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ARTICLE

Phytoplankton Diversity of a Demineralized Urban Wetland of Meghalaya State of Northeast India: The Spatio-temporal Variations and the Role of Abiotic Factors

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ARTICLE INFO

Article history
Received: 14 March 2022
Received in revised form: 7 April 2022
Accepted: 15 April 2022
Published: 5 May 2022

Keywords:
Abundance
Composition
Diversity
Phytoplankton
Rainwater fed
Urban wetland

ABSTRACT

The authors analyze phytoplankton diversity of a small urban wetland of Meghalaya to assess biodiversity and limnology interest of small water bodies. This "slightly acidic-circumneutral, demineralized and soft water" subtropical wetland reveals diverse phytoplankton (64 species), indicates high desmid richness and highlights the speciose littoral constellations of up to 55-58 species per sample. Phytoplankton comprises dominant quantitative component of net plankton and registers Charophyta dominance; Chlorophyta > Bacillariophyta > Dinozoa > Chrysophyta > Cyanobacteria depict sub-dominance, and Euglenozoa and Cryptophyta show poor abundance at the littoral and semi-limnetic regions. The richness of phytoplankton and abundance of phytoplankton, Charophyta, Chlorophyta, Dinozoa, Chrysophyta and Cyanobacteria follow bimodal spatio-temporal variations. *Closterium*, *Cosmarium*, *Staurastrum*, *Micrasterias*, *Netrium*, *Staurodesmus* and *Scenedesmus* are notable genera, and 14 species collectively influence phytoplankton abundance. Phytoplankton registers high species diversity, lower dominance and high evenness. Amongst 15 abiotic factors, only the rainfall and sulphate exert notable influence individually, while the canonical correspondence analysis registers lower cumulative influence of the selected 10 factors on the littoral and semi-limnetic phytoplankton assemblages. This study merits interest for neglected biodiversity and ecology of small aquatic biotopes of India and urban wetlands in particular.

1. Introduction

The small water bodies (ponds and wetlands) are considered as one of the "keystone systems" for biodiversity analysis globally [1-5]. The small wetlands located in modified urban landscapes in particular are likely to depict the regional biodiversity interest by not following the

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DOI: https://doi.org/10.30564/re.v4i2.4520

pattern of reduced taxonomic richness expected in highly modified urbanized environs [4,6]. Further, an attention on a renewed focus on limnology of small water bodies is advocated [7,8] in view of valuable ecological services. Considering the stated importance of small aquatic biotopes, our study analyzes phytoplankton diversity of a small urban wetland of northeast India (NEI) facing the threat of habitat degradation.

Although phytoplankton have been surveyed from varied freshwater environs of India since the last one century, the useful works with a variable focus on phytoplankton diversity are yet limited to the selected lacustrine systems of Mizoram [9] and Meghalaya [10-12] states NEI, and north Bengal [13] as well as the works from Kashmir [14,15], Himachal Pradesh [16-20] and Uttarakhand [21,22] from northwest India (NWI). Besides, other relevant works from NEI relate to the studies from the floodplain lakes of Assam [23-26] and Manipur [27,28]. The Indian literature, however, highlights lack of the detailed studies on plankton diversity of small water bodies [29] despite proliferation of causal reports with limitations of sampling, species determinations and data analysis [10-12]. We extend this generalization to neglected attention on phytoplankton diversity of urban wetlands of India and NEI in particular.

Our study on phytoplankton diversity of a small urban wetland of Meghalaya merits importance in light of the global biodiversity and limnology interest of small aquatic ecosystems, and lacunae on hydrobiological surveys of urban wetlands of India. We analyze the littoral and semi-limnetic phytoplankton assemblages of this wetland to monitor the spatio-temporal variations of species composition, richness, abundance, notable genera, important species, species diversity, dominance and evenness. Remarks are made on the individual and cumulative influence of abiotic factors on phytoplankton diversity. The results of this study are discussed vis-a-vis useful related reports from India and elsewhere from this sub-continent.

2. Material and Methods

2.1 Study Site

The present study is a part of August 2014-July 2015 limnological survey undertaken at the littoral (25°35'33.6"N; 91°53'46.6"E) and the semi-limnetic (25°36'30.3"N; 91°54'01.2"E) regions of a small urban wetland located in the campus of North-Eastern Hill University, Shillong (Figure 1, A-C). This rain-water fed perennial wetland (~ 1.5 ha area; referred as NEHU wetland) indicated *Myriophyllum verticillatum*, *Nelumbo nucifera*, and *Hydrilla verticillata* at the littoral region, while *H. verticillata, Ipomoea aquatica, Nymphoides indica,* and *Spirogyra agilis* were noted at the semi-limnetic region.

2.2 Abiotic Factors

The monthly water samples, collected from the two regions, were examined for various abiotic factors. Water temperature (WT), pH and specific conductivity (Cond) were recorded with Whatman (USA) field probes; dissolved oxygen (DO) was estimated by the Winkler's method, and total alkalinity (TA), total hardness (TH), calcium (Ca), magnesium (Mg), chloride (Cl), dissolved organic matter (DOM), sulphate (SO_4), phosphate (PO_4), nitrate (NO_3) and silicate (SiO_2) were analyzed *vides* APHA [30]. The monthly rainfall data (Rain) was obtained from the local meteorological station.

2.3 Sampling and Analyses

The qualitative and quantitative plankton samples were collected monthly from the two regions by a nylobolt net (#40 µm) and were preserved in 5% formalin. The former, collected by towing plankton net, were screened with a Wild Stereoscopic binocular microscope, and were observed with a Leica stereoscopic microscope. Phytoplankton species were identified following the selected works [31-35]. The quantitative samples were obtained from the two regions by filtering 25 L of water each through plankton net. The quantitative analysis of phytoplankton was done by using a Sedgewick-Rafter counting cell and abundance of various taxa was indicated as n/L.

2.4 Data Analysis

The phytoplankton community similarities were calculated *vide* Sørensen index, the hierarchical cluster analysis was plotted using SPSS (version 20), and species diversity (Shannon-Weiner index), dominance (Berger-Parker index) and evenness (E_1 index) were calculated [36,37]. The significance of the spatial and temporal variations of the abiotic factors and phytoplankton was ascertained by ANOVA (two-way). Pearson correlation coefficients, for the littoral and semi-limnetic regions (r_1 and r_2, respectively), were calculated between abiotic factors and phytoplankton; p values (two-tailed) were calculated and their significance was ascertained after Bonferroni corrections. The cumulative influence of the selected 10 abiotic factors: WT, Rain, Cond, TA, TH, PO_4, NO_3, SO_4, SiO_2 and DOM on the littoral and semi-limnetic phytoplankton were ascertained by the canonical correspondence analysis (CCA) using XLSTAT (version 2020).

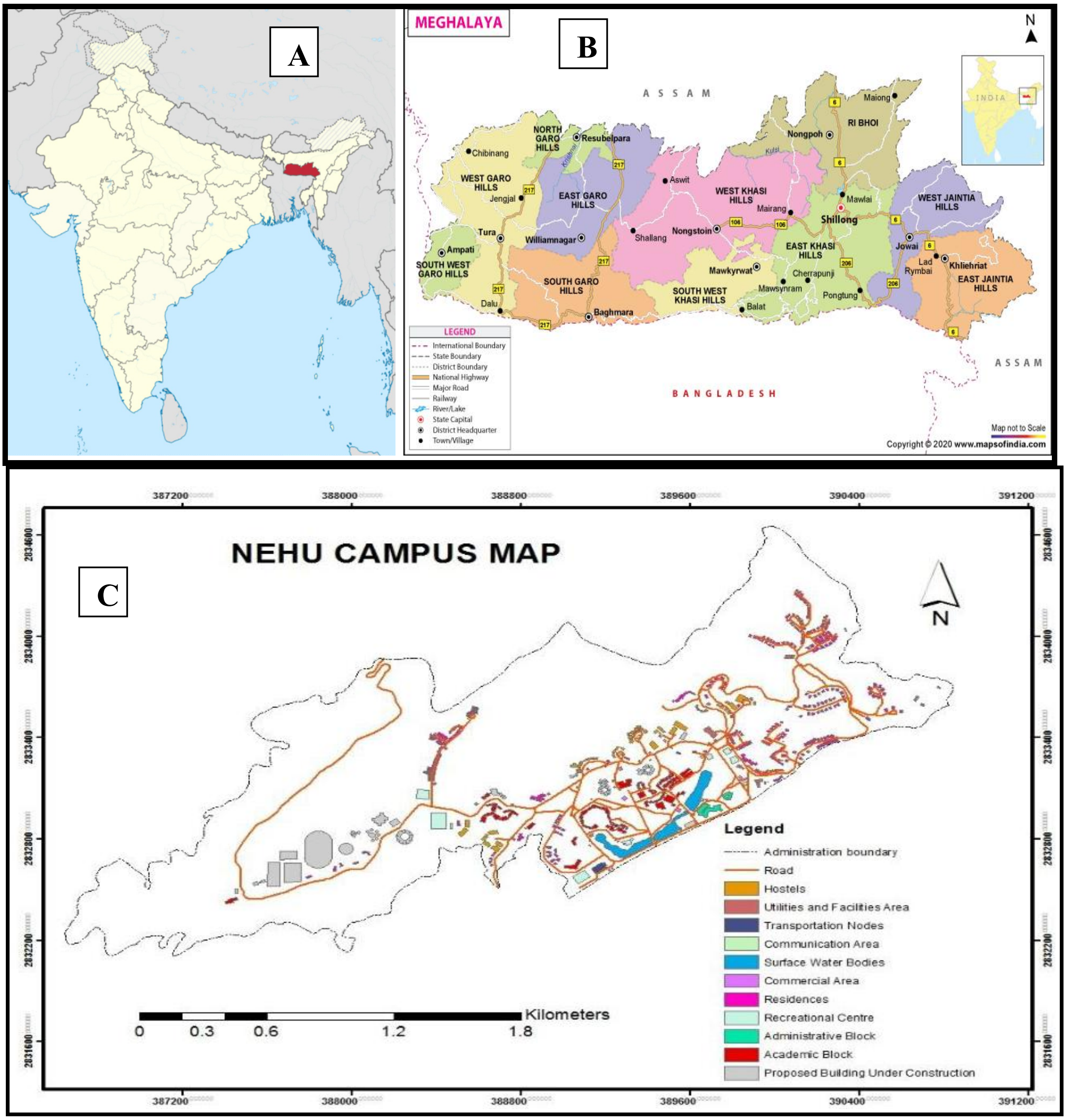

Figure 1. A, Map of India indicating location of Meghalaya state (red color); **B**, District map of Meghalaya indicating location of Shillong city; **C**, Campus map of North-Eastern Hill University, Shillong showing NEHU wetland (blue color)

3. Results

3.1 Abiotic Factors

Water temperature, rainfall, pH, specific conductivity and DO record variations between 12.0 °C-22.5 °C, 12.0 mm-1820.4 mm, 6.02–6.97, 31.0 µS/cm-51.0 µS/cm and 5.6 mg/L-7.6 mg/L, respectively. TA, TH, Ca, Mg and Cl range between 18.0 mg/L-30.0 mg/L, 20.0 mg/L-32.0 mg/L, 8.4 mg/L-27.3 mg/L, 2.7 mg/L-19.5 mg/L and 23.9 mg/L-37.9 mg/L. DOM varies between 0.038 mg/L-0.180 mg/L, while SO_4, PO_4, NO_3 and SiO_2 values range between 0.209 mg/L-1.055 mg/L, 1.711 mg/L-7.898 mg/L, 0.356 mg/L-1.218 mg/L and 0.216 mg/L-0.396 mg/L at the littoral and semi-limnetic regions (Table 1). ANOVA registers the significance of the spatio-temporal variations of various abiotic factors as listed in Table 2.

Table 1. Temporal variations of abiotic parameters

Parameters↓	Littoral region		Semi-limnetic region	
	RANGE	MEAN±SD	RANGE	MEAN±SD
WT (^{o}C)	12.0-22.5	17.4±3.2	12.0-22.5	17.4±3.2
Rainfall (mm)	12.0-1820.4	609.4±652.2	12.0-1820.4	609.4±652.2
pH	6.02-6.97	6.43±0.29	6.40-6.99	6.59±0.19
Cond. (µS/cm)	31.0-50.0	34.8±5.4	32.0-51.0	37.4±5.4
DO (mg/L)	5.6-7.6	6.7±0.5	5.6-7.2	6.3±0.5
TA (mg/L)	18.0-28.0	22.7±3.3	20.0-30.0	24.0±3.5
TH (mg/L)	20.0-32.0	24.8±3.6	22.0-32.0	26.3±3.4
Ca (mg/L)	8.4-23.1	14.3±4.6	8.4-27.3	14.3±6.1
Mg (mg/L)	7.0-17.5	10.5-3.1	2.7-19.5	11.9±4.6
Cl (mg/L)	24.9-36.9	32.2±3.6	23.9-37.9	32.5±4.1
DOM (mg/L)	0.038-0.169	0.103±0.038	0.038-0.180	0.105±0.042
SO_4 (mg/L)	1.711-7.898	4.602±1.886	2.040-6.516	4.613±1.565
PO_4 (mg/L)	0.251-1.055	0.717±0.250	0.209-1.035	0.748±0.247
NO_3 (mg/L)	0.356-1.214	0.780±0.319	0.503-1.128	0.832±0.253
SiO_2 (mg/L)	0.216-0.396	0.309±0.080	0.252-0.396	0.339±0.0527

Table 2. ANOVA indicating significance of abiotic factors

Parameters	Regions	Months
WT	-	$F_{11,23}$ = 7.981, P = 8.32E-05
pH	$F_{1,23}$ = 5.789, P = 0.034	$F_{11,23}$ = 3.572, P = 0.022
Cond	$F_{1,23}$ = 14.978, P = 0.003	$F_{11,23}$ = 19.526, P = 1.12E-05
DO	$F_{1,23}$ = 3.667, P= 0.081	-
TA	$F_{1,23}$ = 5.500, P = 0.039	$F_{11,23}$ = 11.880, P = 0.0002
TH	$F_{1,23}$ = 11.880, P= 0.005	$F_{11,23}$ = 20.307, P= 9.9E-06
Ca	-	$F_{11,23}$ = 20.047, P = 1.06E-05
Mg	-	$F_{11,23}$ = 6.920, P = 0.002
Cl	-	$F_{11,23}$ = 35.850, P = 5.26E-07
DOM	-	$F_{11,23}$ = 63.170, P = 2.6E-08
SO_4	-	$F_{11,23}$ = 16.587, P = 2.74-05
PO_4	-	$F_{11,23}$ = 21.024, P = 8.3E-06
NO_3	-	$F_{11,23}$ = 35.140, P = 5.84E-07
SiO_2	-	$F_{11,23}$ = 2.924, P = 0.044

(-) insignificant variations

3.2 Phytoplankton Richness

The authors report 64 phytoplankton species (Table 3). The littoral and semi-limnetic phytoplankton reveal 62 and 53 species, indicate monthly richness ranging between 29-58 and 35-50 species (Figure 2), and register 54.8-95.7 and 76.5%-95.9% community similarities, respectively. The hierarchical cluster analysis (Figures 3-4) exhibits differences in the cluster groupings. Charophyta includes 33 species and records monthly richness ranging between 12-32 and 15-20 species at the two regions, respectively.

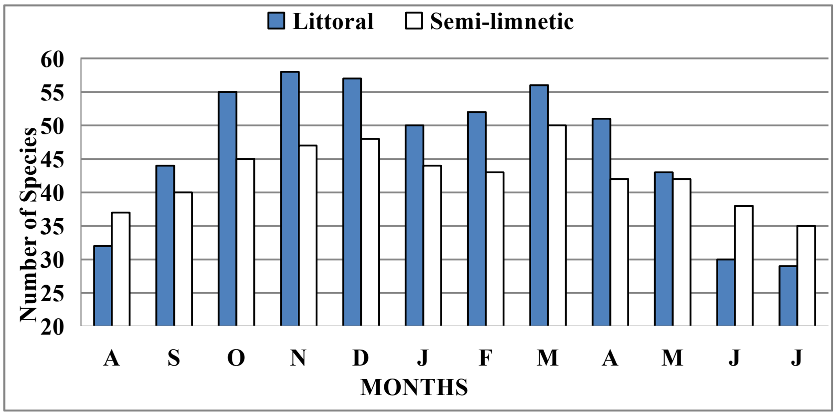

Figure 2. Species richness variations of the littoral and semi-limnetic phytoplankton

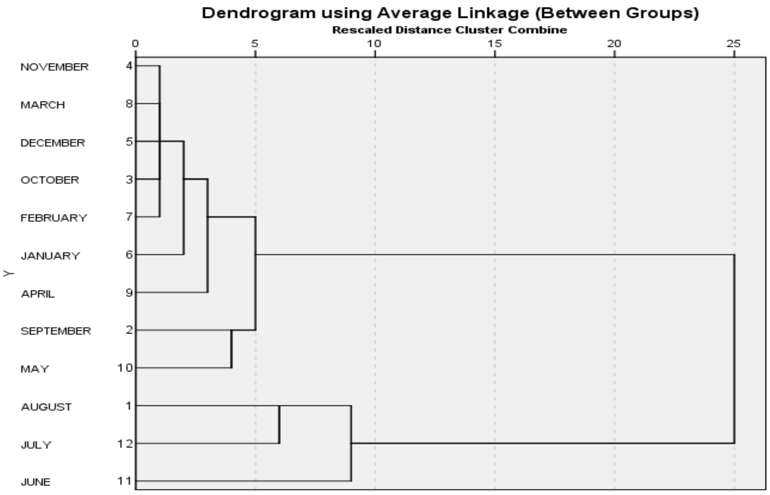

Figure 3. Hierarchical cluster analysis of the littoral phytoplankton assemblage

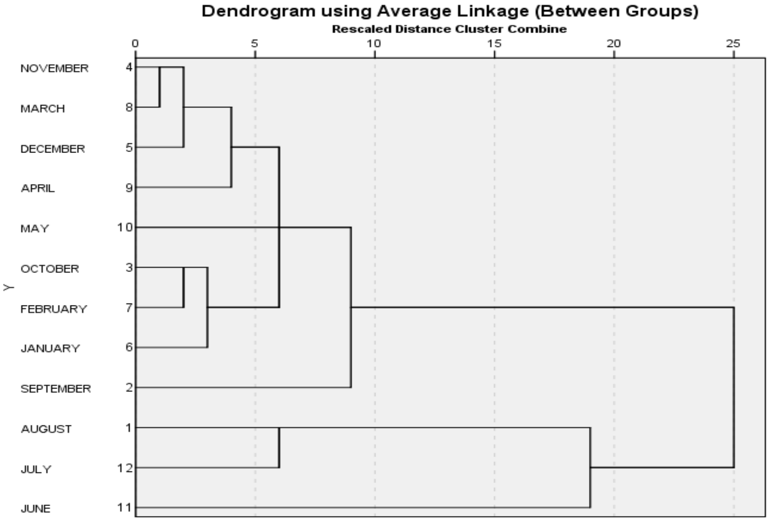

Figure 4. Hierarchical cluster analysis of the semi-limnetic phytoplankton assemblage

Table 3. Temporal variations of phytoplankton

Taxa ↓	**Littoral region**		**Semi-limnetic region**	
Richness				
Phytoplankton Community similarity	62 species: 29–58 54.8%-95.7%	46±10	53 species: 35-50 76.5%-95.9%	43±4
Charophyta	32 species:	12-32 26±6	29 species: 15-20	19±1
Abundance (n/L)				
Net Plankton	439-750	678±148	444-754	587±96
Phytoplankton % of net plankton	174-699 39.2-75.1	431±158 61.4±11.4	199-559 48.0-75.5	374±112 63.2±9.6
Charophyta % of phytoplankton	99-433 56.4-64.5	259±99 60.1 ±2.5	126-351 59.4-68.7	237±73 63.2±24
Chlorophyta % of phytoplankton	26-78 10.9-15.4	56±17 13.5 ±1.7	21-66 8.9-14.7	45±23 12.3±2.0
Dinozoa % of phytoplankton	12-64 6.2-10.2	35±17 7.9±1.1	16-44 6.1-9.0	28±10 7.4±1.0
Bacillariophyta % of phytoplankton	10-38 4.0-10.5	27±9 6.5±1.9	10-32 4.3-10.1	24±8 6.4±1.6
Chrysophyta % of phytoplankton	10-40 4.3-8.2	24±9 5.7±1.0	10-32 3.8-6.4	20±8 5.3±0.8
Cynaobacteria % of phytoplankton	10-43 2.7-6.8	25±11 5.8±1.2	10-28 3.8-6.4	17±6 4.6±0.7
Euglenophyta	0-7		0-5	
Cryptophyta	0-3		0-3	
Important genera (n/L)				
Closterium	23-68	41±11	30-90	59±18
Cosmarium	27-92	59±20	2-52	39±7
Micasterias	8-48	26±12	14-40	26±9
Netrium	10-38	25±9	12-35	23±8
Scenedesmus	20-60	41±13	16-50	31±9
Staurastrum	17-64	48±21	16-72	42±17
Staurodesmus	8-48	27±12	8-48	26±13
Important genera % of phytoplankton	115-442 56.5-68.2	268±94 62.8±3.0	132-386 58.2-70.1	247±74 66.0±3.0
Important species (n/L)				
Ceratium hirudinella	6-30	17±7	8-26	14±6
Closterium acrosum	10-46	26±10	18-36	24±7
Cosmarium contractum	10-40	25±8	18-40	25±8
Cosmarium decoratum	10-42	24±10	10-40	23±9
Dinobryon sociale	10-40	24±9	10-32	20±8
Micrasterias arcuata	6-36	20±9	8-34	18±8
Navicula radiosa	10-28	20±6	8-28	16±6
Netrium digitus	10-30	21±7	10-30	19±6
Peridinium cincitum	6-30	17±7	8-2	13±5
Scenedesmus acuminatus	12-48	33±11	6-32	15±8
Staurastrum arctiscon	8-44	24±11	10-34	20±8
Staurastrum freemani	6-36	20±8	8-32	17±8
Staurodesmus convergens	8-44	25±11	6-32	24±7
Spirulina agilis	10-30	18±7	8-26	16±6
Important species % of phytoplankton	132-522 54.1-80.5	313±113 73.3±4.7	140-440 69.2-92.4	275±90 74.5±6.1
Diversity indices				
Species diversity	3.132-3.592	3.386±0.163	3.267-3.433	3.344±0.051
Dominance	0.066-0.103	0.103±0.020	0.060-0.088	0.076±0.008
Evenness	0.852-0.930	0.800±0.024	0.856-0.939	0.892±0.022

3.3 Phytoplankton Abundance

Phytoplankton (Table 3) record abundance ranging between 174 n/L-699 n/L and 199 n/L-559 n/L (Figure 5), and it comprises 39.2%-75.1% and 48.0%-75.5% of net plankton abundance at the littoral and semi-limnetic regions, respectively. Charophyta indicates abundance (Table 3) varying between 84 n/L-192 n/L and 79 n/L-190 n/L (Figure 6). Chlorophyta, Bacillariophyta, Dinozoa and Chrysophyta abundance varies between 35-97 n/L and 24-73 n/L, 20-58 n/L and 28-45 n/L, 21-41 n/L and 13-43 n/L, and 7-44 n/L and 8-48 n/L at the two regions (Table 3), respectively; these groups indicate the spatio-temporal density variations as shown in Figures 7-8. Euglenozoa (0-7 n/L and 0-5 n/L) and Cryptophyta (0-3 n/L and 0-3 n/L) record poor abundance. The spatio-temporal significance of richness and abundance of phytoplankton (*vide* ANOVA) is indicated in Table 4.

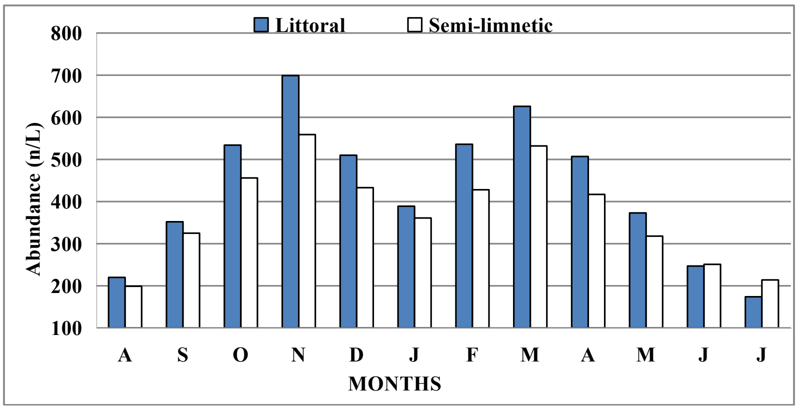

Figure 5. Temporal variations of the littoral and semi-limnetic phytoplankton abundance

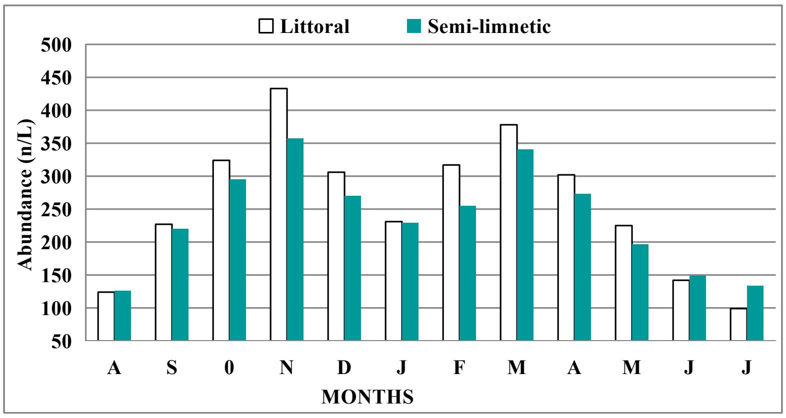

Figure 6. Temporal variations of the littoral and semi-limnetic Charophyta abundance

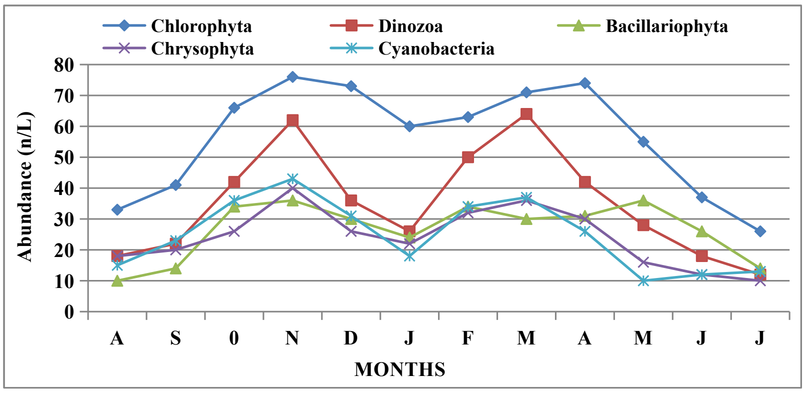

Figure 7. Temporal variations of abundance of the sub-dominant groups (Littoral region)

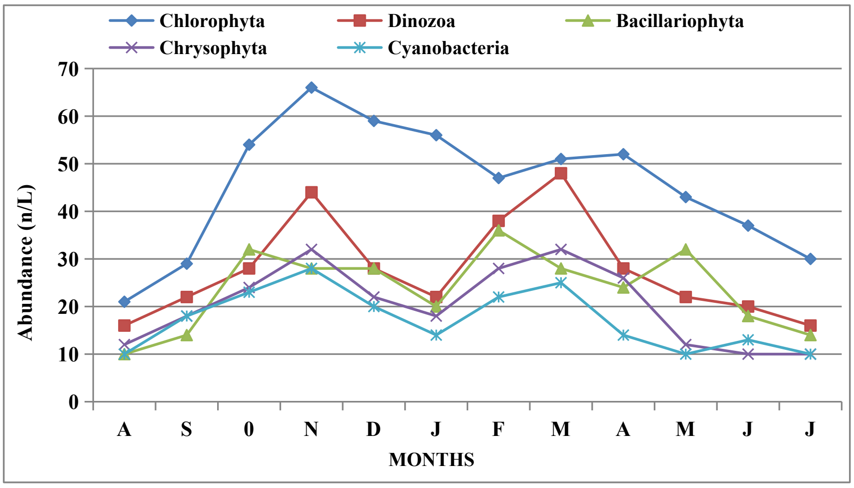

Figure 8. Temporal variations of abundance of the sub-dominant groups (Semi-limnetic region)

3.4 Important Taxa and Diversity Indices

Closterium, *Cosmarium*, *Micrasterias*, *Netrium*, *Scenedesmus, Staurastrum* and *Staurodesmus* are quantitatively notable genera at both the littoral and semi-limnetic regions (Table 3). *Ceratium hirudinella, Closterium acrosum, Cosmarium contractum, C. decoratum, Dinobryon sociale, Micrasterias arcuata*, *Navicula radiosa, Netrium digitus, Peridinium cincitum, Scenedesmus acuminatus, Staurastrum artiscon, S. freemani, Staurodesmus convergens* and *Spirulina agilis* are notable species (Table 3) at the two regions. Phytoplankton species diversity (Figure 9), dominance and evenness range between 3.132-3.592 and 3.267-3.433, 0.066-0.103 and 0.060-0.088, and 0.852-0.930 and 0.856-0.939 at the two regions, respectively (Table 3). The spatio-temporal significance of species diversity, dominance and eveness (*vide* ANOVA) is indicated in Table 4.

3.5 Biotic Correlations

The significant corrections between phytoplankton assemblages are indicated in Tables 5 and 6.

Table 4. ANOVA indicating the spatio-temporal significance of phytoplankton

Parameters	Regions	Months
Richness		
Phytoplankton	-	$F_{11,23}$ = 4.995, P= 0.0008
Charophyta	-	-
Abundance		
Phytoplankton	$F_{1,23}$ = 14.383, P = 0.003	$F_{11,23}$ = 30.121, P= 1.3E-06
Charophyta	$F_{1,23}$ = 6.073, P = 0.031	$F_{11,23}$ = 33.836, P= 7.1E-07
Chlorophyta	$F_{1,23}$ = 24.371, P = 0.0004	$F_{11,23}$ = 16.208, P= 3.1E-05
Bacillariophyta	$F_{1,23}$ = 9.136, P = 0.011	$F_{11,23}$ = 26.589, P= 2.5E-06
Dinozoa	$F_{1,23}$ = 11.624, P = 0.006	$F_{11,23}$ = 13.786, P= 6.8E-05
Chrysophyta	$F_{1,23}$ = 38.029, P = 7F-05	$F_{11,23}$ = 72.314, P= 1.3E-08
Cyanobacteria	$F_{1,23}$ = 22.801, P = 0.0006	$F_{11,23}$ = 10.017, P= 0.0003
Important genera	$F_{1,23}$ = 14.032, P = 0.0032	$F_{11,23}$ = 75.679, P= 9.9E-09
Closterium	$F_{1,23}$ = 48.490, P = 2.4E-05	$F_{11,23}$ = 11.693, P= 0.0001
Cosmarium	$F_{1,23}$ = 21.312, P = 0.0007	$F_{11,23}$ = 3.252, P= 0.031
Micrasterias	-	$F_{11,23}$ = 9.646, P= 0.0003

Table 4 continued

Parameters	Regions	Months
Netrium	-	$F_{11,23}$ = 6.523, P= 0.002
Scenedesmus	$F_{1,23}$ = 22.601, P = 0.0006	$F_{11,23}$ = 9.102, P= 0.0004
Staurastrum	$F_{1,23}$ = 12.843, P = 0.004	$F_{11,23}$ = 46.175, P= 1.4E-07
Staurodesmus	-	$F_{11,23}$ = 177.038, P= 9.9E-11
Important species	$F_{1,23}$ = 151.244, P = 9.0E-08	$F_{11,23}$ = 41.052, P= 2.6E-07
Ceratium hirudinella	$F_{1,23}$ = 7.032, P = 0.022	$F_{11,23}$ =10.045, P= 0.0003
Closterium acrosum	-	$F_{11,23}$ = 13.559, P= 7.4E-05
Cosmarium contractum	-	$F_{11,23}$ = 102.458, P= 1.9E-09
Cosmarium decoratum	-	$F_{11,23}$ = 667.600, P= 6.9E-14
Dinobryon sociale	$F_{1,23}$ = 38.028, P = 7E-05	$F_{11,23}$ = 72.314, P= 1.3E-08
Micrasterias arcuata	-	$F_{11,23}$ = 10.353, P= 0.0003
Navicula radiosa	$F_{1,23}$ = 9.843, P = 0.010	$F_{11,23}$ = 10.345, P= 0.0003
Netrium digitus	-	-
Peridinium cincitum	$F_{11,23}$ = 10.569, P= 0.008	$F_{11,23}$ = 10.586, P= 0.0002
Scenedesmus acuminatus	$F_{1,23}$ = 18.184, P = 0.001	$F_{11,23}$ = 6.324, P= 0.002
Staurastrum arctiscon	$F_{1,23}$ = 6.557, P = 0.026	$F_{11,23}$ = 14.064, P= 6.2E-05
Staurastrum freemani	$F_{1,23}$ = 13.646, P = 0.003	$F_{11,23}$ = 57.608, P= 4.3E-08
Staurodesmus convergens	-	$F_{11,23}$ = 147.015, P= 2.7E-10
Spirulina agilis	$F_{1,23}$ = 12.629, P = 0.004	$F_{11,23}$ = 29.308, P= 1.5E-06
Diversity indices		
Species Diversity	-	-
Dominance	$F_{1,23}$ = 5.844, P = 0.034	-
Evenness	-	$F_{11,23}$ = 15.331, P= 4E-05

(-) indicates insignificant variations

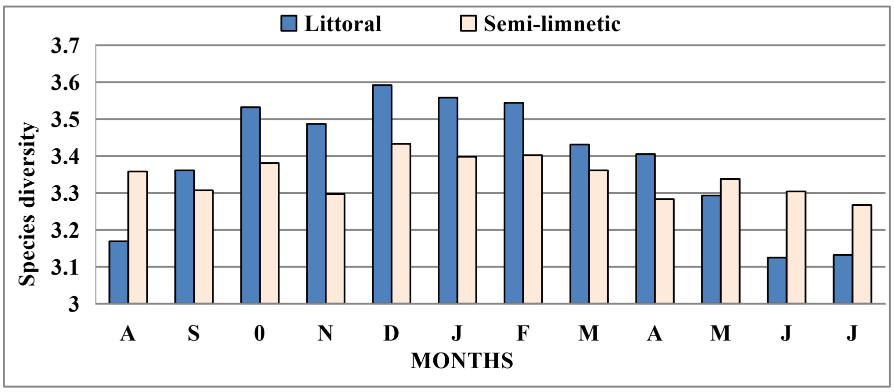

Figure 9. Temporal variations of the littoral and semi-limnetic phytoplankton species diversity

Table 5. The significant Biotic correlations

Biotic factors	Biotic factors	Littoral region	Semi-limnetic region
Charophyta richness	Phytoplankton richness	r_1= 0.975, p < 0.0001	-
Phytoplankton richness	Phytoplankton abundance	r_1= 0.942, p < 0.0001	
Phytoplankton abundance	Net plankton abundance	r_1= 0.988, p < 0.0001	r_2= 0.986, p < 0.0001
	Charophyta abundance	r_1= 0.998, p < 0.0001	r_2 = 0.994, p < 0.0001
	Chlorophyta abundance	r_1= 0.935, p <0.0001	r_2 = 0.860, p = 0.0014
	Dinozoa abundance	r_1= 0.962, p <0.0001	r_2 = 0.913, p = 0.0002
	Bacillariophyta abundance	r_1= 0.764, p = 0.0101	r_2= 0.724, p = 0.0179
	Chrysophyta abundance	r_1= 0.998, p < 0.0001	r_2 = 0.994, p < 0.0001
Phytoplankton abundance	14 important species	r_1 = 0.944, p < 0.0001	r_2 = 0.987, p < 0.0001
	Closterium acrosum	r_1 = 0.866, p = 0.0012	r_2 = 0.756, p = 0.0114
	Cosmarium contractum	r_1 = 0.797, p = 0.0058	r_2 = 0.865, p = 0.0012
	Cosmarium decoratum	r_1 = 0.970, p < 0.0001	r_2 = 0.979, p < 0.0001
	Netrium digitus	r_1 =0.868, p =0.0011	r_2 =0.844, p = 0.0021
	Staurastrum arctiscon	r_1 = 0.926, p <0.0001	r_2 = 0.938, p <0.0001
	Staurastrum freemani	r_1 = 0.956, p <0.0001	r_2 = 0.979, p <0.0001
	Scenedesmus acuminatus	r_1 = 0.916, p = 0.0002	r_2 = 0.851, p = 0.0018
	Dinobryon sociale	r_1 = 0.953, p <0.0001	r_2 = 0.949, p <0.0001
	Ceratium hirudinella	r_1 =0.946, p <0.0001	r_2 = 0.921, p = 0.0002
	Peridinium cincitum	r_1 = 0.943, p <0.0001	r_2 = 0.845, p = 0.0021
	Spirulina agilis	r_1 = 0.887, p = 0.0006	r_2 = 0.896, p = 0.0005
	Micrasterias arcuata	r_1 = 0.861, p = 0.0014	-
Charophyta abundance	*Closterium acrosum*	r_1 = 0.878, p = 0.0008	r_2 = 0.784, p = 0.0073
	Cosmarium contractum	r_1 = 0.805, p = 0.0050	r_2 = 0.868, p = 0.0011
	Cosmarium decoratum	r_1 = 0.973, p < 0.0001	r_2 = 0.972, p < 0.0001
	Micrasterias arcuata	r_1 = 0.871, p = 0.0010	r_2 = 0.700, p = 0.0242
	Netrium digitus	r_1 = 0.863, p =0.0013	r_2 =0.848, p = 0.0019
	Staurastrum arctiscon	r_1 =0.932, p <0.0001	r_2 =0.938, p <0.0001
	Staurastrum freemani	r_1 =0.968, p <0.0001	r_2 = 0.984, p <0.0001
	Scenedesmus acuminatus	r_1 = 0.896, p =0.0005	r_2 =0.926, p = 0.0001
Chlorophyta abundance	*Scenedesmus acuminatus*	r_1 =0.916, p = 0.0002	r_2 =0.844, p =0.0021
Bacillariophyta abundance	*Navicula radiosa*	r_1 =0.834, p = 0.0027	r_2 = 0.878, p = 0.0008
Dinozoa abundance	*Ceratium hirudinella*	r_1 = 0.985, p <0.0001	r_2 = 0.976, p <0.0001
	Peridinium cincitum	r_1 = 0.972, p <0.0001	r_2 = 0.965, p <0.0001
Cyanobacteria abundance	*Spirulina agilis*	r_1 = 0.976, p <0.0001	r_2 = 0.984, p <0.0001

(-) insignificant correlation

Table 6. The significant Biotic correlations

Biotic factors	Biotic factors	Littoral region	Semi-limnetic region
Species diversity	Phytoplankton richness	r_1= 0.933, p < 0.0001	-
	Charophyta richness	r_1= 0.919, p = 0.0002	-
	Phytoplankton abundance	r_1= 0.790, p = 0.0065	-
	Charophyta abundance	r_1= 0.786, p= 0.0035	-
	Chlorophyta abundance	r_1= 0.842, p = 0.0022	-
	Chrysophyta abundance	r_1= 0.723, p = 0.0181	-
	Cyanobacteria abundance	r_1 = 0.733, p = 0.0159	-
	Cosmarium decoratum	r_1 = 0.748, p = 0.0128	-
	Staurastrum arctiscon	r_1 = 0.792, p = 0.0063	-
	Staurastrum freemani	r_1 = 0.676, p = 0.0319	-
	Staurodesmus convergens	r_1 = 0.707, p = 0.0222	-
	Scenedesmus acuminatus	r_1 = 0.779, p = 0.0079	-
	Dinobryon sociale	r_1 = 0.723, p = 0.0181	-
	Peridinium cincitum	r_1 = 0. 676, p = 0.0319	-
Dominance	Phytoplankton abundance	r_1= –0.695, p = 0.0257	-
	Charophyta abundance	r_1 = –0.707, p = 0.0222	-
	Chrysophyta abundance	r_1 = –0.701, p = 0.0229	-
	Dinozoa abundance	r_1 =–0.682, p = 0.0296	-
	Evenness abundance	r_1 = –0.738, p = 0.0152	-
	Closterium decoratum	r_1 = –0.677, p = 0.0315	-
	Staurastrum freemani	r_1 = –0.792, p = 0.0063	-
	Staurodesmus convergens	r_1 = –0.736, p = 0.0156	-
	Dinobryon sociale	r_1 = –0.701, p = 0.0239	-
	Peridinium cincitum	r_1 = –0.679, p = 0.0306	-
Evenness	Phytoplankton richness	r_1 = –0.834, p = 0.0027	r_2 = –0.782, p = 0.0075
	Phytoplankton abundance	r_1 = –0.858, p = 0.0015	r_2 = –0.909, p = 0.0003
	Charophyta abundance	r_1 = –0.868, p = 0.0011	r_2 = –0.922, p = 0.0001
	Chlorophyta abundance	r_1 = –0.811, p = 0.0044	r_2 = –0.808, p = 0.0047
	Chrysophyta abundance	r_1 = –0.798, p = 0.0057	r_2 = –0.797, p = 0.0058
	Cyanobacteria abundance	r_1 = –0.687, p = 0.0282	r_2 = –0.747, p = 0.0130
	Dinozoa abundance	r_1 = –0.837, p = 0.0025	r_2 = –0.812, p = 0.0043
	Closterium acrosum	r_1 = –0.936, p < 0.0001	r_2 = –0.887, p = 0.0006
	Cosmarium contractum	r_1 = –0.842, p = 0.0042	r_2 = –0.904, p = 0.0003
	Cosmarium decoratum	r_1 = –0.811, p = 0.0044	r_2 = –0.860, p = 0.0014
	Micrasterias arcuata	r_1 = –0.911, p = 0.0002	r_2 = –0.762, p = 0.0104
	Netrium digitus	r_1 = –0.815, p = 0.0041	r_2 = –0.740, p = 0.0144
	Staurastrum arctiscon	r_1 = –0.768, p = 0.0095	r_2 = –0.906, p= 0.0003
	Staurastrum freemani	r_1 = –0.891, p = 0.0005	r_2 = –0.898, p = 0.0004
	Staurodesmus convergens	r_1 = –0.734, p = 0.0157	r_2 = –0.785, p = 0.0071
	Scenedesmus acuminatus	r_1 = –0.879, p = 0.0008	r_2 = 0.801, p = 0.0045
	Dinobryon sociale	r_1 = –0.798, p = 0.0057	r_2 = 0.797, p = 0.0058
	Ceratium hirudinella	r_1 = –0.828, p = 0.0031	r_2 = –0.819, p = 0.0038
	Peridinium cincitum	r_1 = –0.809, p = 0.0046	r_2 = –0.751, p = 0.0123
	Spirulina agilis	r_1 = –0.721, p = 0.0186	r_2 = –0.754, p = 0.0118

(-) insignificant correlation

3.6 Influence of Abiotic Factors

The significant corrections of abiotic factors on phytoplankton are indicated in Table 7. The CCA registers low and broadly identical cumulative influence (57.09% and 58.12%) of 10 abiotic factors on the littoral and semi-limnetic phytoplankton assemblages, respectively (Figures 10-11).

Table 7. The significant influence of abiotic factors

Biotic factors	Biotic factors	Littoral region	Semi-limnetic region
Water temperature	Phytoplankton richness	-	$r_2 = –0.673$, p= 0.0329
	Charophyta abundance	$r_1 = –0. 712$, p= 0.0209	$r_2 = –0.740$, p= 0.0114
	Bacillariophyta abundance	$r_1 = –0.727$, p= 0.0172	$r_2 = –0.757$, p= 0.0122
	Species diversity	$r_1 = –0.714$, p = 0.0204	-
Rainfall	Phytoplankton richness	$r_1 = –0.891$, p= 0.0005	$r_2 = –0.891$, p= 0.0005
	Charophyta richness	$r_1 = –0.883$, p= 0.0011	$r_2 = –0.883$, p= 0.0011
	Phytoplankton abundance	$r_1 = –0.778$, p= 0.0040	$r_2 = –0.839$, p= 0.0024
	Charophyta abundance	$r_1 = –0.839$, p= 0.0024	$r_2 = –0.837$, p= 0.0025
	Chlorophyta abundance	$r_1 = –0.837$, p= 0.0025	$r_2 = –0.852$, p= 0.0017
	Dinozoa abundance	$r_1 = –0.852$, p= 0.0017	$r_2 = –0.748$, p= 0.0128
	Chrysophyta abundance	$r_1 = –0.807$, p = 0.0048	$r_2 = –0.807$, p= 0.048
	Cyanobacteria abundance	$r_1 = –0.757$, p= 0.0122	$r_2 = –0.757$, p = 0.0122
	Bacillariophyta abundance	$r_1 = –0.748$, p= 0.0128	-
	Cosmarium decoratum	$r_1 = –0.781$, p = 0.0077	$r_2 = –0.784$, p = 0.0073
	Netrium digitus	$r_1 = –0.697$, p =0.0251	$r_2 = –0.799$, p = 0.0056
	Staurastrum arctiscon	$r_1 = –0.760$, p = 0.0107	$r_2 = –0.853$, p = 0.0017
	Staurastrum freemani	$r_1 = –0.733$, p = 0.0159	$r_2 = –0.787$, p = 0.0069
	Staurodesmus convergens	$r_1 = –0.778$, p =0.0059	$r_2 = –0.750$, p = 0.0125
	Scenedesmus acuminatus	$r_1 = –0.796$, p =0.0002	$r_2 = –0.851$, p = 0.0018
	Dinobryon sociale	$r_1 = –0.807$, p = 0.0048	$r_2 = –0.844$, p = 0.0021
	Ceratium hirudinella	$r_1 = –0.709$, p = 0.0217	$r_2 = –0.731$, p = 0.0163
	Peridinium cincitum	$r_1 = –0.764$, p = 0.0101	$r_2 = –0.702$, p = 0.0236
	Spirulina agilis	$r_1 = –0.669$, p = 0.0344	$r_2 = –0.764$, p = 0.0101
	Species diversity	$r_1 = –0.874$, p = 0.0009	-
Sulphate	Phytoplankton richness	$r_1= 0.933$, p < 0.0001	-
	Charophyta richness	$r_1= 0.919$, p = 0.0002	-
	Phytoplankton abundance	$r_1= 0.790$, p = 0.0065	-
	Chlorophyta abundance	$r_1= 0.842$, p = 0.0022	-
	Chrysophyta abundance	$r_1= 0.723$, p = 0.0181	-
	Cyanobacteria abundance	$r_1 = 0.733$, p = 0.0159	-
	Dinozoa abundance	$r_1 = 0.748$, p = 0.0128	-
	Cosmarium decoratum	$r_1 = 0.792$, p = 0.0063	-
	Staurastrum arctiscon	$r_1 = 0.676$, p = 0.0319	-
	Staurastrum freemani	$r_1 = 0.707$, p = 0.0222	-
	Scenedesmus acuminatus	$r_1 = 0.779$, p = 0.0079	-
	Ceratium hirudinella	$r_1 = 0.723$, p = 0.0181	-
	Dinobryon sociale	$r_1 = 0. 676$, p = 0.0319	-
	Peridinium cincitum		-
	Netrium digitus		
Calcium	Charophyta abundance	$r_1 = 0.721$, p = 0.0186	-
	Closterium decoratum	$r_1 = 0.701$, p = 0.0239	-

(-) insignificant correlation

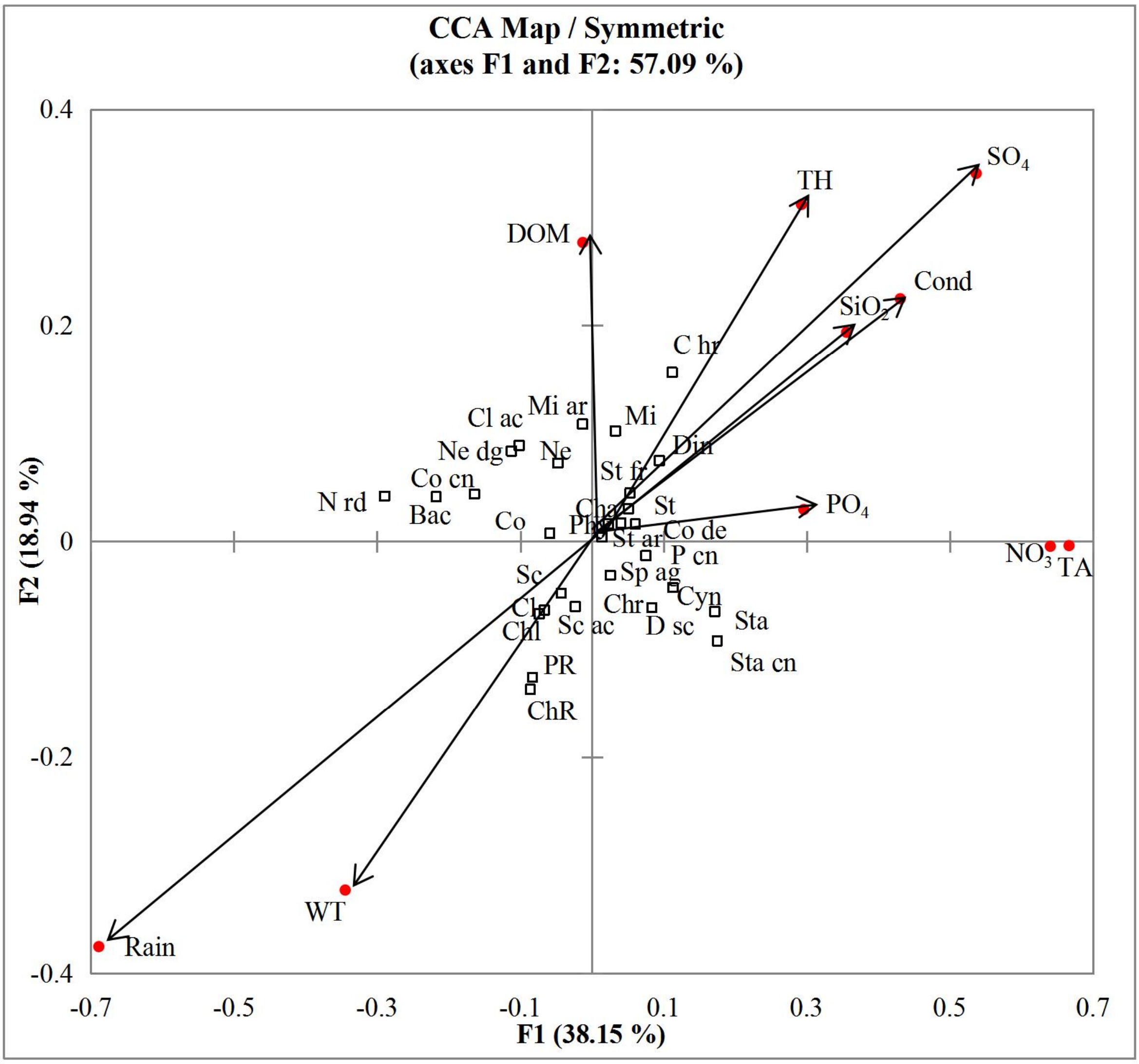

Figure 10. CCA coordination biplot of phytoplankton assemblages and abiotic factors (Littoral)

Abbreviations

Abiotic factors: Cond (specific conductivity), DOM (dissolved organic matter), NO_3 (nitrate), PO_4 (phosphate), Rain (rainfall), SiO_2 (silicate), SO_4 (sulphate), TA (total alkalinity), TH (total hardness), WT (water temperature).

Biotic factors: Bac (Bacillariophyta abundance), C hr (*Ceratium hirudinella* abundance), Cha (Charophyta abundance), ChR (Charophyta richness), Chl (Chlorophyta abundance), Chry (Chrysophyta abundance), Cl (*Closterium* abundance), Cl ac (*Closterium acrosum* abundance), Co (*Cosmarium* abundance), Co cn (*Cosmarium contractum* abundance), Co de (*Cosmarium decoratum* abundance), Cyn (Cyanobacteria abundance), D sc (*Dinobryon sociale* abundance), Din (Dinozoa abundance), Mi ar (*Micrasterias arcuata* abundance), Mi (*Micrasterias* abundance), N rd (*Navicula radiosa* abundance), Ne dg (*Netrium digitus* abundance), Ne (*Netrium* abundance), P cn (*Peridinium cincitum* abundance), PR (phytoplankton richness), Phy (phytoplankton abundance), Sc (*Scenedesmus* abundance), Sc ac (*Scenedesmus acuminatus* abundance), Sp ag (*Spirulina agilis* abundance), St (*Staurastrum* abundance), St ar (*Staurastrum arctiscon* abundance), St fr (*Staurastrum freemani* abundance), Sta (*Staurodesmus* abundance), Sta cn (*Staurodesmus convergens* abundance).

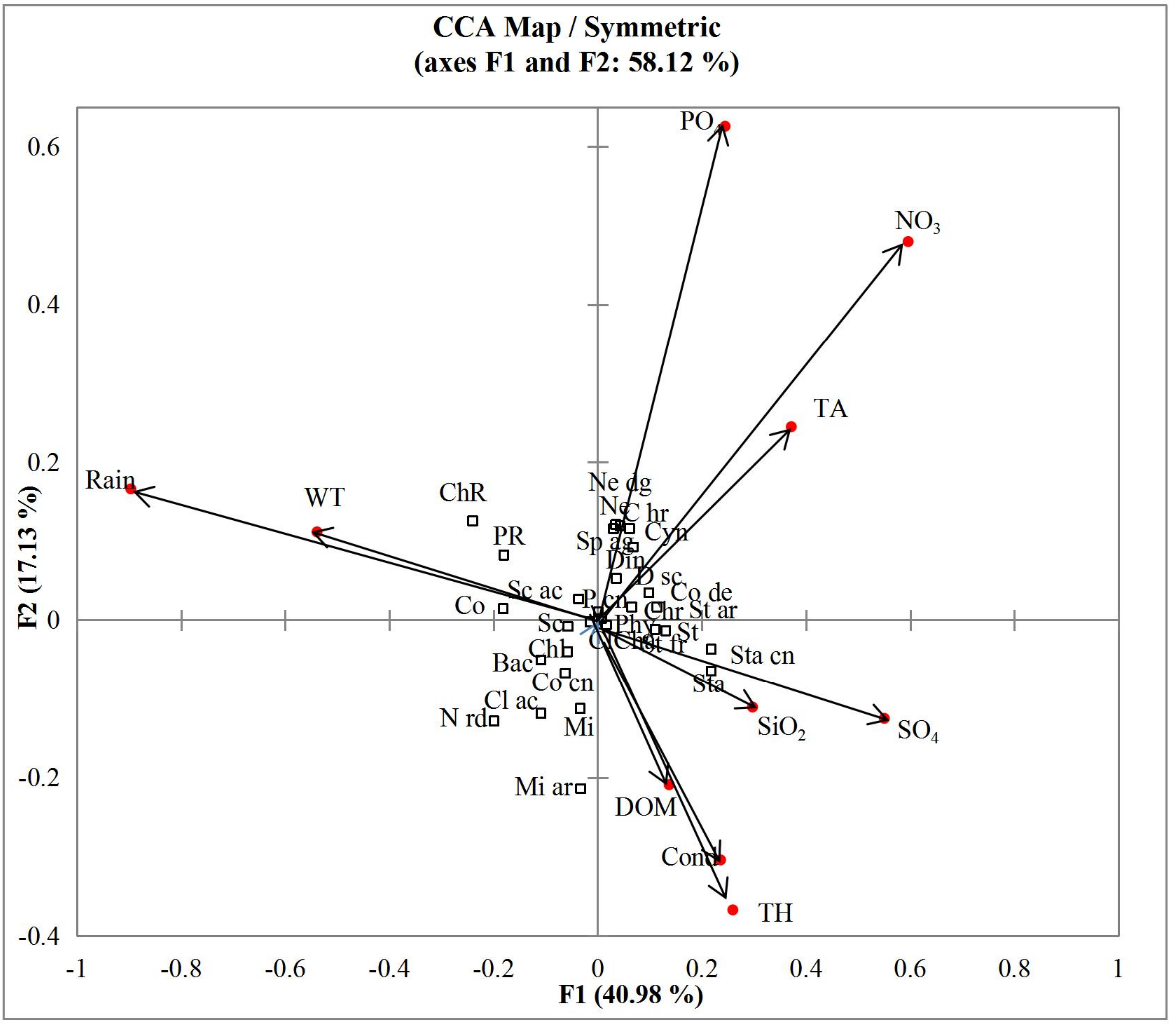

Figure 11. CCA coordination biplot of phytoplankton assemblages and abiotic factors (Semi-limnetic)

Abbreviations

Abiotic factors: Cond (specific conductivity), DOM (dissolved organic matter), NO_3 (nitrate), PO_4 (phosphate), Rain (rainfall), SiO_2 (silicate), SO_4 (sulphate), TA (total alkalinity), TH (total hardness), WT (water temperature).

Biotic factors: Bac (Bacillariophyta abundance), C hr (*Ceratium hirudinella* abundance), Cha (Charophyta abundance), ChR (Charophyta richness), Chl (Chlorophyta abundance), Chry (Chrysophyta abundance), Cl (*Closterium* abundance), Cl ac (*Closterium acrosum* abundance), Co cn (*Cosmarium contractum* abundance), Co de (*Cosmarium decoratum* abundance), Co (*Cosmarium* abundance), Cyn (Cyanobacteria abundance), D sc (*Dinobryon sociale* abundance), Din (Dinozoa abundance), Mi (*Micrasterias* abundance), Mi ar (*Micrasterias arcuata* abundance), N rd (*Navicula radiosa* abundance), Ne dg (*Netrium digitus* abundance), Ne (*Netrium* abundance), P cn (*Peridinium cincitum* abundance), PR (phytoplankton richness), Phy (phytoplankton abundance), Sc (*Scenedesmus* abundance), Sc ac (*Scenedesmus acuminatus* abundance), Sp ag (*Spirulina agilis* abundance), St (*Staurastrum* abundance), St ar (*Staurastrum arctiscon* abundance), St fr (*Staurastrum freemani* abundance), Sta (*Staurodesmus* abundance), Sta cn (*Staurodesmus convergens* abundance).

4. Discussion

The subtropical NEHU wetland depicts the "soft, calcium poor, slightly acidic-circumneutral waters" and low nutrients, while the 'demineralized nature' of this rainwater-fed wetland is attributed to the influx of lower ionic concentration waters from the leached soil and weathered rocks [38,39]. pH, Cond, TA and TH register significant spatial and temporal variations; DO indicates significant spatial variations; and WT, Ca, Mg, Cl, DOM, SO_4, PO_4, NO_3 and SiO_2 register significant temporal variations. In general, the variations of the recorded abiotic factors broadly concur with the reports from NEI [12,38,39] and Bhutan [40].

Sixty-four species (S) known from our net plankton collections reveal notably rich phytoplankton as compared with the reports from Assam [23,24,42-47], Meghalaya [10-13], Mizoram [9], Sikkim [48] and Tripura [49] states of NEI as well as than various Indian reports elsewhere from Gujarat [50], Jammu & Kashmir [51,52], Himachal Pradesh [16-19], Karnataka [53], Kerala [54], Panjab [55], Uttarakhand [56-60] and West Bengal [29,61,62]. The authors also document higher richness than the reports from Bangladesh [63,64], Bhutan [40] and Nepal [65,66]. The comparisons affirm the diverse phytoplankton, and highlight the regional biodiversity interest of "soft and demineralized water" NEHU urban wetland vis-à-vis the pattern of reduced taxonomic richness hypothesized to be expected in urbanized aquatic environs [4].

The differential phytoplankton richness known from the littoral and semi-limnetic regions and higher monthly richness at the littoral region in particular is hypothesized to the greater environmental heterogeneity at the former region. The richness registers significant temporal variations, and follows bimodal patterns of the spatio-temporal variations with peak during autumn and maxima during spring at the littoral region, while the semi-limnetic region registers less prominent periodicity. The peaks and maxima concur with the reports from Assam [26], Manipur [28] and Meghalaya [11,12]. The noteworthy speciose littoral constellations of 55-58 species per sample during October-December and March, and 50 species during March at the semi-limnetic region are hypothesized to the possibility of co-existence of many species due to high amount of niche overlap [67]. The differential community similarities at the littoral (54.8%-95.7%) and semi-limnetic regions (76.5%-95.9%) together with the similarity values ranging between 81-95% in ~60% and ~76% instances at the two regions respectively depict the relatively more heterogeneity of phytoplankton composition at the former region. The hierarchical cluster groupings record closer affinity of species composition amongst October to February collections, and June and August samples record maximum divergence at the littoral region. The semi-limnetic region indicates peak affinity between November and March, and divergence during June and August.

Phytoplankton reveal the speciose Charophyta (~51 % species of S); this feature concurs with the reports from NEI [10-12] but the comparisons with various Indian reports [14,21,22,25,43,46-49,58-60] warrant caution because of lack of inventories for species validations despite clubbing of the members of this group under Chlorophyta. Charophyta significantly influences phytoplankton richness at the littoral region. The reports of four species each of *Closterium, Cosmarium, Micrasterias* and *Staurastrum*; three *Netrium* species; two species each of *Arthrodesmus*, *Euastrum*, *Staurodesmus*, and *Xanthidium*, and one species each of *Desmidium, Docidium, Gonatozygon, Penium* and *Pleurotaenium* characterize high desmid richness comprising significant fractions of phytoplankton (50%) and Charophyta (~97%) species. This notable feature is hypothesized [68,69] to "soft and calcium-poor waters" of NEHU wetland. Nevertheless, our study enlists more desmid genera than the reports Bhutan [40] as well as from NEI [9,11-13,46], NWI [16,56], Gujarat [50], Kerala [54], and West Bengal [62].

Phytoplankton, a dominant component of net plankton, significantly contributes to density variations of the latter; the quantitative predominance of phytoplankton corresponds with the Indian reports from Himachal Pradesh [19], Meghalaya [11,12,38] and Mizoram [9], and the report from Bhutan [40]. ANOVA affirms significant spatio-temporal phytoplankton density variations during our study. The bimodal spatial phytoplankton quantitative variations noted in NEHU wetland concur with certain Indian reports [11,12,14,60]. The autumn peaks noted at both the regions correspond with the reports from Kashmir [14,53], Meghalaya [10], Mizoram [6] and Uttarakhand [21], and Nepal [67]; the spring maxima concur with the reports from Bangladesh [63] and West Bengal [65]; and the lower monsoon abundance concurs [13,27,54,62] but differs from the monsoon peak [40,44,46,48,66]. Amongst the constituent groups, Charophyta depicts quantitative dominance, and Chlorophyta > Bacillariophyta > Dinozoa > Chrysophyta > Cyanobacteria record sub-dominance. The stated pattern (except Cyanobacteria) corresponds with the report of Sharma and Sharma [12]. Charophyta dominance in particular concurs with various reports from NEI [9,11,18,23,24,27,28,38,42]. Besides, the Bacillariophyta sub-dominance concurs with the reports from Manipur [27] and Uttarakhand [21]; the subdominant nature of Dinozoa concurs with the report from Meghalaya [11]; Chrysophyta sub dominance corresponds with the results from NEI [11,23,24,27,28,38]; and Cyanobacteria importance concurs with the reports from Assam [24], Kashmir [14], Mizoram [9] and Meghalaya [10]. Our study depicts poor abundance of Euglenozoa and Cryptophyta; the former corresponds with the reports from NEI [9-12,27].

Of the 37 genera reported from NEHU wetland, only seven genera (*Closterium*, *Cosmarium, Micrasterias, Netrium, Scenedesmus, Staurastrum* and *Staurodesmus*) indicate quantitative importance, collectively contribute to the littoral and semi-limnetic phytoplankton but influence the spatio-temporal density variations of the latter. *Closterium*, *Cosmarium, Scenedesmus* and *Staurastrum* register significant spatio-temporal quantitative variations, and *Micrasterias, Netrium* and *Staurodesmus* record significant temporal variations. Our study reveals the quantitative interest of more genera than various reports from NEI [9-12,27,28] and NWI [58-60]. Besides, 14 species namely *Ceratium hirudinella, Closterium acrosum, Cosmarium contractum, C. decoratum, Dinobryon sociale, Micrasterias arcuata*, *Navicula radiosa, Netrium digitus, Peridinium cincitum, Scenedesmus acuminatus, Staurastrum artiscon, S. freemani, Staurodesmus convergens* and *Spirulina agilis* indicate the relative quantitative importance, collectively form significant fractions of phytoplankton, contribute to the autumn and spring maxima, and significantly influence the spatio-temporal density variations of the latter at two regions. Our study reveals the quantitative interest of more species than listed by the reports from NEI [9-12] and Bhutan [40]. ANOVA registers significant spatio-temporal density variations of *C. hirudinella, D. sociale, M. arcuata*, *N. radiosa, P. cincitum, Scenedesmus acuminatus, Staurastrum artiscon, S. freemani* and *Spirulina agilis*; *Closterium acrosum, Cosmarium contractum, C. decoratum* and *Staurodesmus convergens* register significant temporal variations; and *N. digitus* records significant temporal variations.

Charophyta records higher abundance at the littoral > semi-limnetic regions, significantly influences phytoplankton abundance at the two regions and registers significant spatio-temporal quantitative variations. The bimodal density variations, and the autumn peaks and spring maxima of Charophyta concur with the reports from NEI [11,12]. The desmid genera *Closterium*, *Cosmarium, Micrasterias, Netrium, Staurastrum* and *Staurodesmus* collectively contribute to Charophyta (88.0±4.8%; 89.5±3.6%) and phytoplankton (52.9±2.3%; 57.6±2.4%) abundance, while *Closterium acrosum, Cosmarium contractum, C. decoratum, Micrasterias arcuata*, *Netrium digitus*, *Staurastrum arctiscon, S. freemani, a*nd *Staurodesmus convergens* influence abundance of Charophyta (71.7±5.5%; 71.2±3.8%) and phytoplankton (71.7±5.5%; 71.2±3.8%) at the two regions, respectively. The qualitative importance of desmids vis-a-vis phytoplankton and Charophyta supports the results from the "soft, calcium-poor and demineralized waters" of Meghalaya [10-12] state of NEI and Bhutan [40].

Of the other groups, Chlorophyta, Dinozoa, Chrysophyta, Cyanobacteria and Bacillariophyta individually influence phytoplankton abundance at the two regions and register significant spatio-temporal quantitative variations. Chlorophyta abundance follows the bimodal temporal variations at the two regions influenced by *Scenedesmus acuminatus*; the autumn maxima concur with the report from Meghalaya [12], the pre-monsoon maxima correspond with early summer maxima recorded from Assam [23,24] and Kashmir [14]. Dinozoa bimodal density variations differ from the oscillating pattern [12], while the autumn and spring maxima concur with the report Meghalaya [11] but deviate from winter, summer and monsoon maxima noted from Manipur [27], Uttarakhand [21] and Meghalaya [10], respectively. *Ceratium hirudinella* and *Peridinium cincitum* collectively contribute to Dinozoa abundance in contrast to the importance of *C. hirudinella* [11,12]. Bacillariophyta follows the differential oscillating spatial patterns of density variations; *Navicula radiosa* notably influences the diatom abundance concurrent with the report from Meghalaya [11]. Chrysophyta and Cyanobacteria follow identical bimodal spatial patterns; *Dinobryon sociale* influences Chrysophyta abundance, and the autumn and spring maxima differ from winter peaks [10-12], while Cyanobacteria abundance is influenced by *Spirulina agilis*.

High phytoplankton species diversity with H' values > 3.3 reported from the littoral region except during June-August, and the semi-limnetic region except during November and July highlights greater environmental heterogeneity of NEHU wetland. ANOVA registers insignificant spatio-temporal variations due to limited monthly diversity differences at the two regions. Our study registers higher species diversity as compared with the reports from NEI [9-11], Kerala [54], Punjab [55], Uttrakhand [57] and West Bengal [29,61], and Bhutan [40]. The bimodal diversity pattern with maxima during October and December and the relatively higher values from October till March at the littoral region are attributed to the positive influence of the richness of phytoplankton and Charophyta, and abundance of phytoplankton, Charophyta, Chlorophyta, Chrysophyta and Cyanobacteria, *Closterium decoratum, Staurastrum arctiscon*, *S. freemani*, *Staurodesmus convergens*, *Scenedesmus acuminatus, Dinobryon sociale* and *Peridinium cincitum*. Higher diversity during October till March at the littoral region affirms inverse influence of water temperature and rainfall.

High evenness and low dominance of phytoplankton are attributed to the lower and equitable abundance of the majority of the "generalist" species, and even the relatively lower abundance of 14 notable species. The results thus affirm that NEHU wetland has resources for utilization by various phytoplankton species due to a low amount of niche overlap as hypothesized by MacArthur [67]. Our study registers significant spatial and temporal variations of dominance and evenness, respectively. In general, the dominance and evenness values concur with various reports from NEI [12,23,24,27,28,42]. The evenness is inversely influenced by phytoplankton richness, and abundance of phytoplankton, Charophyta, Chlorophyta, Chrysophyta, Cyanobacteria, *Closterium acrosum, Cosmarium contractum, C. decoratum, Micrasterias arcuata*, *Netrium digitus, Staurastrum arctiscon*, *S. freemani*, *Staurodesmus convergens*, *Scenedesmus acuminatus*, *Dinobryon sociale*, *Ceratium hirudinella*, *Peridinium cincitum*, and *Spirulina agilis* at the two regions. The dominance registers significant inverse correlation with evenness, and is inversely influenced by abundance of phytoplankton, Charophyta, Dinophyta and Chrysophyta, *Closterium decoratum, Staurastrum freemani*, *Staurodesmus convergens*, *Dinobryon sociale* and *Peridinium cincitum* at the littoral region.

Amongst 15 abiotic factors, an inverse correlation of water temperature on phytoplankton richness is affirmed by the relatively higher richness observed from October-April and October-March at the littoral and semi-limnetic regions, respectively. Besides, an inverse influence of the rainfall on phytoplankton and Charophyta richness at both the regions affirms the periods of lower richness during monsoon season in particular; and the concurrence of the relatively high SO_4 content results in the positive influence on richness of phytoplankton and Charophyta at the littoral region. Overall influence of abiotic factors on the richness noted in NEHU wetland differs from lack of any influence [23] but broadly concurs with the reports from Meghalaya [11,12].

On the other hand, our study registers the individual importance of the rainfall and SO_4 on the quantitative variations of phytoplankton. Higher abundance of phytoplankton, Charophyta, Chlorophyta, Dinozoa, Chrysophyta, Cyanobacteria, *Cosmarium decoratum, Netrium digitus, Staurastrum arctiscon*, *S. freemani, Staurodesmus convergens*, *Scenedesmus acuminatus, Dinobryon sociale*, *Ceratium hirudinella*, *Peridinium cincitum*, and *Spirulina agilis* at the two regions during autumn, winter and spring in particular results in an inverse influence of the rainfall. Besides, lower Bacillariophyta monsoon abundance endorses significant inverse influence of the rainfall at the littoral region. SO_4 exerts positive influence on abundance of phytoplankton, *Cosmarium decoratum, Staurastrum arctiscon*, *S. freemani* and *Scenedesmus acuminatus* at the two regions. It also exerts positive influence on abundance of Chlorophyta, Dinozoa, Chrysophyta and Cyanobacteria, *Dinobryon sociale*, *Ceratium hirudinella* and *Peridinium cincitum* at the littoral region, and on *Netrium digitus* at the semi-limnetic region. Of the other abiotic factors, the water temperature exerts inverse influence on Chlorophyta and Bacillariophyta abundance at the littoral and semi-limnetic regions, respectively, and Ca exerts a significant positive influence abundance of Charophyta and *Cosmarium decoratum* at the littoral region. Our results broadly endorse the importance of fewer abiotic factors [11,12] but deviate from overall limited influence of individual abiotic factors on phytoplankton abundance [9,23,24,27,28,38].

The CCA registers low cumulative influence of the selected 10 abiotic parameters on the littoral (57.09 %) and limnetic (58.12%) phytoplankton assemblages. This trend marks a notable departure than higher cumulative influence of abiotic factors recorded by the reports from NEI [9-12,24] and West Bengal [62]. The CCA biplot indicates inverse influence of the rainfall and water temperature on the richness of phytoplankton and Charophyta, and on abundance of Chlorophyta, *Closterium*, and *Scenedesmus* and *Scenedesmus acuminatus* at the littoral region. Besides, PO_4 reveals positive influence on *Staurastrum arctiscon*; abundance); SO_4, SiO_2 and specific conductivity exert positive influence on abundance of phytoplankton, Charophyta, *Cosmarium decoratum*; and total hardness and SO_4 influence abundance of Dinozoa and *Staurastrum freemani* at this region. On the other hand, the CCA biplot registers positive influence of water temperature and rainfall on *Cosmarium* abundance; total alkalinity; total alkalinity and NO_3 exert positive influence on *Staurastrum artiscon*, *Cosmarium decoratum*, *Dinobryon sociale*, *Peridinium cincitum*, and Chrysophyta abundance; PO_4 positively influences abundance of Dinozoa, Cyanobacteria, *Spirulina agilis* and *Ceratium hirudinella*; and SO_4 and SiO_2 exert negative on abundance of phytoplankton, Charophyta, *Closterium, Staurastrum, Staurastrum freemani, Staurodesmus* and *Staurastrum convergens* at the semi-limnetic region. In general, the limited individual importance and lower cumulative influence of abiotic factors noted *vide* our study suggests the need for attention on the factors associated with microhabitat vs. phytoplankton-macrophytes interactions.

5. Conclusions

The speciose nature and the regional biodiversity interest of phytoplankton of small urban NEHU wetland merits interest in contrast to the reduced taxonomic richness hypothesized in urbanized aquatic environs. High desmid richness; and the peak constellations of up to 55-58 species per sample deserve attention. The low phytoplankton abundance, quantitative importance of Charophyta, sub dominant nature of other groups, the bimodal richness and abundance spatio-temporal patterns of various taxa and high species diversity are notable features. Higher evenness and lower dominance are attributed to the lower and equitable abundance of the majority of the "generalist" species and even the relatively lower abundance of notable species. The limited individual and lower cumulative influence of abiotic factors caution attention on analysis of phytoplankton-macrophytes interactions. This study highlights the scope for more focused studies on phytoplankton of small water bodies of the Indian sub-region.

Author Contributions

This study was conceived and executed by the senior author. The data analysis and manuscript preparation was undertaken jointly by both the authors.

Conflict of Interest

The authors have no conflict of research interests.

Funding

This research received no external funding.

Acknowledgements

The senior author (BKS) thanks the Head, Department of Zoology, North-Eastern Hill University, Shillong for laboratory facilities, and K.R. Sounii Pou for help on various occasions during the field survey. We thank anonymous reviewers for comments and suggestions.

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