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Phytoplankton Responses to Hypolimnetic Aeration in Lake Naukuchiyatal, Central Himalaya, Uttarakhand

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ABSTRACT

In this paper we report the results of impact of hypolimnetic aeration on phytoplankton assemblages in a subtropical lake of India. The study was conducted for a period of two years (2017-2018), and the data obtained were compared with those of unaerated time. The aeration in the hypolimnion was done by a high speed aerator. The aeration appeared to change the phytoplankton assemblage significantly. It reduced the number of species and the standing crop of phytoplankton. Most importantly, due to aeration the Cyanophyeae was completely eliminated while the Chlorophyceae and Bacillariophyceae were increased in number. In general, the light weight species of phytoplankton disappeared or reduced in number as a result of aeration. The Shannon-Weiner diversity index as well as concentration of dominance was also found to be reduced. The share of Chlorophyceae and Bacillariophyceae were increased due to reduced pH and release of competition from Cyanophyceae during aeration.

Key words : *Hypolimnetic aeration, Phytoplankton assemblage, Diversity index, Dominance index.*

Introduction

Nesting at about 1220 m above sea level Lake Naukuchiyatal is the deepest lake in the Kumaun region. The lake water was pristine when the lake was studied for the first time in 1981 (Singh, 1981). Within a very short time period it was recognized as hyper - eutrophic water body (Bhagat, 2002). The eutrophication was evidenced by anoxia in hypolimnion, super - saturation of oxygen in epilimnion, high concentration of phosphorus and nitrogen, development of algal blooms and regular fish mortality during winters. The anoxia of hypolimnion was the main concern. The hypereutrophication of the lake raised the concern of scientists, administrators, regulators and state and central governments. Controlling of and the checking of eutrophication was the main issue. Therefore, to mitigate the problem of eutrophication and to restore the lake to its natural condition the hypolimnetic aeration was started in 2015. In our previous paper (communicated) we discussed physic-chemical responses of aeration in the lake. In the present paper the impact of hypolimnetic aeration on phytoplankton assemblages has been documented.

The Lake

The detailed morphometric and metereological data of the lake are provided in our previous paper (communicated). However, important informations are also being given here. The lake lies between $29^0$45′ and $30^0$34′N latitude and $78^0$45′and $80^0$90′E longitude. The surface area of the lake is 45 ha, the maximum length is 951 m, the maximum width is 692m while the maximum depth is 40.3 m. It is situated in a sub - tropical climate. The ecological services provided by the lake can be found in our previous paper (communicated).

Materials and Methods

For qualitative analysis of phytoplankton water from the shore area (Fig. 1) for a distance of 50m was hauled regularly by a plankton net. The live samples were used to identify the species. For identification, a high magnification microscope (x400) was used in the laboratory. Standard books and literature (Pennak, 1958; Edmonson, 1959; Fitter and Manuel, 1986 and many others) and various keys were used for identification.

For quantitative analysis only one sampling site at the mid lake (Fig. 1) was selected. From that site the water samples were taken by vertical hauling through a plankton net (0.25 µm pore) from 3m depth upto the surface. All the samplings were done at monthly intervals. All the samples (qualitative and quantitative) were transported to the laboratory within a shortest possible time under ideal conditions (Wetzel and Likens, 1979). The counting of the plankton was done on a Sedgwick rafter chamber under the microscope. The density data of phytoplankton were computed as no. per litre of water considering the dilution factor.

Importance value index of each phytoplankton species was calculated as follows

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

Frequency of occurrence was determined as

$$\text{\% frequency of occurrence} = \frac{\text{No. of samples in which the species occurred}}{\text{Total no. of samples taken}} \times 100$$

The Shannon-Weaver diversity index was determined by Shannon-Weaver diversity index (Shannnon and Weaver, 1963) as follows:

Shannon- Weaver Diversity Index

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

Concentration of dominance was calculated using Simpson's index (Simpson, 1949). Here is the formula:

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

Where H˜ is Shannon - Weaver diversity index,

pi is the proportion of species i in terms of number, s is number of species and C is the concentration of dominance

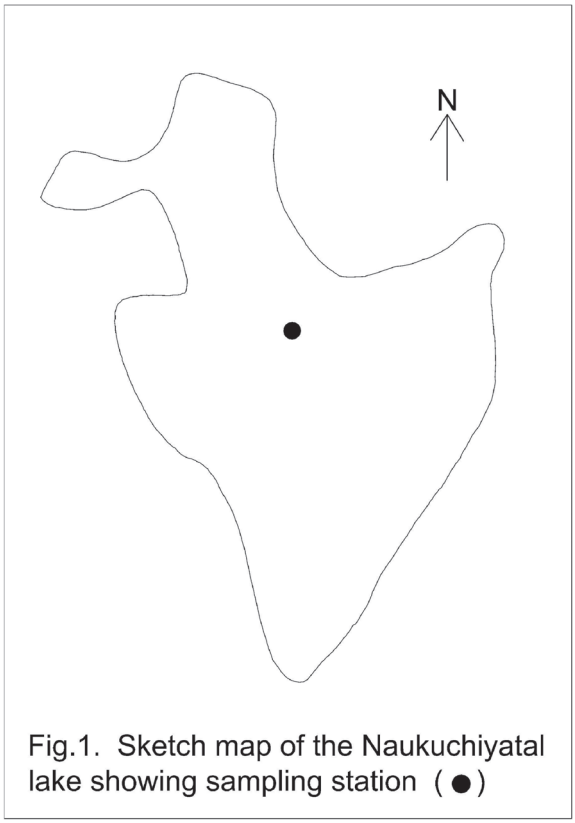

Fig.1. Sketch map of the Naukuchiyatal lake showing sampling station (●)

Results and Discussion

(a) Species content and composition

Twenty six species of phytoplankton were collected during the entire course of study (Table 1). They belonged to Chlorophyceae, Bacillariophyceae, Chrysophyceae and Dinophyceae. The maximum number of species (12) was contributed by group Chlorophyceae followed by Bacillariophyceae (11), Chrysophyceae (2) and Dinophyceae (1) . As indicated in Table 2, the number of species of various groups of phytoplankton varied from month to month. As far as the total species content is concerned, the maximum number of species was noticed in the month of July and September (19) while the minimum number occurred in the month of February (9) during the first year of the study. The variability in species content during the second year was more or less similar except that the maximum num-

Table 1. List of phytoplankton species collected from Lake Naukuchiyatal during the study period.

S. No.	Taxa
	Chlorophyceae
1.	*Ankistrodesmus falcatus*
2.	*Chlamydomonas* sp.
3.	*Chlorococcum humicola*
4.	*Chlorella* sp.
5.	*Closteridium* sp.
6.	*Oedogonium* sp.
7.	*Palmellococus* sp.
8.	*Scenedesmus* sp.
9.	*Spirogyra* sp.
10.	*Staurastrum chaetoceras*
11.	*Ulothrix* sp.
12.	*Vaucheria* sp.
	Bacillariophyceae
13.	*Amphora ovalis*
14.	*Asterionella* sp.
15.	*Bacillaria* sp.
16.	*Cymbella* sp.
17.	*Fragilaria* sp.
18.	*Gomphonema* sp.
19.	*Navicula* sp.
20.	*Nitzschia* sp.
21.	*Pinnularia* sp.
22.	*Rhopalodia gibba*
23.	*Synedra* sp.
	Chrysophyceae
24.	*Chlorobotrys regularis*
25.	*Chlorogibba* sp.
	Dinophyceae
26.	*Peridinium* sp.
Total no. of species	**26**

ber (15) of species during this year was found in June and December.

The aeration altered the species content as well as variety of species significantly. Prior to aeration, the total number of species was 47 which was reduced to 26 during the aeration period (Table 3). The species which disappeared due to aeration were: *Cosmarium granatum, Cosmarium monomazum, Dispora* sp., *Microspora* sp., *Mougeotia* sp., *Treubaria crassispina, Brebissonia boeckii, S.ulna, Tabellaria fenestrate, Gloeobotrys* sp., *Trachychloron biconicum, Microcystis aeruginosa, Nostoc* sp., *Oscillatoria* sp., *Aphanizomenon* sp.,*Tetragonidium* sp., and 5 unidentified. None of the species was new during the aeration period. Furthermore, all the species of Cyanophyceae and Cryptophyceae disappeared due to aeration.

Community and phytoplankton group abundance

During the study period the phytoplankton community abundance varied significantly ($p<0.05$) from one sampling occasion to another. The maximum community abundance was found in April (73.5 x 10^3 cells/l) while minimum (21.5 x 10^3 cells/l) was recorded in February during the first year (Fig. 2). Almost similar trend in fluctuation occurred during the second year of the study. The biannual mean community abundance was 27 x 10^3 cells/l as compared to 790 x 10^3 cells/l during pre-aeration period (Bhagat, 2002). During the peak of first year, *Synedra* sp. (Bacillariophyceae) was the most abundant which contributed 12.5% to the total community abundance at that time. During the second year the peak of community abundance was dominated by *Bacillaria* sp., *Fragilaria* sp. *and Nitzschia* sp., all belonging to Bacillariophyceae. Together, these 3 species shared 35% of total phytoplankton number at

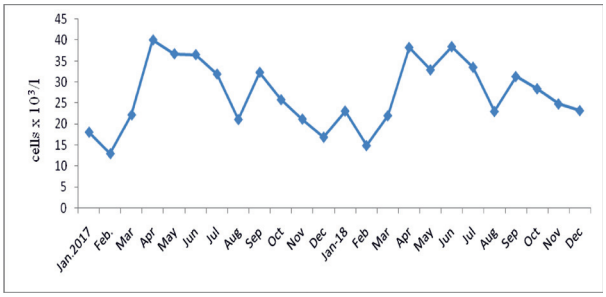

Fig. 2. Seasonal variation in phytoplankton community abundance in Lake Naukuchiyatal during the study period.

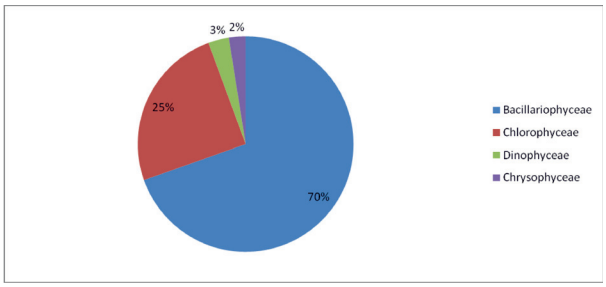

Fig. 3. Percent composition based on biannual mean number of various groups of phytoplankton during the study period (Jan. 2017—Dec.2018)

that time. Based on biannual mean, the percent composition of different groups during the study period revealed that Bacillariophyceae (70%) was the most dominant group followed by Chlorophyceae (25%),

Dinophyceae (3%) and Chrysophyceae (2%) (Fig. 3).

During unaerated period the scenario was different. At that time, although the group Bacillariophyceae was most abundant, it contributed only 49% to the total phytoplankton number. During that time, the group Cyanophyceae was also significant (23.7% of total community abundance) which disappeared during aeration. Thus the number of taxonomic groups, community abundance and share of dominant groups decreased during the aeration period.

It is also evident that the seasonality in the group abundance was significant ($p<0.05$) (Table 4).

(c) Important species of phytoplankton

For determining the important species, Importance Value Index was calculated for each species. Based on I.V.I. values (Table 5), the phytoplankton species were arbitrarily divided into two groups. The first group contained dominant or important species which had I.V.I. - ≥ 40, and the second group contained remaining others regarded as less significant. The important species (first group) in decreasing order of I.V.I. were: *Fragilaria* sp., *Closteridium* sp., *Bacillaria* sp., *Navicula* sp., *Cymbella* sp., *Nitzchia* sp., *Gomphonema* sp., *Chlorella* sp., *Rhopalodia gibba*, *Asterionella* sp. and *Peridinium* sp.. During the unaerated period the important species were: *Synedra ulna*, *Synedra* sp., *Microcystis aeruginosa*, *Peridinium* sp. and an unidentified. Thus the number of important species became quite different during the aeration period as compared to pre- aeration time. The seasonality in the population size of important species are depicted in Fig. 4, and is described below while the population size of less significant species are provided in Table 6.

(d) Seasonal variation in population density of important phytoplankton species

***Fragilaria* sp.**

This species occupied the first rank in terms of I.V.I. The density varied from 0.5×10^3 cells/l to 4×10^3 cells/l during the first year and 0.5×10^3 cells/l to 4.50×10^3 cells/l during the second year of study.

***Closteridium* sp.**

Clostridium sp. ranked second and its density ranged from 1.0×10^3 cells/l to 5.0×10^3 cells/l during the first year and 2.0×10^3 cells/l to 4.0×10^3 cells/l during the second year of the study.

***Bacillaria* sp.**

The species was third in rank. The population size varied from a minimum of 0.5×10^3 cells/l to a maximum of 4.0 cells/l x 10^3 cells/ l during the first year and between 0.5×10^3 cells/l and 4.5×10^3 cells/l during the second year of the study.

***Navicula* sp.**

It occupied the fourth rank and its density was in the range of 0.20×10^3 cells/l and 3.0×10^3 cells/l during the first year and from 0.5×10^3 cells/l to 3.50 x

Table 2. Monthly changes in species content of different groups of phytoplankton in Lake Naukuchiyatal during the study period.

2017												
Groups	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chlorophyceae	4	4	4	5	3	5	8	7	8	4	4	4
Bacillariophyceae	9	4	5	10	11	11	10	9	9	10	11	10
Chrysophyceae	0	0	1	1	1	1	0	0	1	0	0	1
Dinophyceae	0	1	1	1	1	1	1	1	1	1	1	1
Total	13	9	11	17	16	18	19	17	19	15	16	16

2018												
Groups	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chlorophyceae	5	3	4	3	2	4	4	2	4	3	3	5
Bacillariophyceae	7	4	7	9	10	10	8	8	8	10	9	9
Chrysophyceae	0	1	1	1	1	0	0	0	1	0	0	1
Dinophyceae	0	1	1	1	1	1	0	1	1	1	0	0
Total	12	9	13	14	14	15	12	11	14	14	12	15

Table 3. Presence-absence data for various species of phytoplankton found during aeration and pre-aeration period in Lake Naukuchiyatal

Taxa	During unaeration	During aeration
Ankistrodesmus falcatus	+	+
Chlamydomonas sp.	+	+
Chlorococcum humicola	+	+
Chlorella sp.	+	+
Closteridium sp.	+	+
Cosmarium granatum	+	-
C.monomazum	+	-
Dispora sp.	+	-
Microspora sp.	+	-
Mougeotia sp.	+	-
Oedogonium sp.	+	+
Palmellococus sp.	+	+
Scendesmus sp.	+	+
Spirogyra sp.	+	+
Staurastrum chaetoceras	+	+
Treubaria crassispina	+	-
Ulothrix sp.	+	+
Vaucheria sp.	+	+
Unidentified I	+	-
Unidentified II	+	-
Amphora ovalis	+	+
Asterionella sp.	+	+
Bacillaria sp.	+	+
Brebissonia boeckii	+	-
Cymbella sp.	+	+
Fragillaria sp.	+	+
Gomphonema sp.	+	+
Navicula sp.	+	+
Nitzschia sp.	+	+
Pinnularia sp.	+	+
Rhopalodia gibba	+	+
Synedra sp.	+	+
S.ulna	+	-
Tabellaria fenestrata	+	-
Unidentified I	+	-
Chlorobotrys regularis	+	+
Chlorogibba sp.	+	+
Gloeobotrys sp.	+	-
Trachychloron biconicum	+	-
Microcystis aeruginosa	+	-
Nostoc sp.	+	-
Oscillatoria sp.	+	-
Aphanizomenon sp.	+	-
Unidentified I	+	-
Tetragonidium sp.	+	-
Peridinium sp.	+	+
Unidentified (one species)	+	-
	47	**26**

10^3 cells/l during second year of the study.

***Cymbella* sp.**

The species represented itself as fifth in position and the density ranged from 0.5 x 10^3 cells/l to 4.0 x 10^3 cells/l during the first year and from 0.5 x 10^3 cells/l to 4.0 × 10^3 cells/l during the second year of the study.

***Nitzchia* sp.**

Nitzchia sp. ranked sixth in terms of I.V.I and its density varied from 1.0 x 10^3 cells/l to 5.0 x 10^3 cells/l during the first year and from 1.5 x 10^3 cells/l to 4.5 x

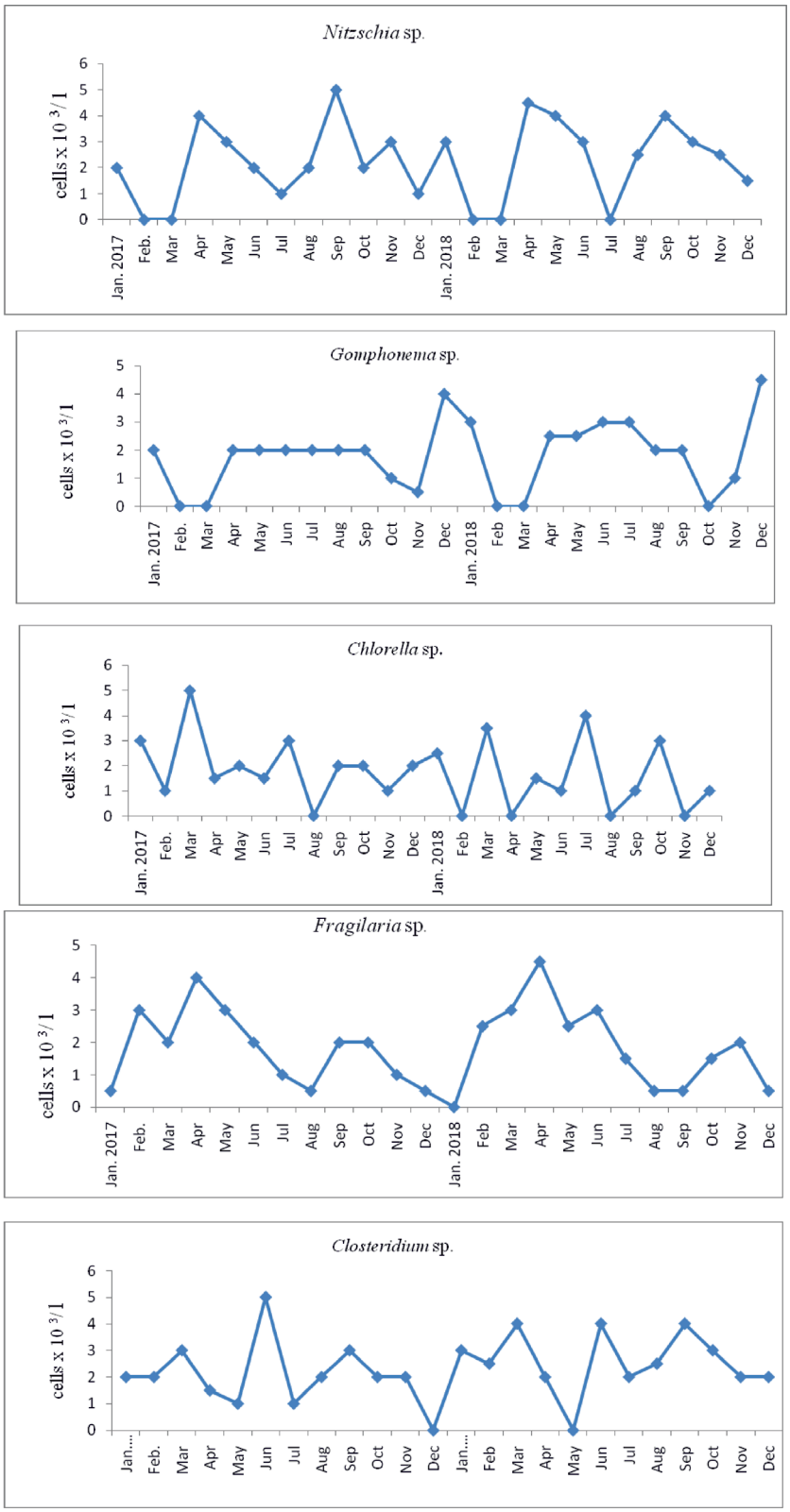

Fig. 4. Seasonal variation in population density (cells x 10^3) of important species of phytoplankton during aeration period (2017-18).

10^3 cells/l during the second year of aeration.

***Gomphonema* sp.**

The species occupied the seventh rank and its density fluctuated between 0.50 x 10^3 cells/l and 4.0 x 10^3 cells/l during first year and from 2.0 x 10^3 cells/l to 4.5 x 10^3 cells/l during second year of study.

***Chlorella* sp.**

Chlorella sp. was eighth in position. Its density was noted between 1.0 x 10^3 cells/l and 5.0 x 10^3 cells/l during the first year and between 1.0 x 10^3 cells/l and 4.0 x 10^3 cells/l during the second year of the study.

Rophalodia gibba

It was ninth in rank. The density varied from 0.5 x 10^3 cells/l to 5.0 × 10^3 cells/l during first year and from 2.0 x 10^3 cells/l to 6.0 × 10^3 cells/l during the second year of the study.

***Asterionella* sp.**

Asterionella sp. occupied the tenth position. Its density fluctuated between 0.20 x 10^3 cells/l and 3.50 x 10^3 cells/l during the first year and between 0.30 x 10^3 cells/l and 3.20 x 10^3 cells/l during the second year of the study.

***Peridinium* sp.**

This species ranked eleventh. Its density ranged between 0.10 and 2.50 during the first year and between 0.20 x 10^3 cells/l and 2.50 x 10^3 cells/l during the second year of the study.

Phytoplankton species diversity and concentration of dominance

The species diversity fluctuated between 0.80 and 1.15 , the maximum being in the month of June and

Table 5. Importance Value Index (I. V. I.) of different phytoplankton species during the study period.

S.No.	Species	I.V.I
1	*Ankistrodesmus falcatus*	31
2	*Chlamydomonas* sp.	30
3	*Chlorococcum humicola*	34
4	*Chlorella* sp.	43
5	*Closteridium* sp.	50
6	*Oedogonium* sp.	8
7	*Palmellococus* sp.	2
8	*Scenedesmus* sp.	2
9	*Spirogyra* sp.	4
10	*Staurastrum chaetoceras*	6
11	*Ulothrix* sp.	6
12	*Vaucheria* sp.	6
13	*Amphora ovalis*	28
14	*Asterionella* sp.	41
15	*Bacillaria* sp.	46
16	*Cymbella* sp.	45
17	*Fragilaria* sp.	51
18	*Gomphonema* sp.	43
19	*Navicula* sp.	45
20	*Nitzschia* sp.	44
21	*Pinnularia* sp.	37
22	*Rhopalodia gibba*	42
23	*Synedra* sp.	37
24	*Chlorobotrys regularis*	17
25	*Chlorogibba* sp.	9
26	*Peridinium* sp.	41

Table 4. Seasonality in group abundance of phytoplankton in Lake Naukuchiyatl during the study period.

2017												
Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chlorophyceae	7.10	4.50	13.20	6.50	3.20	11.52	12.90	4.55	7.80	4.90	4.20	3.60
Bacillariophyceae	11.00	8.30	6.80	32.50	30.00	22.00	18.00	16.00	23.50	20.70	16.80	11.20
Chrysophyceae	0.00	0.00	1.00	0.50	1.00	1.00	0.00	0.00	0.50	0.00	0.00	2.00
Dinophyceae	0	0.2	1.2	0.5	2.5	2	1	0.5	0.5	0.2	0.2	0.1
Total	18.10	13.00	22.20	40.00	36.70	36.52	31.90	21.05	32.30	25.80	21.20	16.90
2018												
Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chlorophyceae	9.60	4.50	11.70	3.50	1.90	10.00	11.50	3.50	8.30	6.04	2.33	5.11
Bacillariophyceae	13.50	6.90	8.30	31.20	27.50	26.40	22.00	18.00	21.00	22.20	22.50	15.10
Chrysophyceae	0.00	2.00	1.50	1.50	1.00	0.00	0.00	0.00	1.50	0.00	0.00	3.00
Dinophyceae	0	1.5	0.5	2	2.5	2	0	1.5	0.5	0.2	0	0
Total	23.10	14.90	22.00	38.20	32.90	38.40	33.50	23.00	31.30	28.44	24.83	23.21

minimum in February (Fig. 5). The overall mean (biannual mean) diversity index of phytoplankton for the whole lake was 1.02. The concentration of dominance behaved opposite to the diversity and ranged between 0.07 in June and 0.19 in February (Fig. 5) with an overall mean for the whole lake of 0.11. A comparison of diversity and dominance data during aeration and prior to aeration revealed that the diversity as well as the concentration of dominance were reduced after aeration. The diversity index was expected to increase while dominance was supposed to decrease as a result of aeration. The decrease in diversity due to aeration was surprising and unexpected.

The changes in phytoplankton community parameters (Table 7) can be attributed to severe stress of changed environmental conditions due to aeration. Several researchers (Lorenzen and Mitchell, 1973, 1975; Lorenzen, 1977; Baker *et al.*, 1981; Schladow and Fisher, 1995; Prepas and Burke, 1997; Webb et *al.*, 1997; Ragazzi *et al.*, 2007; Mc Queen and Story, 2008; Gupta and Gupta, 2012 b; Hehmen, 2012; Joshi, 2013; Zebek, 2016) have also reported changes in species composition, density, biomass, species diversity, etc. as a result of aeration. As suggested by Burgi and Stadelmann (2002), the main reason for depletion in species content seemed to be a vigorous circulation of water from top to bottom, which resulted into up and down drifting of phytoplankton cells. This drifting had not similar effects on all species of

Table 6. Seasonal variation in population densities (cells x 10^3) of numerically less significant species of phytoplankton in Lake Naukuchiyatal during study period.

Species	Jan. 2017	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Ankistrodesmus falcatus	0.1	0.5	0.2	-	-	4	5	-	0.2	-	-	0.5
Chlamydomonas sp.	-	-	-	1	0.2	1	2	0.5	-	0.5	0.2	0.1
Chlorococum humicola	2	1	5	2	-	-	0.5	1	2	-	1	1
Oedogonium sp.	-	-	-	-	-	-	0.40	0.50	0.10	0.40	-	-
Palmellococus sp.	-	-	-	-	-	0.02	-	-	-	-	-	-
Scenedesmus sp.	-	-	-	0.5	-	-	-	-	-	-	-	-
Spirogyra sp.	-	-	-	-	-	-	-	0.05	0.10	-	-	-
Staurastrum chaetoceras	-	-	-	-	-	-	-	-	-	-	-	-
Ulothrix sp.	-	-	-	-	-	-	0.50	0.20	0.30	-	-	-
Vaucheria sp.	-	-	-	-	-	-	0.50	0.30	0.10	-	-	-
Amphora ovalis	-	-	-	4	2	2	3	1	0.5	0.2	0.1	-
Pinnularia sp.	1	-	-	1	1	3	2	5	4	2	4	0.5
Synedra sp.	-	-	0.5	5	6	2	1	-	-	5	2	1.5
Chlorobotrys regularis	-	-	1	0.5	1	1	-	-	-	-	-	-
Chlorogibba sp.	-	-	-	-	-	-	-	-	0.5	-	-	2
Species	Jan. 2018	Feb	Mar	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Ankistrodesmus falcatus	0.10	0.50	0.20	-	-	3	4	-	0.30	-	-	0.60
Chlamydomonas sp.	1	-	-	0.50	0.40	2	1.50	1	-	-	0.30	-
Chlorococum humicola	3	1.50	4	1	-	-	-	-	3	-	-	1.50
Oedogonium sp.	-	-	-	-	-	-	-		-	-	-	-
Palmellococus sp	-	-	-	-	-	-	-	-	-	-	-	-
Scenedesmus sp.	-	-	-	-	-	-	-	-	-	-	-	-
Spirogyra sp.	-	-	-	-	-	-	-	-	-	-	-	-
Staurastrum chaetoceras	-	-	-	-	-	-	-	-	-	0.04	0.03	0.01
Ulothrix sp.	-	-	-	-	-	-	-	-	-	-	-	-
Vaucheria sp.	-	-	-	-	-	-	-	-	-	-	-	-
Amphora ovalis	-	-	-	2	-	1	2	-	-	0.20	-	0.10
Pinnularia sp.	-	-	-	-	-	3.5	4	5	4.5	3	3.5	-
Synedra sp.	-	-	1	4	6	3	2	-	-	5	4	2.5
Chlorobotrys regularis	-	2	1.5	1.5	1	-	-	-	-	-	-	-
Chlorogibba sp.	-	-	-	-	-	-	-	-	1.5	-	-	3

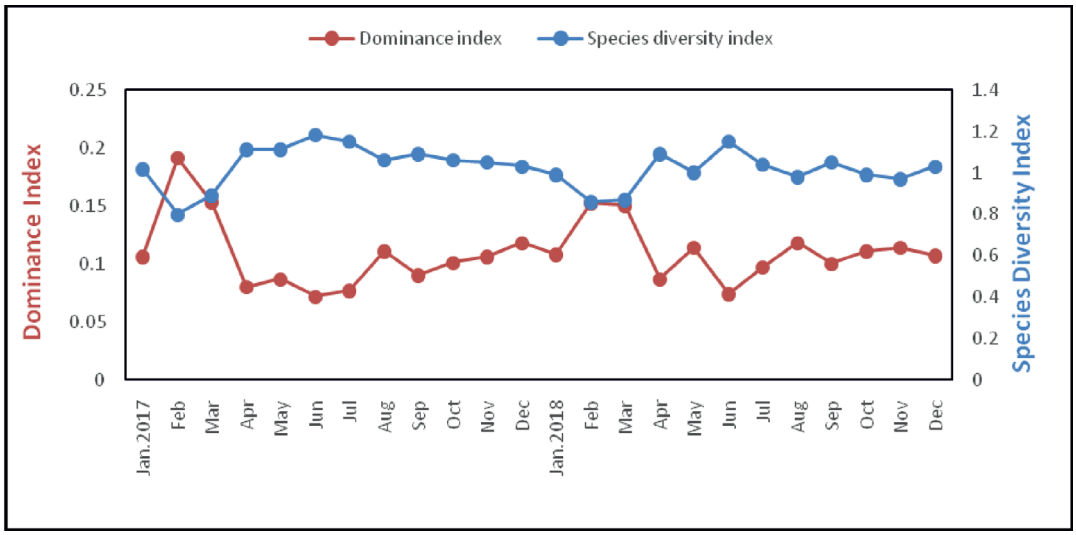

Fig. 5. Seasonal variation in species diversity and concentration of dominance of phytoplankton during aeration period in Lake Naukuchiyatal (2017-18).

phytoplankton. It stimulated the development of algae which were relatively of high specific weight, for example, Bacillariophyceae and some members of Chlorophyceae, and discouraged the development of light species, e.g. members of Cyanophyceae (Burgi and Stadelmann, 2002). This idea is supported by the study of Lund, 1954, 1966; Tundisi,1980; Tundisi *et al*., 1982 and Ryback, 1983, who had not only performed the experiments in the laboratory but also made several observations in the field. Similar to the observation of Gupta, 2008, in the present study also a large number of light species (Cyanophytes), which were present during unaerated time in very high concentration, were seen killed and pushed towards the lake shores. On the other hand species having high specific weight such as members of Bacillariophyceae and Chlorophyceae were noticed to be dominant during aeration. The other factor which could be responsible to change the phytoplankton composition was reduction in water pH. Lorenzen and Mitchell (1975) and Steicken *et al*., (1979), have hypothesized that lowering pH below a certain level could cause the decline in blue green algae. This hypothesis was further confirmed by the studies of Shapiro, 1984, 1990 a, who found the replacement of Cyanophyceae by Chlorophyceae when pH was lowered. Reduction of overall pH in the present study during aeration (6.5 to 7.2) as compared to pre- aeration period (7 to 8.3) could also be responsible for decline in phytoplankton species content and composition as suggested by Shapiro. In contrast to this study, however, the species content increased as a result of aeration in Lake Nainital although the water pH decreased considerably (Gupta and Gupta 2012 b; Joshi, 2013).

As far as the group composition and their dominance were concerned, Bacillariophyceae dominated during the aeration time. This was the effect of

Table 7. Changes in various phytoplankton variables during aeration in Lake Naukuchiyatal .

S. No.	Phytoplankton variables or group	Unaerated period	Aerated period
1.	Species content	47	26
2.	Community composition (based on number)		
1.	Chlorophyceae (%)	21.2	25
1.	Bacillariophyceae (%)	49	70
1.	Cyanophyceae (%)	23.7	-
1.	Others (%)	6.1	5
3.	Community abundance (cells/l)(biannual mean)	$7.9x10^5$	$27x10^3$
4.	Diversity index (H˜)	1.16-3.48	0.80-1.15
5.	Concentration of dominance	0.03- 0.61	0.07-0.19

speedy mixing of the lake as mentioned earlier. Lorenzen (1977), has opined that mixing favours the dominance of Bacillariophyceae and Chlorophyceae by eliminating the competitive advantage of Cyanophyceae. Similar to the present observation, the group Bacillariophyceae and Chlorophyceae were found to be dominant during aeration period in Lake Nainital (Gupta and Gupta, 2012, b, Joshi, 2013,). Forsberg and Shapiro (1980) were of the opinion that changes in group composition of phytoplankton during aeration depends on the mixing rate of the water column. According to them if mixing is slow Cyanophyceae may increase in number but if mixing is vigorous Cyanophyceae decrease and Chlorophyceae and Bacillariophyceae increase in number. In Lake Naukuchiyatal aeration was done with a high speed aerator. This was probably the major cause of disappearance of Cyanophyceae and dominance of Chlorophyceae and Bacillariophyceae. Almost similar effects of aeration on the group composition of phytoplankton have been reported by Gupta (2008), Gupta and Gupta (2012, b) and Joshi (2013) in Lake Nainital.

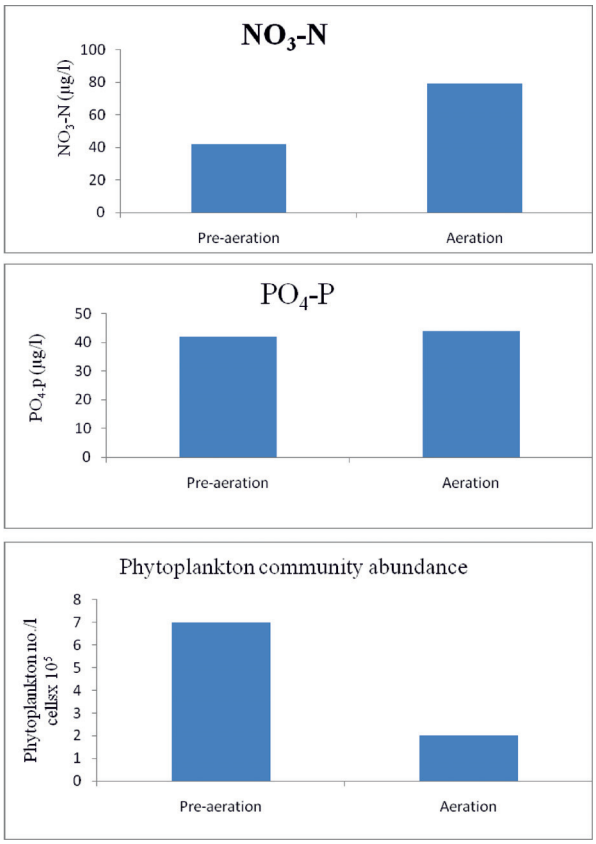

Fig. 6. Relationship between community abundance and nutrients concentration during aeration and pre-aeration period

The community abundance and standing crop of phytoplankton can respond differently to aeration in different water bodies; it has no definite trend. A review of more than 30 cases of aeration by Pastorok *et al.,* 1980, suggested that response of community abundance varied from lake to lake. In some cases the community abundance was increased, in some cases it was decreased while in some it remained unchanged after aeration. Cowell *et al.,* 1987, reported the impact of lake aeration in Lake Brooker, (Central Florida) and documented that the total phytoplankton number reduced significantly after aeration. It has been demonstrated in many studies (Wetzel, 2001) that concentrations of nitrogen, (nitrate-nitrogen) and phosphorus (phosphate-phosphorus) are the chief driving forces of community abundance but in the present investigation the community abundance declined with the increased concentration of nitrate-nitrogen and the phosphate-phosphorus during aeration (Fig. 6). It appeared, therefore, that factors other than nitrogen and phosphorus were responsible for lower community abundance in Lake Naukuchiyatal. This factor was, perhaps, the rapid mixing of lake which killed most of the phytoplankton during aeration as discussed earlier. This result of the present study showed that phytoplankton concentration in a lake undergoing aeration with a high speed aerator may not change with the changing concentration of nitrate and phosphate but mixing rate will decide the changes in phytoplankton abundance (Forsberg and Shapiro, 1980). The decline in phytoplankton community abundance may also be related with decline in concentration of ammonium nitrogen because nitrogen in the form of ammonium is taken more quickly by phytoplankton as compared to nitrogen in the form of nitrate (Cairns *et al.*, 1972). It was noticed that phytoplankton community abundance lowered along with lowering concentration of NH_4-N during aeration.

The data of Shannon- Weiner diversity index and concentration of dominance were found to be lowered during the aeration period as compared to those of pre-aeration time. This was due to disappearance of many species and abrupt decline in density of each species because of aeration. It is a general view that diversity is inversely related with the concentration of the dominance. Our results followed this rule.

In conclusion, it can be stated that high speed aerator can eliminate several nuisance species of the cyanobacteria and their blooms, and encourage the growth of Bacillariophyceae and Chlorophyceae which are beneficial to the lake. It can also reduce the community abundance of phytoplankton.

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