Composition, abundance and ecology of phytoplankton communities of Loktak Lake, Manipur, India

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Abstract: Phytoplankton communities of Loktak Lake (a Ramsar site), studied during November 2002-October 2004, reveal the occurrence of 75 and 71 species, indicate monthly richness ranging between 47±6 and 49±3 species and record 50.0-83.2 and 64.5-84.0 % community similarities during two annual cycles respectively. Chlorophyta (33±5 and 35±5 species) show qualitative dominance and importance of *Closterium* > *Cosmarium* > *Staurastrum* > *Micrasterias* > *Gonatozygon* species. Phytoplankton (206±58 and 220±53 n/l) comprise between 45.1±6.5 and 42.9±5.8 % of net plankton abundance, indicate trimodal annual patterns and record peak abundance during winter. Chlorophyta (111±20 and 119±15 n/l), the dominant quantitative component, indicate winter peaks; *Closterium* > *Staurastrum* > *Gonatozygon* > *Micrasterias* species contribute significantly to their abundance. *Ceratium hirudinella* (43±52 and 39±37 n/l) is the sole important individual species of phytoplankton. Dinophyta > Bacillariophyta are sub-dominant groups and Euglenophyta > Cyanophyta > Chrysophyta show very low densities. Phytoplankton communities are characterized by higher species diversity, higher evenness and lower dominance. Abiotic factors register limited influence on richness and abundance of phytoplankton and on abundance of constituent groups. Multiple regression indicates relatively lower influence of fifteen abiotic factors on richness of phytoplankton and higher cumulative influence on abundance of phytoplankton, Chlorophyta, Dinophyta and Bacillariophyta.

Keywords: Composition, Floodplain Lake, Loktak, Phytoplankton, Ramsar site, synecology

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Introduction

The floodplain lakes cover a water spread area of about 0.12 million ha in northeastern India, are mainly located in the states of Assam and Manipur and exhibit significant fishery production potential (Sugunan 1997). Little is, however, known so far about their biological productivity in general and about composition, abundance and ecology of phytoplankton in particular. Investigations on the latter from northeastern region are confined to fewer preliminary publications from Assam (Yadava et al. 1987; Baruah & Das 1997; Goswami & Goswami 2001) indicating poor ecological data due to inadequate species determination. On the other hand, Sharma (2004) gave useful information on phytoplankton ecology of a floodplain lake of upper Assam while Sharma (in press) analyzed phytoplankton communities of Deepor Beel - a Ramsar site and an important floodplain lake of Assam.

This study on the composition and synecology of phytoplankton of Loktak Lake, a Ramsar site, an important floodplain lake of northeastern India and the largest freshwater wetland of India, is of ecological importance. Observations were made on monthly variations in richness, abundance of phytoplankton, their constituent groups, community similarities, species diversity, dominance and evenness for two annual cycles. Remarks are made on the influence of abiotic factors on richness and abundance of phytoplankton communities.

Materials and Methods

The present study is a part of limnological survey (undertaken during November, 2002 - October, 2003) in Loktak Lake (93°46'-93°55'E & 24°25'-24°42'N; area: 286km^2; max. depth: 4.58m, mean depth: 2.07m; altitude: 768.5m) located in Bishnupur / Imphal districts of Manipur. This large natural freshwater wetland is characterized by floating mats of vegetation called as "Phumdi" which are inhabited by the Critically Endangered Brow-antlered Deer (*Cervus eldi eldi*). Common aquatic plants of this floodplain lake include *Eichhornia crassipes*, *Hydrilla verticellata*, *Euryale ferox*, *Vallisnaria spiralis*, *Utricularia flexuosa*, *Trapa natans*, *Lemna trisula*, *Pistia striates*, *Salvinia*, *Nymphaea* spp., *Nymphoides* spp., *Nelumbo mucifera*, *Potamageton* spp., *Azolla pinnata*, *Sagittaria* spp, and *Cyperus* spp. etc.

The present observations were undertaken at regular monthly intervals at one selected sampling site at Sendra (93°47'45.61''E & 24°30'56.75"N). Water samples collected monthly were analyzed for various abiotic factors following APHA (1992) while water temperature, specific conductivity, pH and dissolved oxygen were recorded by the field probes. Monthly qualitative and quantitative net plankton samples were collected by nylobolt plankton net (No. 25) and were preserved in 5% formalin. The former were screened and phytoplankton taxa were identified following Needham & Needham (1962), Islam & Haroon (1980), Adoni et al. (1985) and Fitter & Manuel (1986). Quantitative plankton samples were analyzed for abundance (n/l) of net plankton, phytoplankton and constituent groups.

Sorensen's index, Shannon's indices, Berger-Parker's index and Pileou's index were calculated following Ludwig & Reynolds (1988) and Magurran (1988). Significance of temporal variations of biotic parameters was ascertained by ANOVA (two-way). Ecological correlations between abiotic and biotic parameters were determined by simple correlation coefficients (r). Multiple regression (R^2) was used to ascertain cumulative effect of 15 abiotic factors (water temperature, rainfall, pH, specific conductivity, dissolved oxygen, free carbon dioxide, alkalinity, hardness, phosphate, nitrate, sulphate, silicate, chloride, dissolved organic matter and total dissolved solids) on phytoplankton and their groups.

Results and Discussion

Abiotic parameters

Water temperature indicates sub-tropical nature of Loktak Lake. Specific conductivity exhibits low ionic concentrations (Table 1) of this Ramsar site and, hence, warrants its inclusion under 'Class I' category of trophic classification vide Talling & Talling (1965). Slightly acidic and soft waters of this floodplain lake depict moderate dissolved oxygen, low free CO_2, low concentration of micro-nutrients and other abiotic factors. In general, the abiotic factors differ from Deepor Beel (Sharma in press), distinctly in the recorded ranges of pH, alkalinity and hardness.

Phytoplankton composition, richness and community similarities

Seventy-five species of phytoplankton (Table 2), belonging to six groups, documented from Loktak exhibit their speciose and diverse nature and, hence, reflect greater environmental heterogeneity of this Ramsar site. Total richness is distinctly higher than only 33 species examined earlier in an unpublished report (Bhatia 1979) from this wetland as well as than 59 species reported from Deepor Beel (Sharma in press). The present collections are characterized by qualitative dominance of Chlorophyta (56 species) and distinct qualitative importance of species of five desmid genera (64.3%) namely *Closterium* (11 spp.) > *Cosmarium* (7 spp.) = *Staurastrum* (7 spp.) > *Micrasterias* (6 spp.) > *Gonatozygon* (5 spp.). Desmid diversity is considered to be an indicator of slightly acidic, Calcium-poor waters with low ionic concentrations (Payne 1986), this interesting generalization is confirmed by the salient features of water quality of Loktak Lake. Further, higher desmid richness is concurrent with phytoplankton communities of various (sub)tropical aquatic environs of northeastern India (Sharma unpublished). The species and generic diversity of Loktak phytoplankton distinctly outnumbers the earlier records of Baruah et al. (1993), Acharjee et al. (1995), Sanjer & Sharma (1995), Goswami & Goswami (2001), and Sharma (2004). The general qualitative dominance of the Chlorophyta observed in this study corresponds with the results of Goswami & Goswami (2001) and Sharma (in press) but differs from the greater diatom richness reported by Baruah et al. (1993) and Sharma (2004).

Table 1. Abiotic factors of Loktak Lake (2002-04)

Abiotic Factors	Range	Mean ± SD
Air temperature ºC	16.4 - 30.8	23.4 ± 4.1
Water temperature ºC	14.5 - 28.5	21.4 ± 4.0
Rainfall mm	0 - 370.4	112.1 ±1 16.8
pH	6.01- 6.74	6.38 ± 0.23
Specific Conductivity µS/cm	75.0 - 132.0	98.9 ± 19.7
Dissolved Oxygen mg/l	4.6 -9.0	6.2 ± 1.1
Free CO_2 mg/l	6.0 - 13.0	9.5 ± 2.1
Alkalinity mg/l	10.0 - 25.0	16.0 ± 4.4
Hardness mg/l	24.0 - 54.0	38.1 ± 8.2
Phosphate mg/l	0.12 - 0.32	0.23 ± 0.12
Nitrate mg/l	0.27 - 0.42	0.34 ± 0.04
Sulphate mg/l	0.54 - 0.99	0.86 ± 0.12
Silicate mg/l	8.40 - 12.70	10.4 ± 1.2
Chloride mg/l	10.0 - 20.1	14.9 ± 3.1
Dissolved organic matter mg/l	0.91 - 2.1	1.38 ± 0.40
Total dissolved solids mg/l	0.20 - 0.81	0.46 ± 0.22

Phytoplankton richness varies between 37-57 (47±6) species and 45-54 (49±3) species during two annual cycles respectively (Table 2); it records significant monthly variations ($F_{11, 23}$ = 4.821, P < 0.005) but shows insignificant annual variations. Richness shows (Fig. 1) peaks during post-monsoon (October) and higher species number during winter (December) during both years and lowest richness is noticed during January (first year) and March (second year). The present study, however, exhibits no definite pattern of periodicity of richness of any group or species of phytoplankton. This generalization concurs with the author's earlier remarks in two floodplain lakes of Assam (Sharma 2004, in press) while Loktak phytoplankton reflect higher range of richness variations. Further, the richness exhibits limited influence of individual abiotic factors and indicates significant negative correlations with nitrate (r = -0.458), sulphate (r = -0.569) and silicate (r = -0.415). Multiple regression also registers relatively lower cumulative influence of 15 abiotic factors on phytoplankton richness (R^2 = 0.579).

Phytoplankton of Loktak Lake indicate community similarities (vide Sorenson's index) ranging between 50.0-84.0% with marginal variations during two successive years of the study period i.e., 50.0-83.2 % (Table 3) and 64.5-84.0 % (Table 4) respectively. The recorded values differ from wider similarity ranges noticed by Sharma (2004, in press). The similarity, however, varies between 70-80 % in majority of instances (72%) included in the matrix during the second year while only 31.2% instances belong to the stated range and 48.5% instances indicate 60-70 % similarity during the first year. Hierarchical cluster analysis shows notable differences in clusters groupings during the study period. It registers higher associations among phytoplankton communities during December-September-August-November-October and exhibits more differences in January-July-June during the first year (Fig. 2). On the other hand, higher associations are observed during January-September-December and more differences are apparent during March-July-February in the following year (Fig. 3).

Chlorophyta, the most speciose component of phytoplankton, include 56 and 51 species during two annual cycles respectively and significantly influence temporal variations of richness of the latter (r = 0.913). Richness of this group registers insignificant monthly and annual variations. It follows (Fig. 4) relatively wider range of variations during first year (20-40, 33±5 species) than in the succeeding year

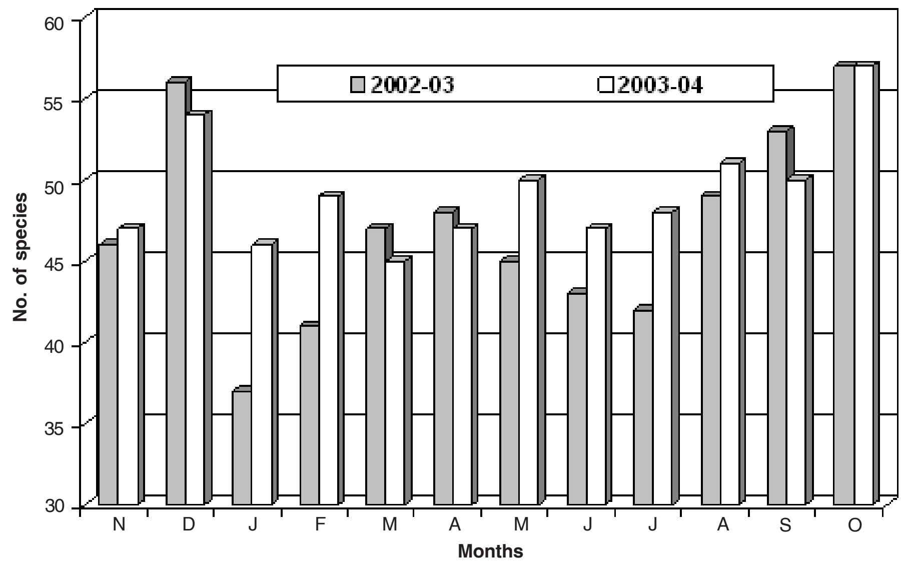

Figure 1. Monthly variations in phytoplankton richness

Table 2. Temporal variations of phytoplankton of Loktak Lake

	2002-03	2003-2004	Study period
Qualitative Chlorophyta > Bacillariophyta > Dinophyta = Cyanophyta = Euglenophyta > Chrysophyta			
Phytoplankton	75 species	71 species	75 species
% Similarity	50.0-83.2	64.5-84.0	50.0-84.0
Monthly Richness			
Phytoplankton	37-57 47±6	45-54 49±3	37-57 48±5
Chlorophyta	24-40 33±5	30-42 35±3	24-42 34±4
Quantitative Chlorophyta > Dinophyta > Bacillariophyta			
Phytoplankton n/l	155-369 206±58	158-323 220±53	155-369 213±56
% composition	38.0-60.0 45.1±6.5	34.8-54.8 42.9±5.8	34.8-60.0 44.1±6.3
Species Diversity	2.520-3.805 3.283±0.354	2.876-3.741 3.507±0.259	2.520-3.805 3.404±0.329
Dominance	0.074-0.523 0.283±0.123	0.055-0.409 0.158±0.103	0.055-0.523 0.180±0.118
Evenness	0.698-0.941 0.853±0.074	0.739-0.956 0.902±0.064	0.698-0.956 0.879±0.075
Different groups (n/l)			
Chlorophyta n/l	78-137 111±20	104-155 119±15	78 -155 115±18
% composition	34.7-77.3 56.2±12.6	38.1 -5.8 56.5±8.3	34.7-77.3 56.2±10.5
Dinophyta n/l	13-193 53±48	17-138 49±36	13-193 51± 43
% composition	6.9-52.3 22.8±12.5	10.4-49.3 20.5±0.9	6.9-52.3 22.0±11.8
Bacillariophyta n/l	11-44 31±10	17-55 38±11	11-55 35±11
% composition	6.7-21.8 15.4±3.7	10.5-22.4 17.3±3.0	6.7-22.4 16.3±3.5
Euglenophyta n/l	2-12 7±3	3-13 7±3	2-13 7±3
% composition	0.5-5.9 3.4±1.7	1.3-4.1 3.0±0.9	0.5-5.9 3.2±1.4
Cyanophyta n/l	1-7 3±2	3-7 5±2	1-7 4±2
% composition	0.3-4.3 1.5±1.4	0.6- 5.1 2.8±1.4	0.3-5.1 2.1±1.5
Chrysophyta n/l	0-1	0-4 2±1	0-4 1±1
Important taxa (n/l)			
Ceratium hirudinella	4-193 43±52	5-130 39±37	4-193 41±45
Closterium spp.	8-4 21±8	17-43 29±9	8-43 25±9
Staurastrum spp.	5-30 17±7	11-24 18±4	5-30 18±6
Gonatozygon spp	6-25 13±6	7-26 17±6	6-26 15±6
Micrasterias spp.	1-26 10±7	3-15 10±3	1-26 10±6
Cosmarium spp.	2-8 5±2	2-11 6±3	2-11 6±2

Table 3. Phytoplankton community similarities (Sorenson's index) 2002-03

	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct
Nov	-	80.4	70.7	69.8	66.7	59.6	68.1	60.7	70.5	77.9	77.6	69.9
Dec		-	65.2	72.9	71.8	71.2	63.4	62.6	67.4	78.1	81.5	76.1
Jan			-	68.4	57.8	50.0	64.2	50.6	69.2	70.6	75.0	62.4
Feb				-	69.0	63.6	70.6	55.4	63.4	60.7	67.4	66.0
March					-	75.8	71.7	60.0	62.9	68.8	72.7	71.2
April						-	68.8	61.5	53.3	66.0	72.0	68.6
May							-	59.1	64.4	63.8	63.9	68.6
June								-	58.8	56.5	71.6	72.0
July									-	65.9	66.0	66.7
Aug										-	83.2	73.6
Sept											-	78.9
Oct												-

Table 4. Phytoplankton community similarities (Sorenson's index) 2003-04

	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct
Nov	-	76.5	66.0	69.4	74.5	72.9	73.5	73.7	72.2	74.8	74.2	78.1
Dec		-	82.0	73.1	76.0	78.4	76.9	75.3	77.7	74.3	79.6	73.9
Jan			-	79.2	69.6	66.0	70.8	73.1	69.5	68.0	84.2	71.8
Feb				-	79.2	63.3	66.0	70.1	76.8	73.3	72.7	84.1
March					-	74.5	72.9	64.5	75.8	74.2	69.5	71.8
April						-	79.6	71.6	70.1	72.7	74.2	76.2
May							-	68.0	70.7	71.3	68.7	76.6
June								-	72.9	69.4	72.9	75.0
July									-	74.0	73.5	69.8
Aug										-	74.0	81.5
Sept											-	75.5
Oct												-

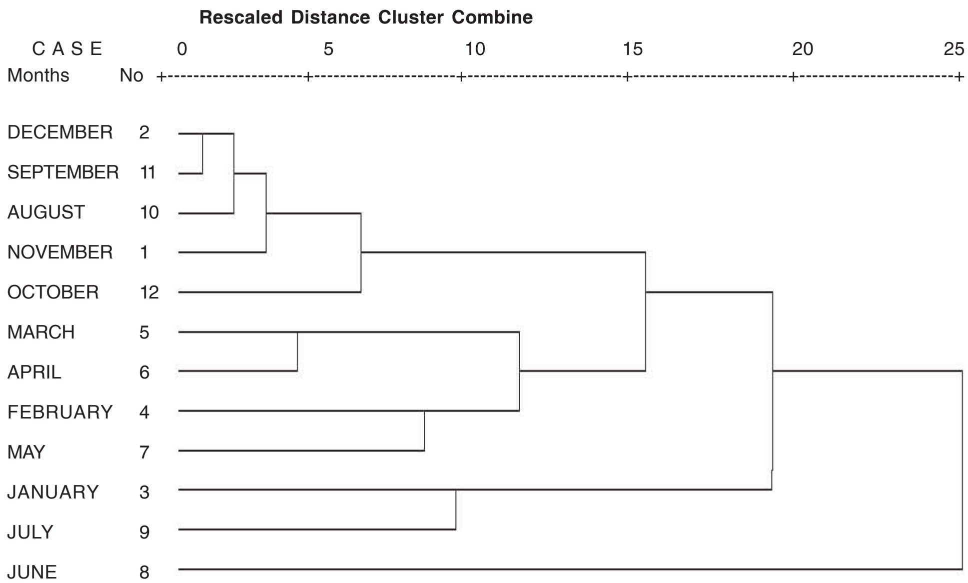

Figure 2. Dendrogram showing hierarchical cluster analysis of phytoplankton communities (2002-03)

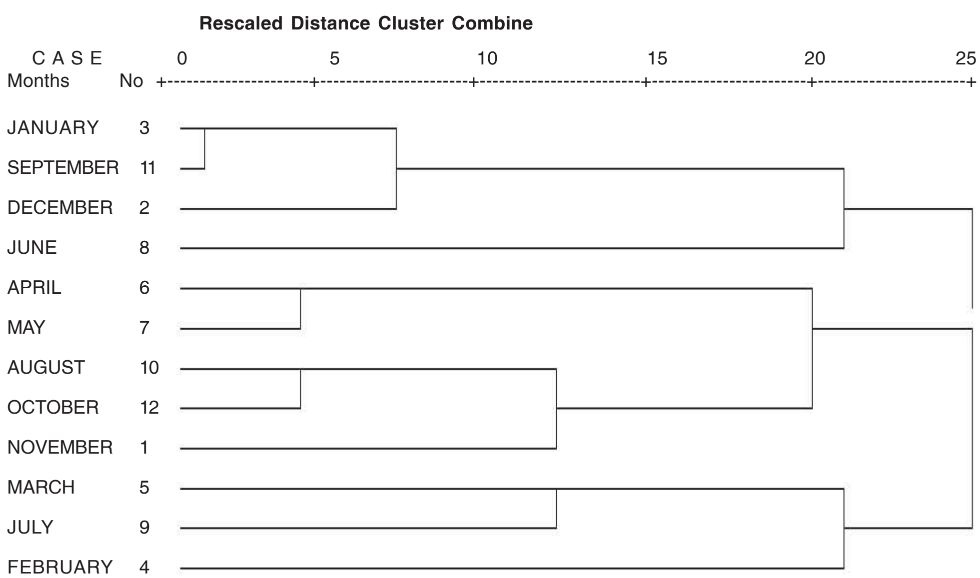

Figure 3. Dendrogram showing hierarchical cluster analysis of phytoplankton communities (2003-04)

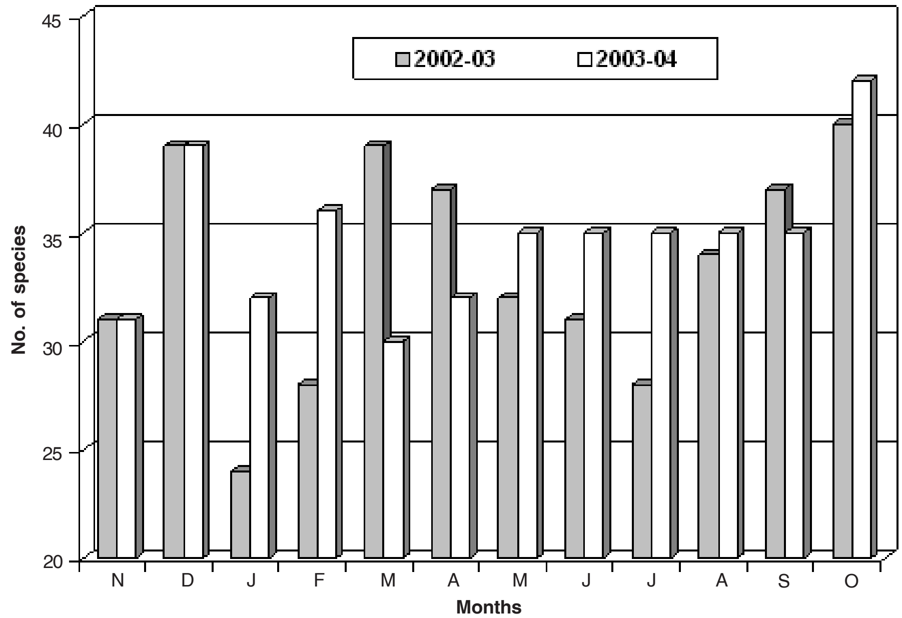

Figure 4. Monthly variations in Cholorophyta richness

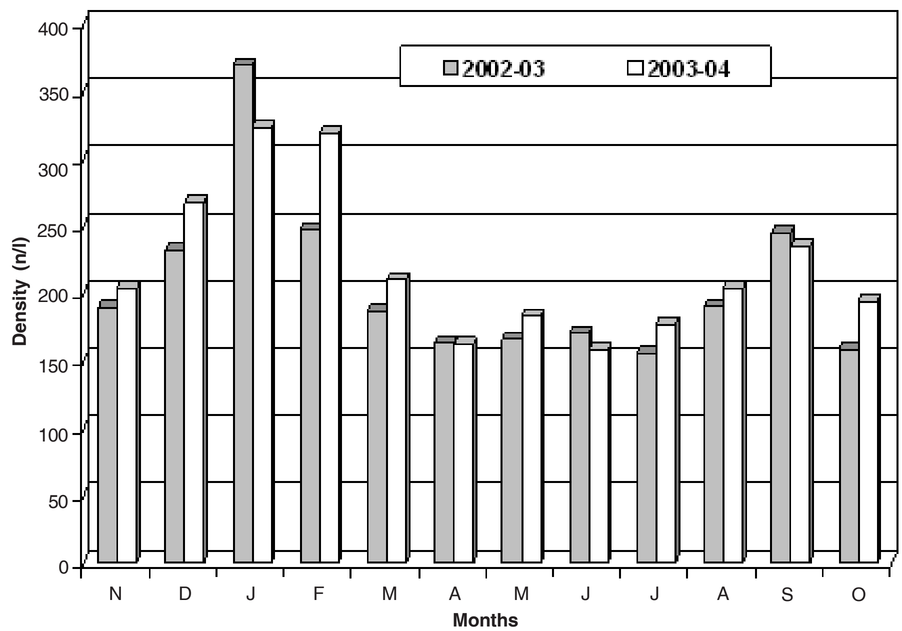

Figure 5. Monthly variations in phytoplankton abundance

(30-42, 35±3 species) and exhibits an indefinite pattern of temporal periodicity with peaks during post-monsoon (October) during both years but shows minima during January, 2002 and February, 2003. The Chlorophyta richness registers no significant correlation with any individual abiotic factor, while multiple regression registers higher commutative influence ($R^2 = 0.829$) of 15 abiotic factors.

Phytoplankton abundance

Phytoplankton form a sub-dominant quantitative component of net plankton (44.1±6.3 %), following zooplankton, throughout the study period except only during January (1st year) and January-February (2nd year). The stated trend corresponds with the results of Sharma (2004, in press) and Sharma & Sharma (2008) while it is in contrast to phytoplankton dominance reported from the floodplain lakes from Kashmir (Kaul & Pandit 1982), Bihar (Rai & Dutta - Munshi 1982; Baruah et al. 1993; Sinha et al. 1994; Sanjer & Sharma 1995), West Bengal (Sugunan 1989), Assam (Yadava et al. 1987; Baruah & Das 1997; Goswami & Goswami 2001), Kerala (Krishnan et al. 1999) and Maharashtra (Patil 2002).

Phytoplankton abundance (Table 2) ranges between 155-369 (206±58 n/l) and 158-323 (220±53 n/l) during the two years respectively; it exhibits significant monthly ($F_{11, 23} = 15.026$, $P < 0.005$) but insignificant annual variations. Abundance follows (Fig. 5) broadly identical trimodal yearly patterns with higher densities during winter season and peaks during January, maxima during post-monsoon (September), a small maxima during June and minima during July. The present results differ from multimodal patterns noticed in Deepor Beel (Sharma in press) and also from the bimodal periodicity reported by Yadava et al. (1987) and Sanjer &

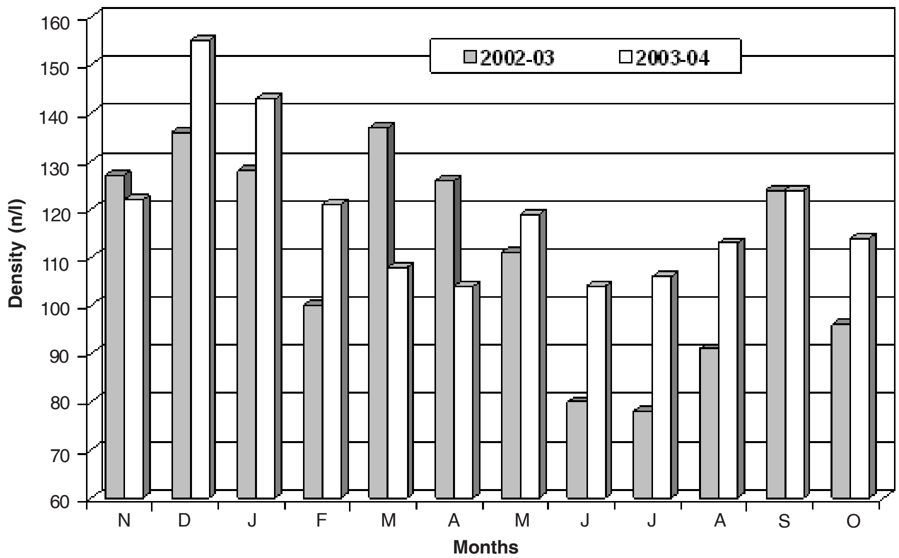

Figure 6. Monthly variations in Chlorophyta abundance

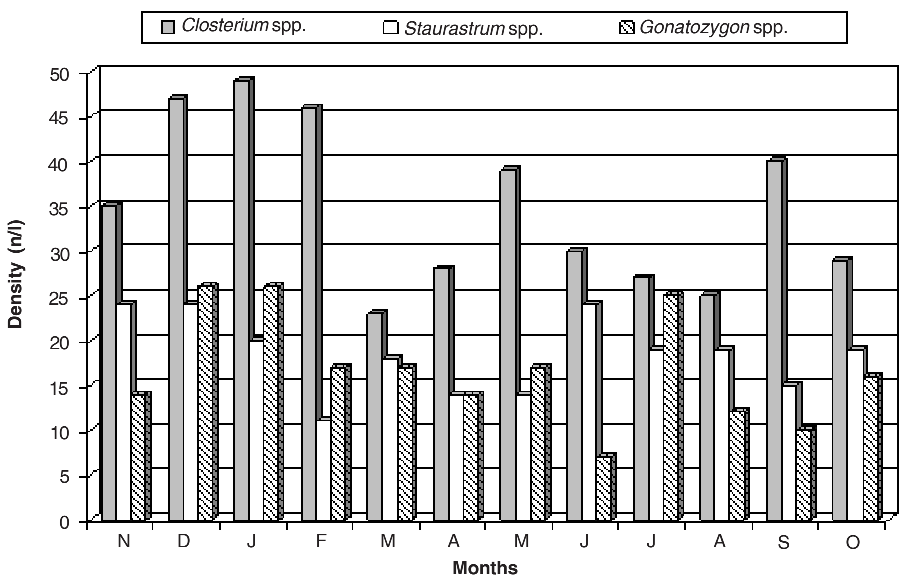

Figure 7. Monthly variations in abundance of dominant genera of Chlorophyta (2002-03)

Sharma (1995). On the other hand, the peak density noticed presently during winter concurs with the results of Yadava et al. (1987) and Sanjer & Sharma (1995) while it differs from early summer maxima reported by Sharma (2004). Phytoplankton abundance in Loktak Lake is yet lower than that from Deepor Beel (Sharma in press), while it is marginally higher than in Samuajan Beel (Sharma 2004). In addition, the density is distinctly lower than the reports from certain beels of West Bengal (Sugunan 1989; Vass 1989) and Bihar (Baruah et al. 1993; Sanjer & Sharma 1995); these differences are attributed to soft nature of water of Loktak with low ionic concentrations and resulting in lower general biological productivity.

Of the recorded parameters, phytoplankton abundance is inversely correlated with water temperature ($r = -0.795$), free carbon dioxide ($r = -0.568$), silicate ($r = -0.490$) and total dissolved solids ($r_1 = -0.465$). On the contrary, fifteen abiotic factors exert significantly higher cumulative influence ($R^2 = 0.952$). Further, the present results record insignificant positive correlation between abundance of phytoplankton and zooplankton. This aspect is in contrast to significant positive correlations between the two communities recorded earlier by Yadava et al. (1987) and Sharma (2004, in press).

Chlorophyta, the sole dominant quantitative component, notably influence temporal variations of phytoplankton ($r = 0.547$) of Loktak Lake and, hence, concur with earlier reports of Yadava et al. (1987), Choudhary & Singh (2001), Goswami & Goswami (2001) and Sharma (in press). The dominance pattern, however, differs from the predominance of the diatoms over the green algae noticed by Baruah et al. (1993) and Krishnan et al. (1999) as well as from nearly equal importance of the two groups reported by Sharma (2004). Chlorophyta abundance (Table 2) ranges between 78-155 (115±18) n/l and comprises between 56.2±10.5 % of phytoplankton. ANOVA registers significant monthly ($F_{11, 23} = 3.084$, $P < 0.005$) and insignificant annual variations in their abundance. The green-algae follow (Fig. 6) trimodal but marginally different annual patterns with higher abundance during winter (December-January), peaks during December and minima during July and June respectively during two years. The

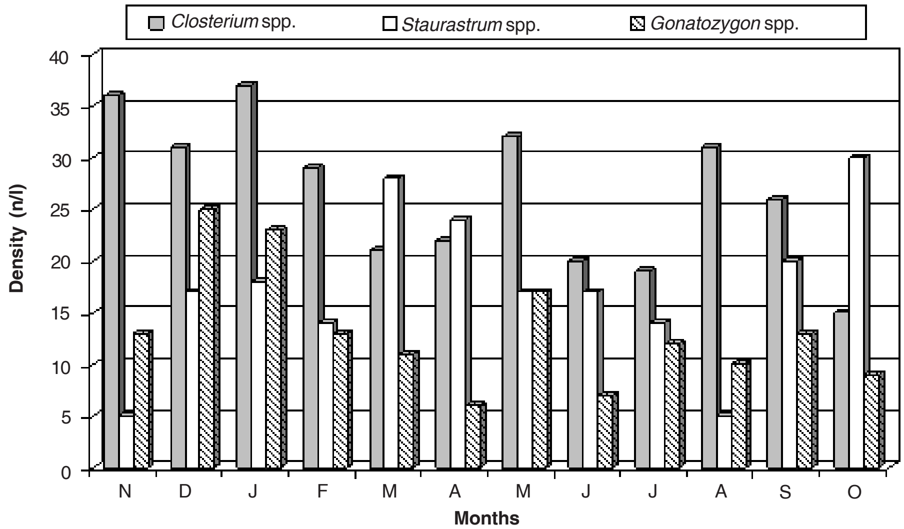

Figure 8. Monthly variations in abundance of dominant genera of Chlorophyta (2003-04)

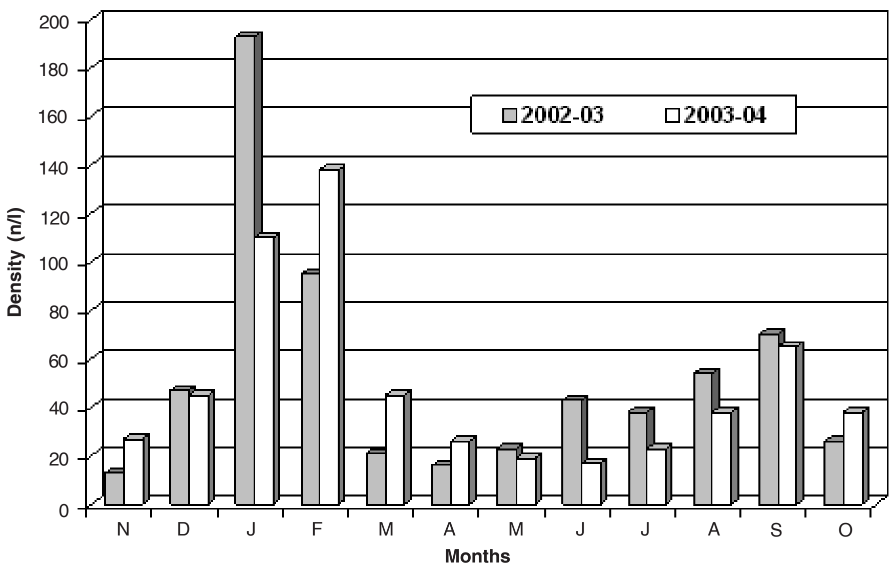

Figure 9. Monthly variations in Dinophyta abundance

present study shows notably higher abundance of this group than the earlier report from Samuajan beel (Sharma 2004), while the density broadly corresponds with the report from Deepor Beel (Sharma in press) but differs distinctly from the same in their higher percentage contributions. Amongst the recorded abiotic factors, Chlorophyta abundance is inversely correlated with water temperature (r = - 0.585), free CO_2 (r = - 0.412), hardness (r = - 0.553), nitrate (r = - 0.473), silicate (r = - 0.565), chloride (r = - 0.559) and total dissolved solids (r = - 0.710), while multiple regression registers higher cumulative influence (R^2 =0.825) of 15 abiotic factors.

Chlorophyta are characterized by quantitative importance of certain desmid taxa (Figs. 7-8) namely *Closterium* spp. (25±9 n/l) > *Staurastrum* spp. (18±6 n/l) > *Gonatozygon* spp. (15±6 n/l) while *Micrasterias* spp. (10±6 n/l) and *Cosmarium* spp. (6±2 n/l) also deserve mention. This salient feature is in contrast to lack of any such dominance pattern noticed in Samuajan (Sharma 2004) and Deepor (Sharma in press) beels of Assam. The stated taxa, however, exhibit lack of definite temporal periodicity. Of these, only *Closterium* spp., and *Gonatozygon* spp. exhibit significant annual ($F_{1, 23}$ = 16.209, P < 0.005; $F_{1, 23}$ = 7.663, P < 0.001) and monthly ($F_{11, 23}$ = 4.335, P < 0.01; $F_{11, 23}$ = 6.511, P < 0.002) variations and register negative correlations with water temperature (r = - 0.525, r = - 0.456).

Dinophyta (13-193, 51±43 n/l, 22.0±11.8%), a sub-dominant quantitative component of phytoplankton of Loktak Lake, follow wider range of abundance and record only significant monthly temporal variations ($F_{11, 23}$ = 7.068, P < 0.001). This group exhibits (Fig. 9) distinctly higher abundance (peaks) during winter (February/January) in both years and notably contributes to higher winter densities of phytoplankton during this period in particular. These interesting features are supported by their inverse correlation with water temperature (r = -0663). Besides, this group is inversely correlated with free CO_2 (r = -0.490), while 15 abiotic factors exercise higher cumulative influence (R^2 =0.839) on their quantitative variations. *Ceratium hirudinella* (4-193, 41±45 n/l), the sole important individual phytoplankton species observed in Loktak Lake, exhibits broadly bimodal periodicity with distinct annual peaks during winter. This species is solely responsible for Dinophyta periodicity as well as for contributing to phytoplankton abundance during winter. ANOVA affirms significant monthly ($F_{11, 23}$ = 7.991, P < 0.005) density

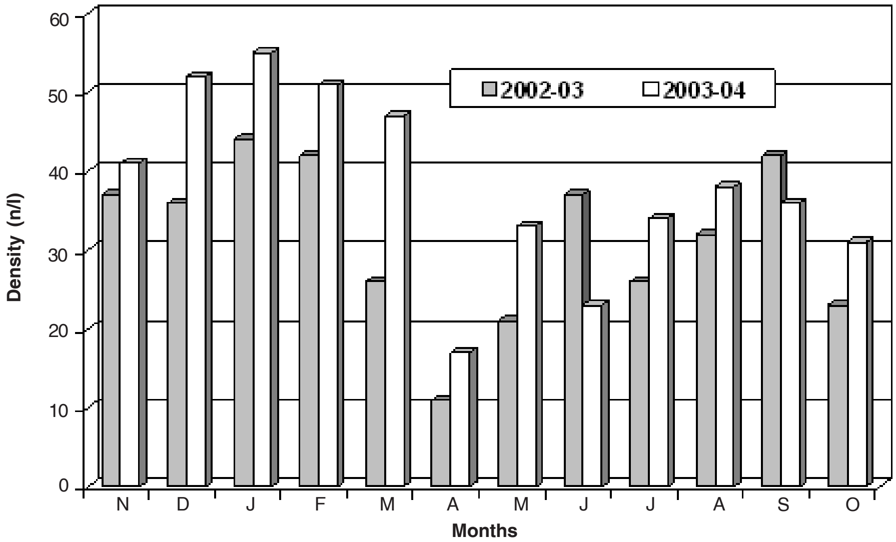

Figure 10. Monthly variations in Bacillariophyta abundance

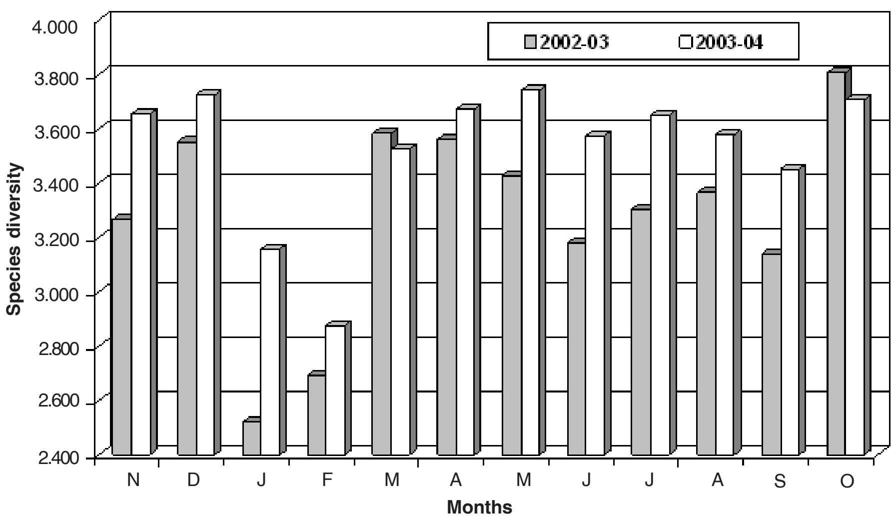

Figure 11. Monthly variations in phytoplankton species diversity

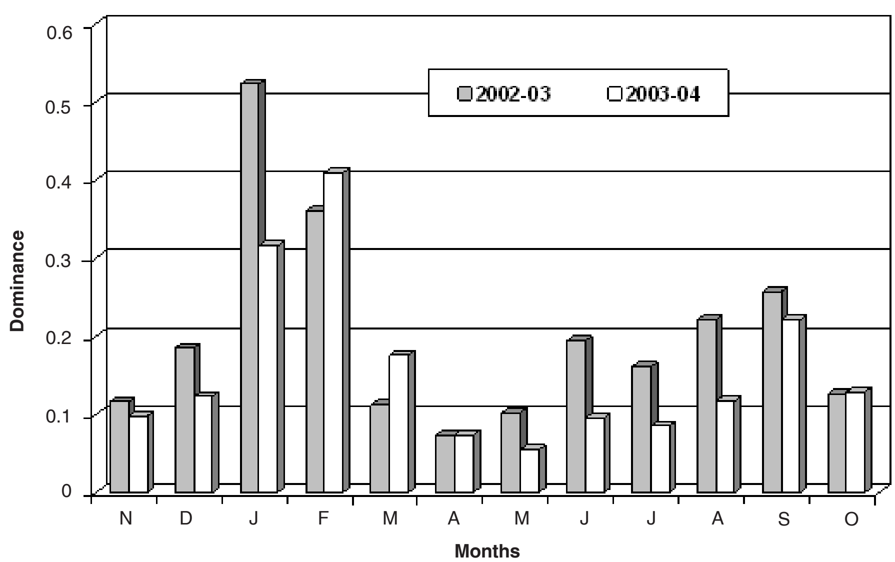

Figure 12. Monthly variations in phytoplankton dominance

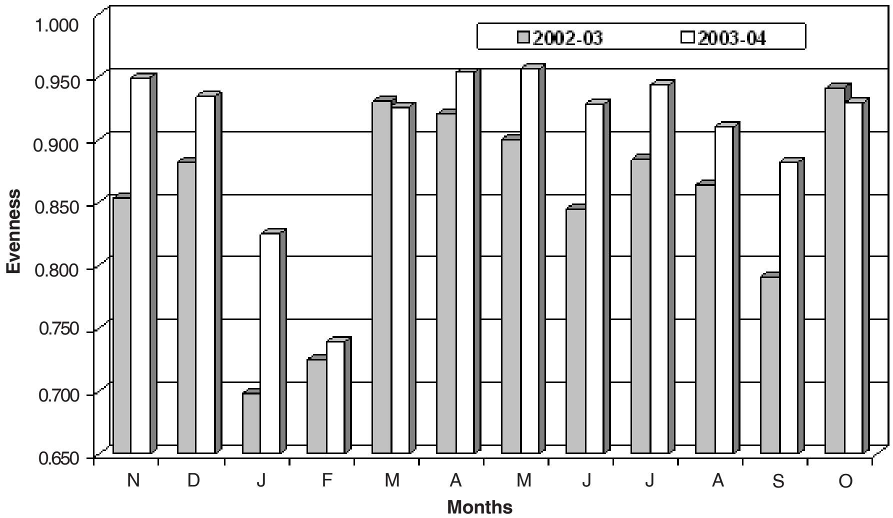

Figure 13. Monthly variations in phytoplankton evenness

variations of *C. hirudinella*. The present observations broadly conform with the results in Deepor Beel (Sharma in press) relating to sub-dominant role of Dinophyta and quantitative significance of *C. hirudinella* but differ from the latter in broader range of variations and winter dominance patterns. These results are, however, in contrast to very poor abundance of this group noticed in Samuajan Beel (Sharma 2004).

Bacillariophyta (35±11 n/l; 16.3±3.5%) form another sub-dominant component of phytoplankton and exhibit significant annual ($F_{1, 23}$ = 6.369, P > 0.02) and monthly ($F_{11, 23}$ = 4.559, P > 0.005) quantitative variations. The abundance of this group is lower than earlier reports of Sharma (2004, in press). The diatoms follow (Fig. 10) multimodal and trimodal annual patters during two years respectively and record higher abundance during winter with peaks in January. The last feature is supported by their inverse correlation with water temperature (r = -0.627). Further, winter peaks observed in this study are in contrast to their summer peaks reported in Deepor Beel (Sharma in press). Besides, Bacillariophyta are inversely correlated with free CO_2 (r = -0.427) and silicate (r = -0.627), while multiple regression registers moderately higher influence (R^2 = 0.774) of 15 abiotic factors.

Euglenophyta > Cyanophyta > Chrysophyta indicate very low densities and contribute insignificant quantitative components of phytoplankton of Loktak Lake. These remarks are in contrast to sub-dominant role of the Cyanophyta and relatively higher abundance of the other two groups noticed in Deepor Beel (Sharma in press).

Species diversity, evenness and dominance

The present results are characterized by higher species diversity of phytoplankton (2.520-3.805, 3.404±0.329); the range may be misleading as its values are higher (< 3.0) in major part of the study period except during winter (January-February). Further, it follows significant annual ($F_{1, 23}$ = 17.084, < 0.005) and monthly ($F_{11, 23}$ = 8.861, P < 0.005) variations. The diversity (Fig. 11) does not follow any definite annual and monthly patterns; peak values are recorded during October (post-monsoon) and May (summer) while minima are noticed during January and February (winter) during two years respectively. Species diversity is positively correlated with richness of Phytoplankton (r = 0.645) and Chlorophyta (r = 0.633) and is negatively correlated with abundance of phytoplankton (r = -0.623), Bacillariophyta (r = -0.440) and Dinophyta (r = -0.835). The present observations indicate higher species diversity than the reports from Dighali Beel (Acharjee et al. 1995) and Samuajan Beel (Sharma 2004) of Assam while range and mean value is also marginally higher than the report from Deepor Beel (Sharma in press). Further, indefinite annual periodicity and summer peak noticed during second year of the present study concur with the results of Deepor phytoplankton (Sharma in press).

Phytoplankton dominance shows wider range (0.055-0.523, 0.180±0.118) and registers significant monthly ($F_{11, 23}$ = 9.298, P < 0.005) and insignificant annual variations. It follows (Fig. 12) trimodal and bimodal annual patterns and shows generally low values during the study period except for peaks in January and February during two years respectively. The later, in turn, correspond with peaks of *Ceratium hirudinella* - the sole dominant species observed in Loktak Lake. Dominance is inversely correlated with species diversity (r = -0.904), and richness of phytoplankton (r = -0.408) and Chlorophyta (r = -0.442) while it is positively correlated with abundance of phytoplankton (r = 0.853), Bacillariophyta (r = 0.590) and Dinophyta (r = 0.972). The salient feature of low dominance though broadly corresponds with earlier reports of Sharma (2004, in press) but differs from the same in the broad range observed presently.

Phytoplankton communities of Loktak Lake exhibit higher evenness (0.698-0.956, 0.879±0.075) which, in turn, reflects equitable abundance of various species; this statement holds valid during major part of the study period except particularly during winter (January and February). Evenness follows (Fig. 13) trimodal and multimodal annual with peaks during October and November and minima during January and February during two years respectively; the last feature again corresponds with peaks of *Ceratium hirudinella*. Evenness is positively correlated with species diversity (r = 0.975), and richness of Phytoplankton (r = 0.460) and Chlorophyta (r = 0.473). It is, however, inversely correlated dominance (r = -0.934), and abundance of Phytoplankton (r = -0.730), Bacillariophyta (r = -0.494) and Dinophyta (r = -0.862). In general, higher evenness and lower dominance broadly concur with earlier results of Sharma (2004, in press) in two floodplain lakes of Assam as well as with phytoplankton communities of certain other aquatic environments of northeastern India (Sharma 1995; Sharma & Lyngdoh 2003; Sharma & Lyngskor 2003).

To sum up, diverse and speciose phytoplankton communities of Loktak Lake are characterized by distinct qualitative importance of Chlorophyta and the desmids. Phytoplankton and their individual groups reflect lack of definite periodicity of richness. Chlorophyta show quantitative dominance; Dinophyta > Bacillariophyta are sub-dominant groups; *Ceratium hirudinella* is the only quantitatively notable species while *Closterium*, *Cosmarium*, *Staurastrum*, *Micrasterias*, *Gonatozygon* species show importance. Phytoplankton communities are characterized by higher diversity, lower dominance and higher evenness. Individual abiotic factors depict little or limited influence on richness and abundance but register higher cumulative influence. The present study limited to one sampling station, though provides useful information on phytoplankton ecology of Loktak, may not reflect full environmental heterogeneity of this interesting Ramsar site. Future investigations on phytoplankton in different parts (pats) of Loktak basin with special focus on periphyton associations with diverse aquatic macrophytes are desired and have been initiated.

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