EISSN 2602-473X

AQUATIC SCIENCES AND ENGINEERING

Aquat Sci Eng 2021; 36(2): 51-65 • DOI: https://doi.org/10.26650/ASE2020740218

Original Article

Phytoplankton Diversity of a Subtropical Reservoir of Meghalaya State of Northeast India

Bhushan Kumar Sharma[1], Sumita Sharma[2]

Cite this article as: Sharma, B.K., & Sharma, S. (2021). Phytoplankton diversity of a subtropical reservoir of Meghalaya state of northeast India. *Aquatic Sciences and Engineering*, *36*(2), 51-65.

ABSTRACT

The littoral and limnetic phytoplankton of 'soft and de-mineralized water' in the Nongmahir reservoir of Meghalaya state of northeast India (NEI) reveal a fairly diverse assemblage of a total of 52 species, depict a higher richness of Chlorophyta and desmids, and record a speciose constellation of 51 species per sample. Phytoplankton form a dominant quantitative component of net plankton and indicate the differential spatial dominance of important groups. Bacillariophyta > Chlorophyta indicate dominance in the littoral region and Chlorophyta records dominance in the limnetic region. *Staurastrum* spp. > *Cosmarium* spp. are important in the two regions. Seventeen 'specialist' species collectively contribute to phytoplankton abundance in the littoral (87.9±6.9%) and limnetic (91.6±3.3%) regions and the rest depict a 'generalist' nature. Phytoplankton records moderate species diversity and variations of dominance and evenness. The spatial monthly variations of composition, richness, similarities, abundance, diversity indices and influence of individual abiotic factors are hypothesised to differences in habitat heterogeneity amongst the two regions. The CCA registers 78.36 and 78.95% cumulative influence of 10 abiotic factors on the littoral and limnetic phytoplankton assemblages, respectively. Our results highlight distinct temporal variations of diversity parameters in comparison with the preliminary survey of June 1995–May 1996. This study is an important contribution to phytoplankton diversity of the reservoirs of India and the subtropical reservoirs in particular.

Keywords: Calcium poor, de-mineralized, soft water, Nongmahir, spatio-temporal variations

ORCID IDs of the author:
B.K.S. 0000-0002-8019-2684;
S.S. 0000-0002-1267-282X

[1]Department of Zoology, North-Eastern Hill University, Shillong, Meghalaya, India

[2]Lady Veronica Road, Shillong, Meghalaya, India

Submitted: 20.05.2020

Revision Requested: 14.09.2020

Last Revision Received: 21.09.2020

Accepted: 22.10.2020

Online Published: 25.01.2021

Correspondence: Bhushan Kumar Sharma
E-mail: profbksharma@gmail.com

INTRODUCTION

Phytoplankton, an integral link of aquatic foodwebs, has been studied from diverse freshwater environs since the inception of the Indian limnology during the early part of the 20th century. A sizeable fraction of the published works with incomplete species inventories and inadequate data-analysis comprise 'routine' ecology reports (Sharma, 2015). The noteworthy phytoplankton diversity Indian studies relate to the lakes of Kashmir (Zutshi et al., 1980; Zutshi and Wanganeo, 1984; Wanganeo and Wanganeo, 1991; Baba and Pandit, 2014; Ganai and Parveen, 2014), Himachal Pradesh (Thakur et al., 2013; Gupta et al., 2018; Jindal et al., 2013, 2014a, 2014b) and Uttarakhand (Sharma and Singh, 2018; Sharma and Tiwari, 2018; Singh and Sharma, 2018). Certain notable works from NEI are from the floodplain lakes (*beels*) of the Brahmaputra river basin of Assam (Sharma, 2004, 2012, 2015; Sharma and Hatimuria, 2017) and *pats* of the floodplains of Manipur (Sharma, 2009, 2010). Nevertheless, there is paucity of works on diversity of phytoplankton assemblages from the sub-tropical reservoirs of India in general and NEI in particular. The related work from NEI belong to the Khawiva reservoir of Mizoram (Sharma and Pachuau, 2016), while Sharma (1995), Sharma and Lyngdoh (2003) and Sharma and Lyngskor (2003) dealt with the preliminary reports of three reservoirs of Meghalaya.

The present study, a follow-up of our limited survey of June 1995–May 1996 (Sharma and Lyngskor, 2003), attempts to provide detailed information on the phytoplankton diversity of the subtropical Nongmahir reservoir of Meghalaya; it assumes limnological importance in light of the stated lacunae. Our observations are based on analyses of monthly littoral and limnetic net plankton with reference to species composition, richness, community similarities, abundance, species diversity, dominance, evenness and trophic status as well as individual and cumulative influence of abiotic factors on phytoplankton assemblages. The results are compared and discussed with reference to studies from the Himalayan and sub-Himalayan sub-tropical lakes of India, and the floodplain lakes and the sub-tropical reservoirs of NEI. We comment on spatial variations of the observed parameters based on the sampled littoral and limnetic regions, and on temporal variations in comparison with an earlier survey of June 1995–May 1996.

MATERIALS AND METHODS

Our observations are based on a limnological survey (January–December, 2015) of the Nongmahir reservoir (25^0 08′ N; 91^0 50′ E; area: 70 ha; maximum depth: 25 m) commissioned in 1979 to serve as a pick up reservoir (Stage III) of the Umiam-Umtru hydroelectric project. It is located in the Ri-Bhoi district (Figure 1, A-B) and at a distance of about 45 km from Shillong city, the capital of Meghalaya state of NEI. This reservoir lacks any aquatic vegetation, and its fish fauna includes *Catla catla, Cirrhinus mrigala, Cyprinus carpio, Clarias batrachus, Danio acquipinnatus, D. dangila, Heteropneustes fossilis, Labeo rohita, Neolissocheilus hexagonolepis, Puntius sophore* and *Tor putitora.*

Water samples as well as qualitative and quantitative net plankton samples were collected at monthly intervals from the littoral and the limnetic regions (Sharma and Sharma, 2020). Water temperature was recorded using a centigrade thermometer, transparency was measured with a Secchi disc, pH and specific conductivity were recorded with field probes, dissolved oxygen was estimated using the modified Winkler's method, while other abiotic factors (total alkalinity, total hardness, calcium, magnesium, chloride, dissolved organic matter, phosphate, nitrate and sulphate) were analyzed following APHA (1992). Rainfall data was obtained from the local meteorological station.

The monthly qualitative net plankton samples, collected by towing a nylobolt plankton net (#40 µm) and preserved in 5% formalin, were screened with a Wild Stereoscopic binocular microscope. Phytoplankton was observed with a Leica stereoscopic microscope (DM 1000) and were identified following the works of Biswas (1949), Islam and Haroon (1980), Prescott (1982), Fitter and Manuel (1986), Anand (1998) and John et al. (2002). The community similarities were calculated vide Sørensen's index and the hierarchical cluster analysis was done using SPSS (version 20). The monthly quantitative net plankton samples were obtained by filtering 25 L of water for each sample through a nylobolt plankton net and were preserved in 5% formalin. Quantitative enumeration of phytoplankton, constituent groups, important taxa and species was done by using Sedgewick-Rafter counting cell and abundance was expressed as n/l. 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 analysis of variance (ANOVA) was used to ascertain the significance of variations of the different abiotic and biotic parameters. Pearson correlation coefficients, for the littoral and limnetic regions (r_1 and r_2, respectively), were calculated between abiotic factors and phytoplankton; p values were calculated *vide* http://vassarstats.net/tabs.html and their significance were ascertained after Bonferroni corrections. The canonical correspondence analysis (XLSTAT 2015) was done to observe the cumulative influence of 10 abiotic parameters (logistic limitations of the study period): water temperature, rainfall, transparency, specific conductivity, dissolved oxygen, total alkalinity, total hardness, phosphate, sulphate and nitrate on phytoplankton assemblages.

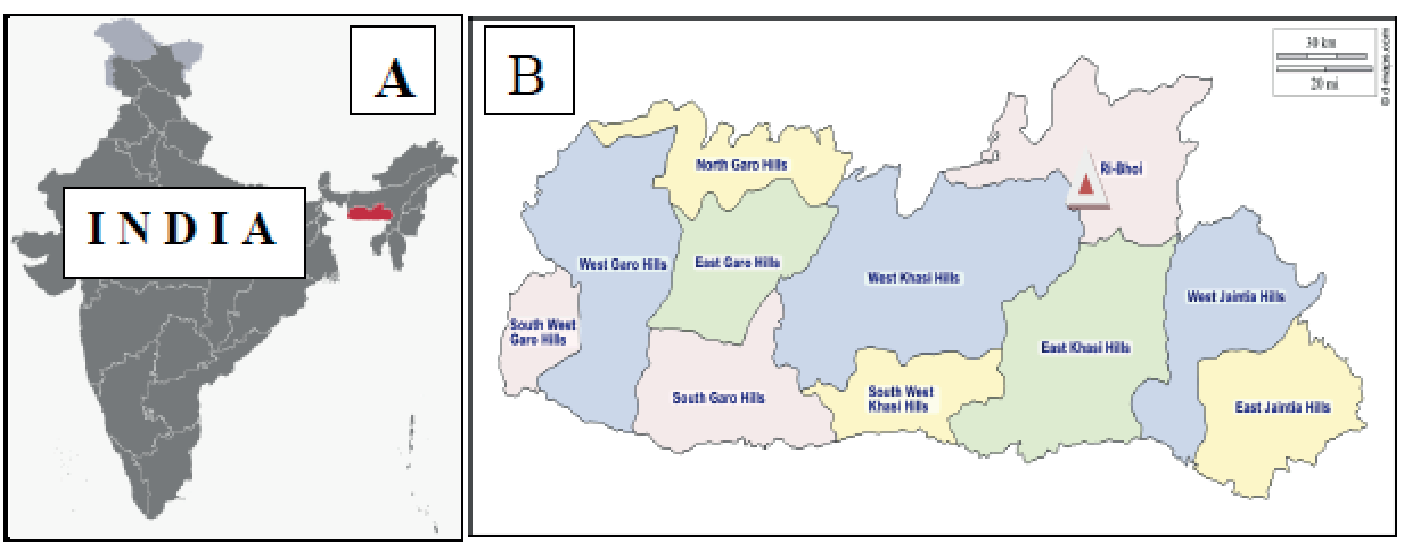

Figure 1. A-B. A, map of India showing Meghalaya state (red color); B, District map of Meghalaya showing location of the Nongmahir reservoir (red triangle) in the Ri-Bhoi district.

RESULTS AND DISCUSSION

Abiotic attributes

The Nongmahir reservoir is characterized by soft, slightly acidic-circum neutral, calcium poor and oxygenated waters with low specific conductivity, free carbon dioxide, chloride and nutrients (Tables 1-2). ANOVA depicts (Table 3) significant variations of transparency, total alkalinity, total hardness and dissolved organic matter between stations and months. Free carbon dioxide registers significant variation between stations. Water temperature, specific conductivity, calcium, magnesium, chloride, phosphate, nitrate and sulphate record significant monthly variations. Low specific conductivity is attributed to the leached and weathered nature of rocks and soils because of high rainfall (Sharma, 1995; Sharma and Bhattarai, 2005; Sharma and Sharma, 2020). This notable feature warrants inclusion of the sampled reservoir under 'Class I' category of trophic classification vides Talling and Talling (1965) and Payne (1986). The present study records temporal variations vis-à-vis the relative increase in specific conductivity, free carbon dioxide, total alkalinity, total hardness, calcium, phosphate and chloride, and decrease in transparency, magnesium, sulphate and nitrate in comparison with our preliminary June 1995–May 1996 survey (Sharma and Lyngskor, 2003).

Species richness

Our report of 52 phytoplankton species (Tables 3-4), belonging to seven groups, marks a distinct three-fold increase as compared with species reported vide the earlier survey (Sharma and Lyngskor, 2003). The richness concurs with 52 species each known from two floodplain lakes of Assam (Sharma, 2004, 2015) and broadly compares with 55 species observed from the Khawiva reservoir of Mizoram (Sharma and Pachuau, 2016). Phytoplankton is distinctly speciose in contrast to the reports from the sub-tropical reservoirs of Meghalaya (Sharma, 1995; Sharma and Lyngdoh, 2003), the floodplain lakes of Assam (Laskar and Gupta, 2009; Gupta and Devi, 2014; Devi et al. 2016; Deb et al., 2019) and Tripura (Bharati et al., 2020) states of NEI, and lakes of Kashmir (Shafi et al., 2013; Jeelani and Kaur, 2012; Chandrakiran et al., 2014; Nissa and Bhat, 2016), Uttarakhand (Rawat and Sharma, 2005; Negi and Rajput, 2015; Sharma and Singh, 2018; Singh and Sharma, 2018, Goswami et al., 2018), Himachal Pradesh (Gupta et al., 2018; Jindal and Thakur, 2014; Jindal et al, 2014b) from India, and adjacent south Asian countries of Bhutan (Sharma and Bhattarai, 2005) and Nepal (Hickel, 1973; Nakanishi et al., 1988). The richness is, however, marginally lower than the reports from Manipur (Sharma, 2009, 2012), Assam (Sharma, 2015), Kashmir (Baba and Pandit, 2014) and Himachal Pradesh (Thakur et al., 2013). The stated comparisons highlight the overall biodiverse nature of phytoplankton of the soft and de-mineralized waters of the Nongmahir reservoir in particular. Further, the 52 and 47 species observed from the littoral and limnetic regions (Table 4) indicate overall homogeneity with ~95% community similarity.

The speciose Chlorophyta (Tables 3-4) of the Nongmahir reservoir broadly compares with the reports from the Khawiva reservoir of Mizoram (Sharma and Pachuau, 2016) and Prashar Lake of Himachal Pradesh (Jindal and Thakur, 2014). Our results, however, depict species-rich Chlorophyta as compared with the reports from the various environs of Meghalaya (Sharma, 1995; Sharma and Lyngdoh, 2003) and Assam (Laskar and Gupta, 2009; Gupta and Devi, 2014; Devi et al., 2016; Bharati et al., 2020) of NEI; and the lakes of Kashmir (Shafi et al., 2013; Baba and Pandit, 2014; Ganai and Parveen, 2014) and Uttarakhand (Negi and Rajput, 2015; Goswami et al., 2018; Sharma and Singh, 2018; Sharma and Tiwari, 2018). Nevertheless, the qualitative importance of the green-algae differs from that of Chlorophyta > Bacillariophyta (Sharma and Lyngskor, 2003; Rawat and Sharma, 2005; Sharma, 2012, 2015; Shafi et al., 2013), Chlorophyta > Cyanophyta (Sharma and Lyngdoh, 2003; Laskar and Gupta, 2009) and Bacillariophyta > Chlorophyta (Sharma, 2004; Baba and Pandit, 2014; Ga-

Table 1. Variations of abiotic factors.

Regions →	Littoral region		Limnetic region	
Factors ↓	**Range**	**Mean ± S.D**	**Range**	**Mean ± S.D**
Water temperature ^{0}C	16.0-24.0	20.7±2.7	16.5-24.5	20.8±2.6
Rainfall mm	1.4-803.2	230.2±227.8	1.4-803.2	230.2±227.8
Transparency cm	75-110	92.5±10.1	80-120	100.8±12.4
pH	6.7-7.2	6.95±0.16	6.8-7.2	6.95±0.13
Specific conductivity µS/cm	40.2-57.8	50.3±5.3	38.8-58.0	50.0±6.3
Dissolved oxygen mg/l	7.0-9.6	8.2±0.7	7.4-9.0	8.3±0.6
Free Carbon dioxide mg/l	9.0-14.0	11.3±1.5	6.0-8.0	7.1±0.9
Total Alkalinity mg/l	24.0-48.0	33.0±6.8	28.0-46.8	36.3±5.7
Total Hardness mg/l	16.8-32.0	23.0±4.8	18.6-38.8	25.6±5.8
Calcium mg/l	9.8-19.2	13.9±3.4	10.0-18.7	13.7±2.6
Magnesium mg/l	1.2-4.2	2.2±0.8	1.0-5.0	2.2±1.1
Chloride mg/l	12.0-18.0	14.5±2.1	1.8-2.8	2.3±0.4
Phosphate mg/l	0.090-0.208	0.151±0.041	0.102-0.234	0.160±0.046
Sulphate mg/l	0.159-2.020	1.022±0.664	0.259-2.004	0.939±0.558
Nitrate mg/l	0.062-0.108	0.090±0.016	0.052-0.110	0.086±0.016
Dissolved organic matter mg/l	2.2-4.8	3.1±0.7	1.6-3.4	2.1±0.6

Table 2. Monthly variations of abiotic factors at littoral and limnetic regions.

Parameters ↓	**Months →**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**
Water temperature (^{0}C)	Littoral	16.0	17.0	19.0	21.0	23.0	23.5	24.0	24.0	22.5	21.0	20.0
	Limnetic	16.5	17.0	19.5	21.0	23.0	23.0	24.5	24.0	22.0	21.0	20.0
Rainfall mm	Littoral	32.0	2.0	39.8	390.8	272.0	803.2	502.1	220.8	169.8	150.0	178.6
	Limnetic	32.0	2.0	39.8	390.8	272.0	803.2	502.1	220.8	169.8	150.0	178.6
Transparency cm	Littoral	90	95	100	95	105	90	80	75	80	90	100
	Limnetic	100	110	120	105	100	90	80	85	90	100	110
pH	Littoral	6.9	7.1	7.2	6.9	6.8	6.7	6.9	7.1	6.8	6.9	**7.2**
	Limnetic	6.9	6.8	7.1	7.1	6.9	6.9	6.8	6.9	6.8	7.2	7.1
Specific conductivity (µS /cm)	Littoral	51.6	47.7	51.4	54.0	56.0	57.8	45.0	40.2	44.2	46.8	52.2
	Limnetic	42.8	48.6	52.2	56.4	57.2	58	49	40.2	38.8	48.6	52
Dissolved oxygen mg/l	Littoral	8.2	9.6	9.0	8.6	7.0	9.0	8.2	8.0	7.0	7.8	7.9
	Limnetic	7.2	7.8	8.6	9.0	8.2	8.8	7.4	8.4	9.0	8.8	7.8
Free Carbon dioxide mg/l	Littoral	10.0	14.0	12.0	10.8	10.0	9.0	10.0	12.0	14.0	11.8	12.0
	Limnetic	6.0	8.0	8.0	6.0	6.0	7.8	8.0	6.8	8.0	6.0	6.0
Total alkalinity mg/l	Littoral	36.0	48.0	40.0	38.0	29.0	27.8	26.0	24.0	26.0	30.0	34.0
	Limnetic	40.2	46.8	44.0	40.2	36.0	34.6	30.0	28.6	28.0	32.8	36.4
Total hardness mg/l	Littoral	28.0	32.0	29.0	28.0	22.0	20.6	20.2	18.0	16.8	19.0	20.0
	Limnetic	30.0	38.8	32.2	29.8	26.4	24.0	20.8	19.8	18.6	20.2	22.6
Chloride mg/l	Littoral	12.0	14.0	16.0	12.0	18.0	16.0	15.9	17.8	14.0	13.2	13.0
	Limnetic	10.2	12.0	14.6	14.0	16.0	17.8	15.0	14.8	12.0	13.2	12.0
Calcium mg/l	Littoral	18.0	19.2	18.6	17.0	15.2	13.2	10.2	9.8	10.0	11.2	11.8
	Limnetic	16.2	18.7	17.0	16.4	14.0	12.2	10.8	10.0	11.2	12.4	12.8
Magnesium mg/l	Littoral	2.8	4.2	2.2	2.8	1.8	1.4	1.2	1.2	1.7	2.0	**2.6**
	Limnetic	3.2	5.0	2.0	3.2	2.0	1.1	1.0	1.1	1.5	1.8	2.0
Phosphate mg/l	Littoral	0.090	0.099	0.104	0.128	0.182	0.190	0.160	0.208	0.190	0.182	0.168
	Limnetic	0.110	0.102	0.094	0.159	0.214	0.234	0.142	0.148	0.190	0.205	0.198
Sulphate mg/l	Littoral	0.159	0.270	0.304	0.478	0.602	1.642	1.820	2.020	2.004	1.023	0.998
	Limnetic	0.259	0.370	0.404	0.478	0.502	1.042	1.320	1.920	2.004	1.023	0.998
Nitrate mg/l	Littoral	0.090	0.098	0.084	0.090	0.078	0.062	0.072	0.080	0.098	0.108	0.120
	Limnetic	0.092	0.082	0.082	0.078	0.069	0.052	0.079	0.089	0.098	0.108	0.110
Dissolved organic matter mg/l	Littoral	3.8	4.2	4.8	2.6	2.2	2.8	3.0	2.2	3.0	3.2	2.8
	Limnetic	3.2	3.4	2.0	1.8	1.6	2.0	2.2	1.8	2.0	2.2	1.8

nai and Parveen, 2014; Negi and Rajput, 2015; Goswami et al., 2018; Sharma and Singh, 2018; Singh and Sharma, 2018; Deb et al., 2019) reported elsewhere from India. Woelkerling and Gough (1976), Payne (1986) and Sharma (1995) hypothesized high desmid diversity to be a notable feature of the soft, calcium-poor and de-mineralized waters. We extend this hypothesis to the rich desmid flora of the Nongmahir reservoir (Table 3) indicating *Staurastrum* (7 species) = *Cosmarium* (7 species) > *Pediastrum* (3 species) > *Micrasterias* (2 species) = *Closterium* (2 species) and one species each of *Anthrodesmus*, *Coelastrum*, *Euastrum*, *Netrium*, *Pleurotaenium*, *Scenedesmus*, *Sirogonium*, *Staurodesmus* and *Xanthidium*. This salient feature concurs with the reports from Meghalaya (Sharma, 1995; Sharma and Lyngdoh, 2003), Mizoram (Sharma and Pachuau, 2016), Assam (Sharma, 2015; Sharma and Hatimuria, 2017) and Himachal Pradesh (Thakur et al, 2013) but differs from the desmid paucity noted vide the earlier survey (Sharma and Lyngskor, 2003).

Our report of high phytoplankton monthly richness (Table 5) in the littoral region > the limnetic region (Figure 2) is hypothesized to greater habitat heterogeneity of the littoral region. Further, the notable speciose constellation / sample of 51 species observed in the littoral region of the Nongmahir reservoir during the winter (January) collection (Figure 2) is attributed to the possibility of co-existence of a number of phytoplankton species due to a high amount of niche overlap as hypothesized by MacArthur (1965). The differential and oscillating monthly phytoplankton richness variations (Figure 2) noted in the present study is affirmed by significant richness differences (vide ANOVA) between stations and months (Table 3). The peak richness noticed during January and December (winter) in the two regions, respectively concurs with the reports from the floodplains of Manipur (Sharma, 2010) and Assam (Devi et al., 2016). The monthly phytoplankton richness registers 50.7-79.6 and 39.4-87.4% community similarities in the littoral and limnetic regions (Table 4), respectively and depicts more heterogeneity in the latter region.

Table 3. ANOVA indicating significance of abiotic factors.

Parameters	Regions	Months
Abiotic factors		
Water temperature	-	$F_{11,23}$=233.294, P=2.19E-11
Transparency	$F_{1,23}$=17.742, P=0.001	$F_{11,23}$=10.871, P=0.0002
pH	-	-
Specific conductivity	-	$F_{11,23}$=11.1508, P=0.0002
Dissolved oxygen	-	-
Free Carbon dioxide	$F_{1,23}$=73.565, P=3.35E-06	-
Total Alkalinity	$F_{1,23}$=23.683, P=0.0005	$F_{11,23}$=30.097, P=1.31E-06
Total Hardness	$F_{1,23}$=30.644, P=0.0002	$F_{11,23}$=43.616, P=1.87E-07
Calcium	-	$F_{11,23}$=31.712, P=9.99E-07
Magnesium	-	$F_{11,23}$=26.706, P=2.44E-06
Chloride	-	$F_{11,23}$=6.0970, P=0.0028
Phosphate	-	$F_{11,23}$=8.972, P=0.0005
Sulphate	-	$F_{11,23}$=30.302, P=1.27E-06
Nitrate	-	$F_{11,23}$=15.625, P=3.68E-05
Dissolved organic matter	$F_{1,23}$=31.132, P=0.0002	$F_{11,23-}$=3.893, P=0.016

(-) indicates insignificant variations

Table 4. Species composition of phytoplankton.

Phytoplankton ↓ Regions →	Littoral	Limnetic
CHLOROPHYTA		
1. *Anthrodesmus convergens*	+	+
2. *Cosmarium botrytis*	+	+
3. *Cosmarium contractum*	+	+
4. *Cosmarium decoratum*	+	+
5. *Cosmarium granatum*	+	+
6. *Cosmarium punctulatum*	+	-
7. *Cosmarium scabrum*	+	-
8. *Cosmarium undulatum*	+	+
9. *Closterium pseudolunula*	+	+
10. *Closterium kuetzingii*	+	+
11. *Coleastrum sphaericum*	+	+
12. *Dictyosphaerium* sp.	+	+
13. *Euastrum sinousum*	+	+
14. *Micrasterias foliacea*	+	+
15. *Micrasterias radians*	+	+
16. *Netrium digitus*	+	+
17. *Pediastrum boryanum*	+	+
18. *Pediastrum duplex*	+	+
19. *Pediastrum simplex*	+	-
20. *Pleurotaenium* sp.	+	+
21. *Scenedesmus acuminatus*	+	+
22. *Sirogonium sticticum*	+	+
23. *Staurastrum artiscon*	+	+
24. *Staurastrum sexangulare*	+	+
25. *Staurastrum sonthalianum*	+	+
26. *Staurastrum formosum*	+	+
27. *Staurastrum paradoxum*	+	+
28. *Staurastrum leptocladum*	+	+
29. *Staurastrum rotula*	+	+
30. *Staurodesmus dejectus*	+	+
31. *Spirogyra orientalis*	+	+
32. *Xanthidium* sp.	+	+
BACILLARIOPHYTA		
33. *Caloneis* sp.	+	+
34. *Diatoma vulgaris.*	+	+
35. *Frustulia rhomboides*	+	+
36. *Navicula radiosa*	+	+
37. *Pinnularia interrupta*	+	+
38. *Rhopalodia* sp.	+	+
39. *Stauronies* sp.	+	+
40. *Tabellaria flocculosa*	+	+
DINOPHYTA		
41. *Ceratium hirudinella*	+	+
42. *Peridinium cinctum*	+	+
CRYPTOPHYTA		
43. *Cryptomonas* sp.	+	+
CYANOPHYTA		
44. *Microcystis aeruginosa*	+	+
45. *Anabaena sp.*	+	+
46. *Oscillatoria limosa*	+	+
47. *Nostoc* sp.	+	-
48. *Spirulina agilis*	+	+
CHRYSOPHYTA		
49. *Dinobryon sociale*	+	+
EUGLENOPHYTA		
50. *Euglena acus*	+	+
51. *Euglena viridis*	+	-
52. *Phacus longicauda*	+	+
Total phytoplankton species	**52**	**47**

+ present; - absent

Table 5. Qualitative and quantitative variations of phytoplankton.

Taxa ↓ Regions →	Littoral region		Limnetic region	
Richness				
Phytoplankton	52 species: 37-51, 41±5 species		47 species: 23-38, 31±6 species	
Community similarity	50.7-79.6%		39.4-87.4%	
Chlorophyta	32 species: 19-31, 23±2 species		29 species: 15-22	19±2
Quantitative				
Net Plankton n/l	436-1736	1053±421	363-1346	747±325
Phytoplankton n/l	295-1555	854±154	234-983	529±256
Percentage of net plankton	58.4-89.6	76.7±9.9	41.8-63.0	57.7±5.3
Species Diversity	1.425-3.143	2.570±0.528	1.875-2.741	2.503±0.218
Dominance	0.136-0.514	0.264±0.131	0.145-0.567	0.241±0.106
Evenness	0.379-0.836	0.696±0.146	0.532-0.739	0.738±0.067
Different Groups				
Chlorophyta n/l	89-699	313±204	63-763	312±320
Percentage of phytoplankton	6.3-67.1	39.8±17.7	15.7-78.5	52.1±19.9
Bacillariophyta n/l	74-1352	356±417	17-307	75±85
Percentage of phytoplankton	8.2-86.9	35.6±23.2	2.2-74.7	19.0±19.9
Chrysophyta n/l	18-502	97±129	10-192	68±65
Percentage of phytoplankton	1.3-46.1	11.6±12.1	2.4-26.1	11.0±8.2
Dinophyta n/l	9-80	38±23	15-111	47±25
Percentage of phytoplankton	0.6-22.7	6.4±5.9	3.6-17.8	9.6±5.0
Cyanophyta n/l	20-69	36±17	7-96	47±25
Percentage of phytoplankton	1.4-7.5	5.0±2.0	1.6-16.7	4.8±4.0
Important taxa (n/l)				
Staurastrum spp.	42-457	191±149	38-555	217±77
Cosmarium spp.	15-200	63±55	5-144	44±46
Important species (n/l)				
Navicula radiosa	40-800	208±248	4-229	39±64
Diatoma vulgaris	2-530	103±177	1-40	11±11
Dinobryon sociale	19-502	97±127	10-192	68±65
Staurastrum artiscon	7-167	55±49	7-196	54±48
Staurastrum paradoxum	10-160	51±43	3-120	45±38
Cosmarium contractum	10-148	46±41	1-120	34±38
Tabellaria flocculosa	6-101	31±31	2-60	19±20
Ceratium hirudinella	6-68	29±22	9-105	40±26
Sirogonium sticticum	2-170	28±48	0-95	21±30
Staurastrum sonthalianum	2-98	28±29	1-130	41±45
Staurastrum formosum	5-97	23±27	2-108	30±31
Staurastrum rotula	1-72	15±22	1-89	30±29
Staurastrum sexangulare	1-31	13±10	1-52	14±14
Spirulina agilis	5-42	17±11	1-80	16±22
Staurodesmus dejectus	1-39	11±9	0-40	15±14
Cosmarium granatum	1-42	11±13	1-22	8±8
Microcystis aeruginosa	5-32	14±8	3-15	7±3

This generalization is affirmed by similarity values ranging between 61-80% in ~72% instances in the limnetic region as against ~ 83% instances in the former region. The heterogeneity is endorsed by different hierarchical cluster groupings (Figures 3-4) with peak affinity between January-July followed by September-December while February community records maximum species divergence in the littoral region. The limnetic phytoplankton indicates peak affinity between June-July and records maximum divergence during March. Chlorophyta indicate a richness (Table 5) varying between 19-31 > 15-22 species (Figure 2); it registers significant variations (vide ANOVA) between stations and months (Table 6) and significantly influences phytoplankton richness (r_1= 0.692, p = 0.027; r_2= 0.787, p = 0.007) in the two regions.

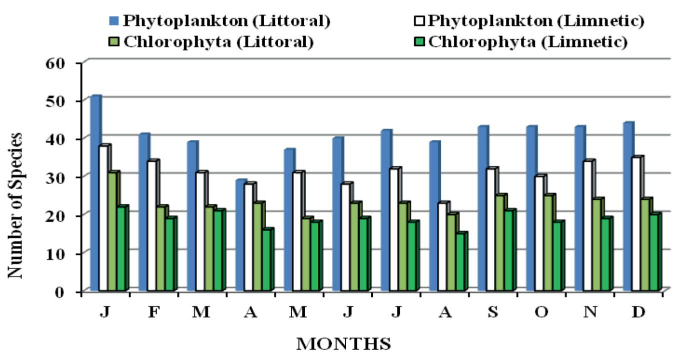

Figure 2. Monthly species richness variations of phytoplankton and Chlorophyta.

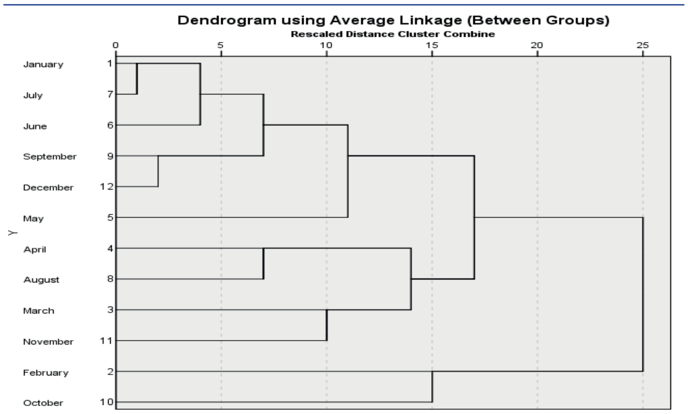

Figure 3. Hierarchical cluster analysis of Phytoplankton assemblages (Littoral region).

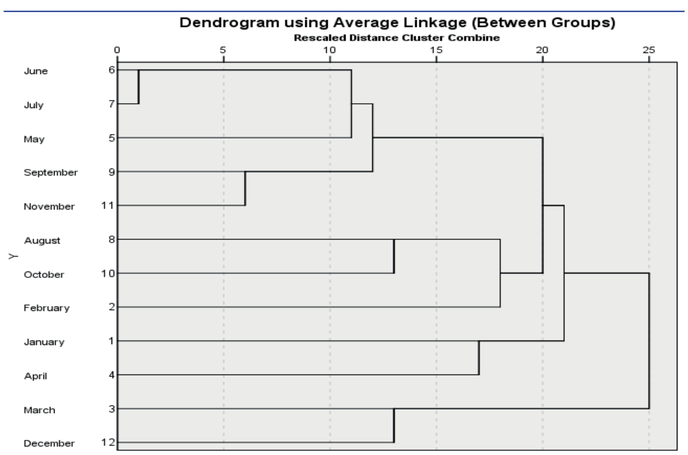

Figure 4. Hierarchical cluster analysis of Phytoplankton assemblages (Limnetic region).

Abundance

The Nongmahir reservoir indicates the highest phytoplankton abundance in comparison with other subtropical lacustrine environs of NEI (Sharma, 1995; Sharma and Lyngdoh, 2003; Sharma and Pachuau, 2016), while the density is notably higher than our earlier survey (Sharma and Lyngskor, 2003). Phytoplankton comprises the dominant component (76.7±9.9, 57.7±5.3%) and contributes significantly to net plankton ($r_1 = 0.995$, $p < 0.0001$; $r_2 = 0.963$, $p < 0.0001$) in both the regions, respectively. Wider phytoplankton density variations in the littoral > limnetic regions (Table 5) are affirmed by significant variations between stations and months registered vide ANOVA (Table 6); high abundance in the former region is hypothesized to its habitat heterogeneity. The quantitative dominance of phytoplankton of the sampled reservoir concurs with the results from Meghalaya (Sharma, 1995; Sharma and Lyngdoh, 2003) and Mizoram (Sharma and Pachuau, 2016), Himachal Pradesh (Jindal and Prajapat, 2005; Jindal and Thakur, 2014), Assam (Sharma and Hatimuria, 2017) and Kerala (Krishnan et al., 1999). This study records oscillating monthly phytoplankton density variations (Figure 5) with wider oscillations in the littoral region. Pre-monsoon maxima observed in both regions and autumn peak in the limnetic region (Figure 5) concur with the results of Sharma and Pachuau (2016) and the former corresponds with the report of Sharma (2015). The autumn peak recorded in the limnetic region concurs with the report from Kashmir (Baba and Pandit, 2014) and Uttarakhand (Sharma and Singh, 2018), and the winter maxima in the two regions agree with the reports of Wanganeo and Wanganeo (1991), Sharma (1995, 2004, 2009, 2010), Sharma and Lyngdoh (2003), Sharma and Hatimuria (2017) and Goswami et al. (2018). Bacillariophyta influence autumn phytoplankton peak, Chrysophyta>Chlorophyta contribute to the winter maxima and Chlorophyta > Bacillariophyta result in pre-monsoon maxima in the littoral region. Chlorophyta mainly contribute to pre-monsoon phytoplankton peak and Bacillariophyta > Chlorophyta contribute to winter maxima in the limnetic region. Our results thus highlight differential spatio-temporal quantitative influence of important phytoplankton groups of the Nongmahir reservoir.

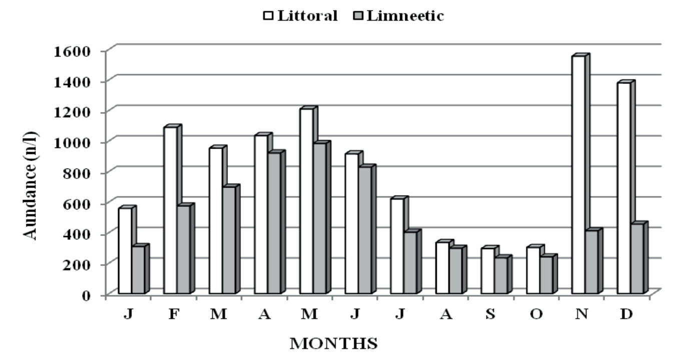

Figure 5. Monthly variations in Phytoplankton abundance.

Our study highlights the quantitative importance of *Navicula radiosa* > *Diatoma vulgaris* > *Dinobryon sociale* > *Staurastrum artiscon*> *S. paradoxum* > *Cosmarium contractum* > *Tabellaria flocculosa* > *Ceratium hirudinella* ≥ *Sirogonium sticticum* > *Staurastrum sonthalianum* > *S. formosum* > *S. rotula* > *Spirulina agilis* > *Microcystis aeruginosa* > *Staurastrum sexangulare* > *Cosmarium granatum* > *Staurodesmus dejectus* in the littoral region (Table 5). Besides, *Dinobryon sociale* > *Staurastrum artiscon* > *S. paradoxum* > *S. sonthalianum* > *Ceratium hirudinella* ≥ *Navicula radiosa* > *Staurastrum formosum* > *S. rotula* >

Table 6. ANOVA indicating significance of Phytoplankton assemblages.

Parameters	Regions	Months
	Richness	
Phytoplankton	$F_{1,23}$=71.768, P=3.77E-06	$F_{11,23}$=5.545, P=0.0042
Chlorophyta	$F_{1,23}$=146.520, P=3.17E-06	$F_{11,23}$=3.479, P=0.0191
	Abundance	
Phytoplankton	$F_{1,23}$=9.777, P=0.009	$F_{11,23}$=2.956, P=0.042
Chlorophyta	-	$F_{11,23}$=42.833, P=2.06E-07
Bacillariophyta	$F_{1,23}$=7.538, P=0.019	-
Chrysophyta	-	$F_{11,23}$=3.089, P=0.037
Dinophyta	-	-
Cyanophyta	$F_{1,23}$=7.919, P=0.017	$F_{11,23}$=10.783, P=0.0002
	Diversity indices	
Species diversity	-	-
Dominance	-	$F_{11,23}$=5.171, P=0.005
Evenness	-	$F_{11,23}$=3.646, P=0.021
	Abundance of important taxa	
Staurastrum spp.	-	$F_{11,23}$=44.087, P=1.36-06
Cosmarium spp.	$F_{1,23}$=12.819, P=0.004	$F_{11,23}$=29.909, P=2.43E-06
	Abundance of important species	
Navicula radiosa	$F_{1,23}$=8.366, P=0.014	-
Diatoma vulgaris	-	-
Dinobryon sociale	-	$F_{11,23}$=3.089, P=0.037
Staurastrum artiscon	-	$F_{11,23}$=16.984, P=3.33E-06
Staurastrum paradoxum	-	$F_{11,23}$=8.341, P=0.0007
Cosmarium contractum	$F_{1,23}$=6.748, P=0.024	$F_{11,23}$=25.141, P=3.33E-06
Tabellaria flocculosa	-	-
Ceratium hirudinella	-	-
Sirogomium sticticum	-	$F_{11,23}$=13.077, P=8.79E-05
Staurastrum sonthalianum	-	$F_{11,23}$=5.886, P=0.003
Staurastrum formosum	-	$F_{11,23}$=14.208, P=5.87E-05
Staurastrum rotula	$F_{1,23}$=6.627, P=0.026	$F_{11,23}$=9.019, P=0.0004
Staurastrum sexangulare	-	$F_{11,23}$=6.531, P=0.002
Spirulina agilis	-	$F_{11,23}$=6.158, P=0.003
Staurodesmus dejectus	-	$F_{11,23}$=4.708, P=0.008
Cosmarium granatum	-	$F_{11,23}$=10.364, P=0.0002
Microcystis aeruginosa	$F_{1,23}$=12.736, P=0.004	-

(-) indicates insignificant variations

Cosmarium contractum > *Sirogonium sticticum* > *Staurastrum sexangulare* > *Spirulina agilis* > *Staurodesmus dejectus* > *Diatoma vulgaris* register importance in the limnetic region (Table 5) while *Cosmarium granatum* > *Microcystis aeruginosa* also deserve attention. We categorize these 17 species as 'specialists' which collectively contribute notably (776±411, 490±277 n/l; 87.9±6.9%, 91.6±3.3%) to phytoplankton abundance in the two regions, respectively. The Nongmahir reservoir records a notably rich assemblage of 'specialist' species as compared with the reports from the Khawiva reservoir of Mizoram (Sharma and Pachuau, 2016) and the floodplains of Assam (Sharma, 2015; Sharma and Hatimuria 2017). Of the stated species, *Cosmarium contractum, Staurastrum rotula, Navicula radiosa* and *Microcystis aeruginosa* register significant density variations (vide ANOVA) between the two regions (Table 6), while *Cosmarium contractum, C. granatum, Dinobryon sociale, Sirogonium sticticum, Spirulina agilis, Staurastrum artiscon, S. formosum, S. paradoxum, S. rotula, S. sexangulare, S. sonthalianum* and *Staurodesmus dejectus* affirm significant monthly density variations (Table 6). *Navicula radiosa* (r_1 = 0.776, p = 0.008) individually influences phytoplankton abundance in the littoral region, and *Cosmarium contractum* (r_2= 0.866, p = 0.0012), *Staurastrum artiscon* (r_2 = 0.757, p = 0.011), *S. formosum* (r_2 = 0.772, p= 0.009), *S. paradoxum* (r_2 = 0.678, p = 0.031), *S. sexangulare* (r_2 = 0.878, p = 0.0008), *S. sonthalianum* (r_2 = 0.920, p = 0.0002), *Staurodesmus dejectus* (r_2 = 0.845, p = 0.0021) influence abundance in the limnetic region.

The Nongmahir reservoir depicts quantitative dominance of Chlorophyta (52.1±19.9.0%) and its significant contribution to phytoplankton abundance in the limnetic region (r_2=0.919, p = 0.0002), while this group indicates importance (39.8±17.7%) at the littoral region (Table 5). The significant density variations (Table 6) noted between regions (vide ANOVA) endorse differential spatial importance of Chlorophyta. This study depicts a higher abundance of the green-algae than the reports from the reservoirs of Meghalaya (Sharma, 1995; Sharma and Lyngdoh, 2003) and Mizoram (Sharma and Pachuau, 2016) and the floodplain lakes (Sharma, 2004, 2009, 2010, 2012, 2015; Sharma and Hatimuria, 2017) of NEI; abundance is notably higher than in the earlier survey (Sharma and Lyngskor, 2003). Chlorophyta follows nearly identical patterns of monthly density variations in both the regions (Figure 6) with peak abundance in May; the latter concurs with the reports of the floodplains lakes of Assam (Sharma, 2012, 2015; Sharma and Hatimuria, 2017) and Nigeen Lake of Kashmir (Shafi et al., 2013).

Cosmarium contractum (r_1= 0.941, p < 0.0001), *C. granatum* (r_1= 0.883, p =0.001), *Staurastrum artiscon* (r_1= 0.884, p = 0.001), *S. formosum* (r_1= 0.800, p = 0.006), *S. paradoxum* (r_1= 0.749, p= 0.013), *S. sonthalianum* (r_1= 0.735, p= 0.015) and *S. rotula* (r_1= 0.782, p = 0.008) influence Chlorophyta abundance in the littoral region and *Cosmarium contractum* (r_2=0.954, p < 0.0001), *Staurastrum artiscon* (r_2= 0.857, p = 0.0002), *S. formosum* (r_2= 0.703, p<0.023), *S. paradoxum* (r_2=0.855, p=0.0016), *S. sonthalianum* (r_2= 0.926, p=0.0001), *S. sexangulare* (r_2= 0.804, p = 0.0051), and *Staurodesmus dejectus* (r_2= 0.914, p = 0.0002) influence abundance in the limnetic region. The stated species collectively (278±204 and 290±225 n/l; 83.1±9.9 and 90.0±5.6%) contribute to Chlorophyta abundance (r_1= 0.998, p < 0.0001; r_2= 0.999, p < 0.0001) in the two regions, respectively. Further, *Staurastrum artiscon* (167 n/l) > *Cosmarium contractum* (148 n/l) > *S. paradoxum* (101 n/l) > *S. rotula* (72 n/l) > *S. sonthalianum* (50 n/l) > *C. granatum* (42 n/l) > *S. formosum* (40 n/l) contribute to pre-monsoon Chlorophyta maxima in the littoral region; *Staurastrum artiscon* (196 n/l) > *Cosmarium contractum* (120 n/l) > *S. sonthalianum* (111 n/l) > *S. paradoxum* (92 n/l) > *S. rotula* (89 n/l) influence pre-monsoon maxima in the limnetic region. In general, the quantitative importance of desmids concurs with the reports of Sharma (2009, 2010) and Sharma and Lyngdoh (2003), Hulyal and Kaliwal (2009) and Thakur et al. (2013).

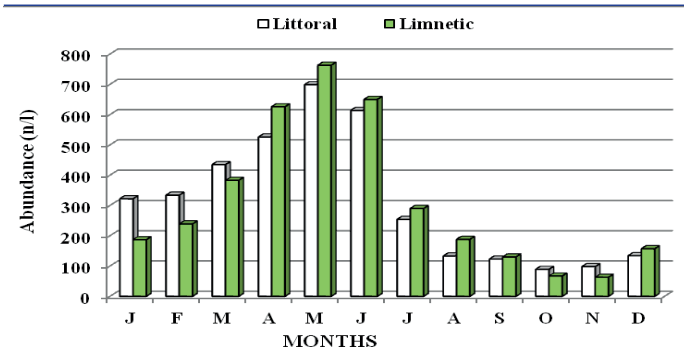

Figure 6. Monthly variations in Chlorophyta abundance.

Staurastrum spp. (191±149 and 217±77 n/l) > *Cosmarium* spp. (63±55 and 44 ± 46 n/l) together comprise notable fractions of phytoplankton (31.1±17.1 and 47.3±20.8%) and Chlorophyta (76.8±17.4 and 78.9±17.2%) abundance in the littoral and limnetic regions, respectively. ANOVA (Table 6) registers a significant monthly density variation of the two desmids, while *Cosmarium* spp. registers a significant density variation between the two regions of the Nongmahir reservoir. Further, *Staurastrum* spp. (r_1= 0.955, p < 0.0001) and *Cosmarium* spp. (r_1= 0.945, p < 0.0001) influence Chlorophyta abundance as well as pre-monsoon peak and winter maxima in the littoral region (Figures 7-8). Besides, *Staurastrum* spp. (r_2=0.889, p=0.0006; r_2=0.983, p< 0.0001) and *Cosmarium* spp. (r_2= 0.873, p= 0.0002; r_2= 0.961, p < 0.0001) influence abundance and influence pre-monsoon peaks and winter maxima of phytoplankton and Chlorophyta in the limnetic region, respectively (Figures 7-8). The importance of *Staurastrum* spp. > *Cosmarium* spp. observed vide the present study differs from the reports of *Staurastrum* spp. > *Xanthidium* spp. > *Cosmarium* spp. from the Khawiva reservoir of Mizoram (Sharma and Pachuau, 2016); *Closterium* spp.> *Staurastrum* spp. > *Gonatozygon* spp. > *Micrasterias* spp. > *Cosmarium* spp. from Loktak Lake of Assam (Sharma, 2009); and *Closterium* spp.> *Gonatozygon* spp. > *Micrasterias* spp. > *Staurastrum* spp. from Utra Pat and *Closterium spp. > Cosmarium spp. > Staurastrum spp. > Xanthidium* spp. from Waithou Pat of Manipur (Sharma, 2010).

Phytoplankton depicts higher Bacillariophyta (Table 5) abundance in the littoral region (Figure 9), comprise an important quantitative component (35.6±23.2%) of phytoplankton (r_1=0.766, p=0.010), and record bloom during November-December (peak

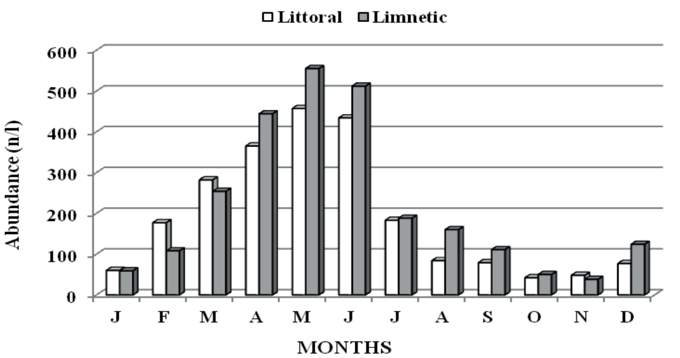

Figure 7. Monthly variations in *Staurastrum* spp. abundance.

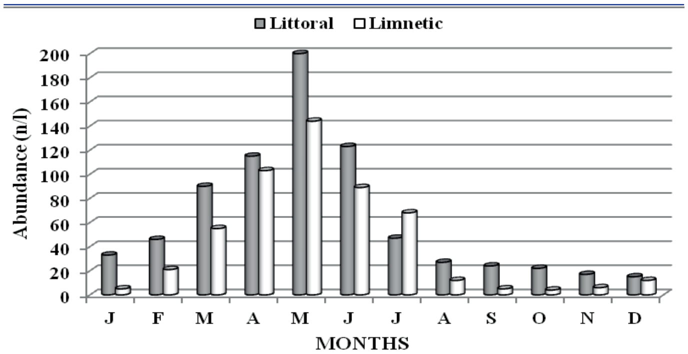

Figure 8. Monthly variations in *Cosmarium* spp. abundance.

during autumn) and maxima during pre-monsoon (May). In contrast, this group indicates sub-dominance (19.0±19.9%) in the limnetic region (Figure 9) with peak in autumn (November). The differential spatial importance of Bacillariophyta is affirmed by significant density variations (vide ANOVA) between the two regions (Table 6). The diatom dominance and sub-dominance at the two regions, respectively concurs with the results from Samuajan beel (Sharma, 2004) and the dominance in the former region corresponds with the reports from Deepor beel (Sharma, 2015) and Bhereki Beel (Sharma and Hatimuria, 2017) of Assam, and lakes of Himachal Pradesh (Jindal and Prajapat, 2005; Jindal et al., 2014b), Kashmir (Baba and Pandit, 2014; Nissa and Bhat, 2016) and Uttarakhand (Goswami et al., 2018). Bacillariophyta sub-dominance corresponds with the reports from Loktak Lake of Manipur (Sharma, 2009) and Holmari and Ghotonga beels (Sharma and Hatimuria, 2017) of Assam, and lakes of Kashmir (Shafi et al, 2013) and Uttarakhand (Sharma and Singh, 2018). Autumn Bacillariophyta peak in the littoral region concurs with the report from Nigeen Lake of Kashmir (Nissa and Bhat, 2016) and winter bloom in this region corresponds with the reports from Kashmir (Wanganeo and Wanganeo, 1991; Baba and Pandit, 2014), Meghalaya (Sharma and Lyngdoh, 2003) and Manipur (Sharma, 2009).

Navicula radiosa, *Diatoma vulgaris* and *Tabellaria flocculosa* collectively comprise a significant fraction of Bacillariophyta of the Nongmahir reservoir in the littoral (342±416 n/l; 89.2±7.0%) and limnetic (69±83 n/l; 87.6±13.9 %) regions, and contribute to phytoplankton (r_1= 0.765, p =0.009) and Bacillariophyta (r_1= 0.999, p < 0.0001), and Bacillariophyta (r_2= 0.998, p < 0.0001) abundance in the two regions, respectively. In addition, *N. radiosa* (800 n/l) > *D. vulgaris* (530 n/l) influence autumn phytoplankton and Bacillariophyta peaks in the littoral region, while *N. radiosa* (229 n/l) > *T. flocculosa* (60 n/l) influence autumn peak in the limnetic region. These remarks are further affirmed by significant influence of *N. radiosa* (r_1= 0.999, p < 0.0001) and *D. vulgaris* (r_1= 0.976, p < 0.0001), and *N. radiosa* (r_2 = 0.984, p < 0.0001) and *T. flocculosa* (r_2 = 0.895, p < 0.0005) on Bacillariophyta abundance in the two regions, respectively.

Chrysophyta (represented by *Dinobryon sociale*) forms a subdominant phytoplankton component in the two regions with relatively wider quantitative variations (Table 5) in the littoral region; ANOVA

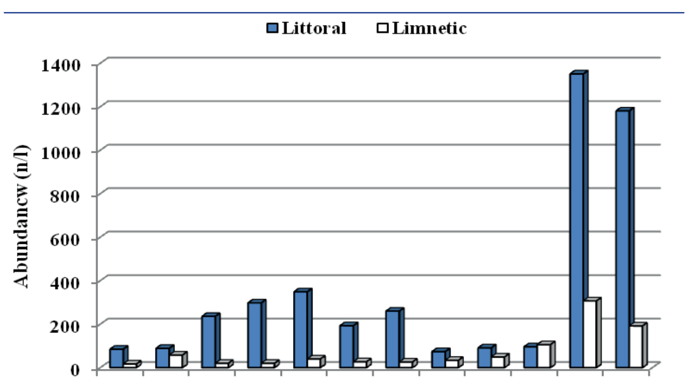

Figure 9. Monthly variations in Bacillariophyta abundance.

registers its significant density variations between months (Table 6). Chrysophyta depicts importance at both the regions from February-May; it records bloom (peak) during winter (February) in the littoral region and during April in the limnetic region (Figure 10). Our results are in contrast to poor Chrysophyta abundance reported from various floodplain lakes and reservoirs of NEI (Sharma, 1995, 2009, 2010, 2012, 2015; Sharma and Lyngdoh, 2003; Sharma and Lyngskor, 2003). Dinophyta, another sub-dominant group, records relatively lower abundance (Table 5) in the limnetic region > the littoral region and depicts insignificant density variations (vide ANOVA) between the two regions. This group indicates oscillating patterns of monthly density variations with peak during winter (February) and maxima during monsoon (August) in the littoral region (Figure 11), and peak during monsoon (June) in the limnetic region (Figure 12). Dinophyta abundance is influenced by *Ceratium hirudinella* at the two regions (r_1= 0.978, p < 0.0001; (r_2= 0.989, p < 0.0001). The winter peaks of Dinophyta and *C. hirudinella* agree with the report Loktak Lake of Manipur (Sharma, 2009) but differ from the summer maxima recorded from Garhwal (Sharma and Singh, 2018). Our results differ from poor Dinophyta abundance reported vides Sharma and Lyngdoh (2003), Sharma and Lyngskor (2003) and Sharma (2010).

Cyanophyta, yet another sub-dominant group (Table 5) of phytoplankton, is largely influenced by *Spirulina agilis* (r_1 = 0.978, p <0.0001; r_2 = 0.995, p < 0.0001) > *Microcystis aeruginosa* (r_1 =

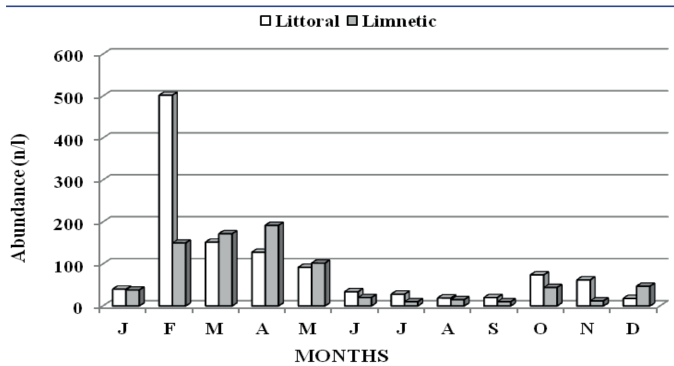

Figure 10. Monthly variations in Chrysophyta abundance.

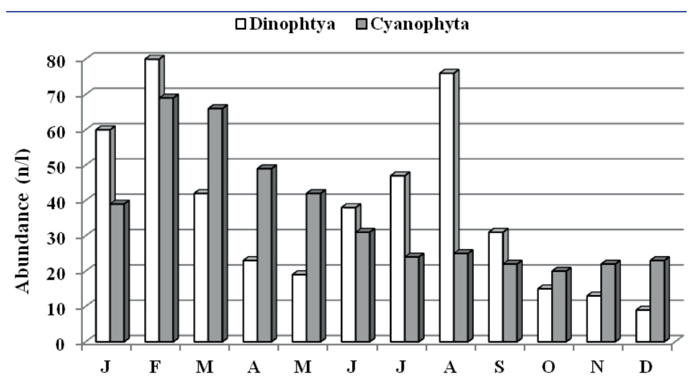

Figure 11. Monthly variations in Dinophyta and Cyanophyta abundance (Littoral region).

0.910, p = 0.0003) in the littoral and limnetic stations, respectively. ANOVA indicates significant density variations of this group between months (Table 6). The blue green algae depict oscillating monthly density variations with peak during winter (February) in the two regions (Figures 11-12). The sub-dominance of Cyanophyta concurs with the reports from Himachal Pradesh (Jindal and Prajapat, 2005), Assam (Sharma, 2015), Mizoram (Sharma and Pachuau, 2016) and Kashmir (Baba and Pandit, 2014). Euglenophyta and Cryptophyta record poor abundance in the Nongmahir reservoir corresponding with the reports of Sharma and Lyngdoh (2003), Sharma (2009) and Sharma and Pachuau (2016).

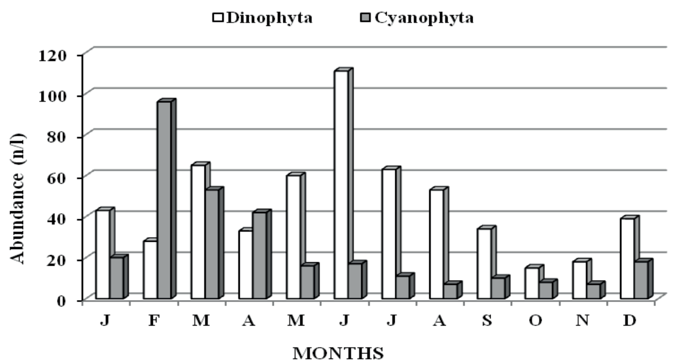

Figure 12. Monthly variations in Dinophyta and Cyanophyta abundance (Limnetic region).

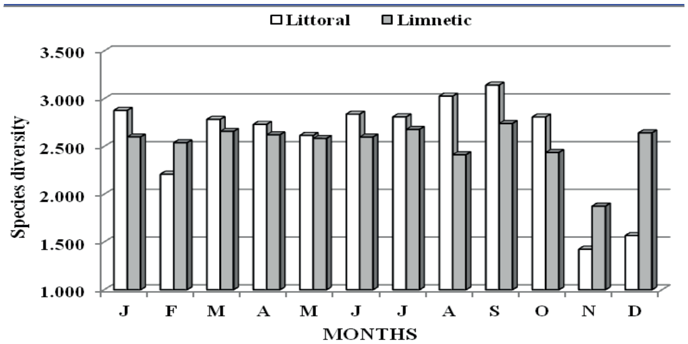

Figure 13. Monthly variations in phytoplankton species diversity.

Diversity indices

Our study highlights the moderate species diversity (Table 4) of Phytoplankton of the Nongmahir reservoir. It depicts differential spatial monthly variations with higher values in the littoral > limnetic regions during January and March-October, and the limnetic > littoral pattern during February and November-December (Figure 13). The diversity compares with the report from Khawiva reservoir from Mizoram (Sharma and Pachuau, 2016) vis-à-vis moderate diversity, overall variations and few instances of higher values, while this study records higher diversity than the reports from Meghalaya (Sharma, 1995, Sharma and Lyngdoh, 2003; Sharma and Lyngskor, 2003). Further, the species diversity is inversely influenced by abundance of phytoplankton (r_1= -0.808, p = 0.005), Chlorophyta (r_1= -0.834, p= 0.003) and Chrysophyta (r_1= -0.909, p= 0.0003), *Navicula radiosa* (r_1= -0.911, p= 0.0002) and *Diatoma vulgaris* (r_1= -0.891, p = 0.0005) in the littoral region, and by Bacillariophyta (r_2= -0.772, p= 0.008) and *N. radiosa* (r_2= -0.832, p= 0.003) in the limnetic region. It is inversely influenced by dominance (r_1= -0.879, p = 0.0008; r_2= -0.847, p = 0.002) as also affirmed by concurrence of the lowest diversity during autumn with peak dominance in both regions. The diversity is positively influenced by phytoplankton evenness (r_1= 0.984, p < 0.0001; r_2= 0.916, p = 0.0002) in the two regions, respectively. We consider the Shannon Weiner diversity index for assessing the health of aquatic biotopes (Wilhm and Dorris 1968; Masson 1998). In general, phytoplankton diversity variations noted vide the present study depict the 'meso-trophic' status of the Nongmahir reservoir, while H' value > 3.0 during monsoon (August and September) in the littoral region reflects the shift to a 'meso-eutrophic' nature. The stated remarks concur with trophic status assessment of this reservoir based on our zooplankton species diversity results (Sharma and Sharma, 2020).

Our observations depict monthly differences of phytoplankton dominance in the two regions (Table 4); this generalization is also affirmed by significant monthly dominance variations noted vide ANOVA (Table 6). Peak dominance and maxima are noted during autumn (November) and winter (February), and winter (December) and winter (January) in the littoral and limnetic regions, respectively. The 'specialist species' influence higher dominance while low values during certain months concur with equitable abundance of the 'generalist species' as suggested by McNaughton (1967). These remarks are affirmed by the positive influence of Bacillariophyta (r_1= 0.686, p = 0.029; r_2= 0.754, p = 0.012), *Navicula radiosa* (r_1= 0.684, p = 0.0292; r_2= 0.812, p = 0.003) on dominance in the two regions and that of *Diatoma vulgaris* (r_1= 0.731, p = 0.0163) in the limnetic region in particular. The extant of dominance variations broadly correspond with the reports of Sharma and Pachuau (2016) and Sharma and Hatimuria (2017).

Phytoplankton depicts differential variations of evenness (Table 5) in the littoral and the limnetic regions; ANOVA registers significant evenness variations between months. High evenness during several months is attributed to equitable abundance of the majority of taxa (Washington, 1984) while dominance of certain species results in moderate evenness. This generalization is affirmed by an inverse correlation of evenness vs. dominance (r_1 = -0.910, p= 0.0003; r_2 = - 0.925, p = 0.0001) in the two regions as well as by inverse influence of abundance of *Navicula radiosa* (r_1 = -0.886, p = 0.0006) and *Diatoma vulgaris* (r_1= -0.896, p= 0.0005) in the littoral region, and of *Navicula radiosa* (r_2 = -0.882, p = 0.0007) at the limnetic region. Further, evenness is inversely influenced by abundance of phytoplankton (r_1= -0.728, p = 0.017), Chlorophyta (r_1= -0.763, p = 0.010) and Chrysophyta (r_1= -0.887, p = 0.0006) in the littoral region and by Bacillariophyta abundance (r_2= -0.842, p = 0.002) in the limnetic regions.

Influence of abiotic factors

Inverse influence of water temperature on phytoplankton richness (r_2=-0.728, p=0.017) in the limnetic region of the Nongmahir reservoir is attributed to lower richness during warmer months (April - June and August), while more richness variations in the littoral region result in insignificant inverse correlation with temperature. High phytoplankton abundance concurrent with the periods of high ionic concentration results in positive influence by specific conductivity (r_1= 0.836, p = 0.0026; r_2= 0.803, p = 0.0052) at the two regions, while high abundance during February-March, November-December coincides with the relatively higher transparency (r_1= 0.718, p= 0.019) in the littoral region. The importance of specific conductivity concurs with the report of Sharma and Lyngdoh (2003) and Sharma and Bhattarai (2005).

The positive influence of dissolved oxygen on Chlorophyta (r_1= 0.731, p = 0.016) and *Staurastrum artiscon* (r_1= 0.751, p = 0.035) in the littoral region is attributed to concurrence of a higher abundance of these taxa with the relatively high dissolved oxygen during February-April and June. The positive influence of chloride on Chlorophyta (r_2= 0.719, p = 0.0191), *Cosmarium contractum* (r_2= 0.715, p = 0.020) and *Staurodesmus dejectus* (r_2= 0.750, p = 0.012) in the limnetic region results from a concurrence of high abundance of three taxa and a marked influx of chloride with rainwater during early monsoon. Further, the higher abundance of *Staurastrum formosum* during the early-monsoon months in the littoral region affirms positive influence by rainfall (r_1= 0.815, p = 0.004) and higher densities of this desmid in the limnetic region coincides with periods of the relatively high specific conductivity (r_2= 0.758, p = 0.011). *Cosmarium granatum* is inversely influenced by nitrate (r_1= -0.706, p = 0.026) in the littoral region, and *Staurastrum sexangulare* is positively influenced by nitrate (r_2= 0.770, p = 0.009) in the limnetic region. Peak abundance of *Sirogomium sticticum* during winter results in inverse influence by water temperature (r_1= -0.744, p = 0.014; r_2= -0.764, p = 0.0101) in the littoral and limnetic regions; this species is positively influenced by total alkalinity (r_2= 0.700, p = 0.024), total hardness (r_2= 0.776, p = 0.008) and dissolved organic matter (r_2= 0.875, p = 0.006) in the limnetic region. The positive influence of water temperature (r_2= 0.711, p = 0.002), rainfall (r_2= 0.830, p = 0.003) and chloride (r_2= 0.880, p = 0.0008) on *Staurastrum paradoxum* in the limnetic region is attributed to higher abundance during warmer early and mid-monsoon periods which also coincides with the influx of chloride. Our results thus highlight the differential spatial influence of abiotic factors on Chlorophyta and its notable species in the two regions.

The notable feature of lack of significant influence of abiotic factor on Bacillariophyta abundance concurs with the reports of Sharma (2009) and Sharma and Pachuau (2016). Chrysophyta is positively influenced by dissolved oxygen (r_1= 0.678, p = 0.031), total alkalinity (r_1= 0.783, p = 0.007) and total hardness (r_1= 0.725, p = 0.028) in the littoral region and by total alkalinity (r_2= 0.770, p = 0.009) and total hardness (r_2= 0.789, p = 0.006) in the limnetic region. Cyanophyta is positively influenced by dissolved oxygen (r_1= 0.803, p = 0.005), total alkalinity (r_1= 0.773, p = 0.009) and total hardness (r_1= 0.905, p = 0.0003) in the littoral region. These remarks are endorsed by important species of blue-green algae i.e. *Spirulina agilis* with positive correlations with dissolved oxygen (r_1= 0.842, p = 0.002), total alkalinity (r_1= 0.817, p = 0.004), total hardness (r_1= 0.921, p = 0.0002), while *Microcystis aeruginosa* indicates the positive influence of dissolved oxygen (r_1= 0.735, p = 0.015), total hardness (r_1= 0.733, p = 0.016) in the littoral region. Cyanophyta is positively influenced by total alkalinity (r_2= 0.829, p = 0.003), total hardness (r_2= 0.913, p = 0.0002) and sulphate (r_2= 0.847, p = 0.002), while *S. agilis* is positively influenced by total alkalinity (r_2= 0.796, p = 0.006) and total hardness (r_2= 0.895, p = 0.0005) in the limnetic region. Our results thus indicate overall conducive influence of total alkalinity and total hardness in promoting higher abundance Chrysophyta and Cyanophyta. Dinophyta is positively influenced by rainfall (r_2= 0.695, p=0.025) and chloride (r_2= 0.786, p=0.0067), while *Ceratium hirudinella* is positively influenced by chloride (r_2= 0.734, p = 0.016) in the limnetic region. These relationships are affirmed by a high abundance of these taxa during monsoon which also marks the influx of chloride. In general, the present study registers the differential importance of water temperature, rainfall, transparency, specific conductivity, dissolved oxygen, total alkalinity and total hardness on phytoplankton assemblages. Referring to notable individual phytoplankton species, our results indicate a distinct departure from the reports of Sharma (1995, 2009. 2010, 2012, 2015), Sharma and Lyngdoh (2003), Sharma and Lyngskor (2003) and Sharma and Pachuau (2016) and Sharma and Hatimuria (2017) yielding little insight on the influence of abiotic factors vis-a-vis important species.

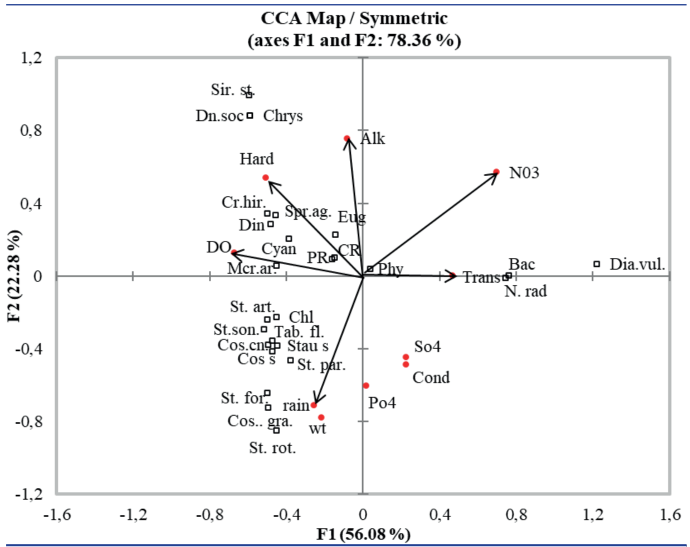

Figure 14. CCA coordination biplot of phytoplankton and abiotic factors (Littoral region).

Abbreviations: Abiotic factors: Alk (alkalinity), Cond (conductivity), DO (dissolved oxygen), hard (hardness), rain (rainfall), Trans (transparaency), No3 (nitrate), Po4 (phosphate), So4 (sulphate), wt (water temperature. **Biotic factors:** Bac (Bacillariophyta), Chl (Chlorophyta), Chry (Chrysophyta), Cos. cn. (*Cosmarium contractum*), Cos.gra. (*Cosmarium granatum*), Cos s (*Cosmarium* spp.), CR (Chlorophyta richness), Cr. hir. (*Ceratium hirudinella*), Crypt (Cryptophyta), Cyan (Cyanophyta), Dia. vul. (*Diatoma vulgaris*), Din (Dinophyta), Dn. soc. (*Dinobryon sociale*), Eug (Euglenophyta), Mcr. ar (*Microcystis aeruginosa*), N rad. (*Navicula radiosa*),PR (phytoplankton richness), Phy (Phytoplankton), Sir. st. (*Sirogonium sticticum.)*, Spr. ag. (*Spirulina agilis*), Staur s (*Staurastrum* spp.), St. art. (*Staurastrum artiscon),* St. for. (*Staurastrum formo-*

sum), St. par. (*Staurastrum paradoxum*). St. rot. (*Staurastrum rotula*), St. son. (*Staurastrum sonthalianum),* St. sex. (*Staurastrum sexangulare*), Tab. fl. (*Tabellaria flocculosa*)

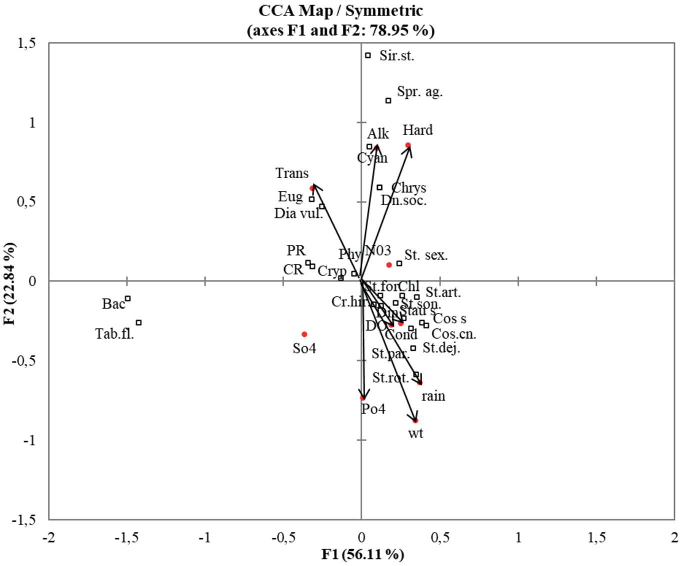

Figure 15. CCA coordination biplot of phytoplankton and abiotic factors (Limnetic region).

Abbreviations: Abiotic factors: Alk (alkalinity), Cond (conductivity), DO (dissolved oxygen), hard (hardness), rain (rainfall), Trans (transparaency), No3 (nitrate), Po4 (phosphate), So4 (sulphate), wt (water temperature. **Biotic factors:** Bac (Bacillariophyta), Chl (Chlorophyta), Chry (Chrysophyta), Cos. cn. (*Cosmarium* contractum); Cos s (*Cosmarium* spp.), CR (Chlorophyta richness), Cr.hir. (*Ceratium hirudinella*), Crypt (Cryptophyta), Cyan (Cyanophyta), Dia. vul. (*Diatoma vulgaris*), Din (Dinophyta), Dn. soc. (*Dinobryon sociale*), Eug (Euglenophyta), PR (phytoplankton richness), Phy (Phytoplankton), Sir. st. (*Sirogomium sticticum),* Spr. ag. (*Spirulina agilis*), Staur s (*Staurastrum* spp.*),* St. art. (*Staurastrum artiscon),* St. for. (*Staurastrum formosum),* St. par. (*Staurastrum paradoxum*). St. rot. (*Staurastrum rotula*), St. son. (*Staurastrum sonthalianum),* St. sex. (*Staurastrum sexangulare*), St. dej. (*Staurodesmus dejectus*), Tab. fl. (*Tabellaria flocculosa*)

The Canonical correspondence analysis (CCA) registers the high cumulative influence (78.36 and 78.95%) of 10 abiotic factors, along first two axes, on phytoplankton assemblages in the littoral and limnetic stations, respectively. The CCA co-ordination biplot indicates the influence of transparency and nitrate on phytoplankton abundance; hardness on phytoplankton and Chlorophyta richness, and on abundance of Cyanophyta, Dinophyta, *Dinobryon sociale* and *Spirulina agilis*; dissolved oxygen on *Microcystis aeruginosa*; alkalinity and hardness on Euglenophyta in the littoral region. The CCA biplot depicts the influence of alkalinity and hardness on Chrysophyta and *Dinobryon sociale*; transparency on richness of phytoplankton and Chlorophyta, and phytoplankton and Euglenophyta abundance; specific conductivity on Chlorophyta, *Staurastrum* spp., *S. artiscon*, *S. formosum*, *S. sonthalianum*; specific conductivity, dissolved oxygen and rainfall influenced Dinophyta, *Ceratium hirudinella*; rainfall influenced *Staurastrum paradoxum* and *Staurodesmus dejectus*; rainfall and water temperature influenced *Staurastrum rotula* in the limnetic region. Phytoplankton assemblages of the Nongmahir reservoir depict higher cumulative influence of abiotic factors than the reports from the Khawiva reservoir (Sharma and Pachuau, 2016) of Mizoram; Bhereki and Holmari beels (Sharma and Hatimuria, 2017), and in the littoral station of Deepor beel (Sharma, 2015) of Assam, while it broadly compares with the report from Ghotonga (Sharma and Hatimuria, 2017) beel of Assam. The comparisons with the reports of Sharma (1995, 2004), Sharma and Lyngskor (2003) and Sharma and Lyngdoh (2003), however, deserve caution because of lack of CCA analyses.

CONCLUSIONS

The soft, slightly acidic-circum neutral, calcium poor and de-mineralized waters of the Nongmahir reservoir in particular depict fairly biodiverse phytoplankton, speciose Chlorophyta with diverse desmids, and interesting constellation of 51 species per sample. Our study highlights the quantitative dominance of phytoplankton vis-a-vis net plankton. The differential spatial dominance of Bacillariophyta and Chlorophyta, importance of 17 'specialist' species and *Staurastrum* spp. > *Cosmarium* spp. in the littoral and the limnetic regions, resources utilization both by 'specialist' and 'generalist' species, high cumulative influence of 10 abiotic factors on phytoplankton assemblages and meso-trophic status of the Nongmahir reservoir are noteworthy features. The differential spatial variations of species richness, abundance, diversity indices and influence of individual abiotic factors are hypothesised to habitat heterogeneity amongst the littoral and limnetic regions of the sampled reservoir. Overall, this study is an important contribution to phytoplankton diversity of the reservoirs of India in general and the subtropical reservoirs in particular.

Ethics committee approval: Ethics committee approval is not required for this study.

Conflict of Interest: The authors have no conflicts of interest to declare.

Acknowledgements: The senior author (BKS) thanks the Head, Department of Zoology, North-Eastern Hill University, Shillong for laboratory facilities and various research students for the field work help on several occasions. We thank our reviewers: Prof. Dr. Yelda Aktan Turan and Dr. E. Kasaka for useful comments and suggestions. We thank Prof Dr. Özkan Özden, Editor-in-Chief, ASE for support and encouragement during the review process, and to Alan Newson for the proofreading of our manuscript.

Disclosure: -

REFERENCES

Anand, N. (1998). *Indian Freshwater Microalgae*. Bishen Singh Mahendra Pal Singh, Dehradun, 94 p.

APHA (1992). *Standard methods for the examination of water and wastewater* (18th Ed.). American Public Health Association, Washington D.C. 1198 p.

Baba, A.I. & Pandit, A.K. (2014). Composition, diversity and population dynamics of phytoplankton at Saderkot in Wular Lake, Kashmir. *Journal of Ecosystem & Ecography,* 4(1), 142. [CrossRef]

Bharati, H., Deshmukhe, G., Das, S.K., Kandpal, B.K., Sahoo, L., Bhusan, S. & Singh, Y.J. (2020). Phytoplankton communities in Rudrasagar Lake, Tripura (North-East India) – A Ramsar Site. *International Journal of Bio-resource and Stress Management*, 11(1), 001-007. [CrossRef]

Biswas, K. (1949). Common fresh and brackish algal flora of India and Burma. *Records Botanical Survey of India,* 15(2), 1–169.

Chandrakiran, Sharma, K.K. & Sharma, R. (2014). Phytoplankton community response to changing physico-chemical environment of a subtropical Lake Mansar, India. *International Journal of Biosciences,* 4(11), 95–103. [CrossRef]

Deb, S., Saikia, J. & Kalamdhad, A.S. (2019). Ecology of Deepor beel wetland, a Ramsar site of Guwahati, Assam with special reference to algal community. *European Journal of Biomedical and Pharmaceutical Sciences*, 6(2), 232–243.

Devi, M.B., Gupta, S. & Das, T. (2016). Phytoplankton community of Lake Baskandi anua, Cachar District, Assam, North East India – An ecological study. *Knowledge and Management of Aquatic Ecosystems,* 417, 2. [CrossRef]

Fritter, R. & Manuel R. (1986). *Field guide to the Freshwater life of Britain and North-West Europe*. William Collins Sons & Co. Ltd, London, 382 p.

Ganai, A.H. & Parveen, S. (2014). Effect of physico-chemical conditions on the structure and composition of the phytoplankton community in Wular Lake at Lankrishipora, Kashmir. International *Journal of Biodiversity and Conservation*, 6(1), 71–84. [CrossRef]

Goswami, M., Das, T., Kumar, S. & Mishra, A. **(**2018). Impact of physico-chemical parameters on primary productivity of Lake Nainital. *Journal of Entomology and Zoology Studies*, 6(4), 647-652.

Gupta, S. & Devi S.S. (2014). Ecology of Baskandi anua, an oxbow lake of south Assam, North East India. *Journal of Environmental Biology,* 35, 1101–1105.

Gupta, S., Singh, D., Rawat, M.S. & Ahmed, R (2018). Phytoplankton community in relation to physicochemical characteristics of Renuka Lake and Parshuram Tal (H.P.), India. *International Journal of Scientific Research and Reviews*, 7(3), 769-780.

Hickel, B. (1973). Limnological investigation in lakes of the Pokhra valley. *Internationale Revue der gesamten Hydrobiologie,* 58(5), 659–672. [CrossRef]

Hulyal, S.K. & Kaliwal, B.B. (2009). Dynamics of phytoplankton in relation to physico-chemical factors of Almatti reservoir of Bijapur district, Karnatak state. *Environmental Monitoring & Assessment,* 153 (1-4), 45–59. [CrossRef]

Islam, A.K.M.N. & Haroon, A.K.Y. (1980). Desmids of Bangladesh. *Internationale Revue gesamten Hydrobiologie,* 65(4), 551–604. [CrossRef]

Jindal, R. & Prajapat, P. (2005). Productivity and trophic status of Renuka wetland (Distt. Sirmour, Himachal Pradesh. *Indian Journal of Ecology,* 32(2), 180–183.

Jindal, R. & Thakur, R.K. (2014). Hydrobiology and productivity of Kuntbhyog Lake, (District Mandi, Himachal Pradesh), India. *International Journal of Environmental Engineering*, 6 (4), 449–459. [CrossRef]

Jindal, R., Thakur, R.K., Singh, U.B. & Ahluwalia, A.S. (2013). Plankton diversity and water quality assessment of three freshwater lakes of Mandi (Himachal Pradesh, India) with special reference to planktonic indicators. *Environmental Monitoring & Assessment*, 185 (10), 8355–8373. [CrossRef]

Jindal, R., Thakur, R.K., Singh, U.B. & Ahluwalia, A.S. (2014a). Phytoplankton dynamics and species diversity in a shallow eutrophic, natural mid-altitude lake in Himachal Pradesh (India): role of physicochemical factors. *Chemistry and Ecology*, 30(4), 328–338. [CrossRef]

Jindal, R., Thakur, R.K., Singh, U.B. & Ahluwalia, A.S. (2014b). Phytoplankton dynamics and water quality of Prashar Lake, Himachal Pradesh, India. *Sustainability of Water Quality and Ecology*, 3–4, 101–113. [CrossRef]

Jeelani, M. & Kaur, H. (2012). Ecological Understanding of Anchar Lake, Kashmir. *Bionano Frontier*, 5(2), 57–61.

John, D.M., Whitton, B.A. & Brook, A.J. (2002). *The Freshwater Algal Flora of the British Isles: An Identification Guide to Freshwater and Terrestrial Algae*. Cambridge University Press: Cambridge, UK.

Krishnan, K.H., Thomas, S., George, S., Murugan, R.P., Mundayoor, S. & Das, M.R. (1999). A study on the distribution and ecology of phytoplankton in the Kuttanad wetland ecosystem, Kerala. *Pollution Research*, 18, 261–269.

Laskar, H.S. & Gupta, S. (2009). Phytoplankton diversity and dynamics of Chatla floodplain lake, Barak valley, Assam, North East India-A seasonal study. *Journal of Environmental Biology,* 30(9), 1007–1012.

Ludwig, J.A. & Reynolds J.F. (1988). *Statistical ecology: a primer on methods and computing*. John Wiley & Sons, New York, 337 p.

MacArthur, R.H. (1965). Patterns of spices diversity. *Biological Reviews*, 40, 510–533. [CrossRef]

Magurran, A.E. (1988). *Ecological diversity and its measurement*. Croom Helm Limited, London, 179 p. [CrossRef]

Masson, C.F. (1998). *Biology Freshwater Pollution* (3rd Edn). Harlow (Essex), Longman.

McNaughton, J. (1967). Relationship among functional properties of California grassland. *Nature*, 216, 168–169. [CrossRef]

Nakanishi, M., Watanabe, M.M., Terashima, A., Soko, Y., Konda, T., Shrestha, K., Bhandary, H.R. & Ishida, Y. (1988). Studies on some limnological variables in subtropical lakes of the Pokhara valley, Nepal. *Japanese Journal of Limnology,* 49, 1–86. [CrossRef]

Negi R.K. & Rajput, V. (2015). Assessment of phytoplankton diversity in relation to abiotic factors of Nainital Lake of Kumaon Himalayas of Uttarakhand State, India. *Asian Journal of Scientific Research*, 8(2), 157–164. [CrossRef]

Nissa, N & Bhat, S.U. (2016). An assessment of phytoplankton in Nigeen Lake of Kashmir Himalaya. *Asian Journal of Biological Sciences*, 9, 27–30. [CrossRef]

Payne, A.R. (1986). *The ecology of Tropical Lakes and Rivers*. John Wiley & Sons, New York.

Prescott, G.W. (1982). *Algae of the Western Great Lakes area*, Otto koeltz Science Publishers, W. Germany, 977 p.

Rawat. M.S. & Sharma, R.C. (2005). Phytoplankton population of Garhwal Himalayan lake Deoria Tal, *Uttranchal Journal of Ecophysiology & Occupational health*, 5, 73–76.

Shafi, N., Ahmad, A. & Pandit, A.K. (2013). Phytoplankton Dynamics of Nigeen Lake in Kashmir Himalaya. *International Journal of Environment and Bioenergy*, 6(1): 13–27.

Sharma B.K.. (1995). Limnological studies in a small reservoir in Meghalaya (N.E. India). In K.H. Timotius & F. Goltenboth (Eds.). *Tropical Limnology,* II, 1–11. Satya Wacana University Press, Salatiga, Indonesia.

Sharma B.K. (2004). Phytoplankton communities of a floodplain lake of the Brahmaputra river basin, Upper Assam. *Journal of Inland Fisheries Association,* 31, 27–35.

Sharma B.K. (2009). Phytoplankton communities of Loktak lake (a Ramsar site), Manipur (N. E. India): composition, abundance and ecology. *Journal of Threatened Taxa*, 1(8), 401–410. [CrossRef]

Sharma, B.K. (2010). Phytoplankton diversity of two floodplain lakes (pats) of Manipur (N. E. India). *Journal of Threatened Taxa*, 2(11), 1273–1281. [CrossRef]

Sharma, B.K. (2012). Phytoplankton diversity of a floodplain lake of the Brahmaputra River basin, Assam, north-east India. *Indian Journal of Fisheries*, 59(4), 131–139.

Sharma, B.K. (2015). Phytoplankton diversity of Deepor Beel- a Ramsar site in the floodplain of the Brahmaputra River Basin, Assam, north-east India. *Indian Journal of Fisheries,* 62(1), 33–40.

Sharma, B.K. & Bhattarai, S. (2005). Hydro-biological analysis of a peat bog with emphasis on its planktonic diversity and population dynamics in Bumdeling Wildlife Sanctuary: eastern Bhutan. *Limnology*, 6, 183–187. [CrossRef]

Sharma, B.K., & Hatimuria, M.K. (2017). Phytoplankton diversity of floodplain lakes of Majuli River Island, Brahmaputra river basin of Assam, northeast India. *International Journal of Aquatic Biology,* 5(5), 295–309. [CrossRef]

Sharma, B.K. & Lyngdoh, R.M. (2003). Abundance and ecology of net and phytoplankton of a subtropical reservoir of Meghalaya (N. E. India). *Ecology, Environment & Conservation,* 9 (4), 497–503.

Sharma, B.K. & Lyngskor, C. (2003). Plankton communities of a subtropical reservoir of Meghalaya (N. E. India). *Indian Journal of Animal Sciences,* 73 (2), 88–95.

Sharma, B.K. & Pachuau, L. (2016). Diversity of Phytoplankton of a subtropical reservoir of Mizoram, northeast India. *International Journal of Aquatic Biology,* 4(6), 360–369.

Sharma, B.K. & Sharma, S. (2020). Zooplankton diversity of a subtropical reservoir of Meghalaya, northeast India with remarks on spatial and temporal variations. *Opuscula Zoologica Budapest,* 50(1), 67–86. [CrossRef]

Sharma, R.C. & Singh, S. (2018). Water quality and phytoplankton diversity of high altitude wetland, Dodi Tal of Garhwal Himalaya, India. *Biodiversity International Journal*, 2(6), 484–493. [CrossRef]

Sharma, R.C. & Tiwari, V. (2018). Phytoplankton diversity in relation to physico-chemical environmental variables of Nachiketa Tal, Garhwal Himalaya. *Biodiversity International Journal,* 2(2), 128–136. [CrossRef]

Singh, S. & Sharma, R.C. (2018). Monitoring of algal taxa as bioindicator for assessing the health of the high altitude wetland, Dodi Tal, Garhwal Himalaya, India. *International Journal of Fisheries and Aquatic Studies,* 6(3), 128–133. [CrossRef]

Talling J.F. & Talling I.B. (1965). The chemical composition of African lake waters. *Internationale Revue der gesamten Hydrobiologie*, 50, 421–463. [CrossRef]

Thakur, R.K., Jindal, R., Singh, U.B. & Ahluwalia, A.S. (2013). Plankton diversity and water quality assessment of three freshwater lakes of Mandi (Himachal Pradesh, India) with special reference to planktonic indicators. *Environment Monitoring & Assessment*, 185 (10), 8355–8373. [CrossRef]

Washington, H.G. (1984). Diversity, biotic and similarity indices. A review with special relevance to aquatic ecosystems. *Water Research*, 18, 653–694. [CrossRef]

Wanganeo, A. & Wanganeo, R. (1991). Algal population in valley lakes of Kashmir Himalayas. *Archiv fur Hydrobiologie,* 121, 219–223.

Wilhm, J.L. & Dorris, T.C. (1968). Biological parameters for water quality criteria: *Bioscience*, 18, 477–481. [CrossRef]

Woelkerling, W. & Gough, S.B. (1976). Wisconsin Desmids. III. Desmid community composition and distribution in relation to lake type and water chemistry. *Hydrobiologia*, 51, 3–32. [CrossRef]

Zutshi, D.P., Subla, B.A., Khan, M.A. & Wanganeo, A. (1980). Comparative limnology of nine lakes of Jammu and Kashmir Himalayas. *Hydrobiologia*, 72, 101–112. [CrossRef]

Zutshi, D.P. & Wanganeo A (1984). The phytoplankton and primary productivity of a high altitude subtropical lake. *Internationale Vereinigung für Theoretische und Angewandte Limnologie Verhandlungen*, 222, 1168–1172. [CrossRef]