Eco. Env. & Cons. 28 (January Suppl. Issue) : 2022; pp. (S398-S410)

ISSN 0971–765X

http://doi.org/10.53550/EEC.2022.v28i01s.057

Long-term Changes in Phytoplankton Assemblages of Lake Khurpatal, Kumaun Himalaya, India

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(Received 16 August, 2021; Accepted 19 September, 2021)

ABSTRACT

This paper focuses on the long-term changes on phytoplankton community of a subtropical lake of Himalaya, Lake Khurpatal. The study was carried out during 2016-2018. The data obtained on phytoplankton assemblages were compared with the data of 1980s. The results showed that all attributes of phytoplankton assemblages were changed in last 35 years. The species richness declined by 27.2% while the community abundance increased by 21% in last 35 years. The most important changes occurred in the group composition of phytoplankton: the Cyanophyceae which was almost absent during 1980s appeared in good quantity during the present study; the concentration of Bacillariophycae increased by 8.5 % while the Cholorophyceae did not change significantly. The Shannon-Weiner diversity index during the present study oscillated from 0.8 to 1.07 while the concentration of dominance varied from 0.12 to 0.25. The high concentration of blue greens during current year suggested that the concentration of nitrogen will further increase in the lake as the bluegreens are capable of fixing the atmospheric nitrogen. Thus, even if the entry of nitrogen into the lake from the catchment area is checked the concentration of nitrogen is likely to increase in the future. It will further increase the trophic status of the lake.

Key words *: Lake Khurpatal, Kumaun Himalaya, Long-term changes, Phytoplankton assembeleges, Eutrophication.*

Introduction

Management of any ecosystem depends on the knowledge of structure and functioning of the ecosystem. Especially information based on long-term studies has been recognized much useful in ecosystem management, because such studies provide useful information on the degradation and other conditions of the catchment. Although, long-term studies have been given much importance abroad (Babanazarova *et al*., 2007; Sharov, 2008; Duan, 2009; Olrik *et al*., 2013; Deng *et al*., 2014a, 2014b, 2019; Harding *et al*., 2016; Dai *et al*., 2018; Qin *et al*., 2019; Borics *et al*., 2020), such studies are limited in India (e.g. Nagdali, 2002).

Situated at an altitude of 1600m above sea level, Lake Khurpatal lies between $29^0 5'$ N latitude and $79^0 27'$ E longitude. Although the lake is a natural water body, it is comparatively small with a surface area of $366m^2$. The maximum length of the lake is 495m and the maximum width is 226m. It was an oligotrophic lake during 1980s (Sharma *et al*., 1982; Jaiswal, 1983). The present study (2016-2018) was conducted to understand the changes in the limnology of the lake after a gap of 35 years. In our previous paper (Singh *et al*., 2022,b), we demonstrated the long-term changes in physico-chemical variables of the lake. In this paper we provide information on the phytoplankton community which changed in the last 35 years.

Materials and Methods

To secure data necessary for the study of phytoplankton assemblages, 3 sampling sites in the shore area of the lake were selected (Fig. 1). Samplings were done at monthly interval. For qualitative analysis of phytoplankton water from shore area for a distance of 50 m was hauled with a plankton net. Live samples were brought to the laboratory; they were identified under the high magnification microscope (x400) with standard literature and keys (Pennak, 1958, Edmondson, 1956, Fitter and Manuel, 1986 and others). For quantitative analysis of the phytoplankton 50 l of water from each site was filtered with a plankton net having pore size 0.25 mm. The filtrates were brought to the laboratory in live condition; and they were counted on a Sedgewick rafter call. The density of each species was determined considering the dilution factors.

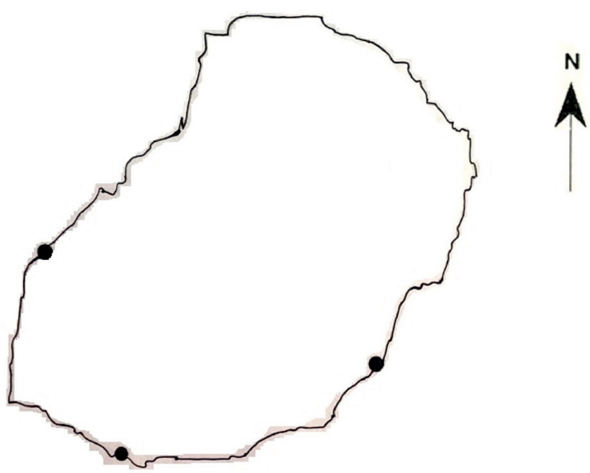


Fig. 1. Sketch map of Lake Khurpatal indicating sampling stations

Importance Value Index (Maindoli, 2019) was determined by the following formula:

$$\text{I.V.I.} = \frac{\text{\% Frequency of occurrence + Relative density of species}}{2}$$

Frequency of occurrence was determined as:

$$\text{\% Frequency of Occurrence} = \frac{\text{No. of samples in species occurred}}{\text{Total no. of samples taken}} \times 100$$

Shannon-Weaver diversity index(Shannon and Weaver, 1963) was calculated as follows:

Shannon-Weaver Diversity Index

$$\overline{H} = -\sum_{i=1}^{S} pi.\log pi$$

where,

$\tilde{H}$ = Shannon - Weaver diversity index,

pi = the proportion of species i in terms of number, and

s = the number of species.

Concentration of dominance (Simpson, 1990) was calculated in the form of Simpson's index as follows:

$$C = \sum_{i=1}^{S} (pi)^2$$

where,

pi = the proportion of species i in terms of number and

s = number of species.

Results and Discussion

Species richness (species content) of phytoplankton

The total number of species collected during the entire study period was 32. Out of these, 31 species could be identified while the one was unidentified. The unidentified species is tallied as 'unidentified' (Table 1). The species belonged to five groups namely Chlorophyceae, Bacillariophyceae, Dinophyceae, Cyanophyceae and Chrysophyceae. Of the five groups, the maximum number of species (16) belonged to group Chlorophyceae while the minimum (1) was represented by Chrysophyceae. Within a year, the species' number varied from one sampling occasion to another being minimum in November, 2016 and maximum in August, 2017. During the next six months the variability in the species number ranged from 13 (December, 2017) to 21 (April, 2018) (Table 2).

A comparison of the present data with that of 35 years back (Jaiswal, 1983) indicated sharp decline in the number of species. Forty-four species were recorded during 1980s against 32 of the present study. Eighteen species which were present during 1980s but could not be found during the present study were: *Peridinium cinctum, C. ventricosa, C. lanceolata, Navicula rhynchocephala, N. sublinearis, Synedra splendens, Amphora* sp., *Gomphonema intricatum, Diatoma vulgare, Epithemia* sp., *Rhopoloidia* sp.,

Table 1. List of phytoplankton species found in Lake Khurpatal during the study period.

Taxonomic group	Taxa
Dinophyceae	1. *Gymnodium fuscum*
	2. *Peridinium willei*
	3. *Ceratium hirundinella*
Bacillariophyceae	4. *Eunotia* sp.
	5. *Cymbella cymbiformis*
	6. *Navicula viridula*
	7. *Synedra ulna*
	8. *Gomphonema constrictum*
	9. *Pinnularia* sp.
	10. *Fragilaria crotonesis*
	11. *Cocconesis* sp.
	12. *Amphora ovalis*
Chlorophyceae	13. *Ankistrodesmus falcatus*
	14. *Coelastrum microporum*
	15. *Chlorella vulgaris*
	16. *Oocystis* sp.
	17. *Pandorina* sp.
	18. *Pediastratum simplex*
	19. *Closterium* sp.
	20. *Cosmarium bioculatum*
	21. *Cosmarium granatum*
	22. *Cosmarium protactum*
	23. *Cosmarium contractum*
	24. *Franceia* sp.
	25. *Chlorococum humicola*
	26. *Volvox* sp.
	27. *Microspora* sp.
	28. *Eudorina elegance*
Cyanophyceae	29. *Merismopaedia* sp.
	30. *Microcystis* sp.
Crysophyceae	31. *Mallomonas* sp.
Others	32. *Unidentified*
Total no. of species = 32	

Dispora sp., *Dictyosphaerium pulchellum, Pleodorina* sp., *Scendesmus quadricule, S. armatus, S. natator,* and *S. furcigerum.* Six species newly appeared during the present study. These were: *Volvox* sp., *Microspora* sp., *Eudorina elegance*, *Microcystis* sp., *Mallomonas* sp. and one unidentified. As far as the phytoplankton group is concerned, there was one group namely Chrysophyceae which was absent during 1980s and it appeared during the present study. This had only one species. (Table 3).

Phytoplankton group abundance and community abundance

The community abundance varied temporarily, and the temporal variation was significant ($p<0.05$). Within a year, the range of community abundance was 22.1 to 82.7×10^4 cells/l. The minimum community abundance was recorded in the month of October, 2017 while the maximum was noticed in August, 2017 (Fig. 2). The seasonality in community abundance showed bimodal pattern. The first peak of abundance occurred in April, 2017 while the second was observed in August, 2017. The magnitude of August peak was about 29% greater than that of the April peak. During the next six months the dynamics of community abundance was by and large similar. The first peak of April was noticed during this period also. During the highest peak of August, 2017 the group Dinophyceae was dominant and it contributed 63% to the peak abundance at that time. Among Dinophyceae, *Peridinium* sp. was the most dominant during August. Hence, the peak of August was attributed to the high concentration of *Peridinium* which contributed 36.2% to the total community abundance at that time. The annual mean community abundance was 41×10^4 cells/l during the present study. A comparison of phytoplankton community abundance data of the present study and the 1980s study indicated that the community abundance during the present study has increased. During the present study community

Table 2. Seasonal variation in species number in various phytoplankton groups in Lake Khurpatal during the study period.

Taxonomic groups	Nov-16	Dec	Jan-17	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-18	Feb	Mar	Apr
Dinophyceae	3	3	3	3	2	2	2	2	2	3	2	2	3	3	3	3	2	2
Bacillariophyceae	5	6	6	6	4	7	6	6	8	8	5	4	7	6	6	7	6	7
Chlorophyceae	5	7	6	9	7	11	10	12	13	13	8	7	5	4	6	7	8	10
Cyanophyceae	0	1	1	1	1	1	1	2	2	2	1	1	1	0	1	0	1	1
Crysophyceae	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	1	0
Others	0	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	1

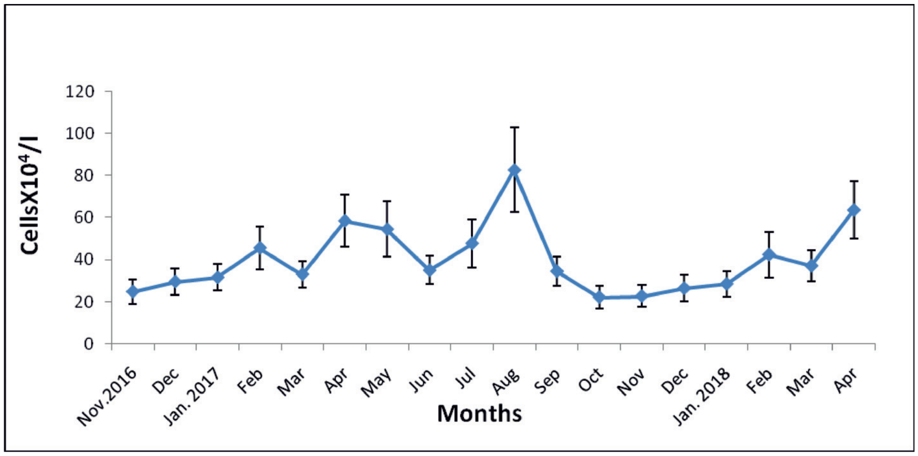


Fig. 2. Seasonal variation in community abundance of phytoplankton during the study period

abundance varied from 22.1 to 82.7 x 10^4 cells/l on an annual basis while it ranged between 8.9 and 38 x 10^4 cells/l during 1980s. (Jaiswal, 1983).

Based on annual mean, the percent composition of different groups during the study period revealed that Dinophyceae (55%) was the most dominant group followed by Chlorophyceae (23%), Bacillariophycea(15%), Cyanophyceae (5%), Chrysophyceae (1%) and others (1%) (Fig. 3). During 1980s (Sharma *et al.*, 1982), the scenario of phytoplankton group composition was different. At that time the group Dinophyceae was the most abundant (69.8%) followed by Chlorophyceae (25.7%) and Bacillariophyceae (4.5%).

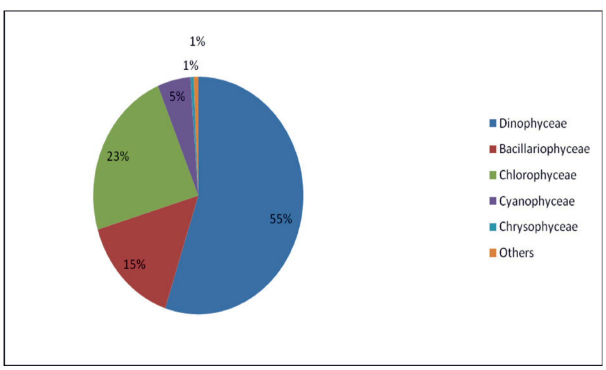


Fig. 3. Percent composition of various group of phytoplankton in Lake Khurpatal. The data are based on annual mean number.

The data on seasonal variation of various groups of phytoplankton showed significant variation from one sampling occasion to another (Fig. 4).

Significant/dominant species

Based on importance value index (Table 4), the phytoplankton species could be arbitrarily divided into two groups. The first group had dominant species, i.e. the species which had I.V.I.e"40. These were: *Gymnodium fuscum, Chlorococum humicola, Peridinium willei, Ankistrodesmus falcatus,Eunotia* sp., *Pandorina* sp., *Fragilaria crotonesis, Chlorella vulgaris, Cosmarium bioculutum, Gomphonema constrictum,Merismopaedia* sp., *Cymbella cymbiformis*, and *Coelastrum microporum*. The second group contained the remaining species and they were referred to as insignificant. The seasonal variation in the population dynamics of important species is indicated in Fig.5, while the data on seasonal variation of population density of insignificant species are provided in Table 5.

Seasonal variation in population density of important species

Gymnodium fuscum

The species belonged to Dinophyceae and ranked first in terms of I.V.I. The population size fluctuated from 7.4 to 22x10^4cells/l during the first year. During next six months the density was found between 10 and 22x10^4cells/l.

Chlorococcum humicola

This species belonged to group Chlorophyceae with second rank in terms of I.V.I. Within a year the density varied from 0.03 (July, 2017) to 3x10^4cells/l (May, 2017) while during the next six months it ranged between 0.9 (November, 2017) and 2.5 x 10^4 cells/l (April, 2018).

Table 3. A comparison of species between 1980s (Jaiswal, 1983) and current study period. * This group was reported to be present by Jaiswal, 1983, however, it was not reported by Sharma *et al*., 1982.

S.No.	Group	Taxa	1983	2016-18
1.	Chlorophyceae	*Ankistrodesmus falcatus*	+	+
		Coelastrum microporum	+	+
		Chlorococcum humicola	+	+
		Chlorella vulgaris	+	+
		Closteridium sp.	+	+
		Cosmarium granatum	+	+
		C.bioculatum	+	+
		C. protactum	+	+
		C. contractum	+	+
		Dispora	+	-
		Oocystis	+	+
		Franceia	+	+
		Pleodorina	+	-
		Pandorina	+	+
		Staurastrum natator	+	-
		S. furcigerum	+	-
		Pediastrum simplex	+	+
		Scenedesma quadricauda	+	-
		S. armatus	+	-
		Dictyosphaerium pulchellum	+	-
2.	Bacillariophyceae	*Amphora ovalis*	+	+
		Amphora sp.	+	-
		Cymbella lanceolata	+	-
		C.cymbiformis	+	+
		C. ventricose	+	-
		Eunotia gracilis	+	+
		Gomphonema constrictum	+	+
		G. intricatum	+	-
		Navicula viridula	+	+
		N. rhynchocephala	+	-
		N. sublinearis	+	-
		Rhopalodia gibba	+	-
		Synedra splendens	+	-
		S.ulna	+	+
		Pinnularia sp.	+	+
		Fragelaria crotonensis	+	+
		Diatoma vulgare	+	-
		Epithemia	+	-
		Cocconeis	+	+
3.	Dinophyceae	*Gymnodinium fuscum*	+	+
		Peridinium willei	+	+
		p. cinctum	+	-
		Ceratium hirundinella	+	+
4.	*Cyanophyceae	*Merismopaedia*	+	+
		Microcystis sp.	-	+
5.	Crysophyceae	*Mallomonas* sp.	-	+
6.	Others	Unidentified	-	+
		Total no. of species	44	32

Peridinium welli

The species belonged to group Dinophyceae and occupied third position in terms of I.V.I. Within a year the density varied from 2.7 to 30x10^{4}cells/l being maximum in August, 2017 and minimum in November, 2016. During the next six months the density was between 2 and 16x10^{4}cells/l.

Ankistrodesmus falcatus

This species belonged to Chlorophyceae with a rank of fourth in order of I.V.I. Within a year the density ranged from 1 (December, 2016 & January, 2017) to 4.8 x 10^4 cells/l (August, 2017) and during next six months it varied from 0.9 (November, 2017) to 4 x 10^4 cells/l (April, 2018).

***Eunotia* sp.**

This species belonged to Bacillariophyceae and ranked fifth in terms of I.V.I. The density was found between 0.3 (May, 2017) and 4 x 10^4 cells/l (January, 2017) during first year and between 1.5 (March, 2018) and 4.5 x 10^4 cells/l (January, 2018) during the next six months of collection.

***Pandorina* sp.**

This species belonged to Chlorophyceae. The species occupied sixth rank in terms of I.V.I. Its density showed variation from 0.01 (November, 2016) to 4.2 x 10^{4}cells/l (May, 2017) during the first year and 0.12 (January, 2018) to 3 x 10^4 cells/l (April, 2018) during the next six months of study.

Fragillaria crotonesis

This species belonged to Bacillariophyceae. The species occupied seventh rank in terms of I.V.I. Its density showed variation from 0.17 (May, 2017) to 1.8 x 10^4 cells/l (November, 2016) during the first year and 0.16 (November, 2017) to 1.6 x 10^4 cells/l (April, 2018) during the next six months of study.

Chlorella vulgaris

This species belonged to Chlorophyceae with a rank of eighth in order of I.V.I. Within a year the density ranged from 0.04 (July, 2017) to 2 x 10^4 cells/l (September, 2017) and during next six months it varied from 0.2 (January, 2018) to 1.8 x 10^4 cells/l (April, 2018).

Cosmarium bioculatum

This species belonged to Chlorophyceae. The species occupied ninth rank in terms of I.V.I. Its density showed variation from 0.06 (July, 2017) to 2x10^{4}cells/l (April, 2017) during the first year and 0.07 (November, 2017) to 3x10^{4}cells/l (April, 2018) during the next six months of study.

Table 4. Importance value index of various phytoplankton species found during the study period.

S. No.	Taxa	I.V.I.
1	*Gymnodium fuscum*	66
2	*Peridinium willei*	61
3	*Ceratium hirundinella*	21
4	*Eunotia* sp.	53
5	*Cymbella cymbiformis*	44
6	*Navicula viridula*	34
7	*Synedra ulna*	26
8	*Gomphonema constrictum*	50
9	*Pinnularia* sp.	17
10	*Fragilaria crotonesis*	51
11	*Cocconesis* sp.	13
12	*Amphora ovalis*	17
13	*Ankistrodesmus falcatus*	53
14	*Coelastrum microporum*	43
15	*Chlorella vulgaris*	51
16	*Oocystis* sp.	25
17	*Pandorina* sp.	52
18	*Pediastratum simplex*	25
19	*Closterium* sp.	17
20	*Cosmarium bioculatum*	51
21	*Cosmarium granatum*	21
22	*Cosmarium protactum*	13
23	*Cosmarium contractum*	8
24	*Franceia* sp.	8
25	*Chlorococum humicola*	65
26	*Volvox*	13
27	*Microspora*	17
28	*Eudorina elegance*	17
29	*Merismopaedia*	48
30	*Microcystis*	12
31	*Mallomonas*	17
32	Unidentified	25

Gomphonema constrictum

This species belonged to Bacillariophyceae and ranked tenth in terms of I.V.I. The density was found between 0.02 (March, 2017) and 0.6x10^{4}cells/l (April, 2017) during first year and between 0.06 (March, 2018) and 0.3x10^{4}cells/l (January, 2018) during the next six months of collection.

***Merismopaedia* sp.**

This species belonged to Cyanophyceae. The species occupied eleventh rank in terms of I.V.I. Its density

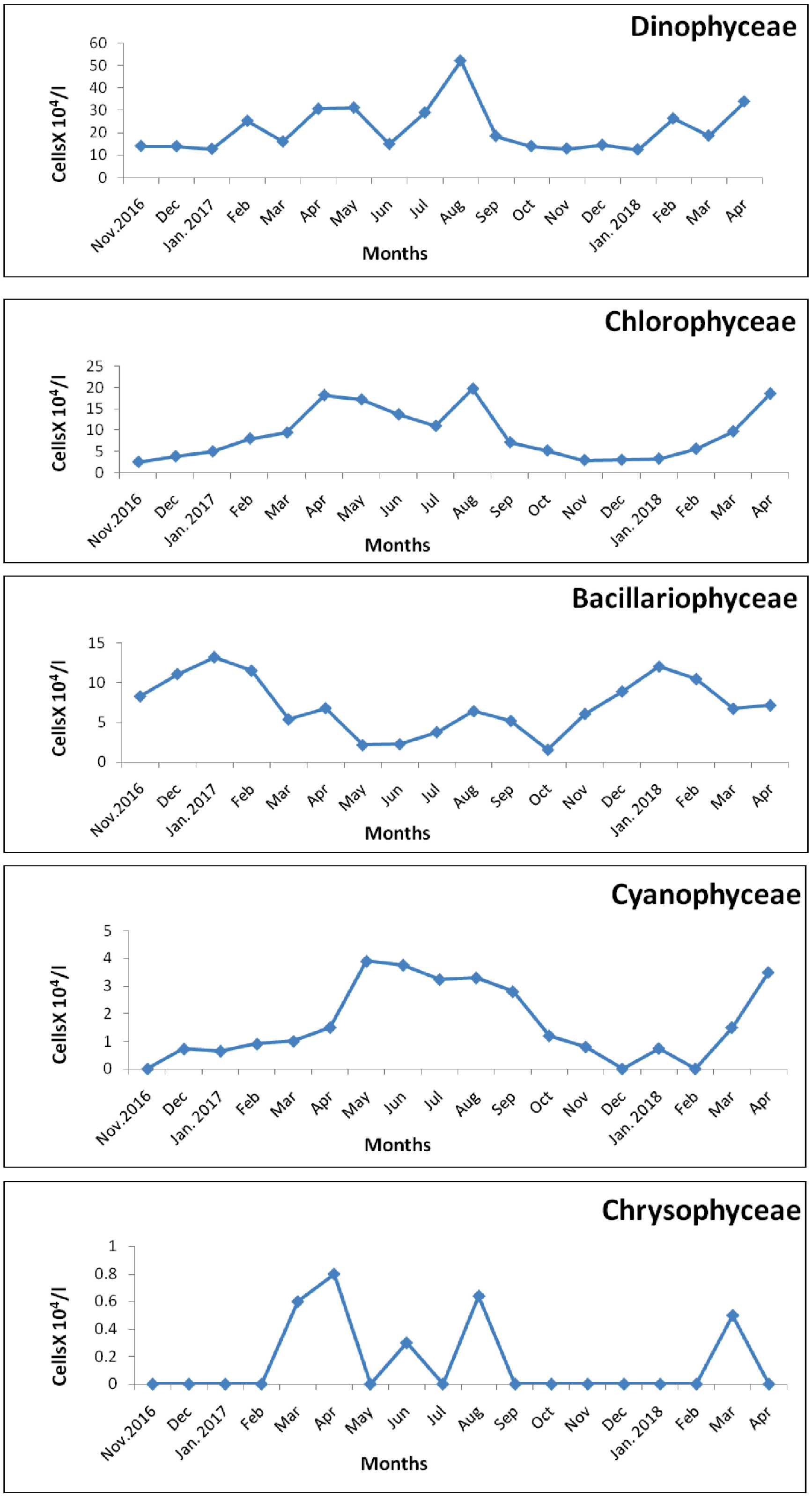


Fig. 4. Seasonal variation in population densities of different phytoplankton groups in Lake Khurpatal during the study period.

Table 5. Seasonal variation in population density of numerically less significant species of phytoplankton in Lake Khurpatal during the study period.

Taxa	Nov-16	Dec	Jan-17	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-18	Feb	Mar	Apr
Ceratium hirundinella	0.35	0.5	0.55	0.3	0	0	0	0	0	0.3	0	0	0.4	0.5	0.46	0.4	0	0
Navicula viridula	0	2	2.8	2	0	0.1	0.2	0	0	0.6	0.4	0.5	0.3	2	1.8	2	1.7	1
Pinnularia sp.	0	0	0	0	0	0.4	0	0.7	0.1	0	0	0	0	0	0	0	0	0
Cocconesis sp.	0	0	0	0	0	0	0	0.6	0.8	0.4	0	0	0	0	0	0.2	0	0
Amphora ovalis	0	0	0	0	0	0.5	0.3	0.2	0.6	0	0	0	0	0	0	0	0.2	0.6
Oocystis sp.	0	0	0	0.2	0	0.6	0.5	0.8	0.6	0.5	0	0	0	0	0	0	0	0.3
Pediastratum simplex	0	0	0	0.2	0	0.6	0	0.7	0.6	0.8	0.4	0	0	0	0	0	0	0
Closterium sp.	0	0	0	0	0	0	.6.4	0.2	0.4	0	0	0	0	0	0	0	0	0
Cosmarium granatum	0	0.1	0	0	0.1	1.2	0.5	0	0	1	0	0.4	0	0	0	0	0.1	0
Cosmarium protactum	0	0	0	0	0	0	0	0.2	0.4	0.8	0	0	0	0	0	0	0.6	0
Cosmarium contractum	0	0	0	0	0	0.1	0	0	0.5	0	0	0	0	0	0	0	0	0.5
Franceia sp.	0	0	0	0	0	0.1	0	0	0	0.4	0	0	0	0	0	0	0	0
Volvox sp.	0	0	0	2	0	0	0	1.2	1	0	0	0	0	0	0	0	0.8	1.5
Microspora sp.	0	0	0	0	0	0	0.4	0.6	0.8	1	0	0	0	0	0	0	0	0.1
Eudorina elegance	0	0	0	0	0	0.2	0	0	0.6	0.4	0.1	0	0	0	0	0	0	0
Microcystis sp.	0	0	0	0	0	0	0	0.1	0	0.8	0	0	0	0	0	0	0	0
Mallomonas sp.	0	0	0	0	0.6	0.8	0	0.3	0	0.6	0	0	0	0	0	0	0.5	0
Unidentified	0	0	0	0	0.7	0.5	0	0	0.8	0.4	0.9	0.2	0	0	0	0	0	0.4

showed variation from 0.6 (January, 2017) to 3.9×10^4 cells/l (May, 2017) during the first year and 0.7 (January, 2018) to 3.5×10^4 cells/l (April, 2018) during the next six months of study.

Cymbella cymbiformis

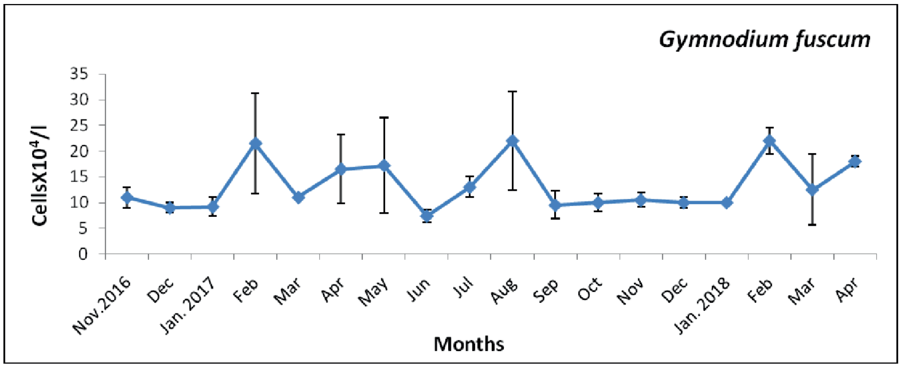
This species belonged to Bacillariophyceae. The species occupied twelfth rank in terms of I.V.I. Its density showed variation from 0.6 (July, 2017) to 3.5×10^4 cells/l (February, 2017) during the first year and 1.8 (April, 2018) to 4×10^4 cells/l (February, 2018) during the next six months of study.

Coelastrum microporum

This species belonged to Chlorophyceae with a rank of thirteen in order of I.V.I. Within a year the density ranged from 0.26 (October, 2017) to 2.4×10^4 cells/l (April, 2017) and during next six months it varied from 0.19 (January, 2018) to 2×10^4 cells/l (April, 2018).

Species diversity and concentration of dominance

Fig. 6 contains data on seasonal variation in Shannon-Weaver diversity index and Simpson's index of dominance. Within a year, the species diversity varied from 0.80 to 1.07 with the maximum value in June, 2017 and minimum in November, 2016. During the next six months, the diversity ranged between 0.79 (February, 2018) and 0.99 (April, 2018). The overall annual mean diversity index was found to be 0.93. The concentration of dominance followed the reverse trend to the diversity and varied between 0.12 and 0.25; being minimum in June, 2017 and maximum in October, 2017. During the next six months, concentration of dominance ranged between 0.16 (April, 2018) and 0.29 (February, 2018). Within a year, the annual mean Simpson's index of dominance was computed at 0.18. The data on Shannon-Weaver diversity index on Khurpatal lake during 1980s are not available for comparison. However, the comparison of data of dominance index during the two study periods (1980s and present) revealed that the concentration of dominance has decreased significantly in last 35 years. During 1980s the concentration of dominance has been reported to vary from 0.22 to 0.68 (Sharma *et al.,* 1982). The high range of concentration of dominance indicates the dominance of only few species in the community


Gymnodium fuscum
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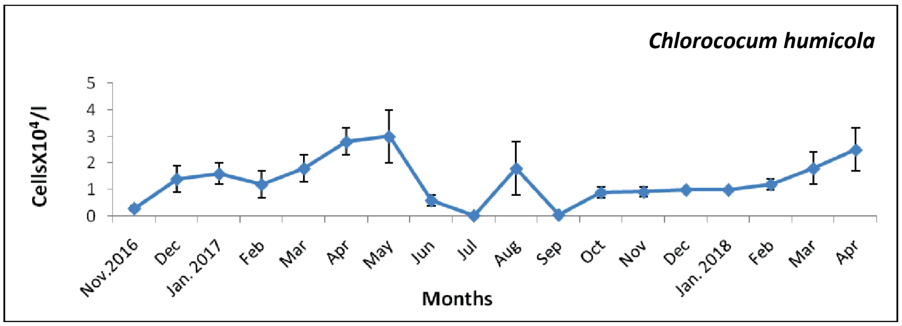
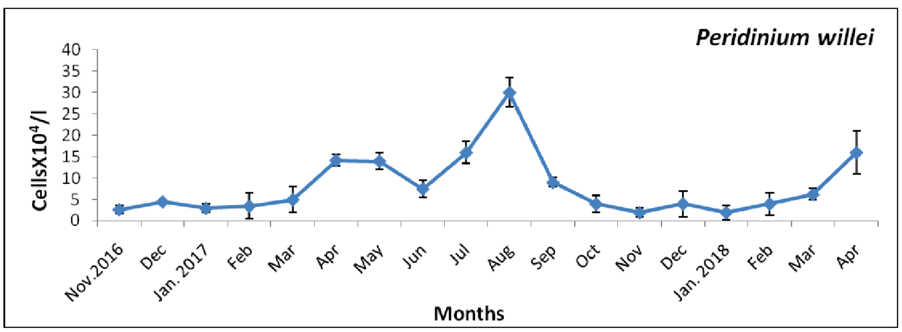
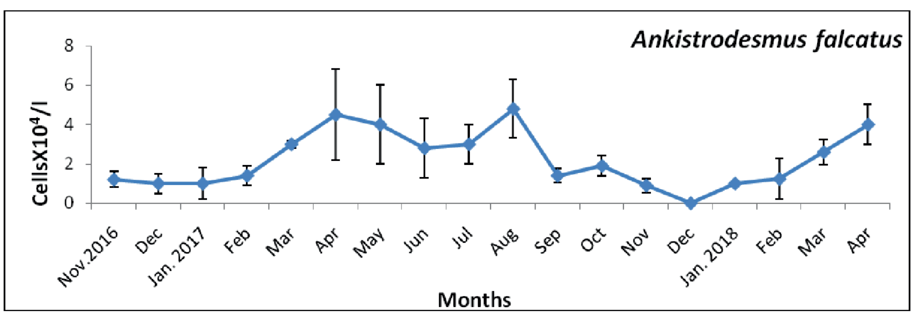
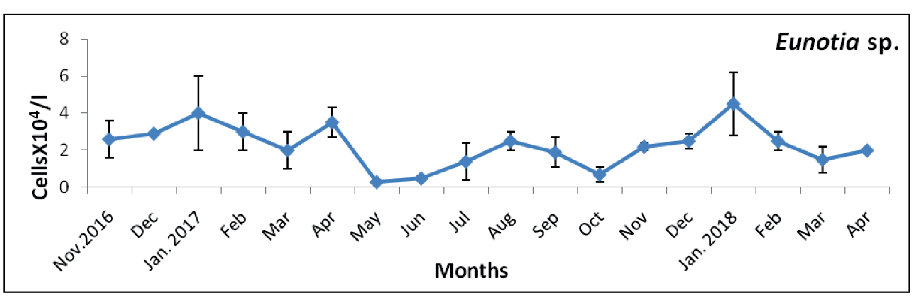
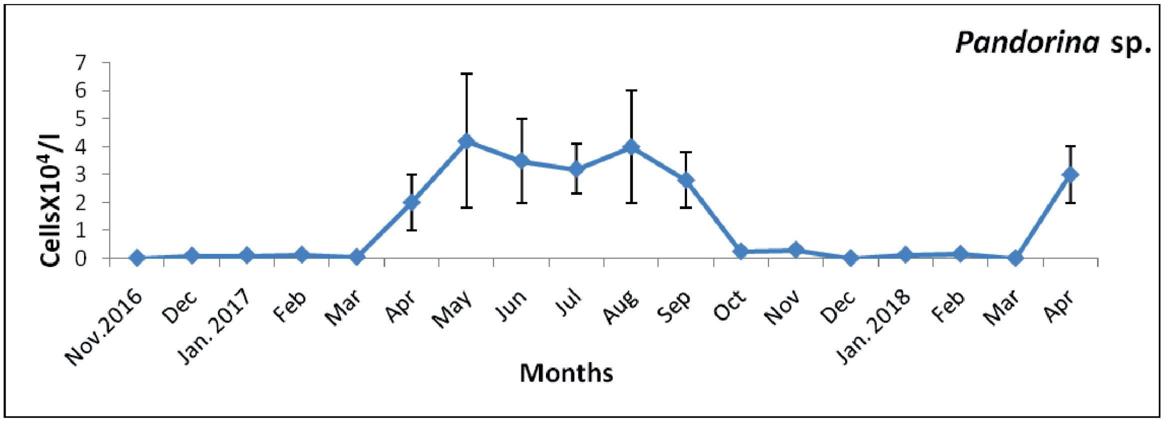
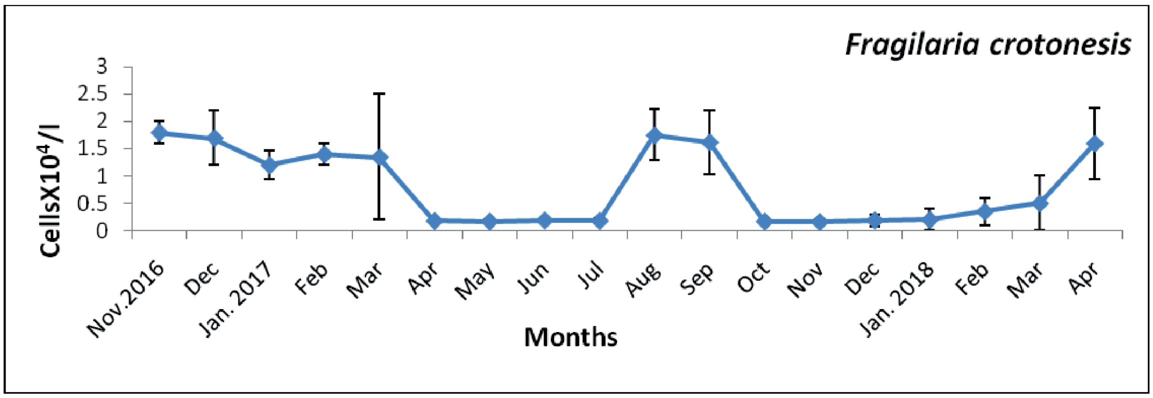

Chlorococum humicola
CellsX10^4/l
Nov.2016 Dec Jan. 2017 Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan. 2018 Feb Mar Apr
Months

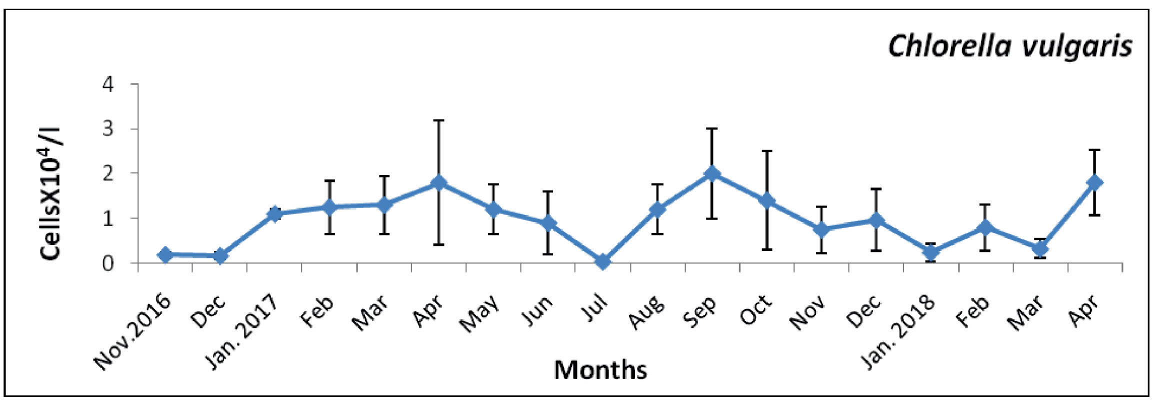

Peridinium willei
CellsX10^4/l
Nov.2016 Dec Jan. 2017 Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan. 2018 Feb Mar Apr
Months


Ankistrodesmus falcatus
CellsX10^4/l
Nov.2016 Dec Jan. 2017 Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan. 2018 Feb Mar Apr
Months


Eunotia sp.
CellsX10^4/l
Nov.2016 Dec Jan. 2017 Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan. 2018 Feb Mar Apr
Months


Pandorina sp.
CellsX10⁴/l
7
6
5
4
3
2
1
0
Nov.2016
Dec
Jan. 2017
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan. 2018
Feb
Mar
Apr
Months


Fragilaria crotonesis
CellsX10⁴/l
3
2.5
2
1.5
1
0.5
0
Nov.2016
Dec
Jan. 2017
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan. 2018
Feb
Mar
Apr
Months


Chlorella vulgaris
CellsX10⁴/l
4
3
2
1
0
Nov.2016
Dec
Jan. 2017
Feb
Mar
Apr
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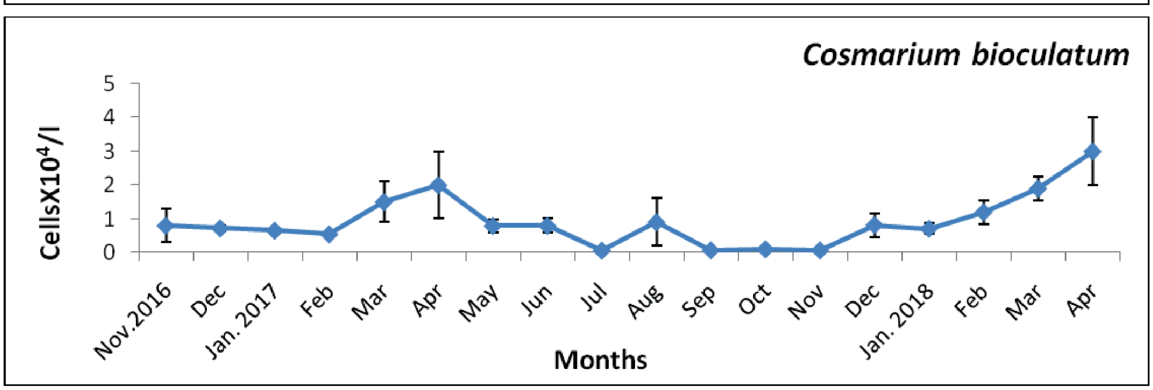
Aug
Sep
Oct
Nov
Dec
Jan. 2018
Feb
Mar
Apr
Months


Cosmarium bioculatum
CellsX10⁴/l
5
4
3
2
1
0
Nov.2016
Dec
Jan. 2017
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Nov
Dec
Jan. 2018
Feb
Mar
Apr
Months

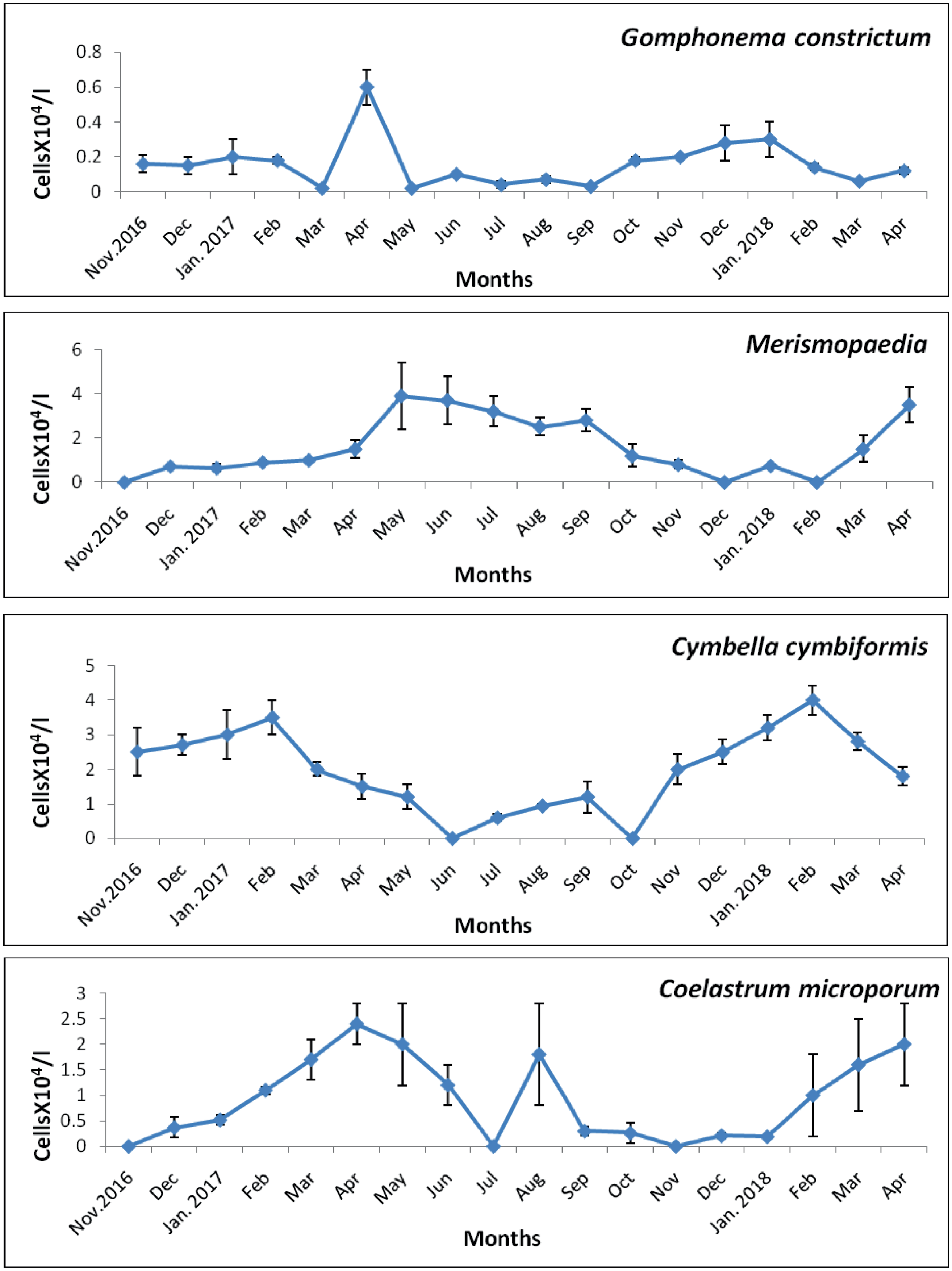

Fig. 5. Seasonal variation in population densities of important phytoplankton taxa during the study period.

while lower concentration of dominance signifies uniform distribution of individuals of greater number of species in the community. Thus, it appeared that during 1980s only few species were dominant while during the present investigation the individuals were dispersed in various species.

The species content of any biota in water bodies depends on several factors. It may vary from lake to lake, from one type of water body to another, from one trophic state to another, from one season to another or from one sampling place to another. Even the method of collection and time of collection may differ from worker to worker. Therefore, any conclusion based on species content may be misleading.

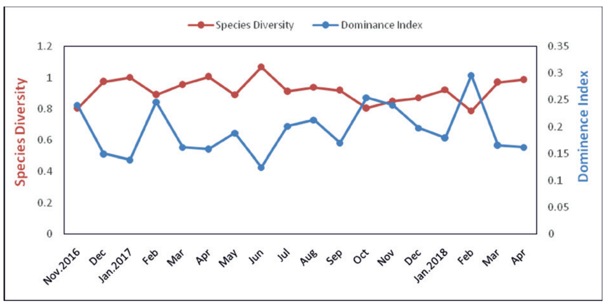

Fig. 6. Seasonal variation in species diversity and concentration of dominance during the study period.

However, in the present study a total of 32 species of phytoplankton was too low than that of old studies (44). Although the lower number of species in the present study was found, it is difficult to attribute any reason for this decline because of above mentioned causes of fluctuations in species number. In general the community abundance in Lake Khurpatal was high throughout the study period. A comparison of current data with that of previous study suggested a higher concentration of phytoplankton in current study. The increase in concentration of phytoplankton community abundance can be attributed to higher concentration of nutrients such as nitrogen and phosphorus (Singh *et al.*, 2022,b) in the present study as compared to 1980s (Jaiswal, 1983).

The group composition of phytoplankton also provides valuable information regarding the changes in environmental conditions in the lake. In the present study six groups of phytoplankton were noticed whereas in the study of 1980s only three groups were reported. Importantly, the group Cyanophyceae was not found during 1980s (Sharma *et al.*, 1982) but it developed after 35 years of time span. This indicated the hyper eutrophic nature of the water body and turn of the lake from oligotrophic to eutrophic. This appearance of Cyanophyceae was caused due to increased concentration of phosphorus in last 35 years (Singh *et al.*, 2022,b). Several workers (Lund, 1971 and Nagdali, 2002) have also reported the development of blue greens because of higher concentration of phosphorus. In terms of density it was noticed that small sized phytoplankton dominated over large size. This type of domination is related with enrichment of the lake by nutrients because small sized phytoplankton are more efficient than large size in energy utilization in chemically rich water (Wetzel, 1983). Although the mean community abundance data during 1980s is not available for comparison, the seasonal data of phytoplankton of that time could be compared with the present ones.

It was clear that the phytoplankton community abundance has increased considerably in the last 35 years. Moreover, the phytoplankton group composition has significantly changed during this period. This change is apparently related to changes in level of organic pollution and nutrients concentration in the lake. It is well known that blue green algae are capable of fixing atmospheric nitrogen into the water bodies. Since there is a substantial percentage of Cyanophyceae present in Lake Khurpatal, it can be expected that there will be further increase in nitrogen concentration in the lake in future, even if the entry of nitrogen from the outside sources is checked. Thus, the appearance of blue-greens can be regarded as a major event of eutrophiaction in last 35 years.

Acknowledgment

We would like to thank Mr. Suman Chowdhury, Mr. Ganesh Mondal and Mr. Sanjay Pandey for their help during the entire course of study.

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