

This work is resulted from limnological investigations undertaken between November 2002 – October 2004, in two floodplain lakes of Manipur namely Waithou Pat (24° 41' N, 93° 55' E; area: 455 ha; max. depth: 1.7 m, mean depth: 1.2 m; altitude: 785 m ASL, Thoubal river basin, Thoubal district) and Utra Pat (24° 41' N, 93° 50' E; area: 185 ha; max. depth: 2.2 m, mean depth: 1.4 m; altitude: 783 m ASL, Nambol river basin, Bishnupur district). Various aquatic plants common in these pats included *Eichhornia crassipes, Hydrilla verticellata, Utricularia flexuosa, Trapa natans, Lemna trisula, Pistia striates, Salvinia, Nymphaea* spp., *Nymphoides* spp., *Azolla pinnata,* and *Sagittaria* sp.

Water samples were collected at monthly intervals between 7.00 am – 9.00 am, at one sampling station each (due to local logistic reasons), from Waithou and Utra pats. Water temperature, pH and specific conductivity were recorded by the field probes, dissolved oxygen was estimated by Winkler's method and other abiotic factors were analyzed following APHA (1992). The qualitative and quantitative plankton samples, collected monthly from two pats, by nylobolt plankton net (No. 25; mesh # 55 µm) by towing and by filtering 25 l water each respectively, were preserved in 5 % formalin. The former were screened and zooplankton species were identified following

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the works of Koste (1978), Michael and Sharma (1988), Sharma (1998), and Sharma and Sharma (1999a, 1999b, 2000, 2008). Quantitative enumeration (ind. L^{-1}) of zooplankton and their constituent groups was done with a Sedgewick-Rafter counting cell.

The zooplankton community similarities were calculated *vide* Sorensen's index and their hierarchical cluster analysis using SPSS (version 11). Species diversity (Shannon's index), dominance (Berger-Parker's index) and evenness (Pileou's index) were calculated following Ludwig and Reynolds (1988) and Magurran (1988). ANOVA (two-way) was used to analyse the significance of temporal variation of the biotic communities as well as abiotic factors. Ecological relationships between abiotic and biotic parameters of Waithou and Utra pats were determined by simple correlation coefficients (r_1 and r_2, respectively); their P values were calculated *vide* http://faculty.vassar.edu/lowry/tabs.html. and significance was ascertained after use of Bonferroni correction ($p < 0.0033$). Canonical correspondence analysis (CCA) (ECOM II: version 2.1.3.137, PISCES Conservation Ltd. 2007) was used to elucidate the relationships between the zooplankton assemblages and their abiotic environment.

RESULTS

The variations in abiotic parameters of Waithou and Utra pats observed during the study period (ranges, average ± SD) and significance of their temporal variations between the two floodplain plain lakes (*vide* ANOVA) have been indicated in Table 1.

This study revealed a total of 121 zooplankton species (Appendix 1) with 110 (68 ± 7) and 103 (61 ± 8) species in Waithou and Utra pats and quailtative importance of Rotifera (35–55, 31–45 species) > Cladocera (12–24, 11–24 species) respectively (Table 2). The zooplankton (242 ± 53 ind. L^{-1}, 189 ± 34 ind. L^{-1}) comprised 56.0 ± 4.3% and 55.1 ± 5.1% of net plankton of Waithou and Utra pats respectively (Appendix 1). Rotifera (119 ± 25 ind. L^{-1}, 87 ± 22 ind. L^{-1}) were dominant quantitative group of zooplankton while Cladocera (59 ± 16 ind. L^{-1}, 55 ± 12 ind. L^{-1}) and Copepoda (32 ± 9 ind. L^{-1}, 25 ± 8 ind. L^{-1}) were sub-dominant components. The species diversity of zooplankton of Waithou and Utra pats varied between 4.049 ± 0.096 and 3.890 ± 0.163 respectively; Rotifera (3.507 ± 0.128, 3.375 ± 0.081) and Cladocera (2.673 ± 0.146, 2.694 ± 0.190) contributed to higher zooplankton diversity in the two pats. The zooplankton dominance ranged between dominance 0.069 ± 0.013 and 0.079 ± 0.031 while their evenness varied between 0.946 ± 0.023, 0.949 ± 0.018) in Waithou and Utra pats respectively (Appendix 1). In addition, the results showed lower dominance (0.069 ± 0.013, 0.079 ± 0.031) with higher evenness (0.946 ± 0.023, 0.949 ± 0.018) of Rotifera as well as lower dominance (0.069 ± 0.013, 0.079 ± 0.031) and higher evenness (0.946 ± 0.023, 0.949 ± 0.018) of Cladocera in the two pats, respectively.

Annual variations in the hierarchical cluster analysis of zooplankton, based on their community similarity values (*vide* Sorensen index), of Waithou pat are indicated in Figs. 1–2 and those of Utra Pat are included in Figs. 3–4. The monthly variations in population densities and species diversity of zooplankton of the sampled pats (Appendix 1) are presented in Figs. 5–6 and Figs. 7–8 respectively. The canonical correspondence analysis (Figs. 9-10) with 13 abiotic factors recorded 55.6% cumulative variance of zooplankton of Waithou Pat; CCA analysis with 15 abiotic factors explained 61.8% cumulative variance of zooplankton of Utra Pat (Table 3); the former was restricted to 13 factors due to limitations caused by certain auto-correlations.

DISCUSSION

The slightly acidic, soft and 'Calcium-poor' waters of the sub-tropical Waithou and Utra pats depicted low ionic concentrations; the last salient feature warranted their inclusion under 'Class I' category of trophic classification *vide* Talling and Talling (1965). The sampled wetlands indicated

Table 1. Abiotic factors of Waithou and Utra pat

Factors↓ Lakes→	Waithou pat		Utra pat		ANOVA
	Range	Mean ± SD	Range	Mean ± SD	
Water Temperature ºC	10.5 – 29.2	21.6 ± 4.8	16.2 – 27.9	22.2 ± 3.5	$F_{1.23}$= 1.644, p = 0.2
Rainfall mm	0 – 480.0	138.2 ± 154.8	0 – 480.0	138.2 ± 154.8	–
pH	5.59 – 6.60	6.21 ± 0.28	5.40 – 6.68	6.23 ± 0.32	$F_{1.23}$ = 2.098, p = 0.04
Sp. Conductivity µS/cm	52.0 – 120.5	92.3 ± 16.8	48.0 – 120.5	77.2 ± 21.6	**$F_{1.23}$=13.439, p= 0.001**
Dissolved Oxygen mg/l	2.4 – 12.0	5.3 ± 1.8	4.0 – 10.0	6.0 ± 1.4	$F_{1.23}$ = 3.708, p = 0.06
Free CO_2 mg/l	6.0 – 20.0	13.7 ± 4.1	6.0 – 18.2	8.7 ± 3.6	**$F_{1.23}$= 10.216, p = 0.004**
Alkalinity mg/l	10.0 – 36.2	19.7 ± 5.6	10.0 – 44.0	19.5 ± 9.4	$F_{1.23}$ = 0.014, p = 0.9
Hardness mg/l	20.1 – 56.0	33.6 ± 7.8	20.0 – 46.0	33.0 ± 7.4	$F_{1.23}$ = 0.158, p = 0.69
Calcium mg/l	6.3 – 15.2	10.9 ± 2.6	4.2 – 14.7	7.8 ± 2.1	**$F_{1.23}$=21.681, p = 0.0001**
Magnesium mg/l	2.0 – 9.6	5.5 ± 2.1	2.0 – 8.7	5.0 ± 1.5	$F_{1.23}$ = 2.319, p = 0.157
Sodium mg/l	1.0 – 9.4	6.4 ± 2.0	1.2 – 8.8	5.9 ± 1.9	$F_{1.23}$ = 2.181, p = 0.153
Potassium mg/l	4.0 – 9.8	6.7 ± 1.9	3.2 – 9.4	6.0 ± 1.6	$F_{1.23}$ = 1.295, p = 0.267
Phosphate mg/l	0.09 – 0.46	0.23 ± 0.08	0.07 – 0.28	0.19 ± 0.06	$F_{1.23}$ = 3.813, p = 0.063
Nitrate mg/l	0.23–0.39	0.33 ± 0.05	0.25–0.41	0.34 ± 0.04	$F_{1.23}$ = 1.234, p = 0.24
Sulphate mg/l	0.48 – 0.94	0.84 ± 0.10	0.61 – 0.96	0.82 ± 0.10	$F_{1.23}$ = 0.166, p = 0.42
Silicate mg/l	5.12 – 12.15	9.1 ± 1.5	6.4 – 9.2	8.3 ± 0.8	$F_{1.23}$ = 7.210, p = 0.013
Chloride mg/l	9.5 – 21.1	14.6 ± 3.9	14.1 – 24.9	17.4 ± 2.6	**$F_{1.23}$= 13.613, p = 0.001**
DOM mg/l	0.11 – 1.05	0.58 ± 0.32	0.45 – 1.0	0.77 ± 0.12	**$F_{1.23}$ = 12.313, p = 0.001**
TDS mg/l	0.28 – 0.71	0.45 ± 0.14	0.31 – 0.92	0.57 ± 0.21	**$F_{1.23}$= 28.445, p > 0.005**

$F_{1.23}$ values indicating significant difference between two pats are indicated in bold

moderate dissolved oxygen, low free CO_2, low concentration of nutrients and other abiotic factors. Amongst the recorded 19 abiotic variables, only seven registered significant temporal variations (*vide* ANOVA) between the pats and, hence, reflected less variations between their water quality.

A total of 121 zooplankton species reported in this study as well as 110 and 103 species recorded from Waithou and Utra pats respectively reflected species rich biocoenoses thus indicating environmental heterogeneity of these wetlands. The zooplankton formed dominant qualitative component of net plankton of both pats; this salient feature concurred with the reports of Sharma & Sharma (2008, 2011) and Sharma (2011) but differed from higher phytoplankton richness observed by Baruah *et al*. (1993), Sinha *et al*. (1994) and Sharma and Hussain (2001). Overall richness was yet notably lower than 189 species and 171 species recorded from Loktak Lake (Sharma & Sharma 2010) and Deepor beel (Sharma 2011), respectively – two Ramsar sites as well as important floodplain lakes located in northeast India. The present report, however, corresponded with 102–118 species recorded from beels of the floodplains of the Brahmaputra river basin of Assam (Sharma & Sharma 2008) while it was distinctly higher than the reports 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, and 71 species (Khan 2003) from West Bengal.

Waithou > Utra pats indicated higher monthly zooplankton richness which, in turn, registered significant monthly variations ($F_{23, 47}$ = 5.919, P < 0.001) and significant temporal variations between two pats ($F_{1, 23}$ = 33.246, P < 0.005). The richness recorded insignificant annual variations in the individual pats but showed significant monthly variations only in Waithou Pat ($F_{11, 23}$ = 3.384, P < 0.02). This study indicated oscillating annual patterns of richness in each pat with peaks during winter; the former generalization concurred with the results of Loktak Pat (Sharma &

Table 2. Temporal variations of zooplankton (range, mean ± SD)

	Waithou Pat		Utra Pat	
QUALITATIVE	Rotifera > Cladocera > Rhizopoda > Copepoda > Ostracoda			
Net Plankton	172 species		164 species	
Monthly richness	94 – 135	107 ± 10	82 – 121	99 ± 11
Zooplankton	110 species		103 species	
Monthly richness	57 – 89	68 ± 7	48 – 77	61 ± 8
Rotifera	35 –55	41 ± 5	31 – 45	36 ± 5
Cladocera	51 – 24	18 ± 2	11 – 24	18 ± 3
QUANTITATIVE				
Net Plankton ind. L^{-1}	286 – 611	386 ± 71	250 – 486	343 ± 56
Zooplankton ind. L^{-1}	177 – 360	222 ± 45	143 – 267	189 ± 34
% composition	47.8 – 66.0	56.0± 4.3	43.2 – 63.4	55.1 ± 5.1
Species Diversity	3.868 – 4.297	4.049 ± 0.096	3.627 – 4.188	3.890 ± 0.163
Dominance	0.032 – 0.084	0.051 ± 0.014	0.037 – 0.146	0.079 ± 0.031
Evenness	0.938 – 0.974	0.962 ± 0.009	0.920 – 0.978	0.949 ± 0.018
Different Groups				
Rotifera ind. L^{-1}	87 – 198	119 ± 25	65 – 135	87 ± 22
% composition	47.5 – 61.9	53.5 ± 3.1	37.5– 55.7	45.9 ± 4.7
Species Diversity	3.217 – 3.801	3.507 ± 0.128	3.084 – 3.754	3.375 ± 0.081
Dominance	0.045 – 0.099	0.069 ± 0.013	0.050 – 0.140	0.075 ± 0.018
Evenness	0.909 – 0.991	0.946 ± 0.023	0.859 – 0.990	0.943 ± 0.028
Cladocera ind. L^{-1}	32 – 99	59 ± 16	37 – 82	55 ± 12
% composition	16.8 – 34.4	26.6 ± 4.2	17.5 – 38.1	29.1 ± 3.2
Species Diversity	2.409 – 3.008	2.673 ± 0.146	2.333 – 2.995	2.694±0.190
Dominance	0.085 – 0.208	0.129 ± 0.026	0.085 – 0.156	0.119±0.019
Evenness	0.853 – 0.973	0.937 ± 0.055	0.825– 0.982	0.935±0.040
Copepoda ind. L^{-1}	13 – 40	25 ± 8	9 – 51	32 ± 9
% composition	6.3 – 18.4	11.4 ± 3.2	5.7 – 28.3	17.5 ± 5.5
Rhizopoda ind. L^{-1}	8 – 31	18 ± 5	6 – 22	14 ± 4
% composition	3.7 – 12.1	8.1 ± 1.9	3.6 – 10.3	6.8 ± 1.7
Ostracoda ind. L^{-1}	0 – 3	1 ± 1	0 – 3	1 ± 1
Important families				
Rotifera				
Lecanidae ind. L^{-1}	19 – 58	36 ± 9	16 – 46	26 ± 8
Brachionidae ind. L^{-1}	15 – 36	22 ± 5	9 – 33	18 ± 6
Lepadellidae ind. L^{-1}	6 – 16	11 ± 3	3 – 12	8 ± 2
Trichocercidae ind. L^{-1}	5 – 19	10 ± 3	3 – 16	11 ± 3
Cladocera				
Chydoridae ind. L^{-1}	18 – 52	30 ± 9	17 – 47	28 ± 7
Daphniidae ind. L^{-1}	6 – 20	12 ± 4	5 – 20	12 ± 4

Sharma 2011). Rotifera (75 species), the most speciose group of zooplankton of Waithou > Utra pats, followed monthly patterns concurrent to that of the latter and significantly contributed to their temporal variations (r_1 = 0.956, $P < 0.0001$; r_2 = 0.904, $P = 0.0001$). The qualitative importance of the rotifers agreed with the reports of Sharma (2000a, 2000b, 2005, 2009a, 2011), Sharma and Sharma (2001, 2010) and Khan (2003). In addition, Cladocera exhibited qualitative importance in the sampled pats.

The zooplankton communities of Waithou and Utra pats registered 86.4% similarity (*vide* Sorensen index), thereby, indicating more homogeneity in their composition. This feature could be attributed to higher similarities of Rotifera (87.2%) and Cladocera (86.7%), the two most species diverse groups, of these pats. This generalization was also supported by occurrence of various cosmopolitan and cosmotropical / pantropical species of zooplankton in both pats in general. Waithou pat indicated 55.6 – 85.4% and

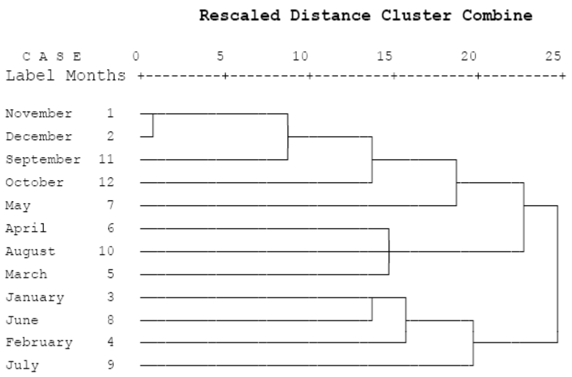

Figure 1. Hierarchical cluster analysis of zooplankton of Waithou Pat (2002-03)

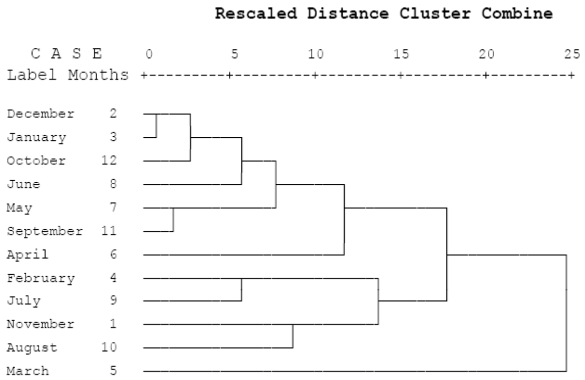

Figure 2. Hierarchical cluster analysis of zooplankton of Waithou Pat (2003-04)

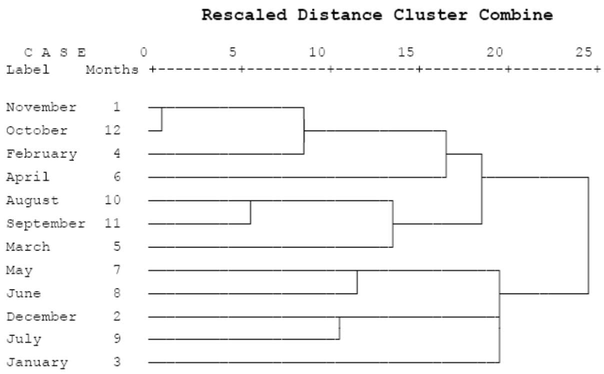

Figure 3. Hierarchical cluster analysis of zooplankton of Utra Pat (2002-03)

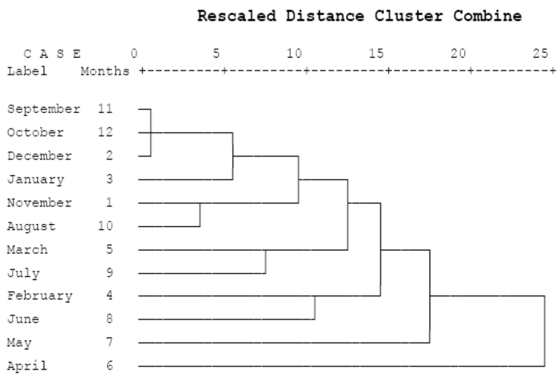

Figure 4. Hierarchical cluster analysis of zooplankton of Utra Pat (2003-04)

46.4 – 82.4% annual zooplankton community similarities (*vide* Sorensen index); the results thus reflected relatively more variations in species composition during second year of the study period. The similarity matrix showed > 60 – 70% similarities in majority of instances (57.6%) during 2002 – 03 while it recorded broadly concurrent maximum instances (37.9% and 36.4% respectively) of 60 – 70% and 70-80% similarities during 2003 – 04.

The hierarchical cluster analysis indicated closer affinity in zooplankton between November – December and diverse composition of February and July communities during 2002 – 03. On the other hand, December – January recorded closer affinity while March samples showed distinct divergence during 2003 – 04. Utra pat exhibited higher zooplankton similarity i.e., 61.1 – 82.7% during 2002 – 03 with 60 – 70% similarity in maximum instances (69.7%). This wetland, however, showed a relatively wide community similarity range (40.4 – 82.1%) during 2003 – 04. The cluster analysis indicated distinct annual variations in monthly groups in this pat; a closer affinity between November – October and distinct difference during January were noticed during 2002 – 03 while September – October samples showed closer affinity and April – May communities exhibited distinct divergence during 2003 – 04.

Zooplankton abundance was relatively higher in Waithou Pat than that of Utra pat; it registered significant monthly ($F_{23, 47} = 5.732$, $P < 0.001$) as well as temporal density variations between two pats ($F_{1, 23} = 27.186$, $P < 0.005$). ANOVA registered significant annual ($F_{1, 23} = 11.010$, P <

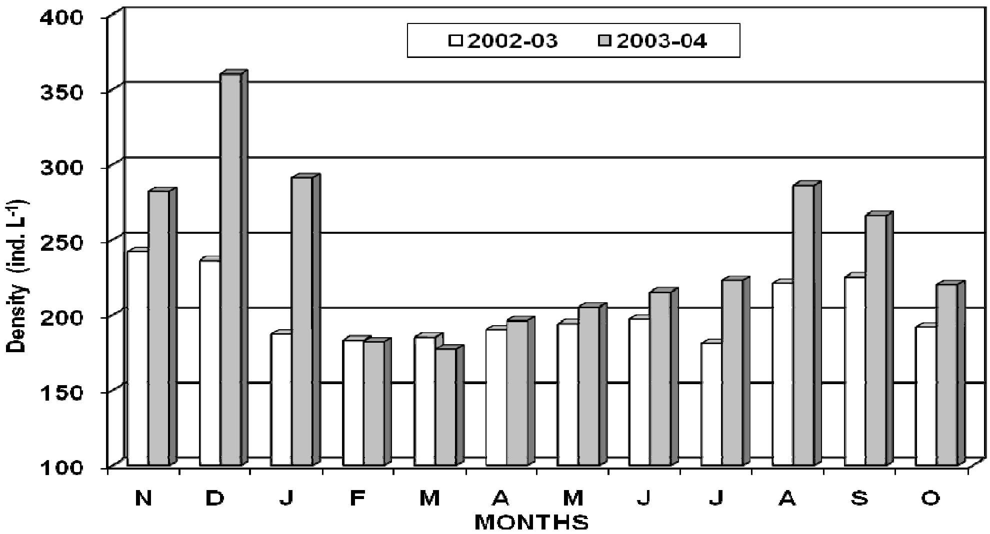

Figure 5. Monthly variations in Abundance of Zooplankton (Waithou Pat)

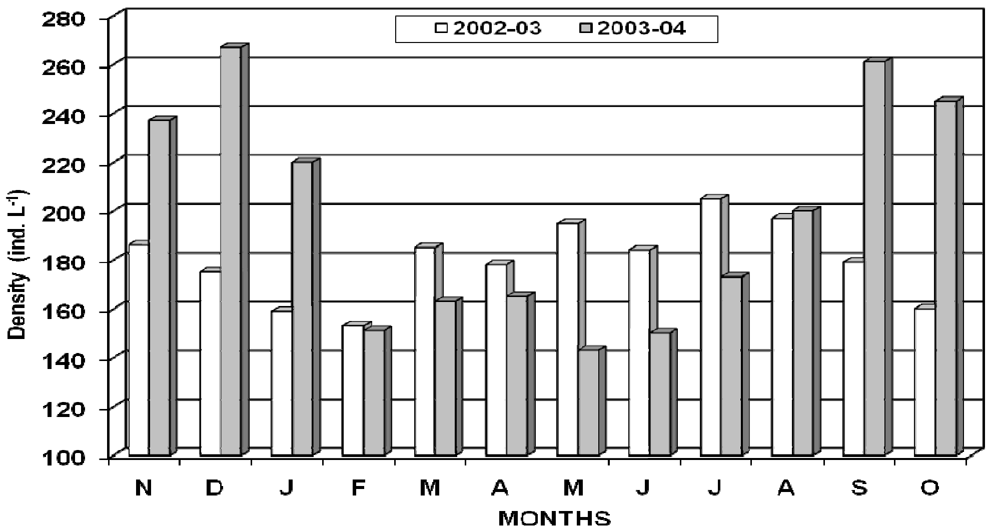

Figure 6. Monthly variations in aundance of zoplankton (Utra Pat)

0.005) and monthly zooplankton density variations ($F_{11,\ 23}$ = 3.384, P < 0.02) in the former wetland while it showed insignificant annual and monthly variations in Utra pat. The recorded abundance was higher than the reports of Yadava *et al.* (1987) and Sharma and Hussain (2001) but is lower than the reports of Rai and Dutta - Munshi (1982), Khan (1987), Vass (1989), Sanjer and Sharma (1995), Khan (2002), Sharma (2011) and Sharma and Sharma (2011). Zooplankton followed oscillating annual quantitative patterns with peaks during winter (December 2003); the later feature agreed with the report of Sharma and Sharma (2011) while the former aspect differed from bimodal patterns noticed by Yadava *et al*. (1987) and Sanjer & Sharma (1995). Zooplankton formed (56.0 ± 4.3% and 55.1 ± 5.1%) important quantitative component of net plankton of Waithou and Utra pats and, hence, concurred with the reports from certain flood-plain lakes of northeast India (Sharma and Hussain 2001, Sharma and Sharma 2010, Sharma 2011). This feature, however, differed from higher phytoplankton abundance reported from the floodplain lakes and wetlands of

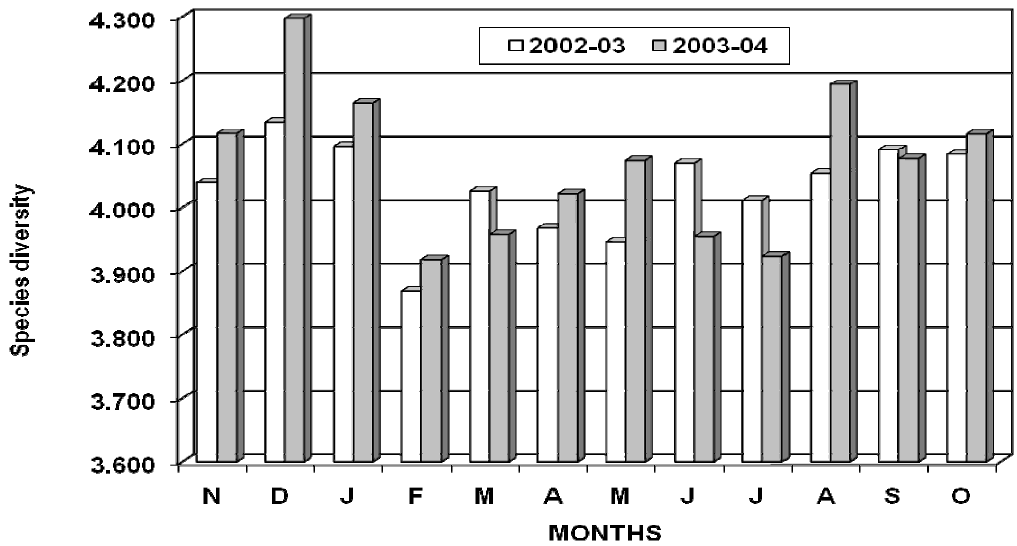

Figure 7. Monthly variations in species diversity of zooplankton (Waithou Pat)

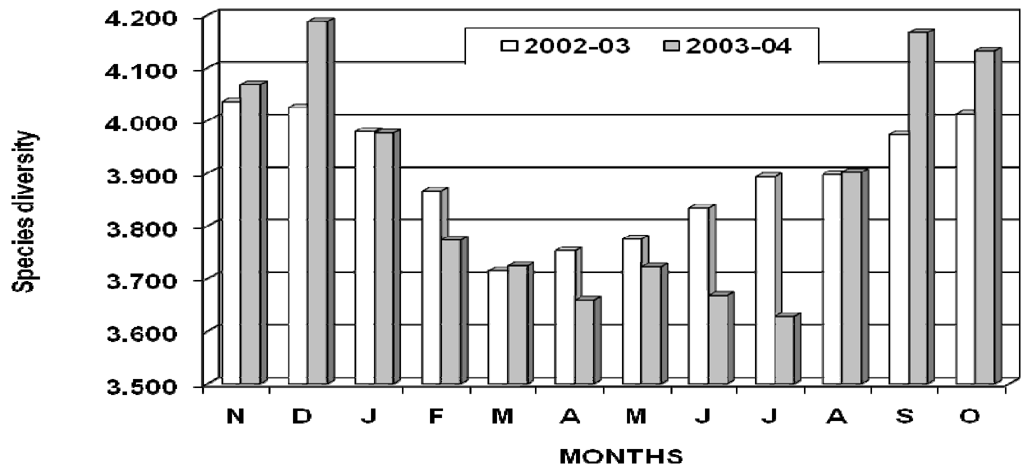

Figure 8. Monthly variations in species diversity of zooplankton (Utra)

Kashmir (Kaul & Pandit 1982), Bihar (Rai & Dutta-Munshi 1982; Baruah *et al*. 1993, Sanjer & Sharma 1995), Assam (Yadava *et al*. 1987) and West Bengal (Sugunan 1989).

Rotifera formed dominant quantitative group of zooplankton of Waithou > Utra pats; their abundance registered significant monthly variations ($F_{23, 47} = 6.433$, $P < 0.005$) and significant temporal variations between two pats ($F_{1, 23} = 78.834$, $P < 0.005$). Besides, the rotifers recorded significant annual ($F_{1, 23.} = 13.350$, $P < 0.005$) and monthly density variations ($F_{11, 23.} = 9.030$, $P < 0.005$) in Waithou pat while they showed only significant annual variations ($F_{1, 23.} = 4.175$, $P > 0.05$) in Utra pat. The quantitative importance of Rotifera agreed with the results of Khan (1987), Sanjer and Sharma (1995), Sharma and Sharma (2001, 2008, 2011) and Sharma (2005, 2011) but differed from their sub-dominant role reported by Yadava *et al*. (1987), Baruah *et al*. (1993), Sharma (2000a), Sharma and Hussain (2001) and Khan (2002). The rotifers densities revealed oscillating annual periodicity in Waithou and Utra pats with peaks during December, 2003 (winter);

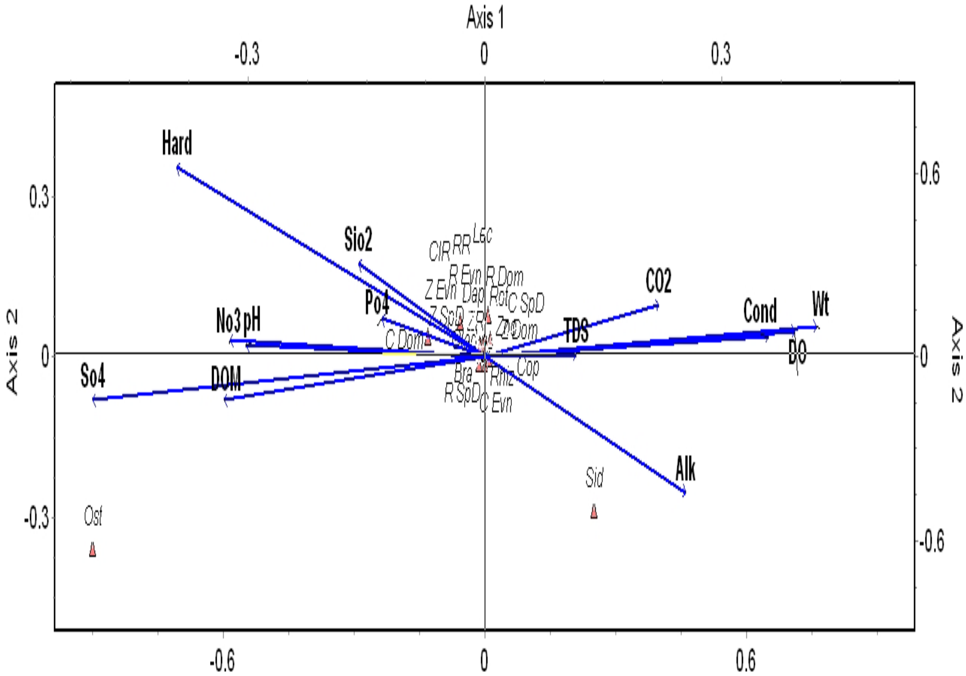

Figure 9. CCA ordination biplot of zooplankton assemblages and environmental variables (Waithou Pat)

Abbreviations. Biotic: Bra (Brachionidae), Cld (Cladocera), C SpD (Cladocera species diversity), C Evn (Cladocera evenness), C Dom (Cladocera dominance), Chy (Chydoridae), Cop (Copepoda), Daph (Daphniidae), Lec (Lecanidae), Ost (Ostracoda), Rhiz (Rhizopoda), RR (Rotifera richness), Rot (Rotifera), R SpD (Rotifera species diversity), R Env (Rotifera evenness), R Dom (Rotifera dominance), Sid (Sididae), Zoo (zooplankton), ZR (zooplankton richness), Z SpD (zooplankton species diversity), Z Dom (zooplankton dominance), Z Evn (zooplankton evenness);

Abiotic: Alk (alkalinity), CO_2 (free carbon dioxide), Cond (conductivity), DO (dissolved oxygen), DOM (dissolved organic matter), Hard (hardness), pH (hydrogen-ion concentration), PO4 (phosphate), NO3 (nitrate), Sio2 (silicate), So4 (sulphate), TDS (total dissolved solids), Wt (water temperature)

the last feature concurred with the results of Sharma and Hussain (2001), and Sharma and Sharma (2011) but differed from summer maxima reported by Yadava *et al.* (1987) and Baruah *et al.* (1993) and Sanjer and Sharma (1995) as well as spring and autumn maxima recorded in the floodplains of the Kashmir valley (Khan, 1987).

Lecanidae > Brachionidae contributed notably to Rotifera abundance in Waithou and Utra. This salient feature concurred with the results from floodplain lakes of northeast (Sharma & Hussain 2001; Sharma 2009a, 2009b, 2010; Sharma and Sharma 2010) while no such trend was apparent in the studies from elsewhere (Yousuf *et al.* 1986; Khan 1987; Baruah *et al*. 1993; Khan 2002). Lepadellidae and Trichocercidae also showed certain importance in the two pats respectively. Sharma (1992) inferred abundance of loricate rotifers during summer and that of illoricates during winter but no such trend was observed in the sampled pats. Further, the present results were characterized by lack of quantitative dominance of any rotifer species; this feature was in contrast to quantitative importance of certain species indicated by Sharma (2000a, 2011).

Cladocera, a sub-dominant quantitative group of zooplankton of Waithou > Utra pats, indicated significant annual variations ($F_{1, 23.}$ = 19.910, $P < 0.001$) and insignificant monthly variations in Waithou pat but showed insignificant annual and monthly variations in Utra pat. This group showed oscillating annual quantitative patterns in the two pats with peak densities during winter (December, 03) in Waithou and post-monsoon (September

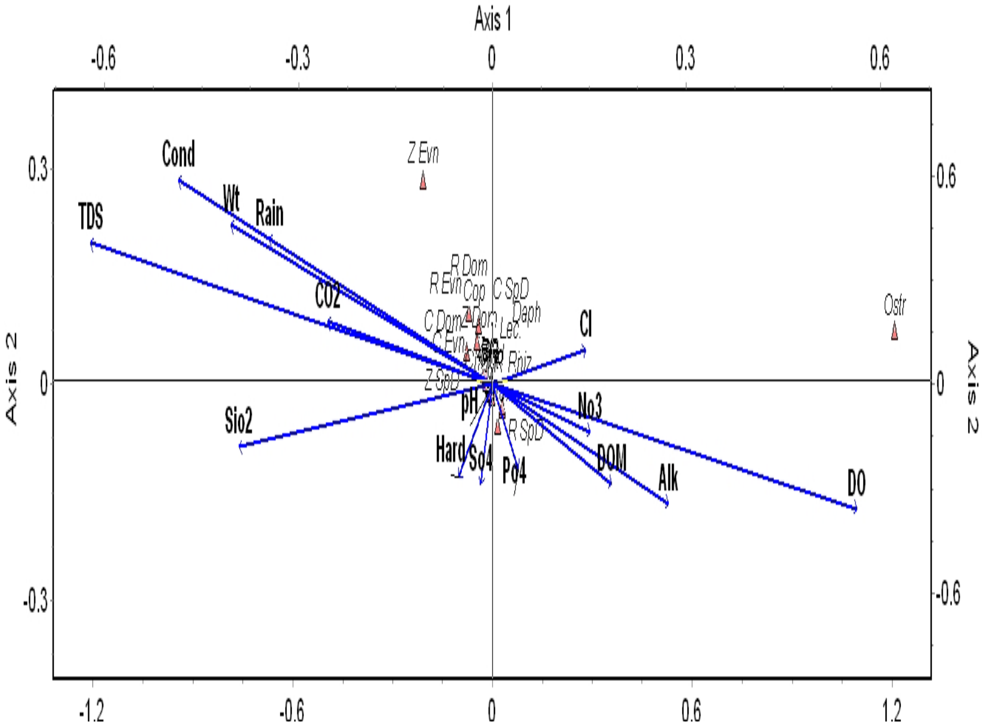

Figure 10. CCA ordination biplot of zooplankton assemblages and environmental variables (Utra Pat)

Abbreviations. Biotic: Bra (Brachionidae), Cld (Cladocera), C SpD (Cladocera species diversity), C Evn (Cladocera evenness), C Dom (Cladocera dominance), Chy (Chydoridae), Cop (Copepoda), Daph (Daphniidae), Lec (Lecanidae), Ost (Ostracoda), Rhiz (Rhizopoda), RR (Rotifera richness), Rot (Rotifera), R SpD (Rotifera species diversity), R Env (Rotifera evenness), R Dom (Rotifera dominance), Sid (Sididae), Zoo (zooplankton), ZR (zooplankton richness), Z SpD (zooplankton species diversity), Z Dom (zooplankton dominance), Z Evn (zooplankton evenness)

Abiotic: Alk (alkalinity), CO_2 (free carbon dioxide), Cond (conductivity), Cl (chloride), DO (dissolved oxygen), DOM (dissolved organic matter), Hard (hardness), pH (hydrogen-ion concentration), PO4 (phosphate), NO3 (nitrate), Rain (rainfall), Sio2 (silicate), So4 (sulphate), TDS (total dissolved solids), Wt (water temperature)

2004) peak in Utra. The reported patterns differed from the reports of Sanjer & Sharma (1995) and Sharma and Hussain (2001). The Cladocera were characterized by quantitative importance of the Chydoridae which, in turn, concurred with the results of Sharma (2011), and Sharma and Sharma (2011) but differed from lack of any such feature as reported by some other investigators (Khan, 1987; Sanjer and Sharma 1995; Sharma and Hussain 2001 and Khan, 2003). Daphniidae, another important family, exhibited identical mean abundance in the two pats.

Copepoda formed another sub-dominant group of zooplankton in Waithou and Utra pats respectively; the stated role was in contrast to their dominance reported by Yadava *et al*. (1987), Baruah *et al*. (1993), Sharma and Hussain (2001) and Khan (2003). This group showed oscillating annual patterns in Waithou and Utra pats but with peaks during late-monsoon (September, 04) in each lake. These patterns differed from bimodal variations noticed by Sharma and Hussain (2001) but concurred with the results of Sharma (2011) and Sharma and Sharma (2011). The Cyclopoids formed dominant component of Copepoda and thus concurred with earlier reports (Khan 1987, Sanjer and Sharma 1995, Sharma and Hussain 2001, Sharma and Sharma 2011 and Sharma 2011). The occurrence of nauplii throughout the study period in both pats showed an active continuous reproductive phase of the cyclopoids

Table 3. Variance explained in the canonical correspondence analysis (CCA) by the first two axes

Sampling Stations ↓ Canonical Axis →		Axis 1	Axis 2
Waithou Pat *			
Total variance in species data =	0.0216		
Sum of canonical Eigen values =	0.0132		
Sum of non-canonical Eigen values =	0.0083		
Canonical Eigen value =		0.00808	0.00392
% variance explained =		37.448	18.190
Cumulative % variance =		37.448	55.639
Utra Pat			
Total variance in species data =	0.0174		
Sum of canonical Eigen values =	0.0124		
Sum of non-canonical Eigen values =	0.0050		
Canonical Eigen value =		0.00964	0.0010995
% variance explained =		55.501	6.330
Cumulative % variance =		55.501	61.831

*attempted with 13 parameters because of limitations by auto-correlations

concurrent with the reports of Sharma (2011), and Sharma and Sharma (2011).

Rhizopoda showed oscillating annual patterns in both years in Waithou and Utra pat. The present results differed from their summer periodicity of these testaceans reported by Yadava *et al.* (1987), Sinha *et al.* (1994) and Sharma and Hussain (2001). Ostracoda, another group of zooplankton, indicated very poor abundance in the sampled pats.

Zooplankton communities of Waithou > Utra pats were characterized by higher species diversity; the former followed the earlier highest Indian report from Loktak lake (Sharma and Sharma 2011) while the later corresponded with the results from Deepor beel (Sharma 2011). The interesting feature of higher diversity with lower densities of majority of species in both the pats could be attributed to fine niche portioning amongst zooplankton species in combination with micro- and macro-scale habitat heterogeneity as hypothesized by Segers (2008) and also affirmed by Sharma and Sharma (2011) and Sharma (2011). Rotifera > and Cladocera contributed to higher zooplankton diversity in the two pats, respectively. The zooplankton diversity showed significant monthly variations ($F_{23, 47} = 4.945$, $P > 0.005$) and significant temporal variations between two pats ($F_{1, 23} = 41.357$, $P < 0.005$). It followed oscillating indefinite annual patterns (Figs. 9–10) but depicted peak values during winter in the two pats individually which, in turn, corresponded with peak richness and abundance of zooplankton as well as Rotifera. The last aspect is supported by significant positive correlations of diversity with richness of zooplankton ($r_1 = 0.920$, $P < 0.0001$; $r_2 = 913$, $P < 0.0001$) and Rotifera ($r_1 = 0.887$, $P < 0.0001$; $r_2 = 0.827$, $P < 0.0001$) and also with abundance of zooplankton ($r_1 = 0.773$, $P < 0.0001$; $r_2 = 0.717$, $P < 0.0001$) and the rotifers ($r_1 = 0.789$, $P < 0.0001$; $r_2 = 0.774$, $P < 0.0001$) respectively in both the pats.

Lower dominance and higher evenness, other interesting features of zooplankton of Waithou and Utra pats, were attributed to lack of quantitative importance of any individual species coupled with low densities of majority of species.

These generalizations were supported by lower dominance and higher evenness of Rotifera and Cladocera in the two pats, respectively. These features concurred with the earlier reports of Sharma and Sharma (2008, 2011) and Sharma (2011). Both dominance and evenness followed oscillating annual patterns without any definite periodicity. The diversity inversely correlated with evenness (r_1 = - 0.584, P = 0.003; r_2 = - 0.827, P < 0.0001) in Waithou and Utra pats respectively but positively correlated with dominance in Utra only (r_2 = 0.737, P < 0.0001).

The present study indicated limited influence of individual abiotic parameters on zooplankton richness; it inversely correlated only with nitrate (r_1 = - 0.577, P = 0.0032) in Waithou pat. This general trend corroborated with the reports of Sharma (2011) and Sharma and Sharma (2011) and was also valid for main qualitative groups; the rotifer richness did not correlate significantly with any abiotic parameter in both pats while Cladocera richness inversely correlated only with nitrate (r_1 = -0.672, P = 0.0003) in Waithou pat. The zooplankton abundance positively correlated with alkalinity (r_2 = 0.607, P = 0.002) only in Utra pat; the limited significance of individual of abiotic parameters corroborated with the reports of Yadava & Dey (1990), Sharma and Hussain (2001), Sharma (2011) and Sharma and Sharma (2011). The Rotifera abundance inversely correlates with pH (r_1 = - 0.667, P = 0.0004) and nitrate (r_1 = - 0.593, P = 0002) in Waithou while it positively correlated with alkalinity (r_3 = 0.639, P = 0.0008) only in Utra pat. On the other hand, Cladocera and Copepoda abundance exhibited no significant correlation with any abiotic factor in Waithou and Utra pats. Canonical correspondence analysis (CCA) with 13 and 15 abiotic factors explained higher (55.6 % and 61.8%) cumulative variance of zooplankton assemblages along axis 1 and 2 in Waithou and Utra pats respectively. This study reflected importance of hardness, water temperature, SO_4, alkalinity in Waithou pat; DO, and conductivity, DO, TDS and water temperature in Utra pat; clustering of various biotic parameters in the centre of the plots; and depicting certain micro-environmental differences between the both pats.

CONCLUSION

The species rich zooplankton of Waithou and Utra pats formed important qualitative and quantitative component of net plankton, and exhibited rich diversity and quantitative importance of Rotifera > Cladocera. The study indicated no definite patterns of richness or abundance of zooplankton or their constituent groups. The results affirmed higher species diversity, higher evenness and lower dominance of zooplankton and main constituent groups, and exhibited lower densities of majority of species. Individual abiotic factors exerted limited influence on richness and abundance of zooplankton. CCA explained high cumulative variance of zooplankton assemblages along axis 1 and 2 in the sampled pats.

Acknowledgements – This study is undertaken partly under the "Potential for Excellence Program (Focus Area: Biosciences) of North-Eastern Hill University, Shillong. The author is thankful to the G. B. Pant Institute of Himalayan Environmental Development, Almora for a research grant during which this study was initiated. Thanks are due to the Head of the Department of Zoology, North-Eastern Hill University, Shillong for the necessary facilities.

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Supporting online material: Appendix 1 (http://opuscula.elte.hu/Tomus42_2/Sharma_App1.pdf)