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Original Article

Phytoplankton diversity of floodplain lakes of the Majuli River Island of the Brahmaputra river basin, Assam, northeast India

Bhushan Kumar Sharma*, Mrinal Kumar Hatimuria

Freshwater Biology Laboratory, Department of Zoology, North-Eastern Hill University, Permanent Campus, Shillong-793 022, Meghalaya, India.

Abstract: Phytoplankton of three floodplain lakes (beels) of the Majuli River Island of upper Assam, northeast India (NEI), sampled during September 2010–August 2012, revealed rich diversity (108 species) with Ghotonga > Holmari ≥ Bhereki beels; richness of Chlorophyta and of *Cosmarium* > *Staurastrum* > *Euastrum* in particular. The monthly richness and community similarities affirmed heterogeneity in phytoplankton composition. Phytoplankton comprised between 59.5±12.5, 57.1±12.3 and 48.6±13.5% of net plankton abundance of Bhereki, Holmari and Ghotonga beels, respectively. Bacillariophyta > Chlorophyta showed quantitative importance in Bhereki while Chlorophyta > Bacillariophyta recorded importance in Holmari and Ghotonga beels. Cyanophyta showed sub-dominance and Dinophyta > Euglenophyta showed low densities in the three beels. Phytoplankton richness and abundance followed oscillating monthly variations; ANOVA registered insignificant richness variations amongst beels. The results are characterized certain monthly and annual variations but mean values depicted high species diversity, low dominance and high equitability. Individual and cumulative influence (*vide* CCA) yielded limited insight on the role of seventeen abiotic factors on phytoplankton in Holmari and Bhereki beels.

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Introduction

Phytoplankton, an integral link of aquatic food-webs, is inadequately analyzed in various studies on the Indian floodplain ecology due to incomplete inventories of taxa while the detailed studies on their diversity in these ecotones are yet limited (Sharma, 2015). This generalization holds valid for the floodplain lakes which form an important component of inland aquatic resources of northeast India (NEI) and the Brahmaputra river basin of Assam in particular. The fewer notable works on phytoplankton diversity from the former region are from selected floodplain lakes (pats) of Manipur (Sharma, 2009, 2010) and beels (Sharma, 2004, 2012, 2015) of Assam.

Majuli River Island, the largest river island and a geographically interesting landform of fluvial geomorphology of the Brahmaputra river system of Assam state of NEI, is dotted with the floodplain lakes (beels) which play an important role in the socio-economic development of the region through significant fisheries potential. The wetlands of the Majuli floodplains remain unexplored for their phytoplankton diversity and thus this study merits biodiversity and ecological importance. The observations are made on monthly variations of richness and abundance of phytoplankton and their constituent groups of three selected beels as well as their community similarities, species diversity, evenness and dominance. The individual and cumulative influence of abiotic factors vis-à-vis monthly variations of richness and abundance are analyzed to understand their ecological importance with reference to phytoplankton assemblages.

Materials and Methods

The present study is a part of a limnological survey undertaken during September, 2010–August, 2012 in Bhereki (94º08′23.3″E, 26º55′40.4″N; 72 m ASL), Holmari (94º12′30.6″E, 26º59′17.3″N) and Ghotonga (94º15′28.7″E, 27º01′52.7″N, 69m ASL) beels of Majuli River Island located in the Jorhat district (Fig.

*Corresponding author: Bhushan Kumar Sharma
E-mail address: profbksharma@gmail.com
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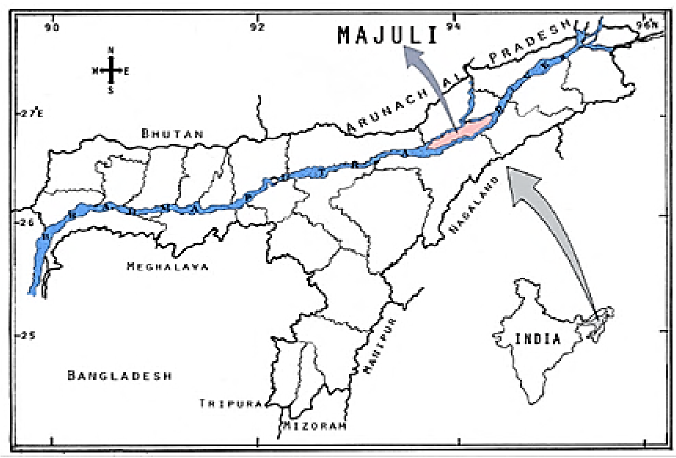

Figure 1. District map of Assam state indicating location of Majuli River Island (insert map of India showing Assam state of northeast India).

1) of Upper Assam (NEI). Various macrophytes noticed in these wetlands included *Eichhornia crassipes, Hydrilla verticellata, Utricularia flexuosa, Trapa natans, Lemna major, L. minor, Pistia striates, Salvinia* sp., *Nymphaea* spp., *Nymphoides* spp., *Potamageton* spp., *Azolla pinnata, Euryale ferox,* and *Sagittaria* sp.

Water samples collected at regular monthly intervals from the selected beels were analyzed for seventeen abiotic factors namely water temperature, rainfall, pH, specific conductivity, dissolved oxygen, free carbon dioxide, total alkalinity, total hardness, calcium, magnesium, chloride, dissolved organic matter, total dissolved solids, phosphate, nitrate, sulphate and silicate. Water temperature, specific conductivity and pH were recorded by field probes, dissolved oxygen was estimated by Winkler's method and other parameters were analyzed following APHA (1992). Monthly qualitative and quantitative net plankton samples were collected by plankton net (# 30 µm) and were preserved in 5% formalin; the former collected by towing plankton net through the littoral and semi-limnetic regions of different beels and the latter by filtering 25 L water each at two sampling stations in each beel.

Qualitative samples were screened and phytoplankton was identified following Islam and Haroon (1980), Adoni et al. (1985) and Fitter and Manuel (1986). Quantitative samples were analyzed by using a Sedegwick-Rafter counting cell for enumeration of abundance (nl^{-1}) of phytoplankton and its constituent groups. Community similarities (Sørensen's index), species diversity (Shannon's index), evenness (Pielou's index) and dominance (Berger-Parker's index) were calculated following Ludwig and Reynolds (1988) and Magurran (1988). The hierarchical cluster analysis based on phyto-plankton community similarities was done using SPSS (version 20). Two-way ANOVA was used to analyze the significance of temporal variations of biotic communities. Ecological relationships between abiotic and biotic parameters of Bhereki, Holmari and Ghotonga beels were determined by Pearson correlation coefficients (r_1, r_2 and r_3 respectively); P-values were computed and their significance was ascertained after the use of Bonferroni correction. The canonical correspondence analysis (XLSTAT, 2015) was done to analyze cumulative influence of 17 abiotic parameters (water temperature, rainfall, pH, specific conductivity, dissolved oxygen, free CO_2, total alkalinity, total hardness, calcium, magnesium, chloride, dissolved organic matter, total dissolved solids, phosphate, nitrate, sulphate and silicate) on phytoplankton assemblages.

Results

The variations (ranges, mean±SD) in abiotic parameters of Bhereki, Holmari and Ghotonga beels are indicated in Table 1 and that of different aspects of phytoplankton diversity are included in Table 2. We observed a total of 108 phytoplankton species, belonging to five groups, with 98, 99 and 103 species from Bhereki, Holmari and Ghotonga beels, respectively (Table 2). Chlorophyta (79 species) included 69, 71 and 75 species in three beels, respectively and recorded richness of Cosmarium > *Staurastrum* > *Euastrum* species. The monthly phytoplankton richness varied between 32-62, 34-71 and 29-60 species (Figs. 2, 3); it recorded 42.5-78.3, 38.8-68.2%; 36.3-74.7, 53.3-79.0% and 38.0-76.7, 38.9-79.5% community similarities (*vide* Sørensen's index) in Bhereki, Holmari and Ghotonga beels during the two years, respectively. The hierarchical cluster

Table 1. Abiotic factors of Bhereki, Holmari and Ghotonga beels (September 2010-August 2012).

factors	Bhereki Beel		Holmari Beel		Ghotonga Beel	
	range	mean±SD	range	mean±SD	range	mean±SD
Water temp. ºC	21.5-27.5	23.7±1.7	21.0-27.5	23.6±1.7	21.5-27.5	23.9±1.7
Rainfall (mm)	0.0-413.7	142.6±133.9	0.0-413.7	142.6±133.9	0.0-413.7	142.6±133.9
pH	6.29-7.41	6.67±0.23	6.56-7.13	6.87±0.13	6.17-6.85	6.51±0.16
Conductivity (μScm^{-1})	102.0-189.0	140.7±24.4	111.0-220.0	173.6±32.5	73.0-182.0	121.4±26.8
Dissolved oxygen (mgl^{-1})	4.8-8.0	6.3±0.9	5.6-8.0	7.1±0.8	4.0-8.0	6.2±1.0
Free CO_2 (mgl^{-1})	6.0-24.0	13.6±4.0	6.0-16.0	10.2±2.8	6.0-20.0	13.8±3.4
Alkalinity (mgl^{-1})	44.0-126.0	70.3±20.7	64.0-116.0	92.3±14.2	38.0-88.0	62.2±13.4
Hardness (mgl^{-1})	42.0-128.0	69.8±20.3	56.0-122.0	89.3±16.9	38.0-84.0	60.8±13.6
Calcium (mgl^{-1})	27.3 - 81.9	43.0±13.1	37.8-73.5	60.2±9.2	25.2-54.6	38.7±7.8
Magnesium (mgl^{-1})	1.3-11.9	6.5±2.8	2.2-11.9	7.1±2.4	1.0-11.3	5.4±2.3
Chloride (mgl^{-1})	6.0-33.0	11.0±5.2	4.0-22.0	8.9±3.5	7.0-40.0	13.1±6.5
DOM (mgl^{-1})	0.041-0.319	0.162±0.062	0.026-0.278	0.113±0.047	0.038-0.353	0.166±0.063
TDS (mgl^{-1})	0.088-0.172	0.137±0.023	0.080-0.160	0.115±0.022	0.104-0.180	0.147±0.020
Phosphate (mgl^{-1})	0.145-3.619	0.963±0.697	0.093-1.582	0.761±0.393	0.165-1.499	0.845±0.414
Nitrate (mgl^{-1})	0.501-4.522	1.855±1.047	0.544-4.411	1.800±1.030	0.499-3.566	1.758±0.838
Sulphate (mgl^{-1})	1.387-17.78	8.789±4.161	0.793-14.075	6.473±3.741	0.925-13.282	7.219±3.600
Silicate (mgl^{-1})	0.140-2.652	0.880±0.547	0.140-2.547	0.825±0.511	0.140-1.187	0.660±0.275

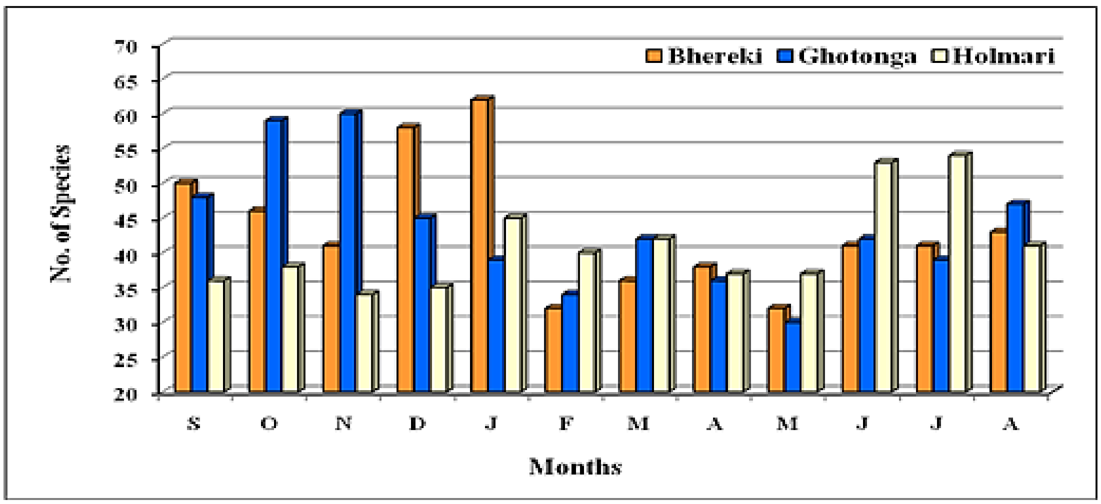

Figure 2. Monthly variations in species richness of phytoplankton (2010-2011).

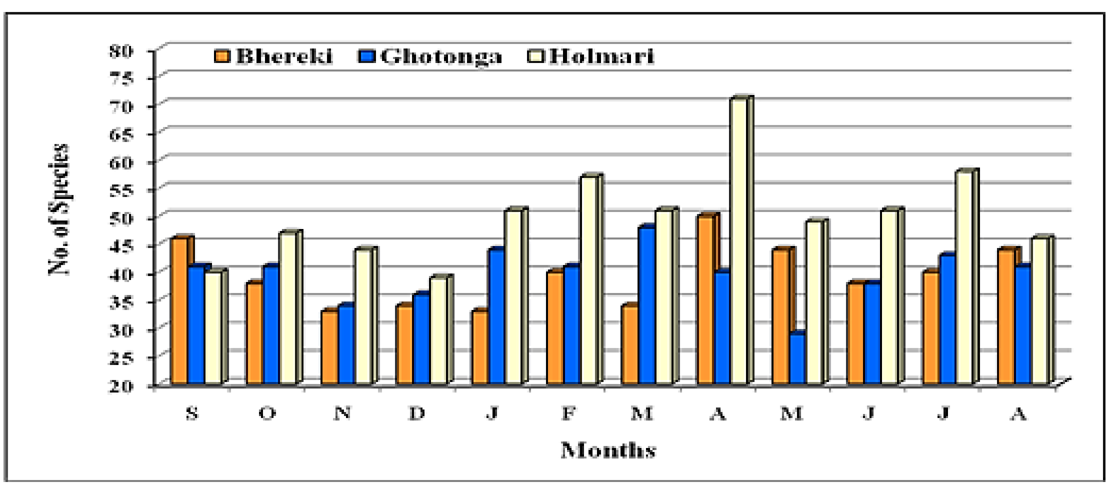

Figure 3. Monthly variations in species richness of phytoplankton (2011-2012).

Table 2. Variations (ranges, mean±SD) of phytoplankton of Bhereki, Holmari and Ghotonga beels (September 2010-August 2012).

	Bhereki Beel		Holmari Beel		Ghotonga Beel	
Richness						
Net Plankton (total)	209 species		212 species		232 species	
Net Plankton (monthly)	77-113	95±11	81-137	102±12	83-134	104±11
Phytoplankton Total	98 species		99 species		103 species	
% similarity	38.8-78.3		36.3-79.0		38.0-76.7	
Phytoplankton (total)	32-62	41±8	14-71	46±9	29-60	42±7
Chlorophyta	16-46	26±7	15-52	29±9	13-48	27±8
Bacillariophyta	4-13	9±2	6-13	10±2	4-13	8±2
Cyanophyta	2-6	4±1	2-6	5±1	1-6	4±2
Quantitative						
Net Plankton	261-1253	663±261	449-1815	682±289	282-1923	628±320
Phytoplankton nl^{-1}	88-936	418±227	207-1292	407±249	93-1627	335±302
% composition	26.8-76.2	59.5±12.5	39.0-84.8	57.1±12.3	22.0-84.6	48.6±13.5
Species diversity	2.256-3.567	2.941±0.311	2.547-3.743	3.042±0.243	1.555-3.541	2.894±0.469
Dominance	0.086-0.464	0.201±0.086	0.091-0.317	0.194±0.049	0.069-0.676	0.254±0.169
Evenness	0.611-0.932	0.793±0.072	0.716-0.907	0.799±0.046	0.462-0.947	0.779±0.123
Chlorophyta nl^{-1}	37-821	153±169	48-596	176±120	28-751	152 ±155
% composition	13.5-87.7	35.1±19.5	21.5-64.6	42.5±10.9	7.0-82.0	44.6±18.8
Bacillariophyta nl^{-1}	17-515	173±144	47-473	120±91	12-278	72±59
% composition	5.3-79.5	40.1±19.9	17.5-52.0	29.6±9.0	5.5-55.1	25.6±15.8
Cyanophyta nl^{-1}	6-209	68±58	14-350	100±77	4-293	59±75
% composition	2.4-34.7	17.1±10.9	3.9-47.5	24.9±12.6	1.4-73.6	20.4±22.4
Dinophyta nl^{-1}	0-47	7±11	0-82	7±17	0-680	40±138
% composition	0.0-17.2	2.3±4.1	0.0-22.9	1.6±4.6	0.0-41.8	4.9±9.0
Euglenophyta nl^{-1}	0-60	18±18	0-29	6±6	2-41	12±10
% composition	0.0-29.6	5.4±6.8	0.0-5.2	1.5±1.4	0.8-16.0	4.6±4.5
Important taxa (nl^{-1})						
Cosmarium spp.	8-277	52±61	4-102	24±22	2-104	24±30
Closterium spp.	0-102	9±22	0-48	12±12	1-93	23±29
Euastrum spp.	0-51	6±11	0-23	3±5	0-15	4±5
Micrasterias spp.	0-51	6±10	0-42	7±9	0-27	8±7
Staurastrum spp.	1-52	12±14	1-108	15±21	0-135	16±27
Staurodesmus spp.	0-100	10±21	0-24	3±5	0-11	3±3
Important species (nl^{-1})						
Elakatothrix gelatinosa	0-67	**22±15**	5-125	**39±30**	0-88	**22±22**
Tabellaria fenestrata	0-60	**16±16**	6-71	**23±16**	0-82	**11±18**
Navicula cuspidata	0-61	16±17	0-61	12±15	0-109	8±22
Selenastrum gracile	0-90	9±19	0-52	11±14	0-175	10±35
Nostoc sp.	0-65	10±14	0-63	19±19	0-58	8±14
Amphora normani	0-188	10±37	0-13	5±3	0-69	12±16
Cymbella ventricosa	0-93	10±18	0-36	7±8	0-58	14±17
Rhopalodia sp.	0-100	24±25	0-45	17±13	0-21	4±5
Oscillatoria sp.	0-122	22±34	0-76	15±23	0-24	4±6
Phormidium sp.	0-70	17±17	0-128	47±43	0-28	8±9
Phacus pleuronectes	0-58	14±16	0-24	5±5	1-27	10±7
Peridinium sp.	0-47	7±11	0-82	6±17	0-680	37±138
Aphanocapsa sp.	0-25	3±6	0-51	8±15	0-269	35±75

analysis (Figs. 4-9) indicated high phytoplankton affinities between December vs. January and again between June vs. July samples of Bhereki beel during the first year; and between June vs. August and again between February vs. March collections during second year while peak divergence is noticed February > April and December > June during two years, respectively. In Holmari beel, maximum affinity is recorded between June and July, 2011 and between February and April, 2012, during the two years respectively. In Ghotonga beel, high affinities are indicated between June-July-August while maximum divergence is noted during January > April and during May > November in two years, respectively.

Phytoplankton abundance ranged between 88-936 (418±227), 207-1292 (407±249) and 93-1627 (335±302) nl^{-1} (Figs. 10-11) and comprised between

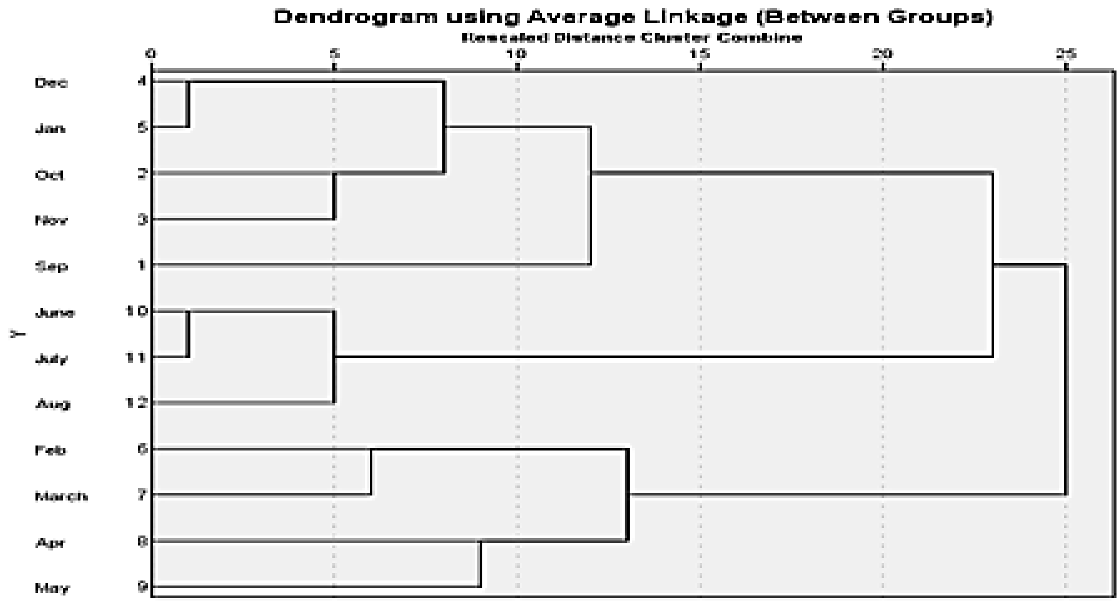

Figure 4. Hierarchical cluster analysis of phytoplankton of Bhereki beel (2010-2011).

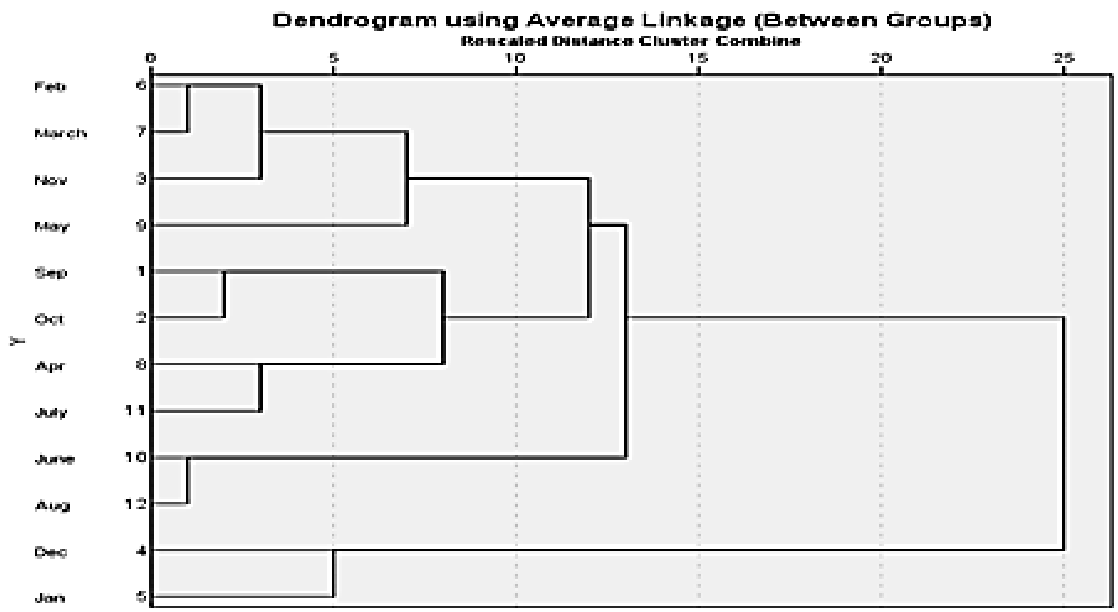

Figure 5. Hierarchical cluster analysis of phytoplankton of Bhereki beel (2011-2012).

59.5±12.5, 57.1±12.3 and 48.6±13.5% of net plankton of Bhereki, Holmari and Ghotonga beels, respectively. Chlorophyta abundance ranged between 37-821 (153±169), 48-596 (176±120) and 28-751 (152±155) nl^{-1} and comprised 35.1±19.5, 42.5±10.9 and 44.6± 18.8% of phytoplankton of three beels, respectively (Table 2). Bacillariophyta formed 40.1±19.9% of phytoplankton in Bhereki (173±144 nl^{-1}) and 29.6± 9.0% in Holmari (120±91 nl^{-1}) and 25.6±15.8% in Ghotonga (72±59 nl^{-1}) beels (Table 2). Cyanophyta density varied between 68±58, 100±77 and 59±75 nl^{-1} while Dinophyta density ranged between 7±11, 7±17 and 40±138 nl^{-1} and that of Euglenophyta between 18±18, 6±6 and 12±10 nl^{-1} in Bhereki, Holmari and Ghotonga beels, respectively. Phytoplankton species diversity, dominance and evenness varied (Table 2) between 2.256-3.567, 2.547-3.743 (Figs. 12, 13) and 1.555-3.541; 0.086–0.464, 0.091-0.317 and 0.069-0.676; and 0.611-0.932, 0.716-0.907 and 0.462-0.947 in the sampled beels,

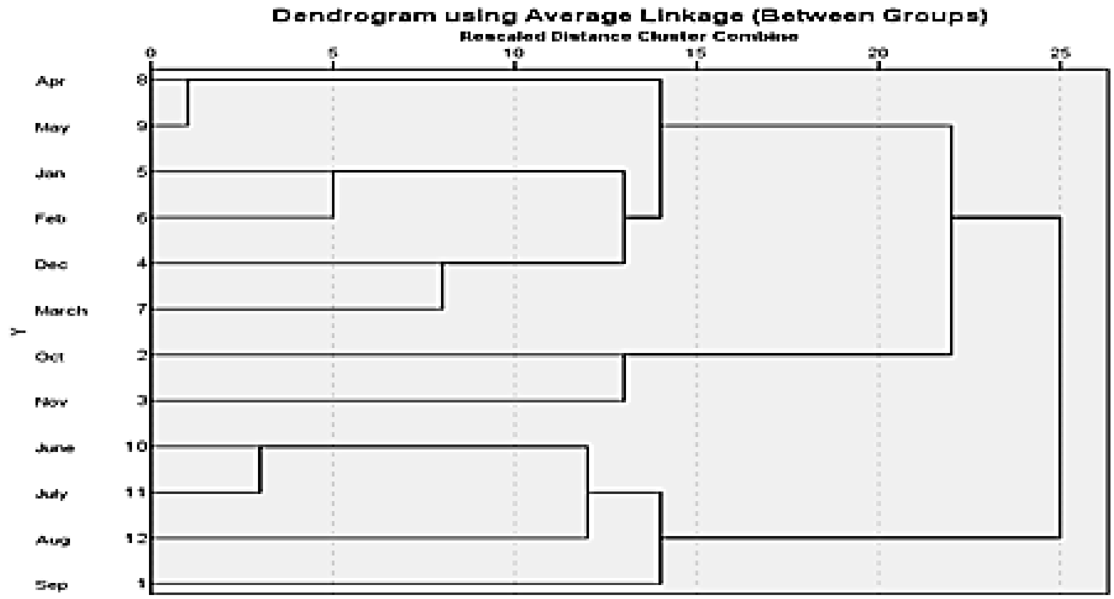

Figure 6. Hierarchical cluster analysis of phytoplankton of Holmari beel (2010-2011).

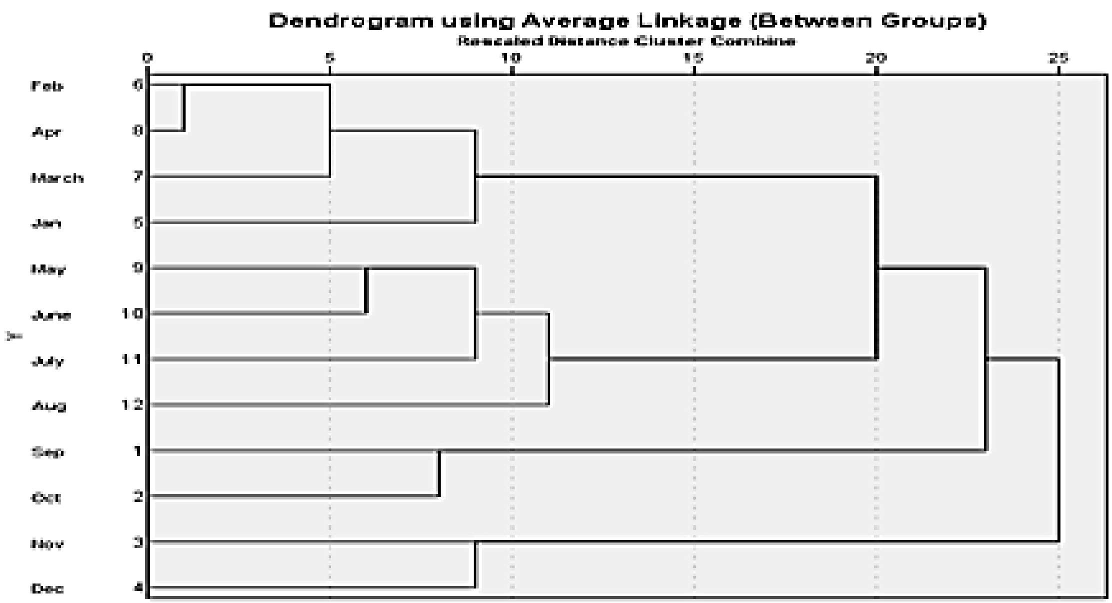

Figure 7. Hierarchical cluster analysis of phytoplankton of Holmari beel (2011-2012).

respectively.

This study registered insignificant influence of individual abiotic factors on phytoplankton richness and abundance. Chlorophyta richness is positively correlated with sulphate (r_2=0.549, *P*=0.0027) in Holmari beel; Chlorophyta abundance is positively correlated significantly with pH (r_1=0.581, *P*=0.0029) in Bhereki beel and it is inversely correlated with dissolved organic matter (r_3=-0.586, *P*=0.0026) in Ghotonga beel. No individual factor significantly influenced Bacillariophyta density in any beel. Cyanophyta density is significantly correlated directly with silicate (r_1=0.550, *P*=0.0027) and inversely with total hardness (r_1=-0.544, *P*=0.0030) and magnesium (r_1=-0.614, *P*=0.0007) in Bhereki beel; it is correlated indirectly with total hardness (r_3=-0.610, *P*=0.0008) in Ghotonga beel. This study registered insignificant influence of abiotic parameters on Dinophyta in the sampled beels while Euglenophyta recorded positive correlation in Holmari beel (r_2=0.547, *P*=0.0028). The CCA ordination biplots of phytoplankton assemblages (Figs. 14-16) recorded 51.79%, 51.67% and 74.81%

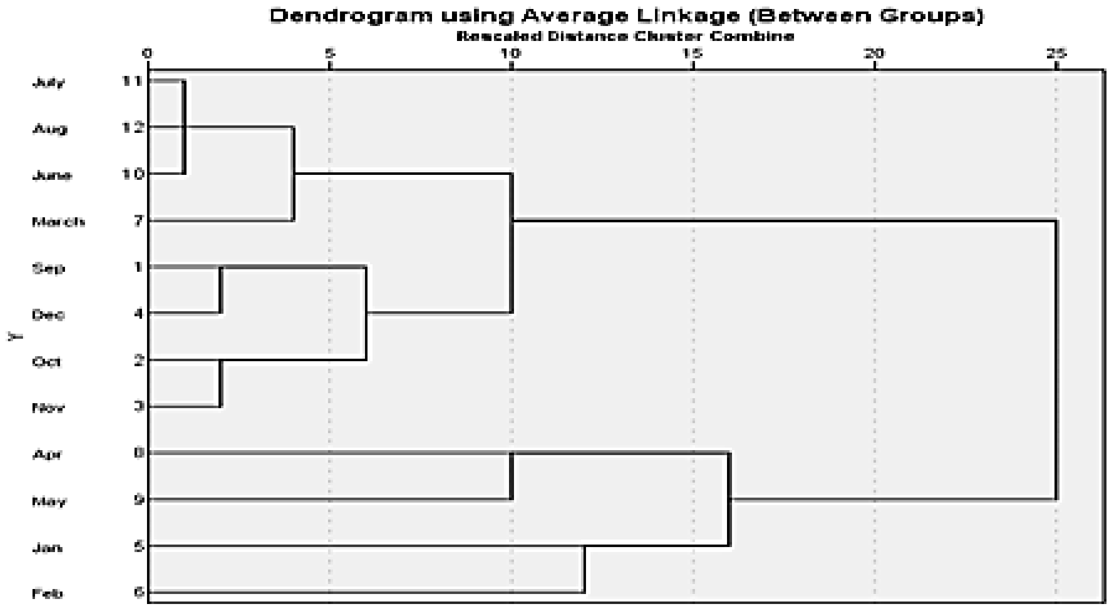

Figure 8. Hierarchical cluster analysis of phytoplankton of Ghotonga beel (2010-2011).

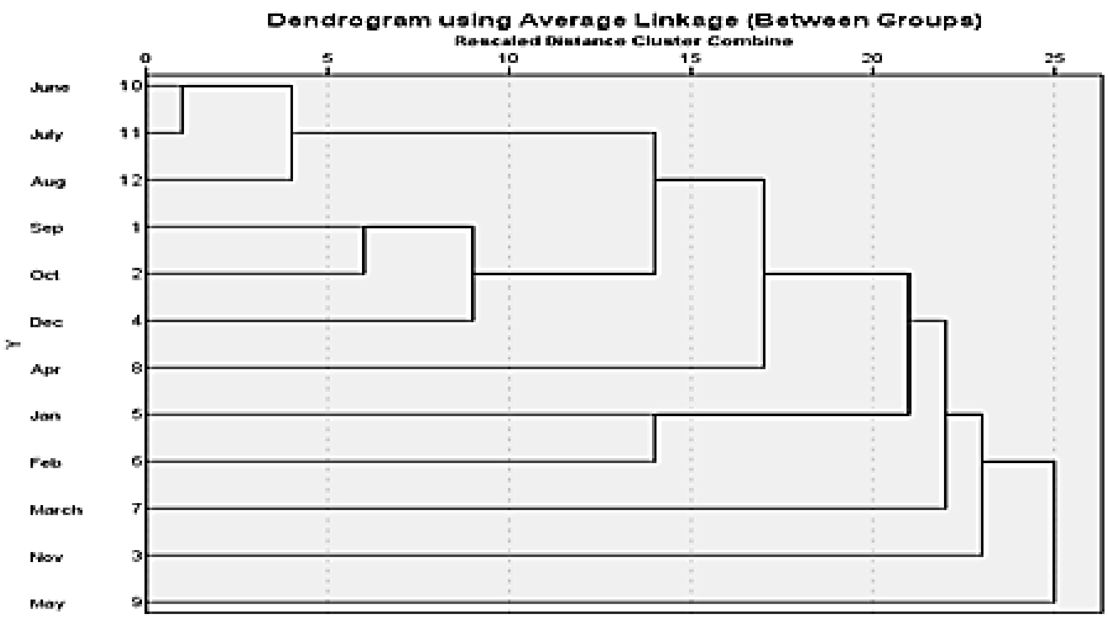

Figure 9. Hierarchical cluster analysis of phytoplankton of Ghotonga beel (2011-2012).

cumulative influence of 17 abiotic factors along first two axes in Bhereki, Holmari and Ghotonga beels, respectively.

Discussion

Water temperature concurred with the geographical location of the sampled beels. Bhereki and Holmari beels indicated slightly acidic to circum-neutral waters, whereas Ghotonga beel showed slightly acidic waters. Specific conductivity exhibited low ionic concentration; this interesting feature warranted their inclusion of all beels under 'Class I' category of trophic classification *vide* Talling and Talling (1965). All three beels are characterized by moderately hard water character, moderate dissolved oxygen, low free CO_2, low chloride content, and low concentrations of dissolved organic matter, total dissolved solids and nutrients.

A total of 108 species recorded in this study characterized species-rich nature of phytoplankton with Ghotonga > Holmari ≥ Bhereki beels; the biodiverse character is hypothesized to habitat

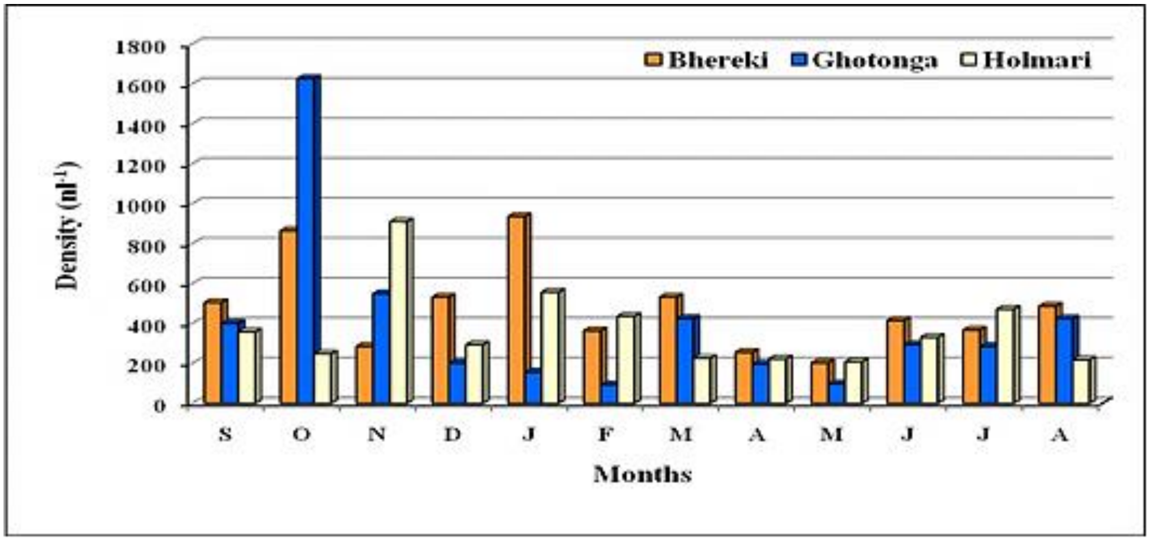

Figure 10. Monthly variations in abundance of phytoplankton (2010-2011).

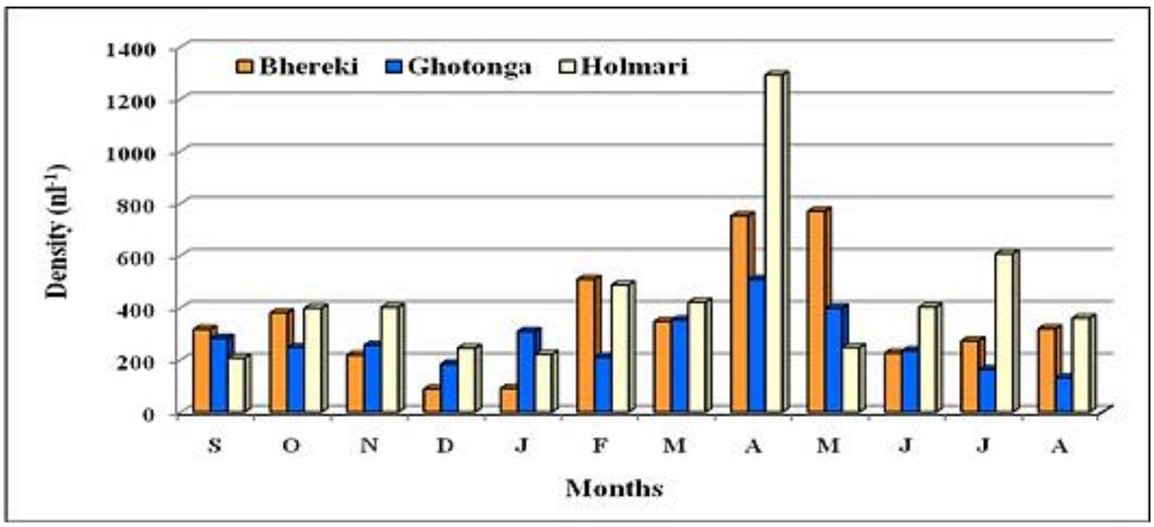

Figure 11. Monthly variations in abundance of phytoplankton (2011-2012).

diversity and environmental heterogeneity of the Majuli beels. Phytoplankton is more diverse than the reports from the floodplains of Manipur (Sharma, 2009, 2010) and Assam (Sharma, 2004, 2012, 2015), and is notably diverse than 'ad-hoc' ecology reports from certain beels of Assam (Barbaruah and Dutta, 2014; Gupta and Devi, 2014) and Bihar (Baruah et al., 1993**;** Sanjer and Sharma, 1995). Our results also indicated higher richness than the reports from nine lakes (Zutshi et al., 1980), Dal lake (Zutshi and Vass, 1982) and Nilang lake (Wanganeo et al., 1996) of the Kashmir Himalayas; and Nainital lake, Uttarakhand (Negi and Rajput, 2015). The comparisons affirmed biodiversity value of phytoplankton of the Majuli beels.

Phytoplankton richness followed concurrent monthly variations in Bhereki and Ghotonga beels than marginally higher value in Holmari beel. ANOVA indicated insignificant variations of richness amongst three beels; it indicated significant annual variations ($F_{1, 23}$=12.516, P=0.004) in Holmari beel. This study showed indefinite periodicity of richness in the three beels and thus endorsed the reports from floodplain lakes of NEI (Sharma, 2004, 2009, 2010). Chlorophyta, the speciose group, is characterized by richness of desmid genera *Cosmarium* > *Staurastrum* > *Euastrum* in all beels. This feature is an indicator of waters with low ionic concentrations and low calcium content (Woelkerling and Gough, 1976; Payne, 1986; Sharma, 1995); this salient feature corresponded with

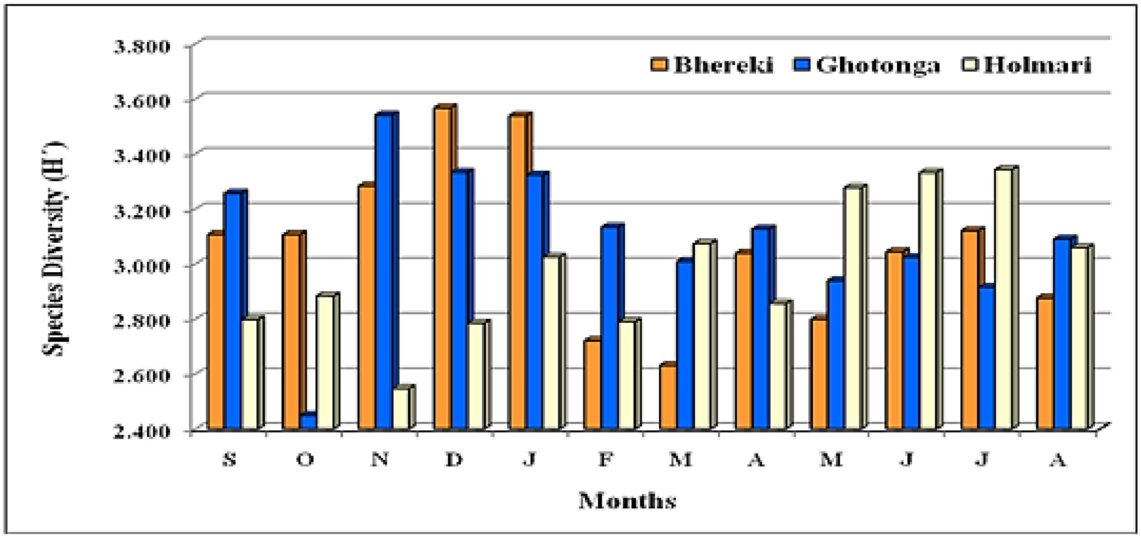

Figure 12. Monthly variations in species diversity of phytoplankton (2010-2011).

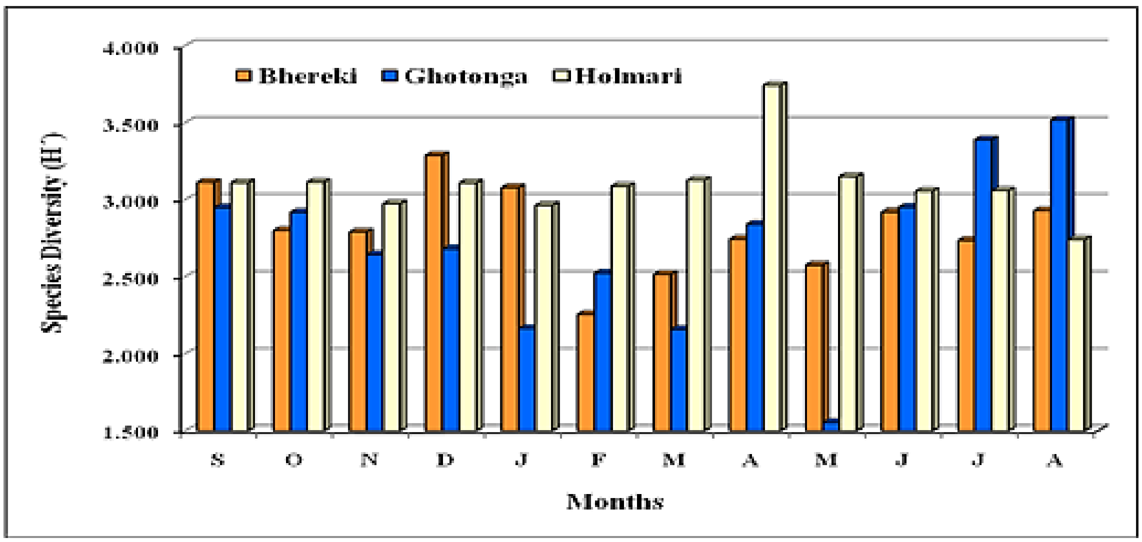

Figure 13. Monthly variations in species diversity of phytoplankton (2011-2012).

the results from the floodplains of Manipur (Sharma, 2009, 2010, 2015) and Assam (Sharma 2012, 2015) and also with the results from Meghalaya (Sharma 1995; Sharma and Lyngskor, 2003; Sharma and Lyngdoh, 2003). The phytoplankton community similarities suggested heterogeneity in species composition in Bhereki, Holmari and Ghotonga beels. The similarities recorded inter-annual differences in Bhereki and Holmari beels in particular. It recorded 51-70% and 60-70% similarities in ~94% and ~96% instances during two years, respectively in Bhereki beel; 51-60% and 61-70% similarities in ~50% and ~54% instances during two years, respectively in Holmari beel; and 41-60% and 51-60% similarities in ~70% and ~80% instances during two years, respectively in Ghotonga beel. The cluster analysis affirmed more affinities in early monsoon particularly in Bhereki and Ghotonga beels but in general affirmed heterogeneity in their monthly composition in all beels. The results differed from phytoplankton homogeneity reported by Sharma (2009, 2010, 2015).

Phytoplankton abundance followed the stated order: Bhereki > Holmari > Ghotonga beel with wider range in the last beel; ANOVA registered insignificant quantitative variations amongst beels and insignificant annual and monthly variations in individual beels.

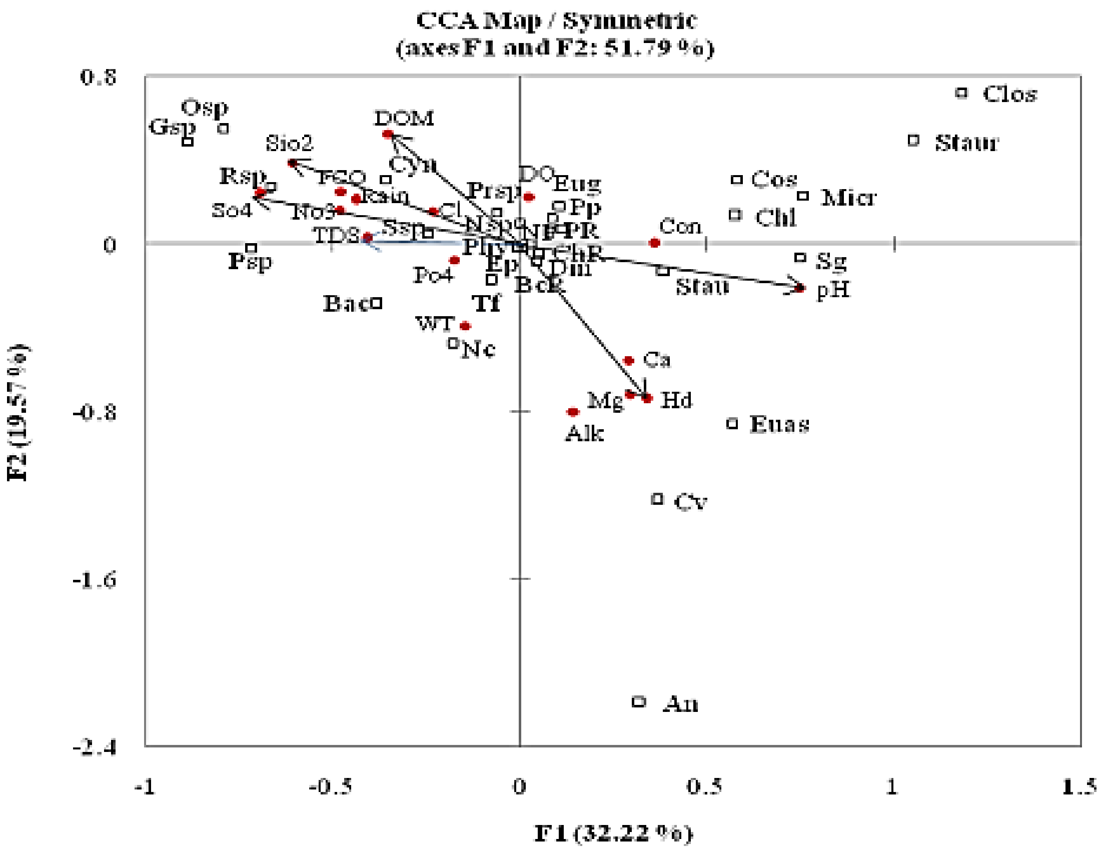

Figure 14. CCA ordination biplot of Phytoplankton and abiotic factors (Bhereki beel). **Abbreviations: Abiotic:** Alk (alkalinity), Ca (Calcium), Cl (Chloride), Con (conductivity), DO (dissolved oxygen), DOM (dissolved oxygen matter), FCO (free carbon dioxide), Hd (Hardness), Mg (Magnesium), pH (hydrogen-ion concentration), No3 (nitrate), Po4(phosphate), Rain (rainfall), Sio2 (silicate), So4 (sulphate), TDS (Total dissolved solids), Wt (water temperature). **Biotic:** An (*Amphora normani*), Bac (Bacillariophyta), BcR (Bacillariophyta richness), ChR (Chlorophyta richness), Chl (Chlorophyta), Cv (*Cymbella ventricosa*), *Clos* (*Clostridium*), *Cos* (*Cosmarium)*, Cyn (Cyanophyta), Din (Dinophyta), Eg (*Elakatothrix gelatinosa*), Euas (*Euastrum*), Eug (Euglenophyta), Gsp (*Gomphonema* sp.), Micr (*Micrasterias*), NP (net plankton), Nsp (*Nostoc* sp.), Nv (*Navicula cuspidata*), Osp (*Oscillatoria* sp.), Phsp (*Phormidium* sp.), Phy (Phytoplankton), Pp (*Phacus pleuronectes*), PR (Phytoplankton richness), Psp (*Pinnularia* sp.), Rsp (*Rhopalodia* sp.), Sg (*Selenastrum gracile*), Ssp (*Spirulina* sp.), Stau (*Staurastrum*), Staur (*Staurodesmus*), Tf (*Tabellaria fenestrata*).

This study recorded higher abundance than the results from Wular lake of Kashmir (Ganai et al., 2010); Bihar (Baruah et al., 1993; Sanjer and Sharma, 1995); Loktak Lake (Sharma, 2009) and two floodplain lakes (Sharma, 2010) of Manipur; and Samuajan (Sharma, 2004), Ghorajan (Sharma, 2012) and Deepor (Sharma, 2015) beels of Assam.

Phytoplankton formed dominant component of net plankton in Bhereki beel and Holmari beels but registered sub-dominant role in Ghotonga beel; the former concurred with the reports from floodplain of Bihar (Baruah et al., 1993; Sinha et al., 1994; Sanjer and Sharma, 1995), Assam (Yadava et al., 1987) and Maharashtra (Patil, 2002). The sub-dominance in Ghotonga concurred with the reports from NEI floodplains (Sharma, 2004, 2009, 2010, 2012, 2015) and suggested availability of other food resources such as organic matter absorbed in sediments, detritus, bacteria, etc. as hypothesized by Sharma (2012). The phytoplankton followed oscillating monthly quantitative variations during two years with peak densities during winter, summer and post-monsoon in Bhereki, Holmari and Ghotonga beels, respectively. The lack of periodicity concurred with the reports of Sharma (2010, 2012) but differed from the trimodal patterns reported from Loktak Lake (Sharma, 2009) and Deepor beel (Sharma, 2015). The winter peak in the first beel concurred with the reports of Yadava et al. (1987), Sanjer and Sharma (1995), Sharma and Lyngdoh (2003), Sharma and Lyngskor (2003) and

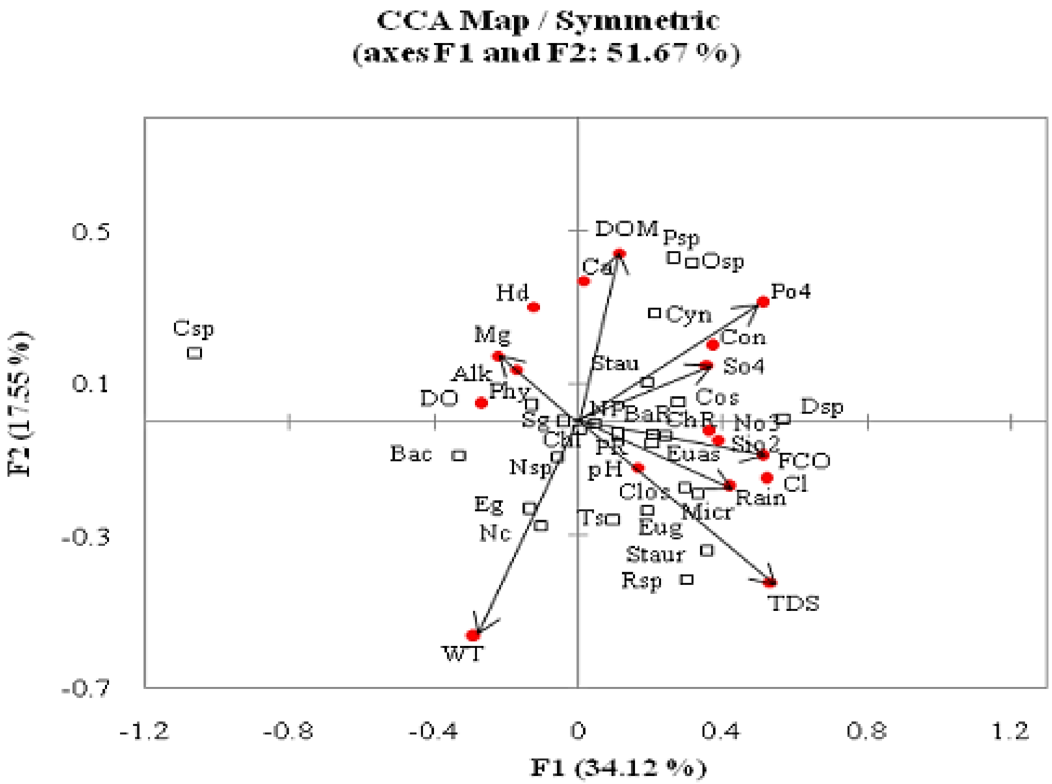

Figure 15. CCA ordination biplot of Phytoplankton and abiotic factors (Holmari beel). **Abbreviations: Abiotic:** Alk (alkalinity), Ca (Calcium), Cl (Chloride), Con (conductivity), DO (dissolved oxygen), DOM (dissolved oxygen matter), FCO (free carbon dioxide), Hd (Hardness), Mg (Magnesium), pH (hydrogen-ion concentration), No3 (nitrate), Po4(phosphate), Rain (rainfall), Sio2 (silicate), So4 (sulphate), TDS (Total dissolved solids), Wt (water temperature). **Biotic:** Bac (Bacillariophyta), BcR (Bacillariophyta richness), ChR (Chlorophyta richness), Csp (*Caloneis* sp.), Dsp (*Desmidium* sp.), Chl (Chlorophyta), Ct (*Cymbella tumida*), *Clos* (*Clostridium*), *Cos* (*Cosmarium)*, Cyan (Cyanophyta), Din (Dinophyta), Eg (*Elakatothrix gelatinosa*), Euas (*Euastrum*), Eug (Euglenophyta), Micr (*Micrasterias*), NP (net plankton), Nsp (*Nostoc* sp.), Nv (*Navicula cuspidata*), Osp (*Oscillatoria* sp.), Phsp (*Phormidium* sp.), Phy (Phytoplankton), Pp (*Phacus pleuronectes*), PR (Phytoplankton richness), Rsp (*Rhopalodia* sp.), Sg (*Selenastrum gracile*), Stau (*Staurastrum*), Staur (*Staurodesmus*), Tf (*Tabellaria fenestrata*).

Sharma (2009, 2010), while summer peak observed in Holmari beel is concurrent with the reports from certain beels of Assam (Sharma, 2004, 2012, 2015).

Chlorophyta recorded relatively high abundance than the reports from the floodplains of NEI (Sharma, 2004, 2009, 2010, 2015) while it broadly concurred with the results of Sharma (2012). It formed the sole dominant fraction of phytoplankton of Holmari and Ghotonga beels and indicated sub-dominant role in Bhereki beel. This group notably influenced phytoplankton abundance (r_1=0.675, *P*=0.0001; r_2=0.948, *P*<0.0001; r_3=0.908, *P*<0.0001); peak densities of Chlorophyta contributed to phytoplankton maxima in all beels. ANOVA registered insignificant variations of Chlorophyta abundance amongst three beels; it registered significant annual density variations in Bhereki ($F_{1, 23}$=5.002, *P*=0.046) and Ghotonga ($F_{1, 23}$=5.315, *P*=0.041) beels. Chlorophyta is characterized by quantitative importance of *Cosmarium* spp. in Bhereki > Ghotonga > Holmari beels, respectively; *Closterium* spp. and *Staurastrum* spp. in Ghotonga > Holmari > Bhereki beels, respectively while *Staurodesmus* spp. deserved attention in Bhereki beel. The significance of desmid taxa concurred with the results the floodplains of NEI (Sharma, 2009, 2010, 2015). Amongst Chlorophyta species, only *Elakatothrix gelatinosa* indicated importance in Holmari > Ghotonga > Bhereki while *Selenastrum gracile* showed certain importance in Holmari and Ghotonga beels, and *Desmidium* sp. is notable in Holmari beel.

Bacillariophyta formed the dominant group in Bhereki beel and recorded sub-dominance in Holmari and Ghotonga beels; the former concurred with the

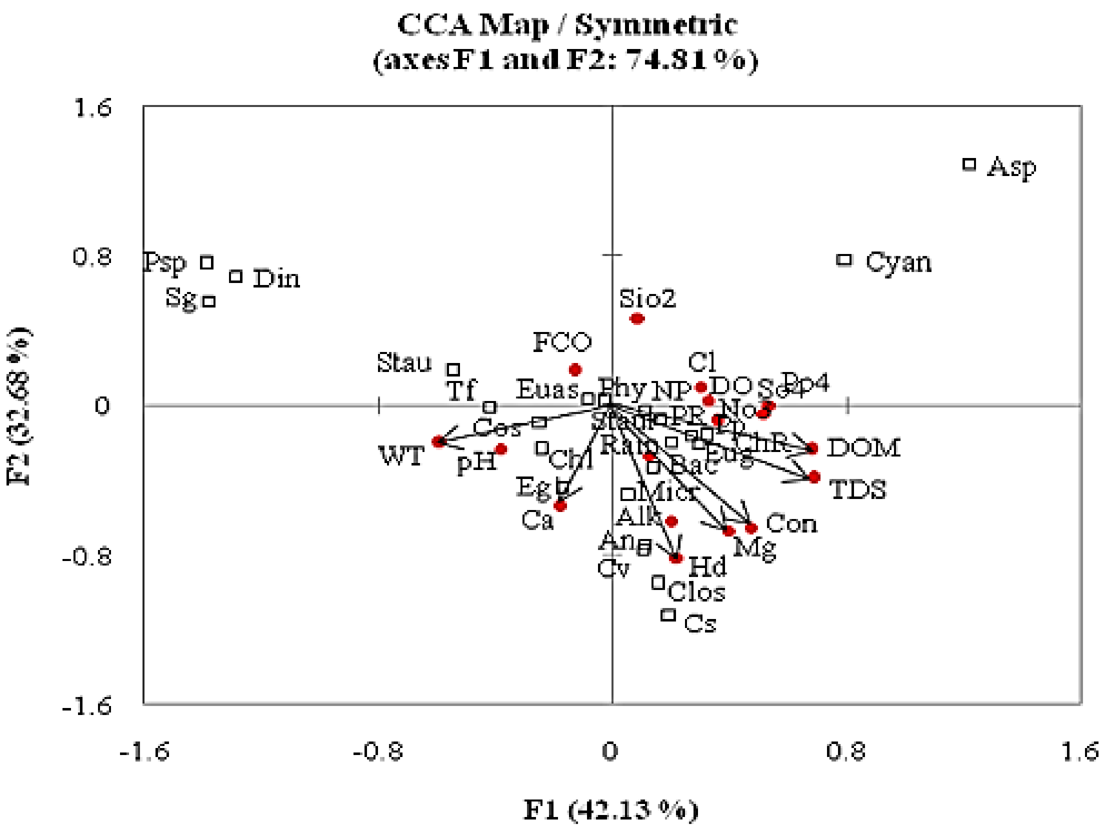

Figure 16. CCA ordination biplot of Phytoplankton and abiotic factors (Ghotonga beel). **Abbreviations: Abiotic:** Alk (alkalinity), Ca (Calcium), Cl (Chloride), Con (conductivity), DO (dissolved oxygen), DOM (dissolved oxygen matter), FCO (free carbon dioxide), Hd (Hardness), Mg (Magnesium), pH (hydrogen-ion concentration), No3 (nitrate), Po4(phosphate), Rain (rainfall), Sio2 (silicate), So4 (sulphate), TDS (Total dissolved solids), Wt (water temperature). **Biotic:** An (*Amphora normani*), Bac (Bacillariophyta), Asp (*Aphanocapsa* sp.), ChR (Chlorophyta richness), Chl (Chlorophyta), Cs (*Closterium setaceum*), Cv (*Cymbella ventricosa*), *Clos* (*Clostridium*), *Cos* (*Cosmarium)*, Cyan (Cyanophyta), Din (Dinophyta), Eg (*Elakatothrix gelatinosa*), Euas (*Euastrum*), Eug (Euglenophyta), Micr (*Micrasterias*), NP (net plankton), Phy (Phytoplankton), Pp (*Phacus pleuronectes*), PR (Phytoplankton richness), Psp (*Peridinium* sp.), Sg (*Selenastrum gracile*), Stau (*Staurastrum*), Staur (*Staurodesmus*), Tf (*Tabellaria fenestrata*).

report from Deepor Beel (Sharma, 2015) while the latter concurred with the report from Loktak Lake (Sharma, 2009). The diatoms recorded significant ($F_{2, 71}$=7.143, P=0.0019) density variations amongst three beels but registered insignificant annual and monthly variations in individual beels. *Gomphonema* sp. > *Rhopalodia* sp. > *Navicula cuspidata* ≥ *Tabellaria fenestrata* > *Pinnularia* sp. > *Amphora normani* > *Cymbella ventricosa* influenced the diatom abundance in Bhereki beel; *Tabellaria fenestrata* > *Caloneis* sp. > *Rhopalodia* sp. > *Navicula cuspidata* > *Cymbella tumida* deserved mention in Holmari beel while *Cymbella ventricosa* > *Amphora normani* > *Tabellaria fenestrata* > *Navicula cuspidata* showed importance in Ghotonga beel.

Cyanophyta played a sub-dominant role concurrent with the reports from Deepor Beel (Sharma, 2010, 2015) and Ghorajan beel (Sharma, 2012). It registered insignificant variations amongst beels but registered significant annual ($F_{1, 23}$=5.169, P=0.044) variations in Ghotonga beel. Dinophyta in Bhereki and Holmari beels, and Euglenophyta in Bhereki, Holmari and Ghotonga beels, respectively, are characterized by low densities. This generalization concurred with the results of Singh et al. (1982), Sharma and Lyngdoh (2003), Sharma and Lyngskor (2003) and Sharma (2010). The sub-dominance of Dinophyta in Ghotonga beel and its contribution to phytoplankton peak in October, 2010 with importance of *Peridinium* sp. is, however, notable. *Phacus pleuronectes* deserved attention in Bhereki > Holmari beels.

Phytoplankton is characterized high diversity with wider monthly variations; Bhereki and Ghotonga beels indicated high diversity (>3.0) during eleven months each and registered higher averages during first year while Holmari beels indicated species diversity >3.0 during 15 months with higher mean during second year. These remarks reflected greater inter-annual variations in habitat diversity vis-a-vis phytoplankton diversity of the sampled beels in general and of Holmari beel in particular. The features of high species diversity with relatively lower densities of large number of species is ascribed to fine niche portioning amongst inhabitant species in combination with high micro- and macro-scale habitat heterogeneity (Sharma, 2012, 2015).

Our results registered low to moderate phytoplankton dominance without confirming to any definite monthly pattern; it recorded insignificant temporal variations amongst beels and indicated significant annual ($F_{1, 23}$=9.143, *P*=0.011) as well as monthly ($F_{11, 23}$=3.984, *P*=0.015) variations in Bhereki beel. High dominance recorded for a specific period both during two years in Ghotonga beel coincided with higher abundance of Cyanophyta as well as with peaks of *Peridinium* sp. during first year and of *Aphanocapsa* sp. during second year, respectively. Likewise, various taxa resulted in the periods of higher dominance in Bhereki and Holmari beels while low dominance with relatively lesser fluctuations during certain months indicated lack of quantitative importance of individual species (McNaughton, 1967). Following MacArthur (1965), it is hypothesized that the Majuli beels provided resources for utilization by fewer or majority of species and thus providing variable conditions from low to high amount of niche overlap.

Phytoplankton is characterized by moderate to high evenness in Ghotonga > Bhereki > Holmari beels, with higher averages during first year and indefinite pattern of monthly variations in all beels. High evenness noticed during several months is attributed to equitable abundance of majority of taxa (Washington, 1984) while dominance of certain species resulted in moderate values during February, 2012 in Bhereki; October, 2010, January-March and May, 2012 in Holmari; and during November, 2010 and August, 2012 in Ghotonga beels. ANOVA registered both insignificant variations of evenness amongst three beels; it exhibited significant annual variations ($F_{1, 23}$=5.541, *P*=0.038).

Individual abiotic factors exerted insignificant influence on phytoplankton richness and abundance. Chlorophyta abundance is positively correlated with pH in Bhereki and inversely correlated with dissolved organic matter in Ghotonga beel. Cyanophyta density is significantly correlated directly with silicate and inversely with total hardness and magnesium in Bhereki beel, and it is correlated indirectly with total hardness in Ghotonga. The canonical correspondence analysis (CCA) with 17 abiotic factors recorded low influence phytoplankton assemblages along first two axes in Bhereki and Holmari beels than in Ghotonga beel. CCA reflected the importance of water temperature, pH, hardness, dissolved organic matter, total dissolved solids, sulphate and silicate in Bhereki beel; water temperature, rainfall, free carbon-dioxide, magnesium and total dissolved solids recorded importance in Holmari beel; and reflected importance of water temperature, specific conductivity, hardness, calcium, magnesium, dissolved organic matter and total dissolved solids in Ghotonga beel. In general, this study yielded limited insight regarding individual and cumulative influence of abiotic factors on phytoplankton diversity; the results thus suggested need to analyse factors associated with microhabitat variations of the sampled beels.

To sum up, the speciose phytoplankton of Bhereki, Holmari and Ghotonga beels, heterogeneity in their composition, richness of Chlorophyta and of certain desmid genera merit biodiversity value. The quantitative importance Chlorophyta in Holmari and Ghotonga beels and of Bacillariophyta in Bhereki beel; lack of any definite temporal variations of phytoplankton richness and abundance; and low to moderate dominance are notable. Variations in composition, abundance, diversity, and dominance suggested habitat diversity during two years of this study. The limited individual and low cumulative influence on phytoplankton assemblages yielded limited insight on overall role of abiotic factors.

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