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ARTICLE

Zooplankton Diversity of a Soft-water and Highly De-mineralized Reservoir of Meghalaya (Northeast India): The Spatio-temporal Variations and Influence of Abiotic Factors

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ABSTRACT

Hydrobiological survey of a 'soft-water' and 'highly de-mineralized' reservoir of Meghalaya state of northeast India is undertaken to analyze zooplankton diversity with reference to the spatio-temporal variations and influence of abiotic factors. The littoral and limnetic zooplankton assemblages of this subtropical reservoir without aquatic vegetation reveal total 36 species, and record lower abundance, quantitative dominance of Rotifera, sub-dominance of Cladocera and Copepoda and moderate species diversity. *Keratella cochlearis, Bosmina longirostris, Polyarthra vulgaris, Mesocyclops leuckarti, Conochilus unicornis* and *Asplanchna priodonta* influence abundance, species diversity, dominance and equitability of zooplankton. We report differential spatial influence of individual abiotic factors with the relatively more importance at the limnetic region, and the canonical correspondence analysis registers 72.5% and 78.8% cumulative influence of 10 abiotic factors on the littoral and limnetic assemblages, respectively. The spatial differences of various diversity aspects and the influence of abiotic factors suggest habitat heterogeneity amongst the two regions. This study is a useful contribution to zooplankton diversity of the subtropical environs, and soft and de-mineralized waters in particular. Our results mark a distinct contrast to the lowest richness and abundance of zooplankton noted from India *vide* the preliminary 1990-91 survey of this reservoir.

1. Introduction

Though zooplankton have attracted attention in several hydro-biological surveys from distant parts of India, the limnology literature indicates proliferation of casual reports with incomplete species inventories and inadequate data-analysis vis-a-vis the paucity of the diversity studies based on the detailed analysis of zooplankton assemblages of the subtropical lacustrine environs of this country and north India [1,2], and soft and de-mineralized waters of the Indian sub-region in particular. Referring to north India, the useful limited works of zooplankton diversity interest from northwest India (NWI) deal with the selected lakes and reservoirs of Jammu & Kashmir [3,4], Himachal Pradesh [5] and Uttarakhand [6-8]. On the other hand, notable contributions

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[1,2,9] extend this lacuna to zooplankton diversity of the subtropical lacustrine environs of northeast India (NEI), while other surveys relate to a sub-tropical rice-field of Arunachal Pradesh [10] and a subtropical urban wetland of Meghalaya [11]. In addition, certain related works from NEI deal with the tropical floodplain lakes of Assam [12-14] and Manipur [15,16].

Our study on zooplankton diversity of 'highly de-mineralized' subtropical reservoir of Meghalaya state of NEI, a follow-up of an earlier limited 1990-91 survey [17], thus merits limnology interest for India and the Indian sub-region in light of the stated remarks. We analyze the littoral and limnetic zooplankton assemblages of this 'very soft-water' reservoir with reference to the spatio-temporal variations of species composition, richness, community similarities, abundance, species diversity, dominance and equitability as well as both the individual and cumulative influence of abiotic factors. Remarks are made on zooplankton diversity of the sampled reservoir in comparison with the related studies from the northwest India and NEI in particular, and the reports elsewhere from India as well as adjoining countries of the Indian sub-region. Besides, we indicate the salient temporal differences of zooplankton diversity vis-a-vis the preliminary survey [17] limited to the limnetic region of this reservoir.

2. Material and Methods

2.1 The Study Site

The present study is based on the limnological survey of a rainwater-fed reservoir (Figure 1, A-C; Lat. 25°34'N; Long.91°56'E, area ~10 ha; max. depth: 15 m; refereed as 'Shillong reservoir') conducted during January-December 2014. This reservoir is located at a distance of about 10 km from Shillong city, the capital of Meghalaya stats of northeast India; it serves as drinking water storage basin and lacks any aquatic vegetation and fish fauna.

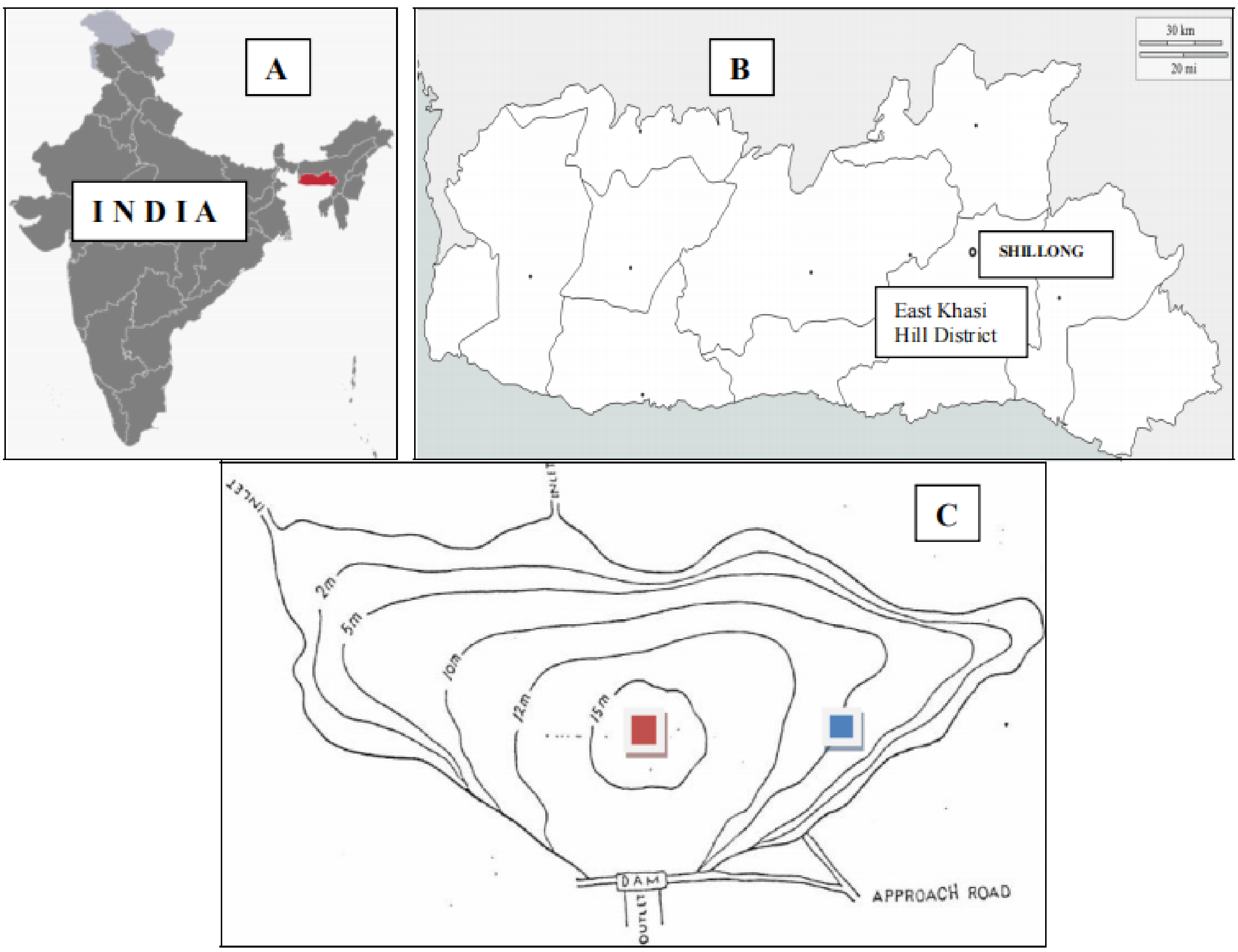

Figure 1 A-C. A, map of India showing Meghalaya state of northeast India (red color); B, map of Meghalaya indicating location of the capital city of Shillong; C, map of Shillong reservoir indicating the littoral (blue color) and limnetic (red color) regions

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2.2 Methods of Study

Water samples were collected at monthly interval from the littoral and the limnetic regions. Water temperature, pH and specific conductivity were noted with the field probes, transparency was recorded with a Secchi disc, dissolved oxygen (DO) was estimated by Winkler's method, and alkalinity, hardness, calcium (Ca), magnesium (Mg), chloride (Cl), phosphate (PO_4) and nitrate (NO_3) were analyzed following APHA [18]. The rainfall data were collected from the local meteorological station. The qualitative and quantitative plankton samples were collected monthly from the two regions and were preserved in 5% formalin. The former were obtained by towing nylobolt plankton net (#40 µm), and were screened with a Wild Stereoscopic binocular microscope for isolation of zooplankton. Various zooplankton, mounted in polyvinyl alcohol-lactophenol mixture, were observed with Leica stereoscopic microscope (DM 1000); the different species were identified following the standard literature [19-27]. The quantitative plankton samples were obtained by filtering 25 L of water each through nylobolt plankton net (#40 µm). The quantitative enumeration of zooplankton was done by using a Sedgewick-Rafter counting cell and abundance was expressed as ind. l^{-1}.

2.3 Data Analysis

The community similarities between monthly zooplankton assemblages were calculated vide Sørensen's index and the hierarchical cluster analysis was done using SPSS (version 20). Species diversity, dominance and evenness were computed vides Shannon-Weiner index, Berger-Parker index and E_1 index, respectively [28,29]. The significance of the spatial and temporal variations of abiotic and biotic parameters was ascertained by two-way ANOVA. Pearson correlation coefficients for the littoral and limnetic regions (r_1 and r_2, respectively) were calculated between abiotic and biotic parameters; p values (2-tailed) were calculated and their significance was noted after applying Bonferroni corrections. The canonical correspondence analysis was done (using XLSTAT 2015) to register cumulative influence of ten abiotic parameters (water temperature, rainfall, transparency, specific conductivity, pH, alkalinity, hardness, Cl, PO_4, and NO_3) on the littoral and limnetic zooplankton.

3. Results

Water temperature, rainfall, transparency, pH, specific conductivity, DO, alkalinity, hardness, Ca, Mg, Cl, PO_4, and NO_3 range between 11.0-21.0 ^oC, 0.6-780.5 mm, 1.6-2.2 m, 5.64-6.67, 11.5-19.2 µS/cm^{-1}, 7.0-8.8 mg l^{-1}, 9.0-16.8 mg l^{-1}, 6.0-13.2 mg l^{-1}; 3.6-7.6 mg l^{-1}, 0.2-0.9 mg l^{-1}, 18.0-42.0 mg l^{-1}, 0.072-0.190 mg l^{-1} and 0.066-0.196 mg l^{-1}, respectively during the study period (Table 1). The significance of spatio-temporal of variations of abiotic factors is indicated in Table 2.

The variations of richness and abundance of zooplankton, abundance of different groups and important species, and diversity indices are indicated in Table 3. The significance of spatio-temporal variations of biotic parameters is indicated in Table 4. The littoral and limnetic zooplankton reveal total 36 species, and record

Table 1. The spatio-temporal variations of abiotic factors

Factors↓	Regions→	Littoral		Limnetic	
		Range	Average ± S.D	Range	Average ± S.D
Water temperature	**^0C**	11.0-21.0	17.1±3.5	11.0-20.5	16.8±3.3
Rainfall	**mm**	0.6-780.5	211.6±223.7	0.6-780.5	211.6±223.7
Transparency	**m**	1.6-2.2	1.88±0.16	1.6-2.2	1.93±0.16
pH		5.65-6.67	6.21±0.22	5.64-6.55	6.16±0.26
Specific conductivity	**µScm^{-1}**	11.5-19.2	15.8±2.5	12.0-19.0	15.8±2.2
DO	**mg l^{-1}**	7.0-8.6	7.8±0.4	7.2-8.8	7.9±0.4
Alkalinity	**mg l^{-1}**	9.0-16.8	11.8±2.3	9.2-16.4	11.7±2.1
Hardness	**mg l^{-1}**	6.2-13.2	8.6±2.2	6.0-13.0	8.7±2.2
Ca	**mg l^{-1}**	3.8-7.6	5.3±1.2	3.6-7.0	5.0±1.3
Mg	**mg l^{-1}**	0.2-0.9	0.2±0.3	0.2-0.8	0.4±0.2
Cl	**mg l^{-1}**	19.0-42.0	30.4±6.7	18.0-40.0	29.4±6.4
PO_4	**mg l^{-1}**	0.072-0.190	0.128 ±0.035	0.080-0.190	0.128±0.031
NO_3	**mg l^{-1}**	0.066-0.196	0.108±0.040	0.070-0.188	0.110±0.036

Table 2. The spatio-temporal significance of abiotic factors

Parameters	Regions	Months
Water temperature	-	$F_{11,23}$=244.629, P=1.62E-11
Transparency	$F_{1,23}$ = 17.742, P = 0.001	$F_{11,23}$ = 9.069, P = 0.0003
pH	-	$F_{11,23}$ = 196.986, P=5.52E-11
Specific conductivity	-	$F_{11,23}$ = 66.715, P=1.94E-08
DO	$F_{11,23}$ = 10.632, P=0.0076	$F_{11,23}$ = 30.779, P=1.17E-06
Alkalinity	-	$F_{11,23}$ = 129..223, P = 5.47E-10
Hardness	-	$F_{11,23}$ = 342.936, P = 2.67E-12
Ca	$F_{1,23}$ = 27.770, P=0.0002	$F_{11,23}$ = 78.814, P = 7.93E-09
Mg	-	$F_{11,23}$ = 17.551, P = 2.06E-05
Cl	$F_{1,23}$ = 15.531, P=0.0023	$F_{11,23}$ = 220.202, P = 3.01E-11
PO_4	-	$F_{11,23}$ = 157.459, P = 1.87E-10
NO_3	-	$F_{11,23}$ = 195.429, P = 5.96E-11

(-) indicates insignificant variations

Table 3. The spatio-temporal variations of zooplankton

QUALITATIVE		Littoral region		Limnetic region	
Zooplankton richness		36; 15-22 (18±2) species		34; 15-25 (19±3) species	
Community similarities		43.7-86.5%		45.2-82.3%	
Rotifera richness		22; 7-13 (11±2) species		20; 10-15 (11±2) species	
QUANTITATIVE					
Net Plankton	ind. l^{-1}	281-1194	647±234	275-560	394±99
Zooplankton	ind. l^{-1}	113-307	218±70	74-238	177±51
Percentage of net plankton		18.5-67.0	37.8±17.3	28.6-73.1	46.6±15.0
Species Diversity		1.822-2.535	2.076± 0.194	1.885-2.706	2.133±0.209
Dominance		0.186-0.411	0.302± 0.057	0.200-0.398	0.298±0.062
Evenness		0.646-0.861	0.719± 0.053	0.680-0.841	0.733±0.043
Different Groups					
Rotifera	ind. l^{-1}	64-228	132±54	50-163	110±33
Percentage of zooplankton		51.1-76.2	59.0±7.9	51.7-70.9	62.6±5.2
Cladocera	ind. l^{-1}	23-84	44±19	13-56	33±13
Percentage of zooplankton		12.4-28.1	20.4±4.6	14.2-25.4	18.4±3.2
Copepoda	ind. l^{-1}	19-57	38±12	12-50	30±11
Percentage of zooplankton		9.04-29.6	18.2±5.7	12.2-26.3	16.6±3.7
Rhizopoda	ind. l^{-1}	1-12	4±3	1-9	4±2
Important Species					
Keratella cochlearis	ind. l^{-1}	21-123	62±27	22-78	51±18
Bosmina longirostris	ind. l^{-1}	20-79	41±18	10-54	32±13
Polyarthra vulgaris	ind. l^{-1}	10-82	29±23	3-42	22±12
Mesocyclops leuckarti	ind. l^{-1}	12-51	30±13	9-38	22±9
Conochilus unicornis	ind. l^{-1}	2-31	12±10	2-32	12±9
Asplanchna priodonta	ind. l^{-1}	5-31	16±8	4-22	13±5

36 and 34 species at the two regions, respectively. The monthly zooplankton richness ranges between 15-22 and 15-25 species (Figure 2) and register 43.7-86.5% and 45.2-82.3% community similarities, and Rotifera record richness between 7-13 and 10-15 species, at the two regions, respectively. Zooplankton hierarchical cluster analysis (Figures 3-4) exhibits differences in the cluster groupings at the two regions.

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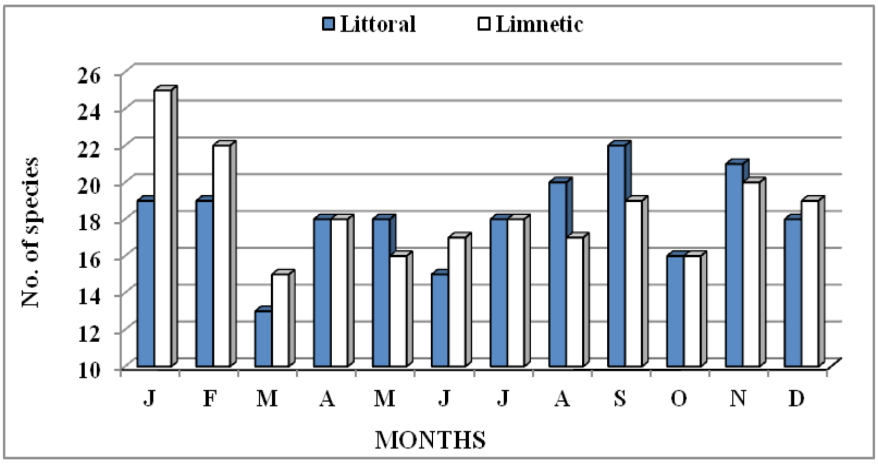

Figure 2. Monthly variations of zooplankton species richness

Table 4. The spatio-temporal significance of zooplankton

Parameters	Regions	Months
Zooplankton richness	-	$F_{11,23}$ = 3.162, P= 0.0344
Rotifera richness	-	$F_{11,23}$ = 3.453, P= 0.0255
Abundance		
Zooplankton	$F_{1,23}$ = 15.849, P = 0.002	$F_{11,23}$ = 11.904, P = 0.0001
Rotifera	$F_{1,23}$ = 6.895, P = 0.015	$F_{11,23}$ = 9.859, P = 0.0003
Cladocera	-	-
Copepoda	$F_{1,23}$ = 49.107, P = 2.25E-05	$F_{11,23}$ = 34.348, P = 6.68E-07
Zooplankton species diversity	-	$F_{11,23}$ = 17.253, P = 2.25E-05
Dominance	-	$F_{11,23}$ = 3.807, P = 0.0181
Evenness	-	$F_{11,23}$ = 9.657, P = 0.0004
Important species		
Keratella cochlearis	$F_{1,23}$ = 6.037, P = 0.032	$F_{11,23}$ = 8.087, P = 0.0008
Bosmina longirostris	-	-
Polyarthra vulgaris	-	$F_{11,23}$ = 4.354, P = 0.011
Mesocyclops leuckarti	$F_{1,23}$ = 25.361, P = 0.0004	$F_{11,23}$ = 16.132, P = 3.14E-05
Conochilus unicornis	-	$F_{11,23}$ = 17.803, P = 1.92E-05
Asplanchna priodonta	-	$F_{11,23}$ = 6.203, P = 0.003

(-) insignificant variations

Zooplankton record abundance ranging between 113-307 and 74-238 ind. l^{-1} (Figure 5), comprise between 18.5-67.0% and 28.6-73.1% of net plankton, indicate species diversity ranging between 1.822-2.535 and 1.885-2.706 (Figure 6), and dominance, and evenness range between 0.186-0.411 and 0.200-0.398 (Figure 7) and 0.646-0.861 and 0.680-0.841 (Figure 8) at the two regions, respectively. *Keratella cochlearis* (62±27, 51±18 ind. l^{-1}), *Bosmina longirostris* (41±18, 32±13 ind. l^{-1}), *Polyarthra vulgaris* (29±23, 22±12 ind. l^{-1}), *Mesocyclops leuckarti* (30±13, 22±9 ind. l^{-1}), *Conochilus unicornis* (12±10, 12±9 ind. l^{-1}) and *Asplanchna priodonta* (16±8, 13±5 ind. l^{-1}) indicate quantitative importance at the two sampled regions (Figures 9-10).

Rotifera record abundance ranging between 71-285 and 57-212 ind. l^{-1} (Figure 11) and comprise between 51.1-76.2 and 51.7-70.9% of zooplankton; Cladocera (23-84 and 13-56 ind. l^{-1}) and Copepoda (19-57 and 12-50 ind. l^{-1}) and comprise between 12.4-28.1 and 14.2-25.4% and 9.04-29.6 and 12.2-26.3% of zooplankton abundance at the littoral and limnetic regions, respectively (Figures 12-13). Rhizopoda and Gastrotricha record poor abundance at the two regions.

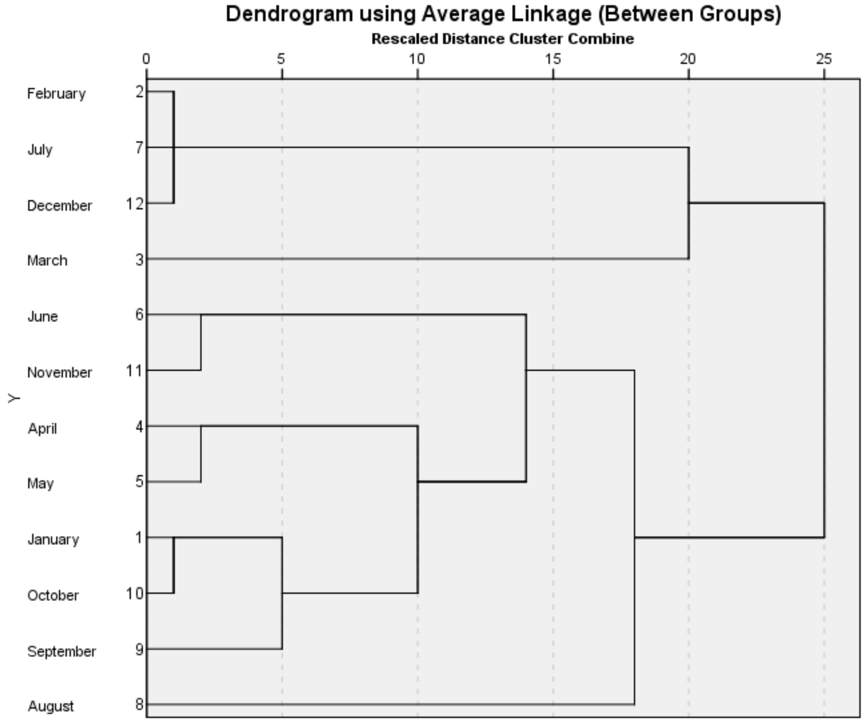

Figure 3. Hierarchical cluster analysis of zooplankton assemblages (Littoral region)

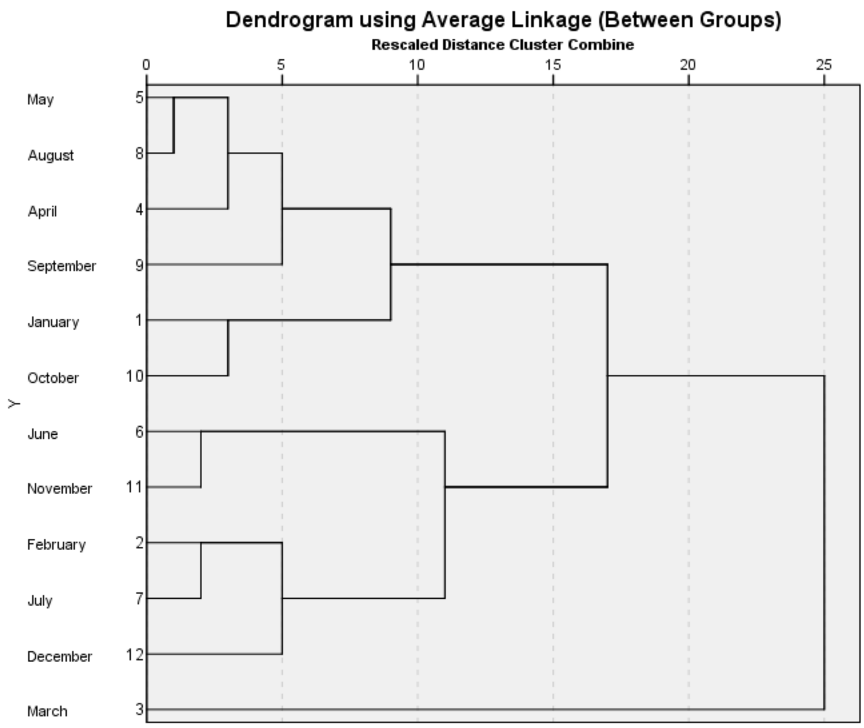

Figure 4. Hierarchical cluster analysis of zooplankton assemblages (Limnetic region)

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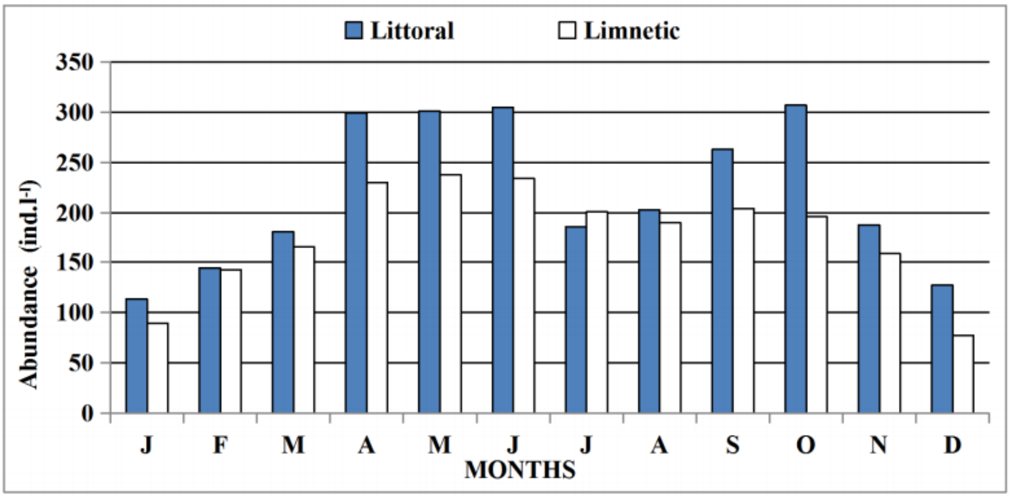

Figure 5. Monthly variations of zooplankton abundance

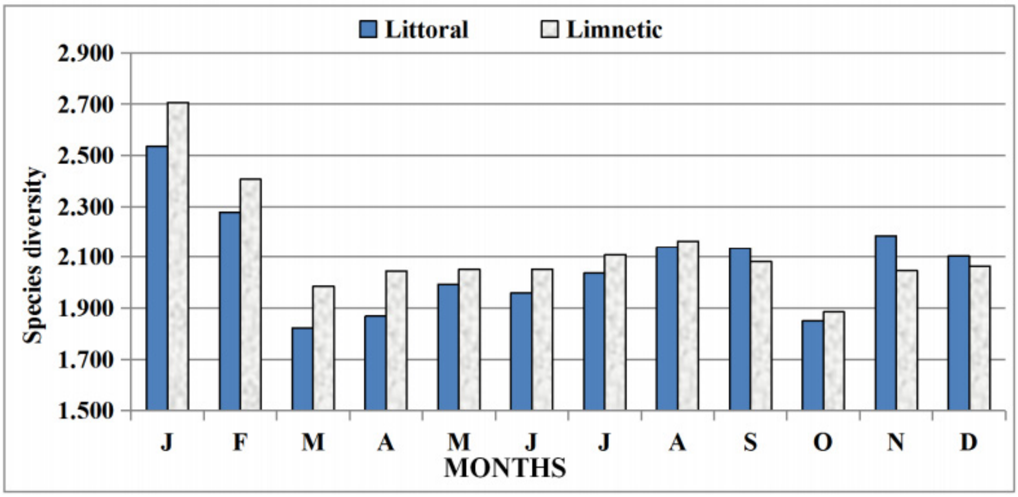

Figure 6. Monthly variations of zooplankton species diversity

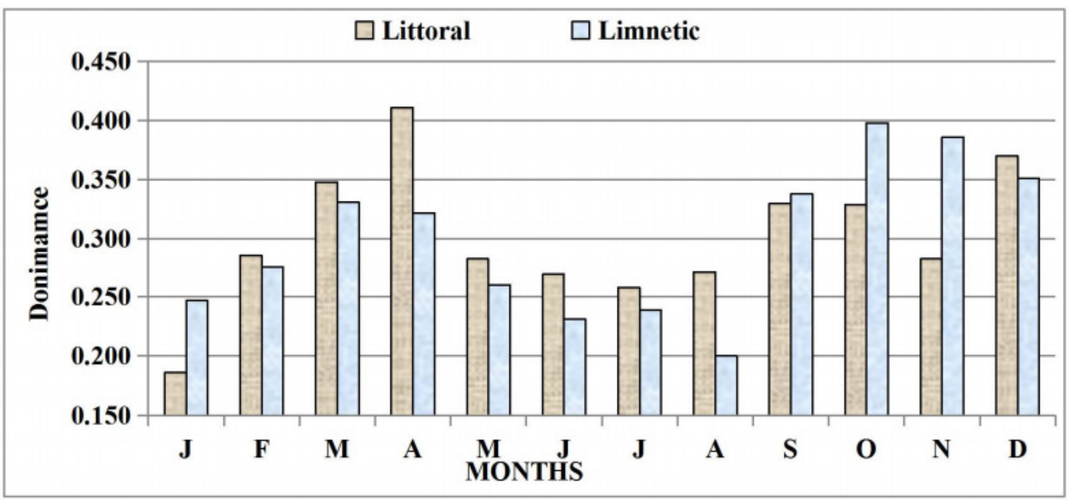

Figure 7. Monthly variations of zooplankton dominance

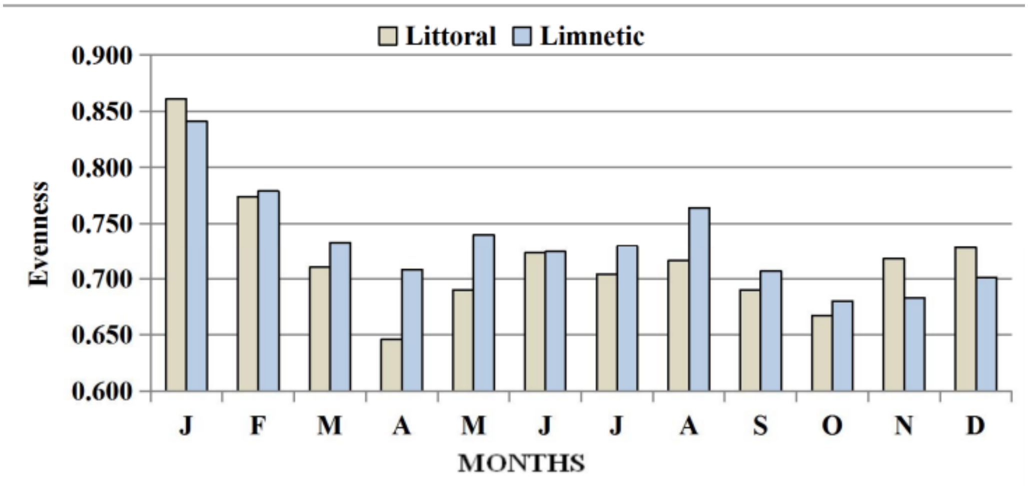

Figure 8. Monthly variations of zooplankton evenness

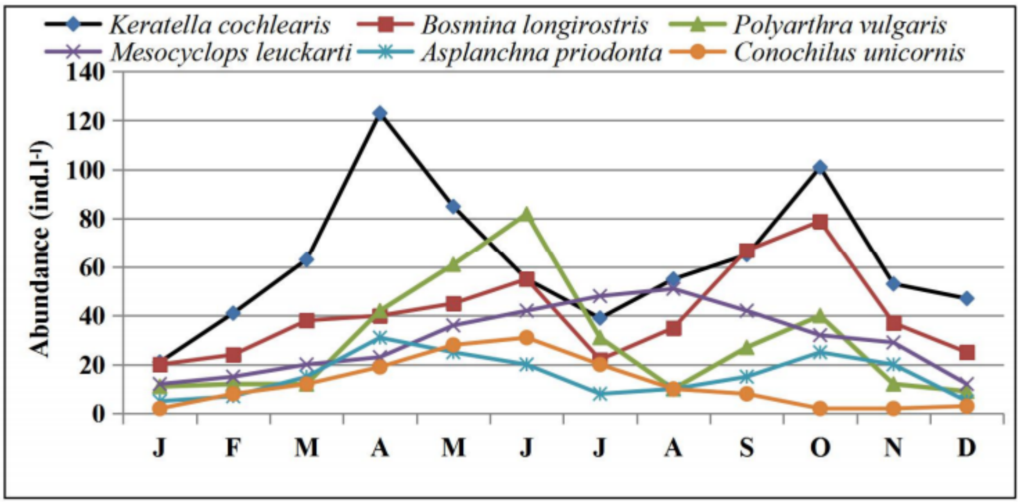

Figure 9. Monthly variations of abundance of important species (Littoral region)

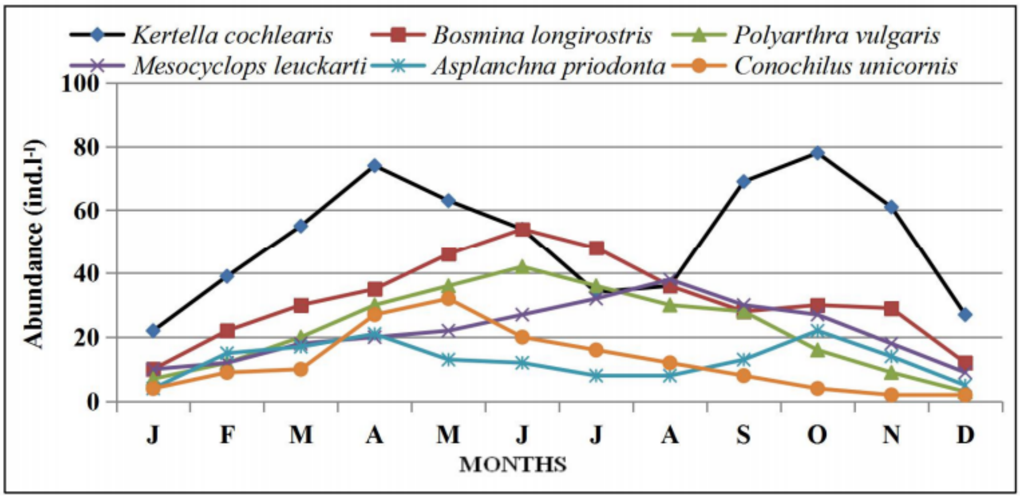

Figure 10. Monthly variations of abundance of important species (Limnetic region)

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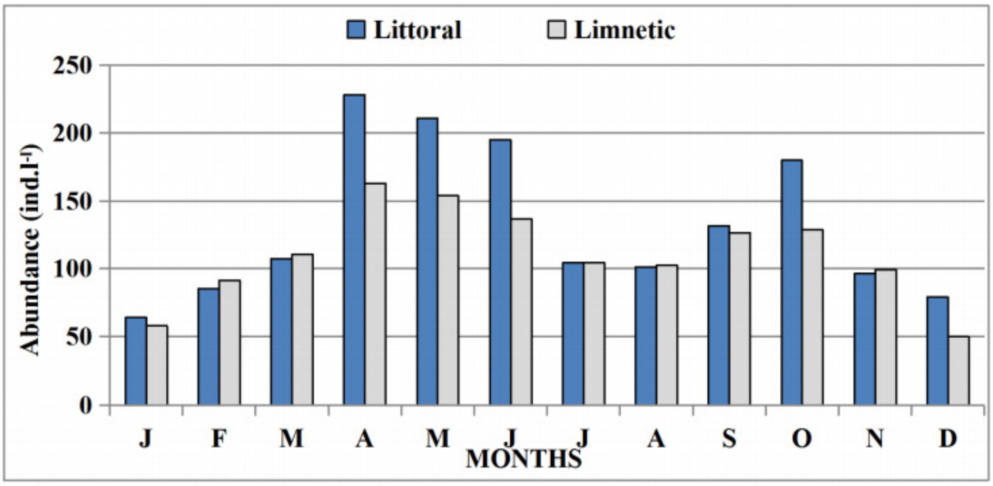

Figure 11. Monthly variations of Rotifera abundance

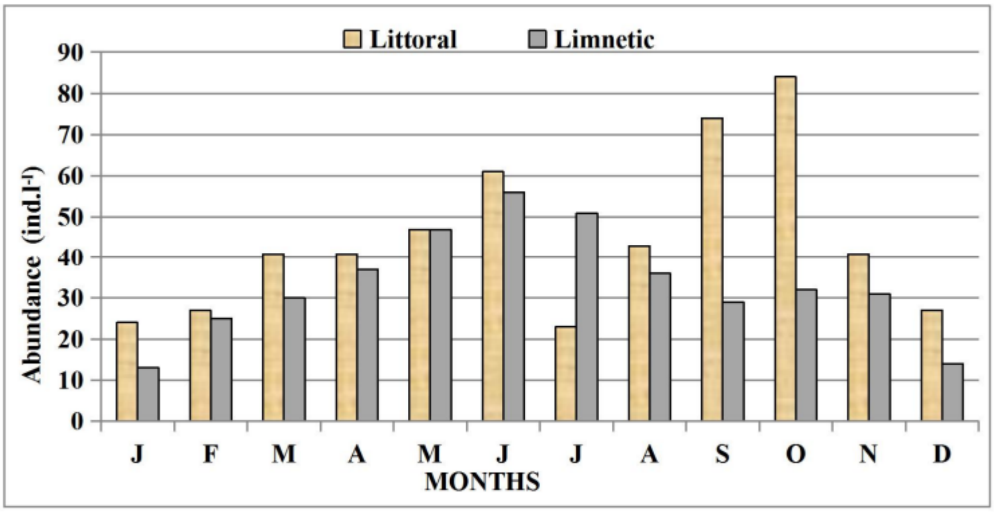

Figure 12. Monthly variations of Cladocera abundance

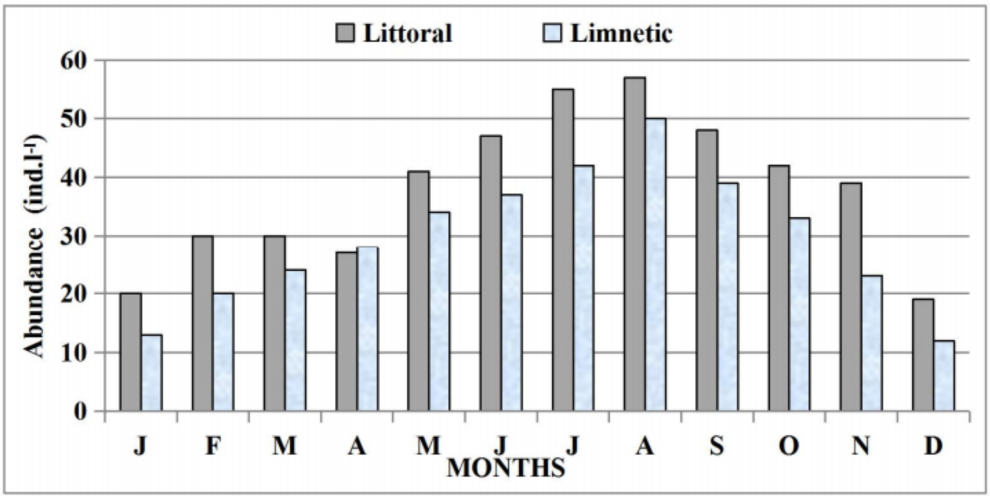

Figure 13. Monthly variations of Copepoda abundance

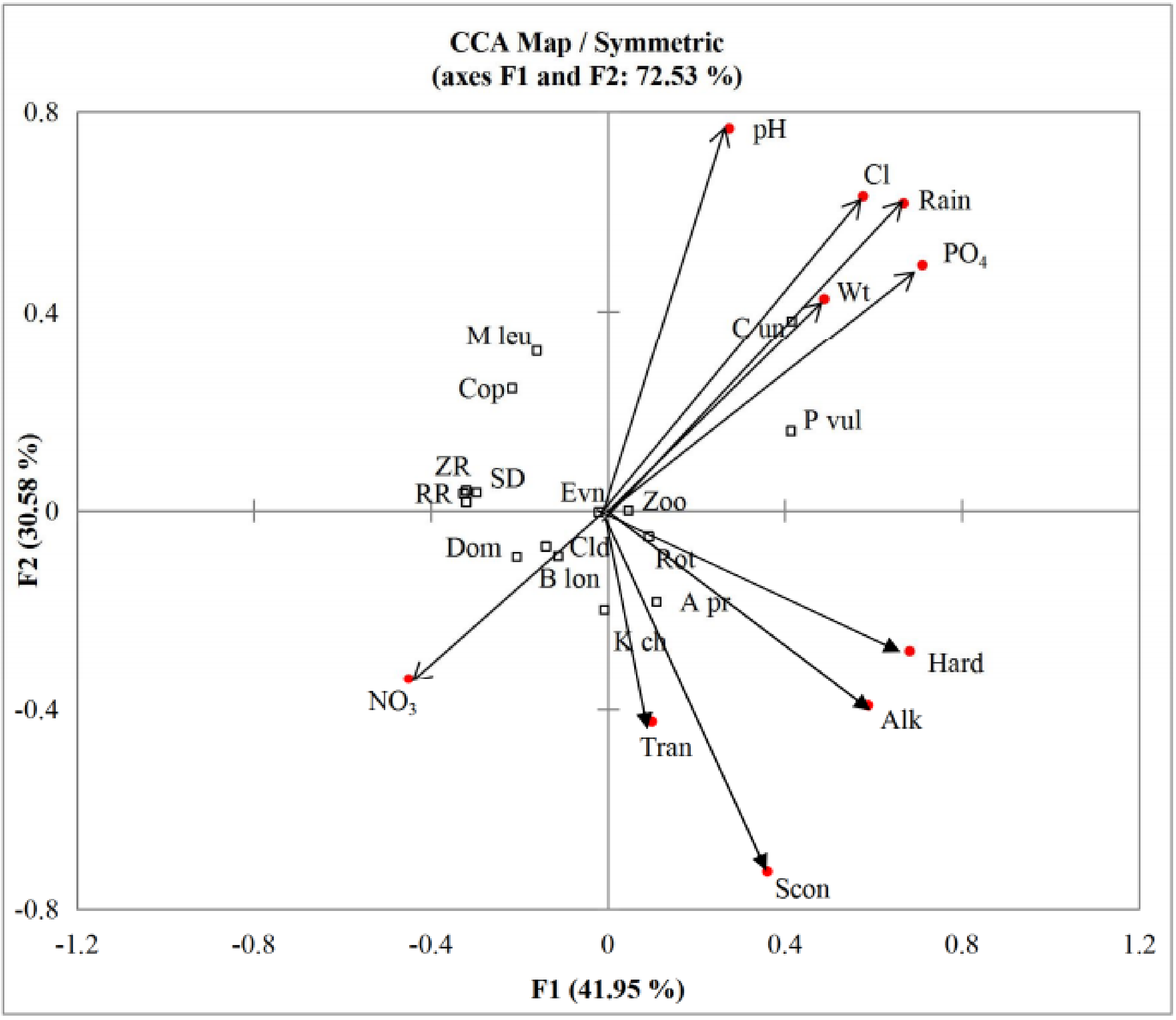

Figure 14. CCA coordination biplot of zooplankton and abiotic factors (Littoral region)

Abbreviations

Abiotic factors: Alk (alkalinity), Cl (chloride), Hard (hardness), NO_3 (nitrate), pH (hydrogen-ion concentration), PO_4 (phosphate), Rain (rainfall), Scon (specific conductivity), Trans (transparency), Wt (water temperature).

Biotic factors: A pr (*Asplanchna priodonta* abundance), B lon (*Bosmina longirostris* abundance), C un (*Conochilus unicornis* abundance), Cld (Cladocera abundance), Cop (Copepoda abundance), Dom (dominance), Evn (evenness), K ch (*Keratella cochlearis* abundance), M leu (*Mesocyclops leuckarti* abundance), P vul (*Polyarthra vulgaris* abundance) Rot (Rotifera abundance), RR (Rotifera richness), SD (species diversity), Zoo (Zooplankton abundance), ZR (Zooplankton richness).

Of the recorded abiotic factors, water temperature exerts an inverse influence on zooplankton (r_2= -0.674, p = 0. 0162), and Rotifera (r_2 = -0.708, p = 0. 0100) richness at the limnetic region. It records a positive influence on abundance of zooplankton (r_1 =0.734, p = 0. 0066; r_2 = 0.912, p < 0. 0001), Copepoda (r_1 =0.833, p = 0. 0008; r_2 = 0.912, p < 0. 0001) and *Mesocyclops leuckarti* (r_1 =0.890, p = 0. 0001; r_2 = 0.901, p < 0. 0001) at the two regions; an inverse influence on zooplankton evenness at the littoral region (r_1= -0.714, p = 0. 0091); and positive influence on abundance of Rotifera (r_2 = 0.779, p = 0. 0028), Cladocera (r_2 = 0.836, p = 0. 0007), *Bosmina longirostris* (r_2 = 0.855, p = 0. 0004), and *Polyarthra vulgaris* (r_2 = 0.866, p = 0. 0003) abundance at the limnetic region. Rainfall registers positive correlation on abundance of *P. vulgaris* (r_1 = 0.814, p = 0. 0013), *M.leuckarti* (r_1 =0.694, p = 0. 0123) and *Conochilus unicornis* (r_1 = 0.832, p = 0. 0008) at the littoral region, and on abundance of Cladocera (r_2 = 0.887, p = 0. 0001), *B.longirostris* (r_2 = 0.874, p = 0. 0002), and *P. vulgaris* (r_2 = 0.872, p = 0. 0002) at the limnetic region.

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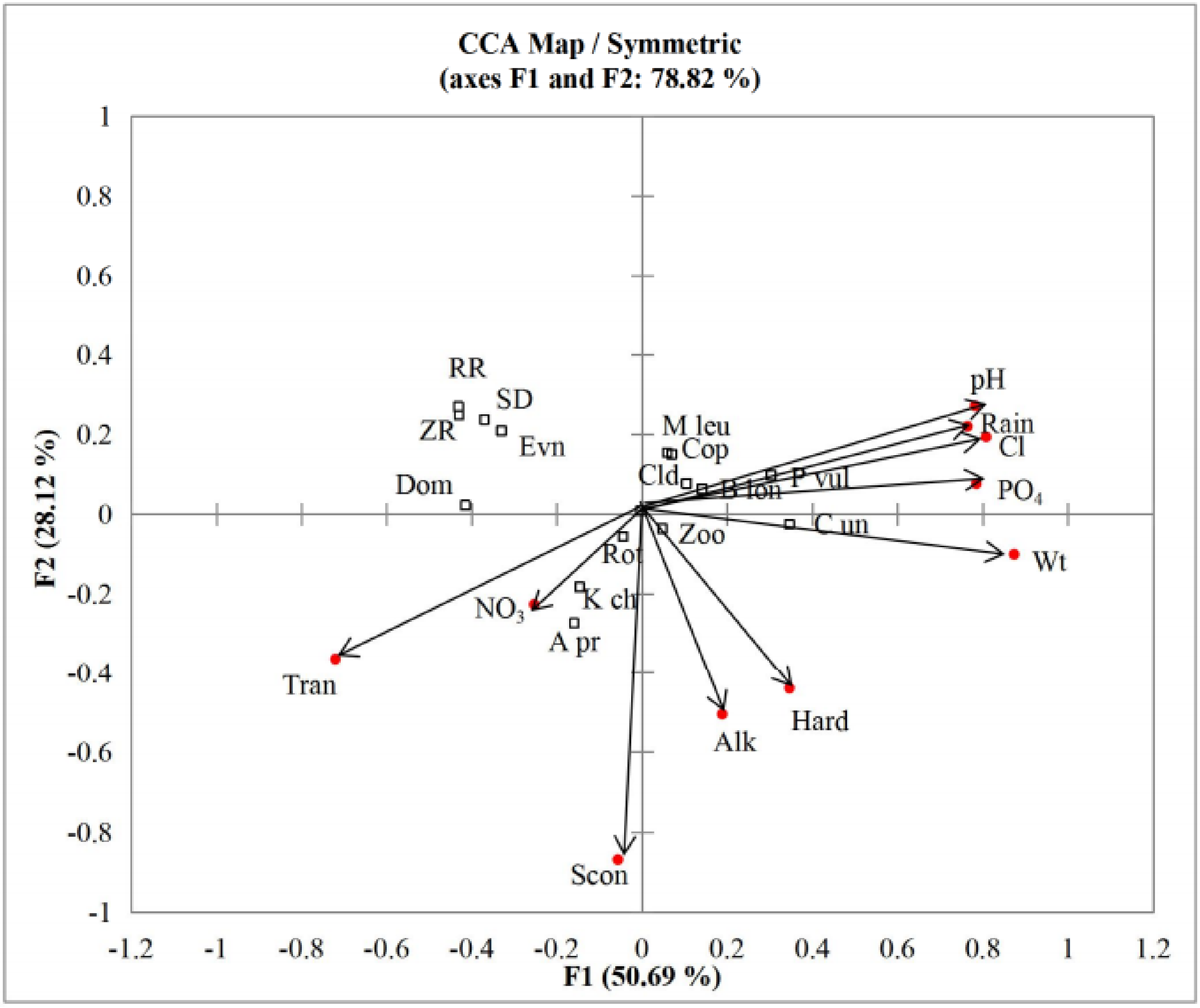

Figure 15. CCA coordination biplot of zooplankton and abiotic factors (Limnetic region)

Abbreviations

Abiotic factors: Alk (alkalinity), Cl (chloride), Hard (hardness), NO_3 (nitrate), pH (hydrogen-ion concentration), PO_4 (phosphate), Rain (rainfall), Scon (specific conductivity), Trans (transparency), Wt (water temperature).

Biotic factors: A pr (*Asplanchna priodonta* abundance), B lon (*Bosmina longirostris* abundance), C un (*Conochilus unicornis* abundance), Cld (Cladocera abundance), Cop (Copepoda abundance), Dom (dominance), Evn (evenness), K ch (*Keratella cochlearis* abundance), M leu (*Mesocyclops leuckarti* abundance), P vul (*Polyarthra vulgaris* abundance) Rot (Rotifera abundance), RR (Rotifera richness), SD (species diversity), Zoo (Zooplankton abundance), ZR (Zooplankton richness).

pH affirms positive correlation with abundance of Copepoda (r_1 =0.879, p = 0. 0002; r_2 = 0.856, p = 0. 0001) and *M. leuckarti* (r_1 =0.860, p = 0. 0001; r_2 = 0.816, p = 0. 0012) at the two regions, while it indicates a positive correlation with abundance zooplankton (r_2 = 0.703, p = 0. 0108), Cladocera (r_2 = 0.755, p = 0. 0045), *B. longirostris* (r_2 = 0.763, p = 0. 0039), and *P. vulgaris* (r_2 = 0.788, p = 0. 0023) at the limnetic region. Specific conductivity registers positive correlation on abundance of *K. cochlearis* (r_1 =0.769, p = 0. 0035; r_2 = 0.864, p = 0. 000312) at the two region and that of *A. priodonta* (r_1 =0.861, p = 0. 00013) at the littoral region. Transparency records an inverse influence on abundance of Copepoda (r_2 = -0.804, p = 0. 0016), *P. vulgaris* (r_2 = -0.788, p = 0. 0002), *M. leuckarti* (r_2 =-0.772, p = 0. 0033) and positive influence on zooplankton dominance (r_2 =0.675, p = 0. 0160) only at the limnetic region.

Cl registers positive correlation on abundance of zooplankton (r_1 = 0.731, p = 0. 0067; r_2 = 0.731, p = 0. 0067), Copepoda (r_1 = 0.767, p = 0. 0036; r_2 = 0.785, p = 0.

0025), *M. leuckarti* (r_1 =0.845, p = 0. 0005; r_2 = 0.749, p = 0. 0051) and *P. vulgaris* (r_1 =0.681, p = 0. 0148; r_2 = 0.803, p = 0. 0017) at the littoral and limnetic regions. Besides, it records a positive influence on abundance of *C. unicornis* (r_1 = 0.744, p = 0. 0055) at the littoral region and that of Cladocera (r_2 = 0.785, p = 0. 00245) and *B. longirostris* (r_2 = 0.861, p = 0. 0003) at the limnetic region. PO_4 exerts positive correlations with abundance of *P. vulgaris* (r_1 = 0.802, p = 0. 0017; r_2 = 0.815, p = 0. 0012) at both the regions. It records an inverse influence on Rotifera richness (r_2= -0.697, p = 0. 0152), and records positive correlations with abundance of zooplankton (r_2 = 0.747, p = 0. 0052), Cladocera (r_2 = 0.918, p < 0. 0001) and B. *longirostris* (r_2 = 0.909, p < 0. 0001) at the limnetic region. Besides, PO_4 exerts positive correlations with abundance *M.leuckarti* (r_1 =0.706, p = 0. 0103) and *C. unicornis* (r_1 = 0.744 p = 0. 0055) at the littoral region. NO_3 shows limited importance at the limnetic region with positive correlations on abundance of Cladocera (r_2 = 0.703, p = 0. 0108) and B. *longirostris* (r_2 = 0.681, p = 0. 0148). The canonical correspondence analysis (CCA) registers the differential cumulative influence of 10 abiotic factors on the littoral (72.5%) and limnetic (78.8%) zooplankton assemblages (Figures 14-15).

4. Discussion

The present study records one of the lowest specific conductivity known from any aquatic environ of the Indian sub-continent [1,2,11,17,30,31]. This notable feature, indicating highly de-mineralized nature of the subtropical Shillong reservoir, is attributed to the weathered and leached nature of rocks and soils of the catchment area due to high rainfall [2]. Besides, this rainwater-fed reservoir indicates very soft, acidic, calcium poor and oxygenated waters, and lower concentrations of PO_4, NO_3, Mg and Cl. ANOVA registers significant spatio-temporal variations of transparency, DO, Ca and Cl, while water temperature, pH, specific conductivity, alkalinity, hardness, Mg, Cl, PO_4 and NO_3 record significant temporal variations.

Total 36 species observed vide our study reveal the relatively less diverse zooplankton of Shillong reservoir devoid of any aquatic vegetation; the richness marks a distinct threefold increase than earlier survey [17]. The species tally is higher as compared with the reports from the lacustrine environs of Jammu & Kashmir [3], Himachal Pradesh [8] and Uttarakhand [6,32-34] from NWI; elsewhere from India from Karnataka [35], Tamil Nadu [36-38] and Telangana [39]; and the reports from Bhutan [31] and Nepal [40]. Our study, however, indicates lower richness than observed from certain subtropical lakes and reservoirs of NEI [1,2,9]. Total 36 and 34 species examined from the littoral and limnetic regions, respectively register ~97% community similarity and depict overall homogeneity of zooplankton composition amongst the two regions.

Zooplankton richness follows oscillating monthly variations; it records peaks during (post-monsoon) and winter (January) at the littoral and limnetic regions respectively, and registers (vide ANOVA) insignificant spatial and significant temporal variations. Rotifera significantly influence the littoral (r_1 = 0.975, p <0.0001) and limnetic (r_2 = 0.918, p=0.0002) zooplankton monthly richness, and register (vide ANOVA) insignificant spatial and significant temporal variations. The notable paucity of *Brachionus* species amongst Rotifera is attributed to soft and acidic waters of the sampled reservoir concurrent with the reports from NEI [1,2,9,11,41,42]. The littoral and limnetic zooplankton assemblages record 43.7-86.5% and 45.2-82.3% community similarities (vide Sørensen's index), respectively. Peak similarities between February-July and May-August collections, the differential monthly cluster groupings noted vide the hierarchical cluster analysis, and 72.9% and 60.6% instances indicating similarity values between 51-70% at the two regions suggest heterogeneity of zooplankton composition within the two regions individually. This generalization is supported by the closer affinities between February-July-December and again between January-October collections at the littoral region while zooplankton indicate closer affinity during May-August at the limnetic region, while March > August, and March assemblages record maximum divergence at the two regions, respectively.

Our results highlight lower zooplankton abundance with significant spatio-temporal variations (vide ANOVA). Lower abundance, attributed to the 'de-mineralized' nature of the sampled reservoir, concurs with the reports from aquatic environs of NEI [1,2,9,11,13,14], and Bhutan [31] but marks a distinct contrast to the lowest density (13±6 ind. l^{-1}) reported from India vide earlier survey [17]. Zooplanktons comprise notable quantitative component of net plankton in contrast to insignificant role noted earlier [17]. The present study records bimodal density variations at the littoral region, and registers maxima during pre-monsoon and post-monsoon); this pattern is less distinctive at the limnetic regions due to limited density differences during May-October in particular. Nevertheless, the stated trends affirm positive correlation of zooplankton abundance with water temperature at the both the regions concurrent with the results of NEI [1], Himachal Pradesh [5], Uttarakhand [34] and West Bengal [43]. Besides, abundance registers positive correlation with Cl at the two regions and with rainfall, pH and PO_4 at the limnetic region. Individual abiotic factors thus depict limited and differential spatial influence on

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zooplankton abundance. The periods of higher abundance concur with the reports from Arunachal Pradesh [10], and Uttarakhand [5] but differ from winter maxima known from Himachal Pradesh [8] and Uttarakhand [7,34],while pre-monsoon peaks correspond with the report from Uttar Pradesh [44].

Zooplankton depicts quantitative dominance of Rotifera, and sub-dominance of Cladocera and Copepoda; the significance pattern differs from the collective quantitative importance of Rotifera, Cladocera and Copepoda [2,44] and that of Rotifera and Copepoda [1], and dominance of Copepoda [7,9]. Rotifera predominance is attributed to the short turn-over over enabling these micro-invertebrates to dominate over other zooplankton groups, and life history r-strategies and the opportunistic character [45-47]. Rotifera importance concurs with the different reports from India [4,11-16,26,36,37,48-51]. *Keratella cochlearis, Bosmina longirostris, Polyarthra vulgaris, Mesocyclops leuckarti, Conochilus unicornis* and *Asplanchna priodonta* collectively (74.7±24.9% and 83.5±7 %) exert significant influence ($r_1 = 0.995$, $p < 0.0001$; $r_2 = 0.995$, $p < 0.0001$) on zooplankton abundance at the two regions. *K.cochlearis* ($r_1 = 0.793$, $p = 0.0062$), *B. longirostris* ($r_1 = 0.797$, $p = 0.0058$), *A. priodonta* ($r_1 = 0.871$, $p = 0.0010$) and *P. vulgaris* ($r_1 = 0.818$, $p = 0.0038$) individually influence zooplankton abundance at the littoral region, while *K. cochlearis* ($r_2 = 0.693$, $p = 0.0115$), *B. longirostris* ($r_2 = 0.883$, $p = 0.0001$), *C. unicornis* ($r_2 = 0.754$, $p = 0.0046$) and *P. vulgaris* ($r_2 = 0.890$, $p = 0.0001$) influence abundance at the limnetic region. We categorize the stated species as ‘specialist’ in contrast to ‘generalist’ nature of rest of the species with lower densities; the former differ from lack of such species reported vide earlier survey [17].

Rotifera follows bimodal monthly density variations concurrent with that of zooplankton, significantly influence abundance of the latter at the littoral ($r_1 = 0.941$, $p < 0.0001$) and limnetic ($r_2 = 0.940$, $p < 0.0001$) regions, and ANOVA registers significant spatio-temporal variations. The rotifers indicate higher abundance at the littoral > limnetic region during April-June and October, and record less spatial differences during the rest of the study period. This group indicates peak abundance during April at both the stations, depicts maxima during October at the littoral region and period of nearly concurrent high abundance during September-October at the limnetic region, and registers significant positive correlation with water temperature only at the limnetic region. The summer Rotifera peaks correspond with the reports from Himachal Pradesh [8] , Bihar [52] and West Bengal [43], and differ from winter maxima recorded Assam [12,13,53] and Manipur [14,15]. *Keratella cochlearis*, the dominant ‘specialist’ species, influences rotifer abundance at the two regions ($r_1 = 0.843$, $p = 0.0022$; $r_2 = 0.830$, $p = 0.0008$). Besides, *Asplanchna priodonta* ($r_1 = 0.899$, $p = 0.0004$; $r_2 = 0.710$, $p = 0.0097$), *Conochilus unicornis* ($r_1 = 0.662$, $p = 0.0190$; $r_2 = 0.761$, $p = 0.0040$) and *Polyarthra vulgaris* ($r_1 = 0.842$, $p = 0.0022$; $r_2 = 0.749$, $p = 0.0051$) influence Rotifera abundance. *K. cochlearis* abundance depicts positive influence of specific conductivity; *P. vulgaris* records positive correlation with rainfall, Cl and PO_4 at both the regions but indicates positive correlation with pH, and an inverse correlation with rainfall at the limnetic region; and *A. priodonta* registers positive correlation with specific conductivity while *C. unicornis* registers positive influence of rainfall, Cl and PO_4 at the littoral region. Abiotic factors thus depict the differential spatial influence on Rotifera and its notable species.

Cladocera indicates lower abundance at the littoral > limnetic regions and register insignificant spatio-temporal variations (vide ANOVA). Our study records distinctly higher abundance of this group than earlier survey [17], while it concurs with the reports from Meghalaya [2] and Assam [14]. The bimodal periodicity with peak in October and maxima in June at the littoral region, and broadly unimodal pattern at the limnetic region with peak during June depict spatial differences in quantitative variations of this group; the abundance pattern at the latter region affirms positive correlation with water temperature and rainfall. Besides, Cladocera abundance registers positive correlations with pH, Cl and PO_4 at the limnetic regions, and with NO_3 at the littoral region. *Bosmina longirostris* ($r_1 = 0.995$, $p < 0.0001$, $r_2 = 0.997$, $p < 0.0001$) exclusively influences Cladocera densities, records peaks during October and June at the two regions respectively, and ANOVA registers insignificant spatio-temporal quantitative variations. *B. longirostris* abundance is positively influenced by water temperature, rainfall, pH, Cl and PO_4 at the limnetic region, and by NO_3 at the littoral region. Our results thus record the differential influence of individual abiotic factors on Cladocera and *B. longirostris,* and the limited importance at the littoral region in particular. The periods of higher cladoceran abundance differ from the winter maxima [2,12], and higher abundance during May-July at the limnetic region concurs with reports from Meghalaya [1,2] and Uttarakhand [7].

Copepoda depicts the relatively wider density variations at the littoral region and registers significant spatio-temporal quantitative variations (vide ANOVA). The littoral and limnetic copepod assemblages follow broadly unimodal and distinctly unimodal abundance patterns, respectively. The relatively higher Copepoda abundance from May-October and peaks during August

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(monsoon) at both the regions is supported by positive correlation with water temperature. Besides, abundance of this group registers positive correlation with pH and Cl at the two regions, and depicts an inverse influence of transparency at the limnetic region. The monsoon peaks and unimodal periodicity of Copepoda differ from pre-monsoon peak and autumn maxima reported from Meghalaya [2,11], Andhra Pradesh [54] and Karnataka [55]. The copepod abundance is influenced by the cyclopoid *Mesocyclops leuckarti* ($r_1 = 0.997$, $p < 0.0001$; $r_2 = 0.985$, $p < 0.0001$); this species registers positive correlation with water temperature, pH and Cl at the two regions, records positive influence of rainfall and PO_4 at the littoral region and depicts an inverse influence of transparency at the limnetic region. Our results thus affirm differential but concurrent spatial importance of the abiotic factors both on Copepoda and *M. leuckarti*. The importance of Cyclopidae and occurrence of nauplii throughout the study affirming active Copepoda reproduction are attributed to the prevalence of stable environmental conditions for these 'k-strategists' [56]. Amongst other zooplankton groups, Rhizopoda records poor abundance [1,2,11,14], while Gastrotricha depicts quantitative insignificance.

The differential spatial influence of individual abiotic factors on zooplankton, the constituent groups and important species, and the relative importance of water temperature, rainfall, pH, Cl and PO_4 on limnetic zooplankton assemblages suggest habitat heterogeneity amongst the littoral and limnetic regions. The limited influence on richness concurs with the results from NEI [1,2,9,11,14,16]. Overall influence on zooplankton abundance differs from much limited role of abiotic factors [1,2,9,13,14] and lack of importance of any individual factor [17]. The canonical correspondence analysis registers broadly concurrent cumulative influence of 10 abiotic factors on the littoral (72.5%) and limnetic (78.8%) zooplankton; the CCA biplots register ~ 42% and ~30%, and ~ 51% and ~28% influence of abiotic factors along axis 1 and 2, respectively at the two regions, respectively. The CCA results record influence of alkalinity and hardness on abundance of zooplankton and Rotifera; specific conductivity on *Asplanchna priodonta*, transparency on *Keratella cochlearis,* and NO_3 on Cladocera and *Bosmina longirostris* abundance, and on zooplankton dominance and evenness at the littoral region. On the other hand, the CCA biplot indicates influence of alkalinity and harness on zooplankton abundance; water temperature influences *Conochilus unicornis* abundance; pH, rainfall and Cl influences abundance of *Bosmina longirostris* and *Polyarthra vulgaris*, and specific conductivity, transparency and NO_3 exert influence on abundance of Rotifera, *K. cochlearis* and *A. priodonta* at the limnetic region. High cumulative influence at the two regions broadly concurs with the reports from Meghalaya [1,2] and Mizoram [9] but deviates from the differential spatial cumulative influence an urban wetland of Meghalaya [11]. In spite of the spatial differences, our results affirm importance of both the individual and cumulative influence of abiotic factors on zooplankton assemblages.

Zooplankton record moderate species diversity at the limnetic > littoral regions; ANOVA registers insignificant spatial and significant temporal diversity variations. Our results depict higher diversity values during January-February (peak in January) at both the regions, and indicate $H^/$ values > 2.0 throughout this study except during March and October at the former region and during January-February, July-September and November-December at the littoral region. Our study registers lower species diversity than the reports of the selected lakes and reservoirs of Meghalaya [1,2] and the relatively lower values than the report from a reservoir of and Mizoram [9]; the differences are attributed to lower zooplankton richness in the sampled reservoir. The concurrence of high diversity values with low densities of zooplankton and important species, affirmed by significant inverse correlations with abundance of zooplankton (r_1= -0.675, p = 0.0160), Rotifera (r_1= -0.678, p = 0.0154), *K. cochlearis* (r_1= -0.738, p = 0.0061), *A. priodonta* (r_1= -0.665, p = 0.0168) and collective abundance of 'specialist species (r_1= -0.727, p = 0.0074) at the littoral region, is hypothesized to fine niche portioning in combination with habitat heterogeneity [57]. The diversity affirms significant inverse relationship with zooplankton dominance (r_1= -0.675, p = 0.0160) at the littoral region. It registers inverse correlation with abundance of *K. cochlearis* (r_2= -0.675, p = 0.0160), and records postive correlation with richness of zooplankton (r_2= 0.883, p = 0.0001) and Rotifera (r_2= 0.832, p = 0.0008) at the limnetic region. The significant positive correlation of species diversity with evenness (r_1= 0.865, p = 0.0012; r_2= 0.8911, p < 0.0001) at the two regions affirms concurrence of diverse zooplankton assemblages during the periods of high equitability.

Zooplanktons indicate low dominance and high evenness; both register insignificant spatial and significant temporal variations (vide ANOVA). The dominance records peak during April and maxima during December at the littoral region, while it records peak during October and maxima during March at the limnetic region. Zooplankton dominance is positively influenced by abundance of *K. cochlearis* (r_1= 0.708, p = 0.0098) at the littoral region. Evenness is inversely influenced by abundance of zooplankton (r_1= -0.739, p = 0.0060),

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Rotifera (r_1= -0.687, p = 0.0136), *K. cochlearis* (r_1= -0.817, p = 0.0011) and *A. priodonta* (r_1= -0.716, p = 0.0199) at the littoral region; it is positively influenced by Rotifera richness (r_2= 0.698, p = 0.0116) and registers inverse correlation with *K. cochlearis* abundance (r_2= -0.665, p = 0.0183) at the limnetic region. The periods of higher evenness and lower dominance correspond with low densities and equitable abundance of the 'generalist' species, while the selected 'specialist' species result in higher dominance during certain months. This trend concurs with the reports from the floodplain lakes of NEI [12-16,26] and an urban wetland of Meghalaya [11]. In general, lower zooplankton dominance and higher equitability affirms that the sampled reservoir has resources for utilization by majority of species due to high amount of niche overlap [58].

5. Conclusions

The lowest specific conductivity known from any aquatic environ of the Indian sub-continent, and very soft, acidic and calcium poor waters are notable features of the subtropical Shillong reservoir. This reservoir devoid of any aquatic vegetation reveals low zooplankton richness with overall homogeneity of species composition amongst the two regions, while the community similarities and the hierarchical cluster groupings suggest heterogeneity of zooplankton composition within the two regions individually. Lower zooplankton abundance attributed to the 'de-mineralized' waters, the dominance of Rotifera, bimodal zooplankton and Rotifera temporal density variations, and the 'specialist natures of six planktonic species are notable features. The subdominant Cladocera record bimodal and broadly unimodal density variations, and Copepoda depict broadly unimodal and distinctly unimodal abundance patterns at the two regions respectively. Zooplankton record moderate species diversity, and lower dominance and higher equitability indicate temporal variations influenced by the specialist species. The spatial differences of richness, abundance, diversity indices and the influence of abiotic factors hypothesize habitat heterogeneity amongst the two regions. This study merits regional and national interest for zooplankton diversity of the subtropical environs, and the soft and de-mineralized waters in particular.

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