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Zooplankton Diversity of a De-Mineralized Subtropical Sacred Lake of Meghalaya State, Northeast India, with Remarks on the Spatio-Temporal Variations

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Abstract

This study analyzes zooplankton diversity of 'soft water' and 'de-mineralized' Thadlaskein Lake of Meghalaya state of northeast India (NEI) vis-à-vis the spatio-temporal variations. The littoral and limnetic zooplankton assemblages reveal a total of 60 species, the speciose constellations of 47-50 species per sample and the species-rich Rotifera. Zooplankton comprises an important quantitative component of net plankton, record low abundance, and Copepoda, Rotifera, and Cladocera collectively influence zooplankton abundance in the two regions. Brachionidae, Bosminidae, Cyclopidae, Diaptomidae and Conochilidae are notable families, and *Bosmina longirostris*, *Ceriodaphnia cornuta*, *Conochilus unicornis*, *Heliodiaptomus viduus*, *Keratella cochlearis* and *Mesocyclops leuckarti* are notable species. Our results record high species diversity, low dominance and high evenness. Individual abiotic factors exert the differential spatial influence on zooplankton and register the relative importance of water temperature, rainfall and transparency. The canonical correspondence analysis registers 82.4 and 67.6% cumulative influence of 10 abiotic factors on the littoral and limnetic assemblages, respectively. The spatial variations of the different aspects of zooplankton diversity and the influence of abiotic factors are hypothesized to habitat heterogeneity amongst the two regions. This study merits interest for zooplankton diversity of India and that of the subtropical lacustrine systems of the country in particular.

Keywords: Composition, Abundance, Ecology, Soft water, Sacred Lake, Zooplankton assemblages

1. Introduction

Zooplankton have been examined in a sizeable number of 'routine' ecology surveys since the inception of limnology in India, but the related literature highlights the distinct paucity of the studies based on the detailed analyses of zooplankton diversity from this country and that of the subtropical aquatic biotopes of north India (Sharma and Sharma, 2021). The studies from the sub-tropical lacustrine systems of northwest India (NWI), with the variable extent of importance, are those of Raina and Vass (1993), Ahangar *et al*. (2012), Slathia and Dutta (2013), Thakur *et al*. (2013), Malik and Panwar (2016) and Sharma and Kumari (2018). The notable diversity works from northeast India (NEI) are limited to the floodplain lakes of Assam (Sharma, 2011a; Sharma and Sharma, 2011, 2012; Sharma and Hatimuria, 2017; Sharma and Noroh, 2020) and Manipur (Sharma, 2011b), while a fewer studies deal with zooplankton assemblages of the selected reservoirs of Mizoram (Sharma and Pachuau, 2013) and Meghalaya (Sharma and Sharma, 2020), and an urban wetland of Meghalaya (Sharma and Sharma, 2021).

The present study on zooplankton diversity of the sub-tropical Thadlaskein Lake of Meghalaya of NEI merits interest in light of the stated lacunae. Based on the detailed analyses of the monthly littoral and limnetic net plankton collections, our study monitors the spatio-temporal variations of zooplankton with reference to species composition, richness, community similarities, abundance, species diversity, dominance and evenness, and the individual and cumulative influence of abiotic factors. The results are compared and discussed with reference to the related works from India and NWI and NEI in particular, and certain relevant reports from the Indian sub-region. This pioneering study on zooplankton assemblages of a sacred lake of NEI merits importance vis-a-vis zooplankton diversity of India.

2. Materials and Methods

The present study is based on the limnological survey of Thadlaskein Lake or 'Pung Sajar Nangli' (Latitude 25.4969 N, Longitude 92.1730 E; area ~5 ha; maximum depth 12 m) undertaken during January–December 2016. This man-made medieval lake is located beside National Highway 6 by the side of Mukhla village and about 10 km from Jowai city of West Jaintia Hills district (Fig. 1 A-D). This sacred lake is revered by the people of Raid Mukhla and is worshipped by the Niamtre community of Meghalaya. It is named after the legacy of a young medieval leader named Sajar Nangli, a rebel general of the Jaintia king, who, along with his clan, gathered at a spot to rest and they dug a lake with the ends of their arrows to commemorate the great exodus of their clan. This lake indicates distinct growth of *Utricularia vulgaris* in the littoral region.

Our observations are based on water and the qualitative and quantitative net plankton samples collected at monthly intervals from the littoral and limnetic regions. Water temperature, pH and specific conductivity were recorded

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Fig. 1A. map of India showing Meghalaya state (red colour); **B.** District map of Meghalaya showing West Jaintia hills district (blue colour); **C.** part map of West Jaintia hills district showing the location of Mukhla village; **D.** Photograph of Thadlaskein Lake indicating the Littoral and Limnetic regions

with the field probes, transparency was measured with a Secchi disc, Dissolved oxygen (DO) was estimated by Winkler's method, and other abiotic factors, namely free carbon dioxide (CO_2), Total Alkalinity (TA), Total Hardness (TH), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Dissolved Organic Matter (DOM), Total Dissolved Solids (TDS), Phosphate (PO_4), Nitrate (NO_3), Sulphate (SO_4) and Silicate (SIO_2) were analyzed following APHA (1992). The rainfall data were obtained from the local meteorological station.

The qualitative net plankton samples were collected by towing nylobolt plankton net (#40 µm) and preserved in 5% formalin. These samples were screened with a Wild Stereoscopic binocular microscope, zooplankton were isolated and mounted in polyvinyl alcohol–lactophenol mixture, and were observed with Leica stereoscopic microscope (DM 1000). The different species were identified following Michael and Sharma (1988), Sharma (1983, 1998), Sharma and Sharma (1999a, 1999b, 2000, 2008, 2013). The community similarities were calculated vide Sørensen's index and SPSS (version 20) was used for the hierarchical cluster analysis. The quantitative net plankton samples, obtained by filtering 25 L of water each through plankton net, were preserved in 5% formalin. The quantitative analysis of zooplankton was done using a Sedgewick-Rafter counting cell and abundance was indicated as n/l. The species diversity (Shannon-Weiner's index), dominance (Berger-Parker's index) and evenness (E_1 index) were calculated vide Ludwig and Reynolds (1988) and Magurran (1988). Two-way ANOVA was used to ascertain the significance of variations of the abiotic factors and zooplankton assemblages. Pearson correlation coefficients, for the littoral and limnetic regions (r_1 and r_2, respectively) were calculated between abiotic factors and zooplankton; p values (the two-tailed) were calculated vide http://vassarstats.net/tabs.html and their significance were ascertained after Bonferroni corrections. The canonical correspondence analysis was done (vide XLSTAT 2015) to ascertain the cumulative influence of 10 abiotic parameters, namely water temperature, rainfall, transparency, specific conductivity, TA, TH, PO_4, NO_3, DOM and TDS on zooplankton.

3. Results and Discussion

The sub-tropical Thadlaskein Lake (Tables 1) is characterized by soft, slightly acidic-circumneutral, calcium poor and oxygenated waters with low specific conductivity, low transparency, free CO_2, Cl, DOM, TDS and nutrients. The de-mineralized nature of this lake is attributed to the leached and weathered nature of the rocks and soils because of high rainfall, and the lowered buffering capacity of the de-mineralized waters (Sharma and Sharma, 2021). ANOVA (Table 2) registers significant spatio-temporal variations of transparency and PO_4; water temperature, specific conductivity, TA, TH, Mg, Cl and DOM register significant monthly variations; and pH, DO, free CO_2, Ca, SO_4, NO_3 and TDS depict insignificant spatio-temporal variations.

A total of 60 species documented from the 'soft' and 'de-mineralized' water Thadlaskein Lake (Table 3) reveal the speciose zooplankton than with the reports from the lakes of Kashmir (Khan, 1987; Raina and Vass, 1993; Ahangar *et al.*, 2012; Jeelani and Kaur, 2014) and Uttarakhand (Mishra *et al.*, 2010; Malik and Panwar, 2016; Sharma and Kumari, 2018; Singh and Sharma, 2020), and the reservoirs of Meghalaya (Sharma, 1995; Sharma and Lyngskor, 2003; Sharma and Lyngdoh, 2004; Sharma and Sharma, 2020) and Mizoram (Sharma and Pachuau,

Table 1. Variations of abiotic factors of Thadlaskein Lake

Regions		Littoral		Limnetic	
Factors		**Range**	**Mean ± S.D**	**Range**	**Mean ± S.D**
Water temperature	^0C	12.0-22.5	18.8 ± 3.6	16.5-24.5	18.7 ± 3.7
Rainfall	mm	12.0-1920.4	613.5 ± 667.9	12.0-1920.4	613.5 ± 667.9
Transparency	cm	47.0-70.0	57.6 ± 7.1	80-120	62.1 ± 7.3
pH		6.38-6.85	6.62 ± 0.17	6.40-6.95	6.67 ± 0.15
Specific conductivity	µS/cm	21.0-27.0	25.1 ±3.4	20.0-29.5	24.7 ± 2.6
DO	mg/l	6.1-8.6	7.2 ± 0.7	6.2-8.4	7.1 ± 0.9
Free CO_2	mg/l	4.0-8.0	6.7 ± 1.2	4.0-9.0	6.0 ± 1.3
TA	mg/l	19.0-28.0	23.4 ± 2.4	20.7-29.0	24.0 ± 2.7
TH	mg/l	16.0-25.0	19.5 ± 4.8	16.9-26.0	21.2 ± 2.2
Ca	mg/l	7.4-10.5	9.4 ± 1.0	7.4-12.6	9.4 ± 1.7
Ma	mg/l	3.8-9.1	6.4 ± 1.8	3.3-9.8	6.3 ± 2.1
Cl	mg/l	20.5-36.5	33.1 ± 5.0	23.0-39.0	32.7 ± 5.1
PO_4	mg/l	0.278-0.547	0.413 ± 0.082	0.210-0.478	0.349 ± 0.091
NO_3	mg/l	0.010-0.041	0.018 ± 0.008	0.007-0.089	0.021 ± 0.022
SO_4	mg/l	4.3-10.0	7.0 ± 1.9	0.7-9.2	4.1 ± 2.4
DOM	mg/l	1.2-4.0	2.4 ± 0.9	1.1-3.4	2.7 ± 1.6
TDS	mg/l	1.0-2.6	1.7 ± 0.5	0.2-3.9	1.3 ± 1.8

2013). Our study also depicts diverse zooplankton as compared with the lacustrine environs from Karnataka (Hulyal and Kaliwal, 2008; Kudari and Kanamadi, 2008; Majagi and Vijaykumar, 2009; Shivashankar and Venkataramana, 2013; Anita *et al*., 2019; Majagi *et al.* 2019) and Tamil Nadu (Manickam *et al*., 2017). The comparisons highlight biodiverse zooplankton assemblage of this sacred lake vis-a-vis the lacustrine environs of India and those of NEI in particular, and also the reports from Nepal (Tiwari and Chhetry, 2009) and Bhutan (Sharma and Bhattarai, 2005). Rotifera, the speciose group, records (Table 3) higher richness as compared with the reports from Meghalaya (Sharma, 1995; Sharma and Lyngskor, 2003; Sharma and Lyngdoh, 2004) and Mizoram (Sharma and Pachuau, 2013), Kashmir (Raina and Vass, 1993; Jeelani and Kaur, 2014; Shah *et al*., 2017; Jamila, 2018) and Uttarakhand (Inaotombi *et al*., 2016). The distinct paucity of the Brachionidae and *Brachionus* spp. amongst Rotifera is attributed to soft-water and slightly acidic-circumneutral nature of the sampled lake. This notable feature concurs with the reports of Sharma and Pachuau (2013), Sharma *et al*. (2016), Sharma and Noroh (2020) and Sharma and Sharma (2021) from NEI.

Zooplankton (Table 3) records nearly identical mean richness (42±4 and 41±5 species) with oscillating patterns of monthly variations (Fig. 2) and contribute to net plankton richness (r_1 =0.873, p = 0.001; r_2 =0.970, p<0.0001) in the two regions. ANOVA registers insignificant spatial and significant temporal richness variations (Table 4). The peak consortium of 50 species in the limnetic collection during December (winter) concurs with a nearly identical report from Nongmahir reservoir of Meghalaya (Sharma and Sharma, 2020). This study also records autumn-winter (November-December) speciose consortia each of 48 species per sample in the littoral region and that of 47 species per sample each during February and November in the limnetic region (Fig. 2). The speciose assemblages of 47-50 zooplankton species per sample thus noted vide our study are hypothesized to the possibility of co-existence of various species because of high amount niche overlap following MacArthur (1965). Rotifera significantly influence (r_1 =0.903, p =

Table 2. ANOVA indicating significance of abiotic factors of Thadlaskein Lake

Parameters	Regions	Months
Water temperature	-	$F_{11,23}$=76.340, P=9.42E-09
Transparency	$F_{1,23}$ = 28.566, P = 0.0003	$F_{11,23}$= 24.923, P = 3.48E-06
pH	-	-
Specific conductivity	-	$F_{11,23}$= 5.133, P= 0.006
DO	-	-
Free CO_2	-	-
TA	-	$F_{11,23}$= 3.783, P = 0.018
TH	-	$F_{11,23}$= 7.116, P = 0.001
Ca	-	-
Mg	-	$F_{11,23}$= 6.171, P = 0.001
Cl	-	$F_{11,23}$= 4.379, P= 0.011
PO_4	$F_{1,23}$ = 43.466, P = 3.9E-05	$F_{11,23}$= 27.915, P = 1.94E-06
SO_4	-	-
NO_3	-	-
DOM	-	$F_{11,23-}$= 6.324, P = 0.002
TDS	-	-

(-) insignificant variations

Table 3. Temporal variations of zooplankton assemblages of Thadlaskein Lake

QUALITATIVE	**Littoral**		**Limnetic**	
Net Plankton	111 species		111 species	
Monthly richness	70-93	80±6	69-99	82±9
Zooplankton Total Richness	60 species		60 species	
Monthly richness	35-48	42±4 species	32-50	41±5 species
Community similarity	64.0-88.9%		56.0-90.0%	
Rotifera Total Richness	33 species		33 species	
Monthly richness	16-26	21±2 species	16-26	20±4 species
QUANTITATIVE				
Net Plankton n/l	368-652	510±103	315-658	482±116
Zooplankton n/l	177-251	211±29	131-221	223±44
Percentage of net plankton	33.9-49.6	42.0±4.8	38.9-58.2	47.1±5.2
Species Diversity	2.816-3.149	3.011±0.109	2.685-3.360	3.032±0.204
Dominance	0.109-0.218	0.153±0.029	0.085-0.232	0.157±0.037
Evenness	0.775-0.907	0.814±0.033	0.760-0.912	0.820±0.048
Copepoda n/l	69-94	74±10	32-129	79±31
Percentage of zooplankton	31.1-41.5	35.5 ± 3.9	21.5-47.5	34.1± 9.4
Rotifera n/l	50-87	69±11	41-97	70±16
Percentage of zooplankton	28.7-35.4	32.5±2.4	20.2-38.3	31.6±5.1
Cladocera n/l	43-77	57±11	52-86	66±11
Percentage of zooplankton	6.8-32.7	24.3±6.4	24.1-39.7	30.4±5.0
Rhizopoda n/l	5-18	11±3	3-13	8±3
Important families n/l	111-180	146±23	90-197	156±35
Percentage of zooplankton	69.0±3.4		69.5±3.5	
Important species n/l	95-147	117±21	60-159	123±34
Percentage of zooplankton	55.1±4.0		54.1±6.5	
Important families (n/l)				
Brachionidae	28-46	38±6	21-45	31±9
Diaptomidae	20-39	31±6	11-53	33±15
Bosminidae	12-40	25±8	14-44	28±9
Cyclopidae	13-31	20±5	8-31	23±10
Daphniidae	12-26	16±4	12-24	17±4
Conochilidae	4-18	10±4	4-23	14±6
Important species (n/l)				
Heliodiaptomus viduus	20-39	31±6	11-53	33±15
Mesocyclops leuckarti	13-31	20±5	8-31	23±10
Keratella cochlearis	12-32	24±6	9-32	18±9
Bosmina longirostris	9-30	21±8	9-40	23±9
Ceriodaphnia cornuta	9-20	12±3	8-30	13±4
Conochilus unicornis	4-18	10±4	4-23	14±6

0.0003; r_2 =0.881, p = 0.0008) zooplankton richness in the two regions; ANOVA (Table 4) registers significant temporal variations of the rotifer richness.

Zooplankton assemblages register 64.0-88.9% and 56.0-90.0% community similarities; peak similarity values between November-December and February-December, and lowest similarities between April-June and March-June depict heterogeneity between the two regions, respectively. This generalization is supported by the differential groupings vide the hierarchical cluster analysis (Fig. 3-4) with maximum species divergence recorded during April in the littoral region and during May > July in the limnetic region. Our results record < 70%, 71-80% and >80% similarities in ~6%, ~67 % and ~27% instances in the littoral region, while the limnetic region records < 70%, 71-80% and >80% similarities in 24%, 53% and 21% instances vide the similarity matrices. The comparisons depict the relatively more zooplankton species heterogeneity in the limnetic region.

Our study highlights (Table 3) low zooplankton abundance in the littoral (211±29 n/l) and limnetic (223±44 n/l) regions. This notable feature, attributed to the 'soft and de-mineralized' nature of Thadlaskein Lake, concurs with our reports from identical water bodies from NEI (Sharma, 2011a; Sharma and Sharma, 2012, 2020, 2021a; Sharma and Pachuau, 2013; Sharma and Noroh, 2020) and Bhutan (Sharma and Bhattarai, 2005). Zooplankton (Table 3) comprise an important component (42.0±4.8 and 47.1±5.2%) and influence net plankton abundance (r_1 =0.987, p < 0.0001; r_2 =0.965, p < 0.0001) in the two stations. ANOVA affirms insignificant spatial density variations but records significant monthly variations (Table 4). The importance of zooplankton concurs with the reports from Assam (Sharma and Hatimuria, 2017), Himachal Pradesh (Jindal and Thakur, 2014) but differs from the distinct quantitative sub-dominance reported from the reservoirs of Meghalaya (Sharma, 1995; Sharma and Lyngdoh, 2003; Sharma and Sharma, 2020) and Mizoram (Sharma and Pachuau, 2013). Zooplankton record peaks with nearly identical abundance during summer (April) and autumn (November) and concurrent high abundance periods during January, March and December in the limnetic region (Fig. 5). Our results record peaks during January and periods of high abundance during February, March and December in the littoral regions (Fig. 5). This study thus depicts the

Table 4. ANOVA indicating significance of zooplankton assemblages of Thadlaskein Lake

Parameters	Regions	Months
Richness		
Zooplankton	-	$F_{11,23}$ = 9.006, P= 0.0005
Rotifera	-	$F_{11,23}$ = 4.791, P= 0.007
Abundance		
Zooplankton	-	$F_{11,23}$ = 3.479, P= 0.025
Rotifera	-	$F_{11,23}$ = 4.779, P= 0.007
Copepoda	-	-
Cladocera	$F_{1,23}$ = 13.793, P = 0.003	$F_{11,23}$ = 5823, P = 0.003
Rhizopoda	$F_{1,23}$ = 4.974, P = 0.047	-
Important families	-	$F_{11,23}$ = 4.892, P = 0.006
Important species	-	$F_{11,23}$ = 4.559, P = 0.009
Important families		
Brachionidae	$F_{1,23}$ = 11.488, P = 0.006	$F_{11,23}$ = 4.268, P = 0.118
Cyclopidae	-	-
Diaptomidae	-	-
Bosminidae	-	$F_{11,23}$ = 3.348, P = 0.031
Daphniidae	-	$F_{11,23}$ = 2.859, P = 0.047
Conochilidae	$F_{1,23}$ = 6.767, P = 0.035	-
Important species		
Keratella cochlearis	$F_{1,23}$ = 9.684, P = 0.009	$F_{11,23}$ = 5.637, P = 0.004
Bosmina longirostris	-	$F_{11,23}$ = 4.091, P = 0.014
Ceriodaphnia cornuta	-	-
Conochilus unicornis	$F_{1,23}$ = 6.767, P = 0.035	-
Heliodiaptomus viduus	-	-
Mesocyclops leuckarti	-	-
Diversity indices		
Species diversity	-	$F_{11,23}$ = 5.185, P = 0.005
Dominance	-	-
Evenness	-	-

(-) insignificant variations

differential and oscillating zooplankton spatial variations without confirming to any definite temporal pattern. The summer peak in the limnetic region concurs with the reports from Meghalaya (Sharma and Sharma, 2021) and Andhra Pradesh (Sharmila and Shameem, 2017), Karnataka (Hulyal and Kaliwal, 2008; Majagi and Vijaykumar, 2009; Shivashankar and Venkataramana, 2013; Anita *et al*., 2019; Majagi *et al*., 2019) and Tamil Nadu (Manickam *et al*., 2017), while higher winter abundance in both the regions corresponds with the reports from Himachal Pradesh (Sharma and Kumari, 2018), and Uttarakhand (Malik and Panwar, 2016; Singh and Sharma, 2020). However, lower monsoon abundance differs from monsoon peaks reported from Arunachal Pradesh (Saikia *et al*., 2017) and Uttarakhand (Thakur *et al*., 2013).

Thadlaskein Lake reveals (Table 3) the collective importance of Copepoda (35.5 ± 3.9 and 34.1± 9.4%), Rotifera (32.5±2.4 and 31.6±5.1%) and Cladocera (24.3±6.4 and 30.4±5.0 %) throughout the study vis-à-vis zooplankton abundance (r_1 =0.996, p < 0.0001; r_2 =0.998, p < 0.0001) in the littoral and limnetic regions. This trend marks a notable departure than distinct dominance of Copepoda (Sharma and Pachuau, 2013; Malik and Panwar, 2016; Sharma and Sharma, 2021) and Rotifera (Khan, 1987; Wani and Subla, 1995; Sharma 2011a, 2011b; Sharma and Sharma, 2008, 2011, 2012; Manickam *et al*., 2017; Jamila, 2018; Sharma and Noroh,

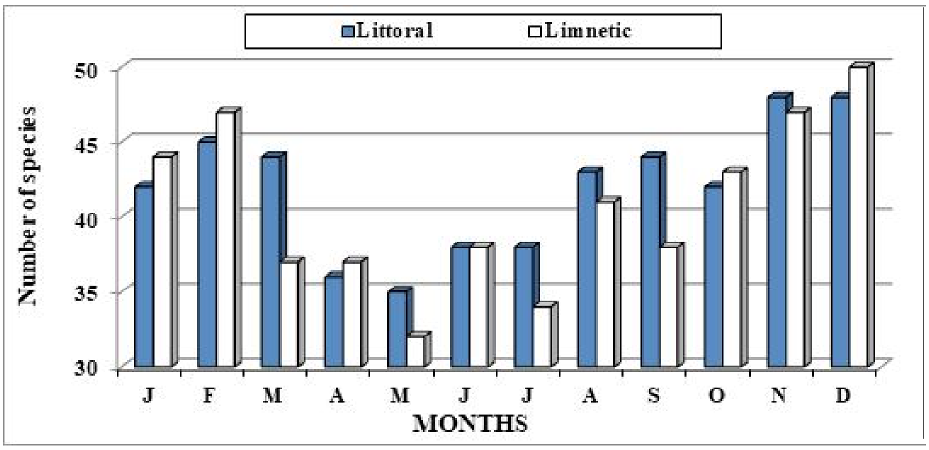

Fig. 2. Monthly variations of species richness of zooplankton of Thadlaskein Lake

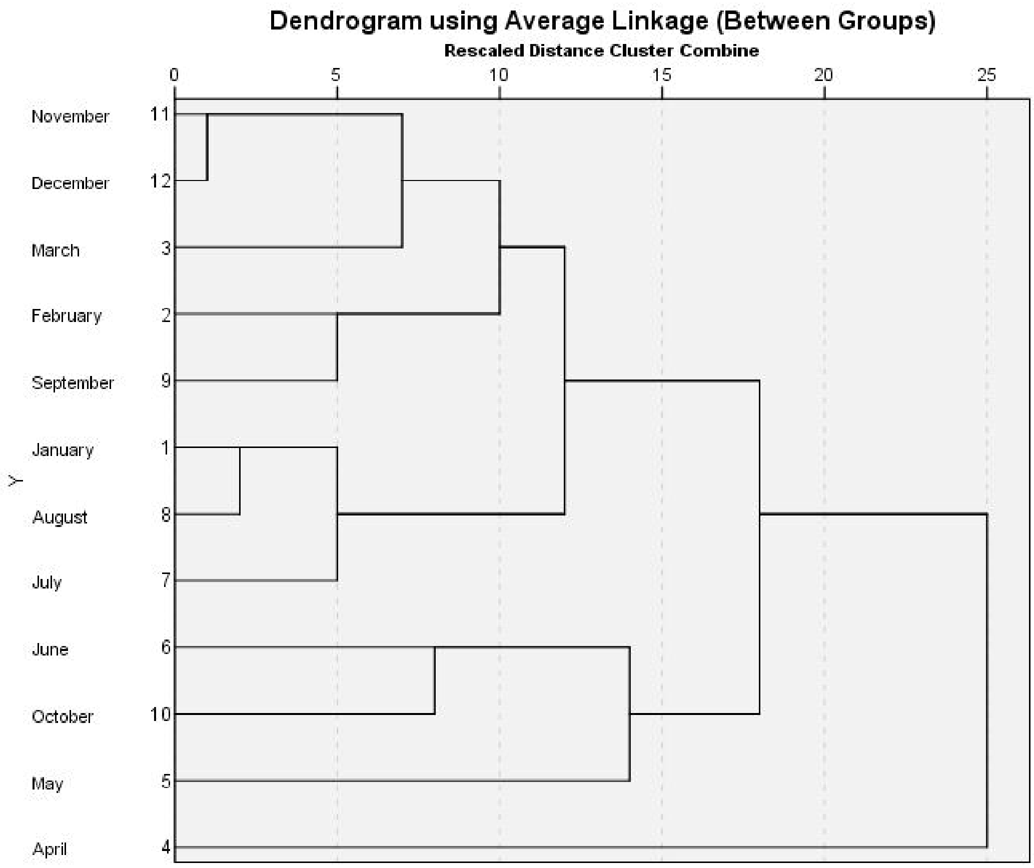

Fig. 3. Hierarchical cluster analysis of zooplankton assemblages (Littoral region)

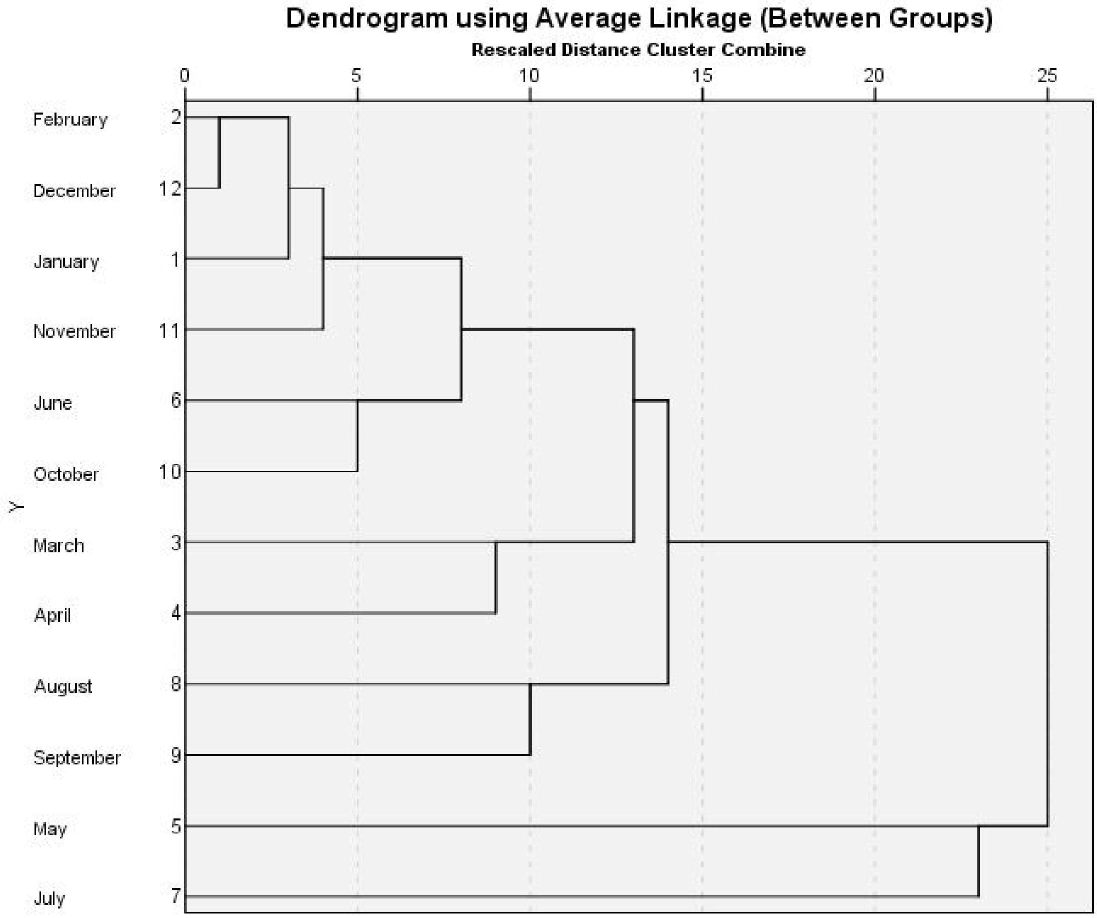

Fig. 4. Hierarchical cluster analysis of zooplankton assemblages (Littoral region)

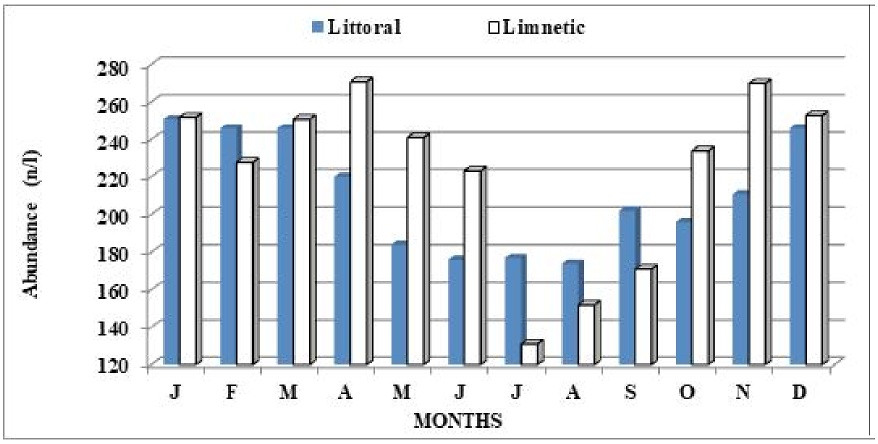

Fig. 5. Monthly variations of zooplankton abundance of Thadlaskein Lake

2020) reported vide the different studies from India. ANOVA registers (Table 4) insignificant spatio-temporal density variations of Copepoda, significant temporal variations of Rotifera and significant spatio-temporal variations of Cladocera during this study.

Zooplankton record the relative quantitative importance (Table 3) of *Heliodiaptomus viduus* > *Keratella cochlearis* > *Bosmina longirostris* ≥ *Mesocyclops leuckarti* > *Ceriodaphnia cornuta* ≥ *Conochilus unicornis* in the littoral, and that of *Heliodiaptomus viduus* > *Mesocyclops leuckarti* ≥ *Bosmina longirostris* > *Keratella cochlearis* > *Ceriodaphnia cornuta* ≥ *Conochilus unicornis* in the limnetic region. The listed species are in contrast to the rest of the 'generalist' species with lower densities. Following MacArthur's (1965) explanation, it is thus hypothesized that Thadlaskein Lake has resources for utilization by a fewer important and a majority of the 'generalist' species. This generalization deviates from exclusive 'generalist' nature of zooplankton species reported from the reservoirs (Sharma, 1995, Sharma and Lyngskor, 2003) and the floodplain lakes (Sharma, 2011b, 2011b, Sharma and Sharma, 2011, 2020, Sharma and Noroh, 2020) of NEI, and the lakes of Himachal Pradesh (Jindal and Thakur, 2014) and Uttarakhand (Malik and Panwar, 2016; Singh and Sharma, 2020). Our study depicts the relative importance of Brachionidae, Bosminidae, Conochilidae, Cyclopidae, Daphniidae and Diaptomidae (Table 3). The important families (r_1=0.692, p = 0.027) and species (r_1=0.685, p=0.029) collectively exert significant influence on zooplankton abundance in the littoral region and these register (ANOVA) insignificant spatial and significant temporal variations (Table 4).

Copepoda indicate (Table 3) relatively wider density variations (Figure 6) in the limnetic region with higher abundance from March-June (peak in April), maxima in autumn (November) and lower abundance during February and July-September (monsoon). The copepods abundance in this region is significantly influenced by the diaptomid *Heliodiaptomus viduus* (r_2= 0.936, p = 0.004) > the cyclopoid *Mesocyclops leuckarti* (r_2= 0.818, p = 0.0174). The copepods, however, follow more oscillating density variations significantly influenced by *Heliodiaptomus viduus* (r_2= 0.791, p = 0.006) in the littoral region. The pre-monsoon peak and autumn maxima of Copepoda noted in the limnetic region (Fig. 6) concur with the reports of Sharmila and Shameem (2017) and Sharma and Sharma (2021). The reports of nauplii, throughout this study, indicate periods of active Copepoda reproduction concurrent with the reports of Sharma and Pachuau (2013), Sharma and Noroh (2020) and Sharma and Sharma (2020, 2021).

Rotifera register the differential spatio-temporal variations (Fig. 7), follow monthly density variations identical to zooplankton except during April-June in the limnetic region, and influence zooplankton abundance in the littoral (r_1=0.839, p = 0.002) and limnetic (r_2=0.760, p = 0.011) regions. Our results indicate the relatively high Rotifera abundance (Table 3) than the reports from the sub-tropical environs of Meghalaya (Sharma, 1995; Sharma and Lyngskor, 2003; Sharma and Lyngdoh, 2004). The abundance broadly concurs with reports from the lakes of Kashmir (Khan, 1987) and is marginally lower than the reports from the floodplain lakes of NEI (Sharma, 2011a, 2011b; Sharma and Sharma, 2011, 2012; Sharma and Noroh, 2020), and Nongmahir reservoir (Sharma and Sharma, 2020) and an urban wetland (Sharma and Sharma, 2021) of Meghalaya. Rotifera record winter (December) peak and winter maxima (January) in the limnetic region; the spring peak in the littoral region; and lower abundance during monsoon at both the regions. The winter peak / maxima concur with the results of Sharma (2011a), Sharma and Sharma (2011, 2012), while lower monsoon abundance differs from monsoon peaks vide the reports of Karuthapandi *et al*. (2016), Sharma and Noroh (2020) and Sharma and Sharma (2020, 2021). Brachionidae (r_1=0.854, p = 0.002; r_2=0.679, p = 0.031) and Conochilidae (r_1=0.893, p =0.0005; r_2=0.797, p=0.006) influence Rotifera abundance in the two regions. *Keratella cochlearis* influences the rotifer abundance at the littoral region (r_1=0.783, p = 0.007), and Brachionidae density at (r_1=0.874, p = 0.0009; r_2=0.972, p <0.0001) in both the regions.

Cladocera follow oscillating monthly density variations (Fig. 8), and record peak and maxima during winter in both the regions current with the reports from two floodplain lakes of Manipur (Sharma 2011a) but differ from pre-monsoon maxima vide the reports of Sharma

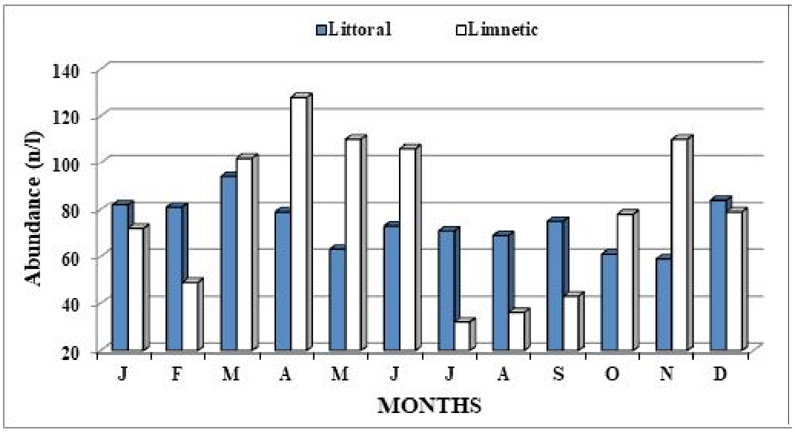

Fig. 6. Monthly variations of Copepoda abundance of Thadlaskein Lake

and Noroh (2020), Malik and Panwar (2016), Singh and Sharma (2020) and Sharma and Sharma (2020, 2021). This group records higher abundance (Table 3) as compared with the reports from Assam (Sharma and Hatimuria, 2017), Kashmir (Khan, 1987), Meghalaya (Sharma, 1995; Sharma and Lyngskor, 2003; Sharma and Lyngdoh, 2004) and Mizoram (Sharma and Pachuau, 2013), and abundance broadly concurs with the reports of Sharma and Noroh (2020) and Sharma and Sharma (2021). Bosminidae (r_1= 0.851, p = 0.002, r_2= 0.696, p = 0.024) influences Cladocera abundance in both the regions, while *Bosmina longirostris* exerts influence in the littoral region (r_1= 0.808, p = 0.005). Rhizopoda, another zooplankton group, records poor abundance concurrent with the results of Sharma and Sharma (2020) but lower than the reports of Sharma and Noroh (2020) and Sharma and Sharma (2021).

Zooplanktons register high species diversity (Table 3) with $H^{/}$ values > 3.0 throughout this study except during March-July and March-June in the littoral and limnetic regions (Fig. 9), respectively; ANOVA registers (Table 4) insignificant spatial and significant temporal diversity variations. The high zooplankton diversity is hypothesized to the overall habitat heterogeneity of Thadlaskein Lake. Further, high species diversity coupled with low densities of a majority of species and even the relatively lower abundance of important species, is hypothesized to fine niche portioning in combination with micro- and macro-habitat heterogeneity following Segers (2008). This attribute concurs with the reports of Sharma (2011a, 2011b), Sharma and Sharma (2011, 2012), Sharma and Pachuau (2013). Our results depict oscillating temporal patterns of zooplankton species diversity with peak values during November and August in the two regions. The diversity registers significant inverse relationship with dominance (r_2= -0.775, p = 0.008) and is positively influenced by evenness (r_2= 0.842, p = 0.002) in the limnetic region. Besides, it is positively influenced by zooplankton (r_1= 0.758, p = 0.011) and Cladocera (r_1= 0.739, p = 0.011) richness in the littoral region, and depicts inverse influence of Copepoda (r_2= -0.830, p = 0.003) and Diaptomidae (r_2= -0.808, p = 0.008) abundance in the limnetic region.

Our results highlight lower zooplankton dominance and high evenness (Table 3); both follow oscillating and differential patterns, and register insignificant spatial and temporal variations (vide ANOVA) in the two regions (Table 4). The dominance records maxima during August and April in the two regions, respectively. It is inversely influenced by abundance of zooplankton (r_1= -0.700, p = 0.024) in the littoral region, and is positively influenced by abundance of Copepoda (r_2= 0.712, p = 0.021) and Diaptomidae (r_2= 0.818, p = 0.004) in the limnetic region. The evenness records maxima during January and July in the two regions, respectively. Further, it registers significant inverse correlation with dominance (r_2= -0.779,

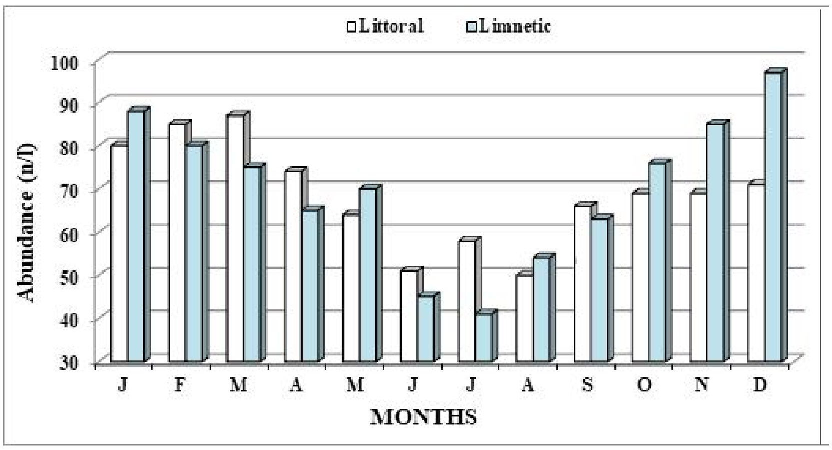

Fig. 7. Monthly variations of Rotifera abundance of Thadlaskein Lake

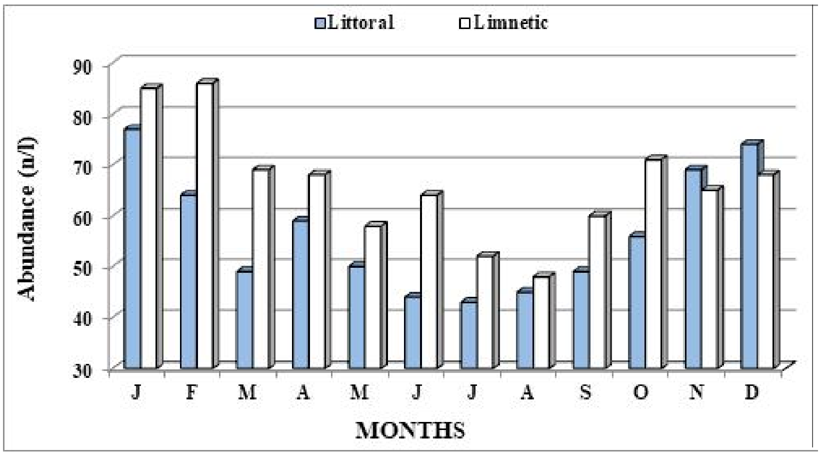

Fig. 8. Monthly variations of Cladocera abundance of Thadlaskein Lake

$p = 0.008$) and is inversely influenced by abundance of Copepoda (r_2= -0.902, $p = 0.0001$), Diaptomidae (r_2= -0.871, $p = 0.001$) and Cyclopidae (r_2= -0.700, $p = 0.024$) in the limnetic region. Higher evenness due to low densities and equitable abundance of a majority of species affirm the 'generalists' nature of zooplankton vis-à-vis the general environment of Thadlaskein Lake. This generalization concurs with the reports from the floodplain lakes of NEI (Sharma 2011a, 2011b; Sharma and Sharma, 2008, 2011, 2012; Sharma and Noroh, 2020) and an urban wetland of Meghalaya (Sharma and Sharma, 2021). Lower dominance and lack of species with distinct quantitative importance affirm that Thadlaskein Lake has resources for utilization by majority of species due to high amount of niche overlap as hypothesized by MacArthur (1965).

This present study registers the differential spatial influence of individual abiotic parameters on richness. This generalization is affirmed by inverse influence of specific conductivity on zooplankton (r_1= -0.863, $p = 0.0013$) and Rotifera (r_2= -0.870, $p = 0.0011$) richness in the littoral region; inverse influence of water temperature on zooplankton richness (r_2= -0.699, $p = 0.0245$) in the limnetic region, while zooplankton (r_2= 0.820, $p = 0.024$), Rotifera (r_2= 0.676, $p = 0.031$) and Cladocera (r_2= 0.716, $p = 0.020$) richness is positively influenced by magnesium (r_2= 0.820, $p = 0.024$) in the limnetic region. Our results differ from much limited influence vis-a-vis richness reported by Sharma and Sharma (2012, 2020, 2021), Sharma and Pachuau (2013) and Sharma and Noroh (2020).

Our study registers the differential spatial influence of individual abiotic parameters abundance of zooplankton assemblages in the two regions, and records the relative importance of water temperature, rainfall and transparency. Water temperature inverse influence on abundance of Rotifera (r_1= -0.753, $p = 0.0019$; r_2= -0.753, $p = 0.0019$) and Cladocera (r_1= -0.815, $p = 0.004$; r_2= -0.778, $p = 0.008$) in the two regions is attributed to lower densities of these groups during warmer periods. These remarks also hold valid vis-à-vis inverse influence of water temperature on abundance of Bosminidae (r_1= -0.782, $p = 0.0075$), Cyclopidae (r_1= -0.785, $p = 0.0071$) and *Bosmina longirostris* (r_1= -0.830, $p = 0.003$) in the littoral region, and on abundance of Brachionidae (r_2= -0.674, $p = 0.025$) and *Keratella cochlearis* (r_2= -0.718, $p = 0.019$) in the limnetic region. Inverse influence of rainfall on abundance of zooplankton (r_1= -0.796, $p = 0.006$; r_2= -0.819, $p = 0.0038$), Rotifera (r_1= -0.855, $p = 0.0016$; r_2= -0.783, $p = 0.007$) and Cladocera (r_1= -0.737, $p = 0.015$; r_2= -0.776, $p = 0.0083$) in the two regions is attributed to lower abundance of these groups during monsoon period. Likewise, inverse influence on abundance of Brachionidae (r_2= -0.763, $p = 0.0103$), Bosminidae (r_2= -0.757, $p = 0.011$), and Conochilidae (r_2= -0.817, $p = 0.004$) in the

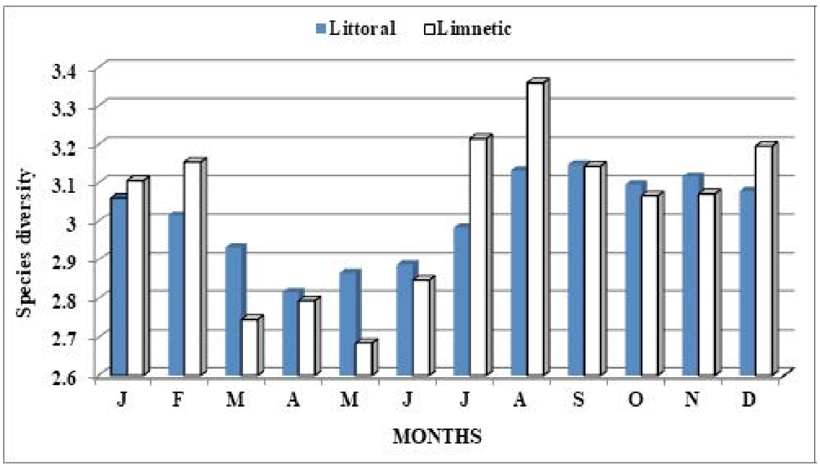

Fig. 9. Monthly variations of zooplankton species diversity of Thadlaskein Lake

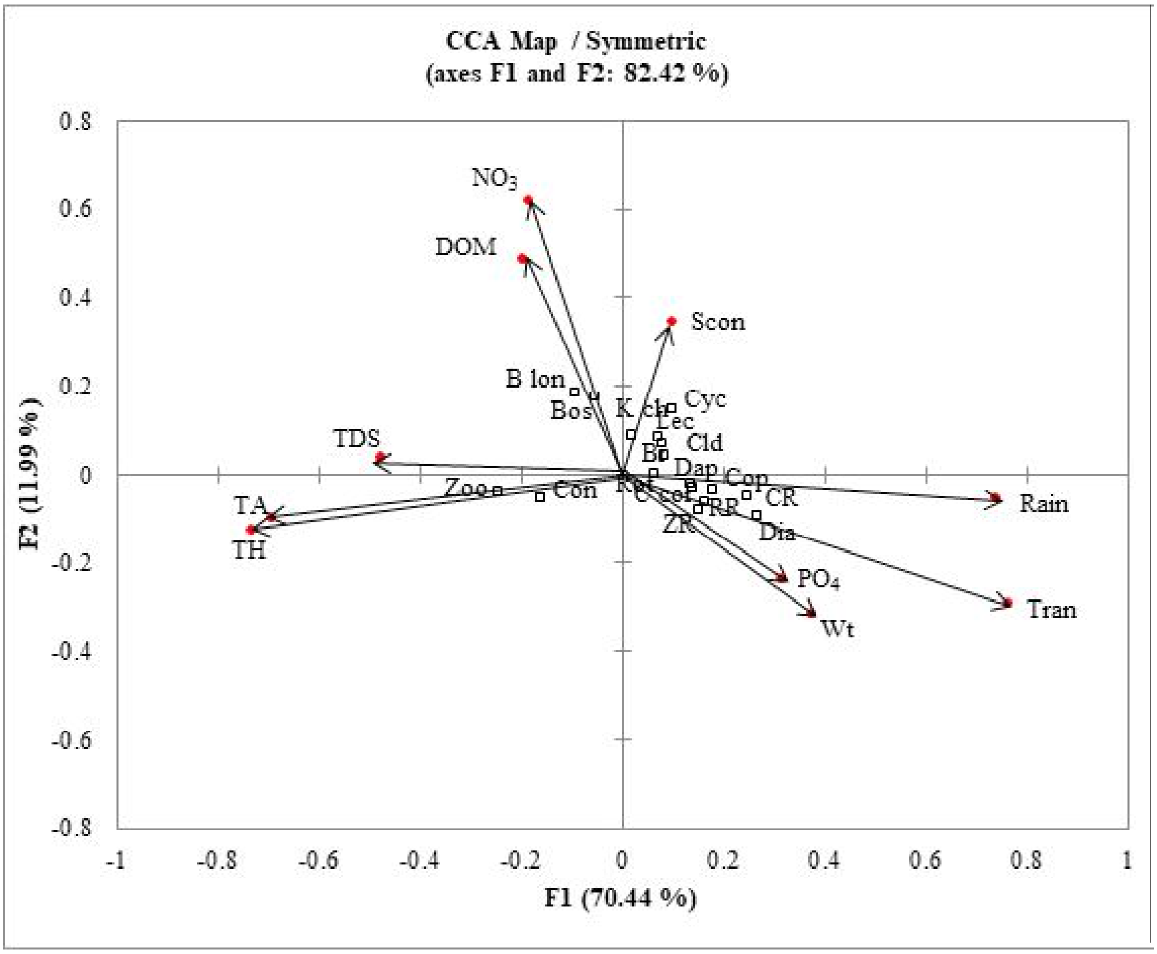

Fig. 10. CCA coordination biplot of zooplankton assemblage and abiotic factors (Littoral region)

Abbreviations: **Abiotic factors:** DOM (dissolved organic matter), NO_3 (nitrate), PO_4 (phosphate), Rain (rainfall), Scon (specific conductivity), TA (total alkalinity), TDS (total dissolved solids), TH (total hardness), Tran (transparency), Wt (water temperature). **Biotic factors:** B lon (*Bosmina longirostris* abundance), Bos (Bosminidae abundance), Br (Brachionidae abundance), C cor (*Ceriodaphnia cornuta* abundance), Chy (Chydoridae abundance), Cld (Cladocera abundance), CR (Cladocera richness), Con (Conochilidae abundance), Cop (Copepoda abundance), Cyc (Cyclopidae abundance), Dap (Daphniidae abundance), Dia (Diaptomidae abundance), K ch (*Keratella cochlearis* abundance), Lec (Lecanidae abundance), Rot (Rotifera abundance), RR (Rotifera richness), Zoo (Zooplankton abundance), ZR (Zooplankton richness).

littoral region depicts lower monsoon abundance of these families. Inverse influence of transparency on abundance of zooplankton (r_1= -0.804, p = 0.005; r_2= -0.749, p = 0.013) in the two regions; and on Rotifera (r_1= -0.812, p = 0.0043), Cladocera (r_1= -0.762, p = 0.010), Brachionidae (r_1= -0.697, p = 0.025), Bosminidae (r_1= -0.819, p = 0.004), Conochilidae (r_1= -0.842, p = 0.002), *Bosmina longirostris* (r_1= -0.848, p = 0.002) and *Keratella cochlearis* (r_1= -0.725, p = 0.018) abundance in the littoral region affirms lower densities of these taxa during period of the relatively lower transparency. Of the other abiotic factors, pH exerts an inverse influence on abundance of Brachionidae (r_1= -0.674, p = 0.030), and Conochilidae (r_1= -0.749, p = 0.013) in the littoral region. The periods of higher TA appear to be conducive to abundance of Rotifera (r_1= 0.686, p = 0.028), *Bosmina longirostris* (r_1= 0.704, p = 0.023) and *Keratella cochlearis* (r_1= 0.711, p = 0.021) at the littoral region as well as abundance of Brachionidae (r_2= 0.673, p = 0.033), Diaptomidae (r_2= 0.752, p = 0.012) and *Keratella cochlearis* (r_2= 0.697, p = 0.025) in the limnetic region. This generalization also holds valid for direct influence of TH on abundance of *Bosmina longirostris* (r_1= 0.678, p = 0.031) and *Keratella cochlearis* (r_1= 0.803, p = 0.005) in the littoral region, and on *Keratella cochlearis* (r_2= 0.727, p = 0.017) in the limnetic region. Mg records direct influence on abundance of Cladocera (r_1= 0.675, p = 0.028; r_2= 0.675, p = 0.022) in the two regions; NO_3 registers direct influence on abundance of zooplankton (r_1= 0.734, p = 0.016) and Rotifera (r_1= 0.769, p = 0.012) in the littoral region and that of Cladocera (r_2= 0.740, p = 0.014) in the limnetic regions; DOM exerts direct influence on abundance of Rotifera (r_1= 0.686, p = 0.028) in the littoral region and that of Cladocera (r_1= 0.796, p = 0.007; r_2= 0.740, p = 0.014) in the two regions; and TDS depicts direct influence on Cladocera abundance (r_1= 0.691, p = 0.027) in the littoral region. Our results, however, deviate from the limited influence of abiotic factors vs. abundance of zooplankton assemblages as reported by Sharma (2011a), Sharma and Sharma (2011, 2020, 2021), Sharma and Pachuau (2013) and Sharma and Noroh (2020).

The canonical correspondence analysis (CCA) registers

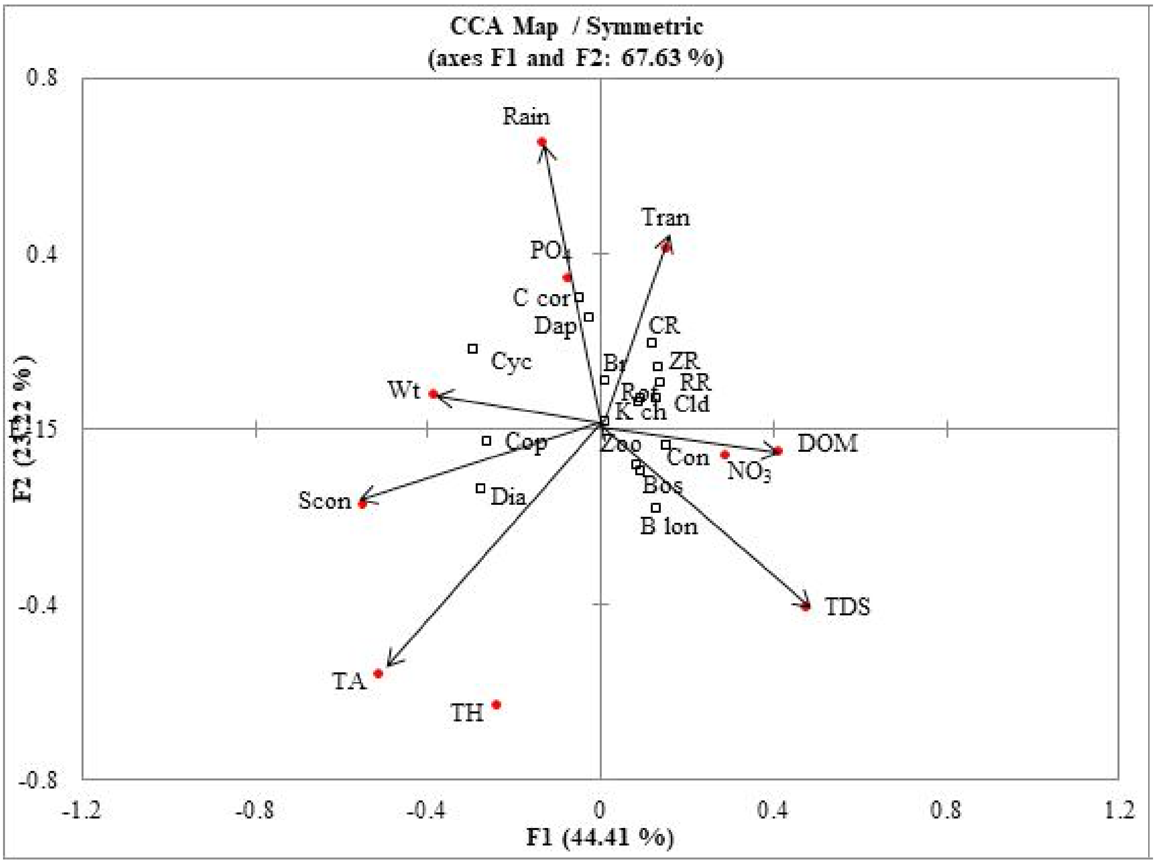

Fig. 11. CCA coordination biplot of zooplankton assemblage and abiotic factors (Limnetic region)

Abbreviations: **Abiotic factors:** DOM (dissolved organic matter), NO_3 (nitrate), PO_4 (phosphate), Rain (rainfall), Scon (specific conductivity), TA (total alkalinity), TDS (total dissolved solids), TH (total hardness), Tran (transparency), Wt (water temperature). **Biotic factors:** B lon (*Bosmina longirostris* abundance), Bos (Bosminidae abundance), Br (Brachionidae abundance), C cor (*Ceriodaphnia cornuta* abundance), Chy (Chydoridae abundance), Cld (Cladocera abundance), CR (Cladocera richness), Con (Conochilidae abundance), Cop (Copepoda abundance), Cyc (Cyclopidae abundance), Dap (Daphniidae abundance), Dia (Diaptomidae abundance), K ch (*Keratella cochlearis* abundance), Lec (Lecanidae abundance), Rot (Rotifera abundance), RR (Rotifera richness), Zoo (Zooplankton abundance), ZR (Zooplankton richness).

the differential cumulative influence of 10 abiotic factors on the littoral (82.42%) and limnetic (67.63%) zooplankton assemblages. The CCA coordination biplot indicates ~ 70% and ~12% influence of abiotic factors along axis 1 and 2, respectively in the littoral station (Fig. 10). Our results record influence of rainfall and transparency on Rotifera and Cladocera richness, and on Copepoda, Daphniidae, Diaptomidae and *Ceriodanphnia cornuta* abundance; water temperature and transparancy on zooplankton richness and Rotifera abundance; and TA and TH on abundance of zooplankton; specific conductivity on abundance of Cladocera, Cyclopidae, Brachionidae and *Keratella cochlearis*, while DOM and NO_3 influence abundance of Bosminidae and *Bosmina longirostris* in the littoral region.

The CCA coordination biplot indicates ~ 44% and ~23% influence of abiotic factors along axis 1 and 2, respectively in the limnetic region (Fig. 11). Specific conductivity influences Copeopoda abundance; specific conductivity and TA influence Diaptomitidae abundance; rainfall influences abundance of Daphniidae and *Ceriodaphnia cornuta*; TDS influences abundance of zooplankton, Bosminidae and *Bosmina longirotris*; and transparency exerts influence on richness of zooplankton, Rotifera and Cladocera, and on abundance of Rotifera, Cladocera and *Keratella cochlearis* in the limnetic region. High cumulative influence at the littoral region broadly concurs with the reports from Meghalaya (Sharma and Sharma, 2020, 2021) and Mizoram (Sharma and Pachuau 2013). Sladecek (1983) proposed QB/T quotient based on the ratios of *Brachionus* and *Trichocerca* species to assess trophic status of aquatic ecosystems. We caution on application of the said quotient vis-à-vis our study in view is distinct paucity of *Brachionus* spp. in soft and slightly acidic - circum neutral waters of Thadlaskein Lake. Nevertheless, application of Shannon Weiner diversity index, as another suitable option for assessing the health of aquatic biotopes (Wilhm and Dorris 1968; Masson 1998), affirms 'meso-trophic' of this lake.

4. Conclusion

The diverse zooplankton assemblage, the speciose constellations of 47-50 species per sample, the species-rich Rotifera with distinct paucity of Brachionidae and *Brachionus* spp. are notable features of soft, slightly acidic - circum neutral and de-mineralized waters of Thadlaskein Lake. The quantitative importance of zooplankton vis-à-vis net plankton, lower zooplankton abundance, the collective influence of Copepoda, Rotifera and Cladocera on the spatio-temporal variations of zooplankton abundance, high species diversity, low dominance, and high evenness are noteworthy. Lack of distinct quantitative importance of any individual species and lower and equitable abundance of the majority of species highlight 'generalist' nature of zooplankton. The spatial variations of the different aspects of zooplankton diversity and the differential spatial influence of abiotic factors are hypothesised to habitat heterogeneity amongst the two regions. This study is a useful contribution to zooplankton diversity of India, and that of the subtropical lacustrine systems of this country.

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