

# Phytoplankton succession in a tropical freshwater lake, Bhoj Wetland (Bhopal, India): spatial and temporal perspective

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Received: 22 October 2014 / Accepted: 4 March 2015 / Published online: 20 March 2015  
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**Abstract** Bhoj Wetland is tropical freshwater system in central India “Bhopal” serving the citizens as one of the major source of water since its inception. Understanding the process of phytoplankton variation can be particularly useful in water quality improvement and management decision. In this study, phytoplankton taxonomic composition, temporal and spatial distribution, and diversity along with limnological abiotic characteristics were studied based on monthly sampling from four sampling stations (between May 2005 and April 2006). A total of 4 classes, 68 genera, and 98 species which belong to Chlorophyceae (52 species), Cyanobacteria (24 species), Bacillariophyceae (19 species), and Euglenophyceae (3 species), respectively, were identified. Phytoplankton assemblages were dominated by Cyanobacteria during summer months and were the most abundant. On an annual average scale, the phytoplankton density varied between  $0.24 \times 10^4$  units/l at station 4 to  $0.46 \times 10^4$  units/l at station 2, and station 2 represented highest population density. The predominant indices of the most predominant species varied between 0.03 and 0.26. Among physicochemical variables, temperature and total dissolved solids played a key role in phytoplankton growth as represented by

statistical linear regression drawn between temperature, total dissolved solids, nitrate, and phytoplankton with  $R^2$  values of 0.6, 0.46, and 0.5, respectively.

**Keywords** Tropical lake · Phytoplankton · Succession · Physicochemical variables

## Introduction

Algae being the major primary producers in various aquatic systems are an important food source for higher organisms. The variation and distribution pattern of phytoplankton in freshwater systems depend on the physicochemical features of the systems (Cetin and Sen 2004). The knowledge of phytoplankton distribution with reference to spatial and temporal pattern is important to know the status of the ecosystem structure and functioning. There is a complexity in studying the phytoplankton community due to the factors influencing it (Huszar 1996 and Dellamano-Oliveira et al. 2003). In lakes, not only light and temperature regulate the seasonal phytoplankton pattern but other variables are also of great relevancy (Espindola et al. 1996). The interaction of the climatological and hydrological factors and their influence over other environmental factors affect the biological distribution in the aquatic systems. Phytoplankton seasonal succession is a well-investigated phenomenon in aquatic ecology, and various studies have described the patterns and underlying mechanisms of the seasonal dynamics (Sommer and Gliwicz 1986; Marshal and Peters 1989; Vanni and Temte 1990;

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Hansson et al. 1998; Rothhaupt 2000). To understand the factors responsible for changes in the distribution pattern of phytoplankton, it is important to determine the relation between environmental factors and phytoplankton dynamics.

## Study area

The tropical Vindhyan Bhoj Wetland also called upper lake is one of the oldest and largest impoundment of India created by Raja Bhoj of Dhar in the eleventh century A.D. by constructing an earthen dam on the River Kolans by virtue of which it is also known as Bhoj Wetland consisting of another lake (Lower Lake) located on its downstream (Upadhyay et al. 2012). Bhoj Wetland is situated at an altitude of 499 m a.s.l., stretching east to west between the districts of Bhopal and Sehore in MP India and fall between the geographical coordinates of 23° 13'–23° 16' N and 77° 18'–77° 24' E. The surface area of the wetland is around 36 km<sup>2</sup>. The catchment area along the north-eastern sides of the wetland is covered with urban settlement; however, the watershed area towards western and northern side of the wetland consists of maximum agricultural land and some rural settlements (Shah and Wanganeo 2013). The water body has been serving citizens of Bhopal as one of the major sources of water for economic as well as recreational activities. In view of its ecological importance, the Ministry of Environment and Forests, Government of India has recognized Bhoj Wetland as wetland of national importance and declared it as Ramsar site in year 2002.

Increasing human population, urbanization, and various types of anthropogenic activities in the watershed has increased the untreated waste load on the lake which ultimately deteriorate the water quality. The status of the wetland is eutrophic to hypereutrophic because of the high nutrients resulting is dense macrophytic and algal growth (Upadhyay et al. 2012). The hydrological regime has been found to be responsible for governing the accumulation of elements escalated by human activities, thus, contributing significantly to total environmental exposure to these substances (Naik and Wanganeo 2008). The present study is focused mainly on the upper lake and will be designated as Bhoj Wetland in this communication. Four stations were selected for the study based on type of activities in the surrounding environment (Fig. 1). Station 1 and station 2 have been

influenced by the tourist activities like boating and local activities including washing, bathing, and idol immersion while station 3 and station 4 have been surrounded by urban development and has agricultural influence.

In order to have an insight into the ecological changes the water body is experiencing, detailed limnological investigations has to be carried out. The aim of this study was to contribute to the knowledge of the phytoplankton community structure and spatial and temporal distribution pattern in Bhoj Wetland considering physical and chemical factors along the study period.

## Materials and methods

Water samples used in this study were collected with a Ruttner sampler (Hydrobios, Germany). Temperature, pH, and total dissolved solids (TDS) were measured using mercury thermometer, digital pH meter, and portable TDS meter, respectively. Dissolved oxygen was analyzed by Winkler method (APHA 1986). Collected water samples were brought to the laboratory for immediate estimation of phosphate and nitrate following (APHA) (1986). Sample aliquots of 250 ml were preserved with Lugol's iodine (1 % final concentration) for analyses of phytoplankton, which were examined after settling and siphoning to 50–100 ml and 1 ml sample taken in Sedgwick rafter cell for counting and identification under inverted microscope (OLYMPUS IX 70, America). Total of 2 ml of sample was analyzed to get the duplicate values, and in the present paper, only average of two values is presented. Phytoplankton species were identified based on the morphology with the help of standard taxonomic literatures (Randhawa 1959; Presscot 1962; Pal et al. 1962; Penak 1978; Michael and Sharma 1988; Edmondson 1992). The results have been expressed as units per liter (Wanganeo and Wanganeo 1991). The species diversity ( $H'$ , ranging from 0 to infinity) and evenness ( $J$ ) were calculated according to Shannon and Wiener (1949) and Tian et al. (2012). The predominant indices ( $d$ ) were calculated according to Berger and Parker 1970:

$$H' = \sum_{i=1}^s \frac{N_i}{N} \log_2 \frac{N_i}{N}$$

$$J = H' / \log_2 Sd = \frac{N_{\max}}{N}$$

where  $N_i$ ,  $N_{\max}$ ,  $N$ , and  $S$  are number of individuals of the  $i$ th species, number of individuals of abundant species,



**Fig. 1** Map of Bhoj Wetland showing location of sampling stations

total number of individuals, and total species (Tian et al. 2012).

Data was processed for Bray-Curtis similarity index using PRIMER version 5.2.8, and the cluster was constructed based on the abundance of phytoplankton after transforming into square root values during the annual study cycle. Following the division into groups from result of cluster analysis, the species having greatest contribution to this division were determined using similarity percentage program (SIMPER). Statistical software PAST was used for statistical Pearson correlation between different variables. A linear regression equation was drawn using regular MS Excel version 2007.

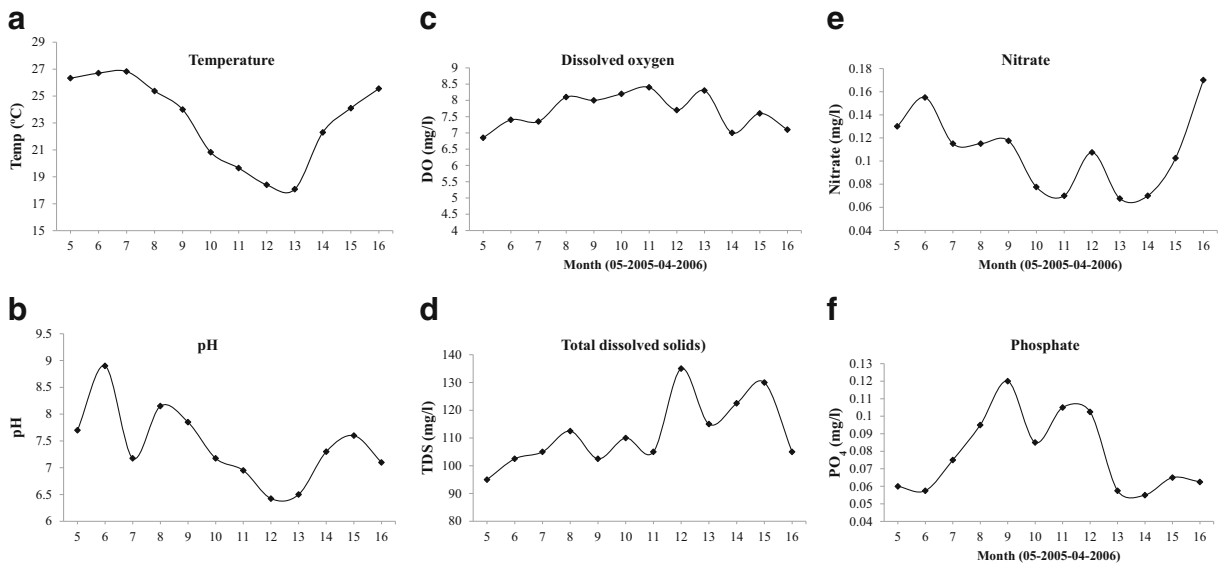
**Results and discussion**

**Physicochemical variables**

Variation of physicochemical variables from in Bhoj Wetland is presented in Fig. 2. The average water temperature varied significantly with time (ranged from 18.1 °C in January to 26.8 °C in July). pH of the water fluctuated between 6.4 and 8.9. Fluctuation in pH between a near neutral to alkaline range has also been

recorded in the wetland by Wanganeo and Ishaq 2011. Alkaline pH has been reported to be mainly a characteristic feature of eutrophic and mesotrophic lakes (Whitemore 1989; Whitemore et al. 2006).

Dissolved oxygen concentration varied from average value of 6.8 to 8.4 mg/l with higher concentration in November and lower in February. The oxygen concentration showed increasing trend from summer onwards. Low oxygen during the peak summer months as also reported by Tian et al. (2012) may be attributed to the temperature rise and stratification which leads to the increased bacterial consumption of oxygen. Total dissolved solids varied from the average of 95 mg/l in May to 135 mg/l in December. Similarly, the nitrate and phosphate which are main causative agents for eutrophication (Upadhyay et al. 2013) also varied from 0.07 to 0.17 mg/l and 0.06 to 0.12 mg/l, respectively. Changes in the concentration of NO<sub>3</sub> in wetland ecosystems generally can be due to agricultural runoff, sewage contamination, and from autochthonous inputs (Wanganeo 1998), and the water body under investigation has been reported to experience high retention of nutrients as it depends largely on its flushing rate (Wanganeo and Ishaq (2011). Vass (1980) and Zutshi et al. (1980) reported the distribution of the main plant nutrients like nitrate and phosphate to be governed by



**Fig. 2** a–e Temporal variability of physicochemical variables in Bhoj Wetland (dots represent average of four sampling stations)

physical factors such as input source to the lake (catchment characteristics), changes in mixing depth during stratification, and complete mixing during isothermal conditions and by biological processes such as algal photosynthesis (Naik et al. 2012).

#### Phytoplankton community composition

A total of 4 classes, 68 genera, and 98 species which belong to Chlorophyceae (52 species), Cyanobacteria (24 species), Bacillariophyceae (19 species), and Euglenophyceae (3 species), respectively, (Table 1) were determined from the Bhoj Wetland. The proportion of the community composition based on species number was Chlorophyceae 53.06 %, Cyanobacteria 24.49 %, Bacillariophyceae 19.39 %, and Euglenophyceae 3.06 %.

The combined number of species during the study period ranged from 60 to 95. It was observed that the species number of Chlorophyceae accounts for the largest part of the total species number. The highest species number was observed in the month of June with Chlorophyceae, Cyanobacteria, Bacillariophyceae, and Euglenophyceae species number of 51, 23, 18, and 3, respectively. The average ratio of Chlorophyceae, Cyanobacteria, Bacillariophyceae, and Euglenophyceae species number to the total number of phytoplankton species observed in a study period were 49.7, 25.8, 21.4, and 3.05 %, respectively. Based on the above results, the

Chlorophyceae and Cyanobacteria were the main dominating components of phytoplankton community in Bhoj Wetland.

About 18 species were found to be dominant with predominant indices ranging between 0.03 and 0.33 (Table 2) representing the species of Chlorophyceae (*Oedogonium* sp.), Cyanobacteria (*Microcystis aeruginosa* M. *pseudofilamentosa*), Bacillariophyceae (*Amphora ovalis*, *Asterionella* sp. *Cocconeis* sp., *Cymbella* sp., *Fragilaria* sp., *Melosira varians*, *Navicula radiosa*, *Navicula* sp., *Neidium iridis*, *Nitzschia palea*, *Pinnularia* sp., and *Tabellaria* sp.).

#### Phytoplankton abundance

The phytoplankton abundance in Bhoj Wetland exhibited distinct spatial and temporal distribution pattern (Fig. 3). The abundance in phytoplankton recorded highest peak during summer and lowest during winter months. The average phytoplankton abundance recorded was  $0.4 \times 10^4$  units/l with a range of  $0.17 \times 10^4$  to  $0.65 \times 10^4$  units/l.

The higher phytoplankton abundance (with an average of  $0.65 \times 10^4$  units/l) was recorded in May and lowest (with an average of  $0.17 \times 10^4$  units/l) in February. Distribution of phytoplankton abundance varied with different stations. The maximum abundance appeared at station 1 in May, while minimum abundance was observed in January at the same station. The

**Table 1** List of phytoplankton species in Bhoj Wetland Bhopal

Chlorophyceae	1. <i>Acanthosphaera</i> sp.	28 <i>P. duplex</i> West and West.
	2. <i>Actinastrum hantzschii</i> Lagerheim.	29. <i>P. simplex</i> Meyen.
	3. <i>Ankistrodesmus falcatus</i> (Corda) Ralf.	30. <i>P. tetras</i> (Ehrenb) Ralfs.
	4. <i>A</i> sp.	31. <i>Protococcus viridus</i> Agardh.
	5. <i>Chlorella</i> sp.	32. <i>Rhizoclonium</i> sp.
	6. <i>Chlorococcum humicola</i> Nageli.	33. <i>Scenedesmus abundans</i> kirchner.
	7. <i>Cladophora</i> sp.	34. <i>S. arcuatus</i> Lemmarman.
	8. <i>Closteriopsis longissima</i> Lemmarman.	35. <i>S. armatus</i> Chodat.
	9. <i>Closterium acerosum</i> Ehrenberg ex Ralfs.	36. <i>S. bijugatus</i> Kutzing.
	10. <i>C. eboracense</i> Turner.	37. <i>S. dimorphus</i> Kutzing.
	11. <i>C. parvulum</i> Nageli.	38. <i>S. obliquus</i> Kutzing.
	12. <i>Coelastrum cambricum</i> Archer.	39. <i>S. perforates</i> (Lemmarman) Hegewald.
	13. <i>C. microporum</i> Nageli.	40. <i>S. quadriquadra</i> (Turpin) Brebisson.
	14. <i>C. reticulatum</i> (Dangeard) Senn.	41. <i>Schizogonium murale</i> Kutzing.
	15. <i>C. sphaericum</i> Nageli.	42. <i>Schroederia setigera</i> (Shorder) Lemmarman.
	16. <i>Cosmarium</i> sp.	43. <i>Sirogonium</i> sp.
	17. <i>Crucigenia crucifera</i> (Wolle) Collins.	44. <i>Spirogyra</i> sp.
	18. <i>Dimorphococcus ehrenbergii</i> Ehrenb.	45. <i>Spirotaenia</i> sp.
	19. <i>D. lunatus</i> Braun.	46. <i>Staurastrum</i> sp.
	20. <i>Elakatothrix gelatinosa</i> Nygaard.	47. <i>Tetraedron minimum</i> (A. Braun) Hansgirg.
	21. <i>Euastrum binale</i> Ehrenb.	48. <i>Ulothrix</i> sp.
	22. <i>Gonatozygon</i> sp.	49. <i>Uronema</i> sp.
	23. <i>Microspora</i> sp.	50. <i>Volvox</i> sp.
	24. <i>Mougeotia</i> sp.	51. <i>Zygnema stellium</i> (Muller) C. Agardh.
	25. <i>Oedogonium</i> sp.	52. <i>Zygnema</i> sp.
	26. <i>Pandorina morum</i> Smith.	
	27. <i>Pediastrum biradiatum</i> Meyen.	
Cyanobacteria	53. <i>Anabaena spiroides</i> Klebahn.	66. <i>Nostoc</i> sp.
	54. <i>Anabaena</i> sp.	67. <i>Oscillatoria acuminata</i> C. Agardh.
	55. <i>Anabaenopsis arnoldii</i> Aptekar.	68. <i>O. curviceps</i> C. Agardh.
	56. <i>Aphanocapsa koordesi</i> Desikachary.	69. <i>O. perornata</i> Skuja.
	57. <i>A. muscicola</i> (Meneghini) Wille.	70. <i>O. princeps</i> Gomont. M.
	58. <i>Aulosira</i> sp.	71. <i>O. pseudogeminata</i> (Schmidle) Anagnostidis & Kkomárek.
	59. <i>Calothrix</i> sp.	72. <i>O. subbrevis</i> Schmidle, W.
	60. <i>Chroococcus</i> sp.	73. <i>Phormidium.</i> sp.
	61. <i>Desmonema</i> sp.	74. <i>Rivularia</i> sp.
	62. <i>Lyngbya limnetica</i> Lemmarman.	75. <i>Spirulina major</i> Gomont, M.
63. <i>Merismopedia</i> sp.	76. <i>S. princeps</i> West and West.	
Bacillariophyceae	64. <i>Microcystis aeruginosa</i> Kutzing.	
	65. <i>M. pseudofilamentosa</i> Crow.	
	77. <i>Achnanthes minutissima</i> Kutzing.	87. <i>M. varians</i> C. Agardh.
	78. <i>Amphora ovalis</i> Kutzing.	88. <i>Navicula radiosa</i> Kutzing.
	79. <i>Asterionella</i> sp.	89. <i>Navicula</i> sp.
	80. <i>Cocconeis</i> sp.	90. <i>Neidium iridis</i> (Ehrenberg) Cleve.
	81. <i>Cymbella</i> sp.	91. <i>Nitzschia palea</i> (Kutzing) Smith, W.
	82. <i>Diploneis subovalis</i> Cleve.	92. <i>Pinnularia</i> sp.
	83. <i>Epithema</i> sp.	93. <i>Synedra rumpens</i> (Kutzing) Hustedt.
	84. <i>Fragilaria</i> sp.	94. <i>S. ulna</i> (Nitzsch) Ehrenberg.
	85. <i>Gomphonema</i> sp.	95. <i>Tabellaria</i> sp.
	86. <i>Melosira granulata</i> (Ehrenberg) Ralf.	
	Euglenophyceae	96. <i>Euglena acus</i> (O.F. Muller) Ehrenberg.
97. <i>E. tripteris</i> (O.F. Muller) Ehrenberg.		
98. <i>Phacus curvicauda</i> Ehrenberg.		

average phytoplankton abundance at station 1, station 2, station 3, and station 4 appeared to be  $0.42 \times 10^4$ ,  $0.46 \times 10^4$ ,  $0.43 \times 10^4$ , and  $0.24 \times 10^4$  units/l, respectively

(Fig. 3). Station 2 and station 3 recorded highest average phytoplankton abundance. The maximum phytoplankton abundance at station 2 can be attributed

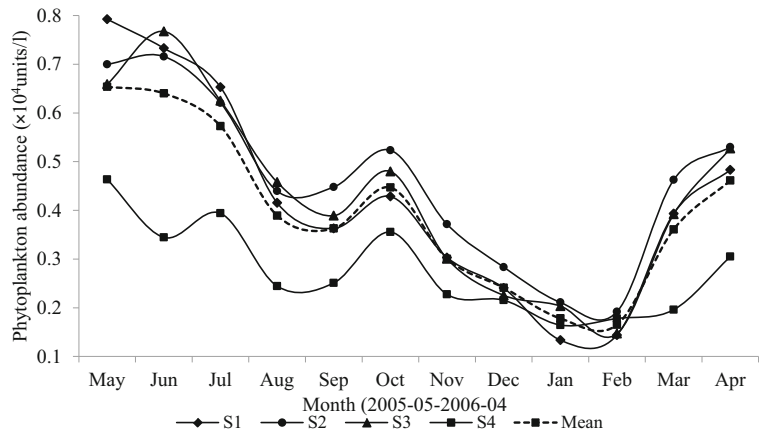
**Table 2** Variation in predominant species of phytoplankton in Bhoj Wetland with predominant indices

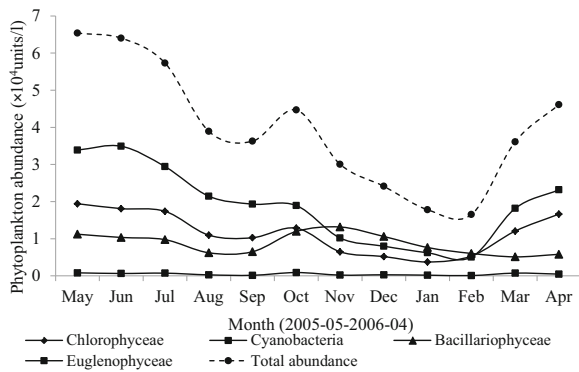
May 2005	<i>Microcystis aeruginosa</i> (0.21) <i>M. pseudofilamentosa</i> (0.05)		<i>Melosira varians</i> (0.04) <i>Navicula radiosa</i> (0.03)
Jun	<i>Microcystis aeruginosa</i> (0.26) <i>M. pseudofilamentosa</i> (0.03)		<i>Navicula</i> sp. (0.03) <i>Nitzschia palea</i> (0.04)
Jul	<i>Microcystis aeruginosa</i> (0.23)	Jan 2006	<i>Microcystis aeruginosa</i> (0.18)
Aug	<i>M. pseudofilamentosa</i> (0.33) <i>Microcystis aeruginosa</i> (0.05)		<i>Amphora ovalis</i> (0.04) <i>Asterionella</i> sp. (0.03)
Sep	<i>M. pseudofilamentosa</i> (0.3) <i>Microcystis aeruginosa</i> (0.05)		<i>Cocconeis</i> sp. (0.05) <i>Cymbella</i> sp. (0.04)
Oct	<i>Microcystis aeruginosa</i> (0.21) <i>Fragilaria</i> sp. (0.05)		<i>Fragilaria</i> sp. (0.04) <i>Melosira varians</i> (0.03)
Nov	<i>Microcystis aeruginosa</i> (0.21) <i>Cymbella</i> sp. (0.03) <i>Fragilaria</i> sp. (0.05) <i>Navicula</i> sp. (0.03) <i>Neidium iridis</i> (0.03) <i>Nitzschia palea</i> (0.03) <i>Pinnularia</i> sp.(0.03)	Feb	<i>Tabellaria</i> sp. (0.04) <i>Oedogonium</i> sp. (0.03) <i>Microcystis aeruginosa</i> (0.14) <i>Cocconeis</i> sp. (0.04) <i>Fragilaria</i> sp. (0.04)
Dec	<i>Microcystis aeruginosa</i> (0.22) <i>Asterionella</i> sp. (0.03) <i>Cymbella</i> sp. (0.03) <i>Fragilaria</i> sp. (0.05)	Mar	<i>Microcystis aeruginosa</i> (0.22) <i>M. pseudofilamentosa</i> (0.04) <i>Fragilaria</i> sp. (0.03)
		Apr	<i>Microcystis aeruginosa</i> (0.17) <i>M. pseudofilamentosa</i> (0.04)

to the human activities leading to the nutrients input at and around the site. Wu and Chou (1998) related variation in phytoplankton with various environmental factors and Sedwick et al. (2002) correlated variation with the nutrients as well as other microelements as nutrient had a positive effect on the growth rate of phytoplankton (Tian et al. 2012). Shams et al. (2012a, b) also related the variation of phytoplankton density to the

trophic conditions of the system. The peak phytoplankton abundance during May was dominated by cyanobacterial forms (Fig. 4). This successive shift in community during the summer may be due to the stratification, and the nutrients are limited to the hypolimnion and metalimnion, and the nitrogen fixers take up the community dominance. Present research shows that phytoplankton abundance of different groups reflects the same trend as the

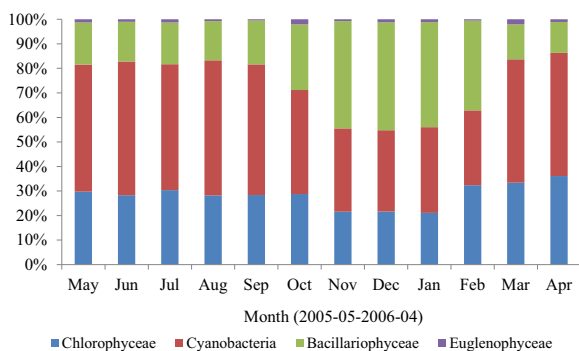
**Fig. 3** Spatial and temporal variation of phytoplankton abundance at four sampling stations





**Fig. 4** Temporal variation of phytoplankton abundance in different classes and total abundance

total phytoplankton abundance (Fig. 4). There is distinct temporal difference of phytoplankton abundance—higher in summer and lower in winter months. This statement is in accordance with the work of Wang et al. (2002). The annual average ratio of Chlorophyceae, Cyanobacteria, Bacillariophyceae, and Euglenophyceae phytoplankton abundance in total was 29.02, 47.93, 21.88, and 1.17 %, respectively. The average Chlorophyceae, Cyanobacteria, Bacillariophyceae, and Euglenophyceae abundance was  $0.15 \times 10^4$ ,  $0.19 \times 10^4$ ,  $0.087 \times 10^4$ , and  $0.005 \times 10^4$  units/l, respectively. It is worth noting that Cyanobacteria and Chlorophyceae were the most dominant forms in Bhoj Wetland (Fig. 5). Microcystis among the Cyanobacteria was the most abundant form than others during summer. Bloom in freshwaters is generally comprised of Microcystis, and it has the ability to dominate and affect the growth of other forms of phytoplankton (Keams and Hunter 2001; Singh et al. 2001; Maske et al. 2010). Euglenophyceae was the least among the phytoplankton groups. The

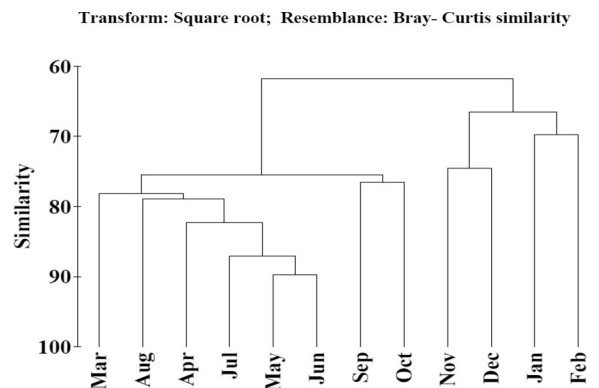


**Fig. 5** Phytoplankton community succession in Bhoj Wetland

maximum abundance of Euglenophyceae was recorded in summer and after rainy season. The organic matter seems to be the factor for their growth. Shams et al. (2012a, b) also reported that *Euglena* species grow rapidly in rich organic medium. The Bray-Curtis cluster analysis based on the square root transformed phytoplankton density detected two well-defined groups revealing temporal variability (Fig. 6). Group I consisted of samples during summer and monsoon (Mar–Oct) while group II consisted of winter months (Nov–Feb). Using similarity percentage (SIMPER) analysis, 37 dominant species were found to be contributing to the two groups with percentage contribution between 1 and 28.47 % (Table 3).

Phytoplankton diversity index and evenness

Diversity is generally measured by species count, with an evenness index, and it may also be measured by a proportional statistics (Stirling and Wilsey 2001; Gao and Song 2005). Diversity indices calculation from Bhoj Wetland was performed on phytoplankton cell abundance. The diversity varied from 2.46 to 3.99 and evenness from 0.35 to 0.91 (Figs. 7 and 8). The results showed an average diversity index and evenness of 3.38 and 0.64, respectively. The highest diversity index was recorded at station 4 in June and the lowest at station 1 in January. As the station 1 experiences lot of pressure in terms of human activities and the tourist activities may be the reason for the low diversity whereas station 4 also has anthropogenic pressure in terms of agricultural input but seems to support the plankton community compared to other sites. The



**Fig. 6** Dendrogram of cluster analysis based on Bray-Curtis similarity index in Bhoj Wetland

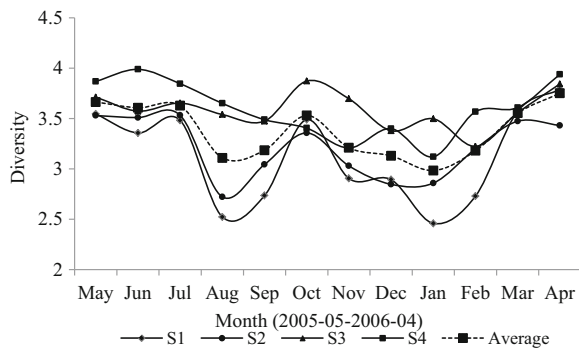
**Table 3** Percent contribution of phytoplankton species in two groups outlined by cluster based on SIMPER analysis

Genera/species	Group I	Group II	Genera/species	Group I	Group II
<i>Microcystis aeruginosa</i>	28.47	22.13	<i>Nostoc</i> sp.	1.1	–
<i>Microcystis pseudofilamentosa</i>	4.32	5.27	<i>Achnanthes minutissima</i>	1.07	2.51
<i>Fragilaria</i> sp.	1.83	–	<i>Closterium acerosum</i>	1.06	–
<i>Calothrix</i> sp.	1.47	–	<i>Ulothrix</i> sp.	1.05	2.54
<i>Oscillatoria acuminatus</i>	1.42	–	<i>Oscillatoria perornata</i>	1.04	–
<i>Nitzschia palea</i>	1.42	2.87	<i>Ankistrodesmus falcatus</i>	1.03	–
<i>Chroococcus</i> sp.	1.38	–	<i>Oscillatoria subbrevis</i>	1.03	–
<i>Gomphonema</i> sp.	1.37	–	<i>Cocconeis</i> sp.	1.02	3.59
<i>Melosira granulata</i>	1.32	–	<i>Oscillatoria pseudogeminata</i>	1	–
<i>Cymbella</i> sp.	1.31	–	<i>Asterionella</i> sp.	0.99	3.32
<i>Oscillatoria princeps</i>	1.28	–	<i>Oedogonium</i> sp.	–	3.44
<i>Anabaena</i> sp.	1.28	–	<i>Cymbella</i> sp.	–	3.28
<i>Anabaena spiroides</i>	1.24	–	<i>Melosira varians</i>	–	3.21
<i>Anabaenopsis arnoldii</i>	1.19	–	<i>Pinnularia</i> sp.	–	2.64
<i>Amphora ovalis</i>	1.13	3.4	<i>Synedra ulna</i>	–	2.02
<i>Closterium eboracense</i>	1.13	–	<i>Synedra rumpens</i>	–	1.97
<i>Oscillatoria curviceps</i>	1.1	–	<i>Neidium iridis</i>	–	1.92
<i>Merismopedia</i> sp.	1.1	–	<i>Navicula</i> sp.	–	1.78
<i>Spirulina major</i>	1.1	–		–	

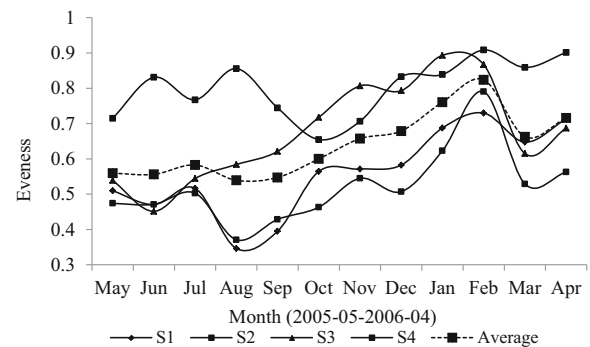
lowest evenness was recorded at station 1 in August and maximum in February. The average diversity indices of phytoplankton for stations 1, 2, 3, 4 were 3.12, 3.21, 3.59, and 3.6, respectively. The phytoplankton species were found to be evenly distributed with respect to stations.

Phytoplankton diversity indices are widely used as an indicator of the water quality (Karydis and Tsirtsis 1996). The values ranging from 0.0 to 1.0 for heavy pollution, 1.0–2.0 for moderate pollution, 2.0–3.0 for light pollution, and 3.0–4.5 for slight pollution have

been established by various researchers (Shanthala et al. 2009; Tian et al. 2012). Low diversity would indicate high pollution and vice versa, and this statement coincides with the research of Margalef (1964). The average diversity indices of phytoplankton were recorded above 3 except during the month of January 2006, but the water quality in January was not worse. The low diversity may be due to the low temperature as the plankton population recorded low abundance during the winter months.



**Fig. 7** Spatial and temporal variation of phytoplankton diversity indices



**Fig. 8** Spatial and temporal variation of phytoplankton evenness



Interaction between phytoplankton and ecological factors

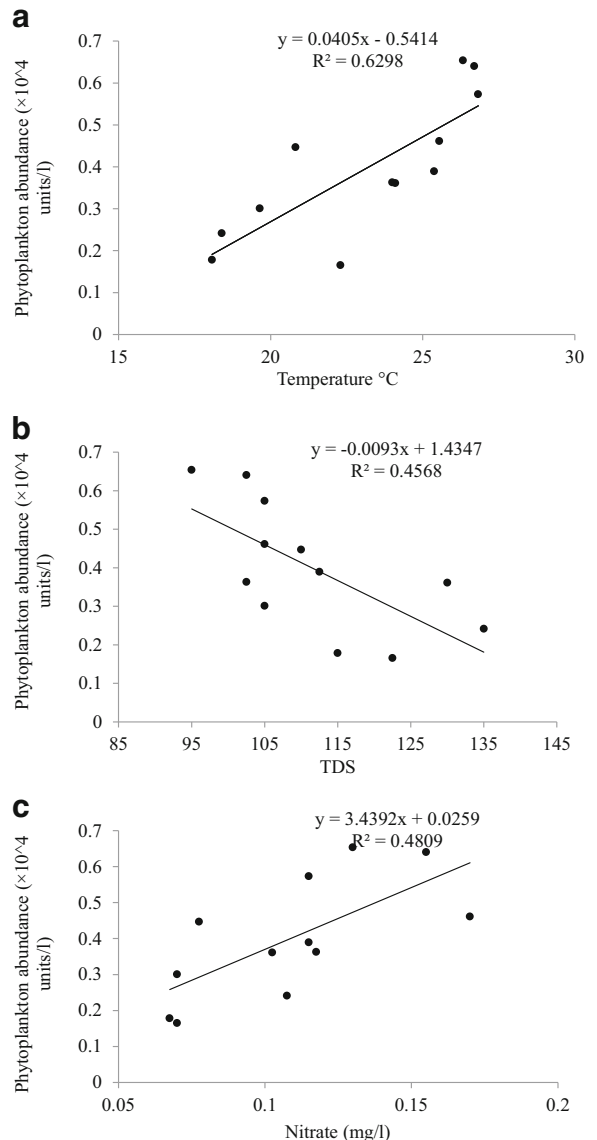
Phytoplankton communities can biologically respond to the environmental variables in the form of spatial and temporal changes with respect to qualitative as well as quantitative aspects of their community structure. Seasonal succession and distribution of plankton species have been reported to be governed by an interrelated effect of light, temperature, oxygen, and nutrients in particular and generally by the other physicochemical conditions (Smith 1924; Marshall 1965; Hutchinson 1967; Sommer and Gliwicz 1986; Yildiz et al. 2007; Davies et al. 2009; Wanganeo 2010).

When a process in nature is controlled by a set of interrelated variables, focused statistical approach may be the only way to discern the relative importance of variables in the natural system (Luoma and Bryan 1982). To illustrate the interaction between physicochemical factors and phytoplankton abundance, Pearson correlations and regression analysis as an integrated approach were applied to examine the relativity. Statistical correlation coefficients between phytoplankton abundance and physicochemical factors are presented in Table 4, and the regression plots are presented in Fig. 9a-c. Present results illustrated that temperature showed significant correlation with phytoplankton abundance ( $r=0.79, P<0.05$ ) and regression equation of  $y=0.040x+0.0541, R^2=0.0629$ . Water temperature is thought to be the important environmental factor influencing the growth and distribution of phytoplankton in lakes (Paerl 1996; Simon and Hildrev 1998; Mosisch et al. 1999; Cetin and Sen 2004). Many

**Table 4** Pearson correlation coefficients between parameters during the study period

	Phyto	Temp	pH	DO	TDS	NO <sub>3</sub>
Phyto						
Temp	<b>0.79</b>					
pH	<b>0.60</b>	<b>0.74</b>				
DO	-0.03	-0.34	-0.12			
TDS	<b>-0.68</b>	<b>-0.52</b>	-0.42	-0.09		
NO <sub>3</sub>	<b>0.69</b>	<b>0.74</b>	0.51	-0.15	-0.38	
PO <sub>4</sub>	-0.21	-0.28	-0.11	<b>0.57</b>	0.02	-0.16

Bold values represent significant correlation at  $P<0.05$ , phytoplankton



**Fig. 9 a-c** Relationship between important physicochemical variables and phytoplankton

freshwater systems reflected the effect of temperature in term of seasonal planktonic variations as described by Lund (1965); Richardson et al. (2000); Izaguirre et al. (2001); and Tsuchida et al. (1984). Cyanobacteria dominance during summer and low abundance during winter months in present investigation may be due to the reason that the growth rate of bloom forming cyanobacteria are related to the temperature and this statement is in agreement with the statements of Robarts and Zohary (1987); Dai et al. (2008); and Mur et al. (1999).

Water clarity and the ecological quality of lakes could be predicted quite well from water transparency (Perdrozo et al. 2008; Kasprzak et al. 2008). Light is a major resource for phytoplankton and has a complex pattern of variability (Litchman 2000). Dissolved solid in water plays a major role in the water clarity and the light passage important for phytoplankton growth. Present results depicted that phytoplankton abundance is in negative correlation with total dissolved solids ( $r=-0.68$ ,  $P<0.05$ ) and regression values of  $y=-0.009x+1.434$ ,  $R^2=0.456$ . Nitrate, a major nutrient, was also found to be positively correlated with phytoplankton abundance ( $r=0.69$ ,  $P<0.05$ ) with regression equation of  $y=3.439x+0.025$ ,  $R^2=0.0480$ . The present results correspond with the studies conducted by Azari et al. (2011) who also reported positive correlation between phytoplankton. In some cases, phytoplankton can grow even in low nutrients also as reported by Lewis (1978) in a study of a tropical lake in the Philippines that the Chlorophyceae, Cyanobacteria, and Dyanophyceae classes contributed with higher values under low nutrient concentration. The present study suggests that temperature, nitrate, and total dissolved solids were the most important variables effecting the dynamics of phytoplankton variation.

## Conclusion

There has been number of pervasive generalizations about the common seasonal succession of phytoplankton in fresh waters but in view of existing literature and present study shows a great diversity of patterns. The temperate pattern of succession involves a winter minimum of phytoplankton adapted to low temperature and a summer burst of cyanobacterial forms followed by a smaller development of green algae. Summer populations vary in relation to the trophic status of the lake. The Bhoj wetland has attracted the audience to the closest in view of its social benefits. The lake has been going through successive changes in terms of biological and physical condition. The present study highlighted some of the successive shifts within the phytoplankton community and can extend to the higher trophic levels as well.

**Acknowledgments** The authors thank the head of the Department of Environmental Science and Limnology Barkatullah University Bhopal, India for their support. The authors are also thankful to reviewers for improving the manuscript.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Informed consent** “Informed consent was obtained from all individual participants included in the study.”

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## **Erratum to: Phytoplankton succession in a tropical freshwater lake, Bhoj Wetland (Bhopal, India): spatial and temporal perspective**

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Published online: 24 April 2015  
© Springer International Publishing Switzerland 2015

**Erratum to: Environ Monit Assess (2015) 187(4):4410  
DOI 10.1007/s10661-015-4410-0**

Please note an error in the original paper by authors, an error has occurred in the Fig. 2 sub figures that the x-axis titles was by mistake not added or not edited properly. So the x-axis title of sub figures of Fig. 2 will be same to all figures a-f.

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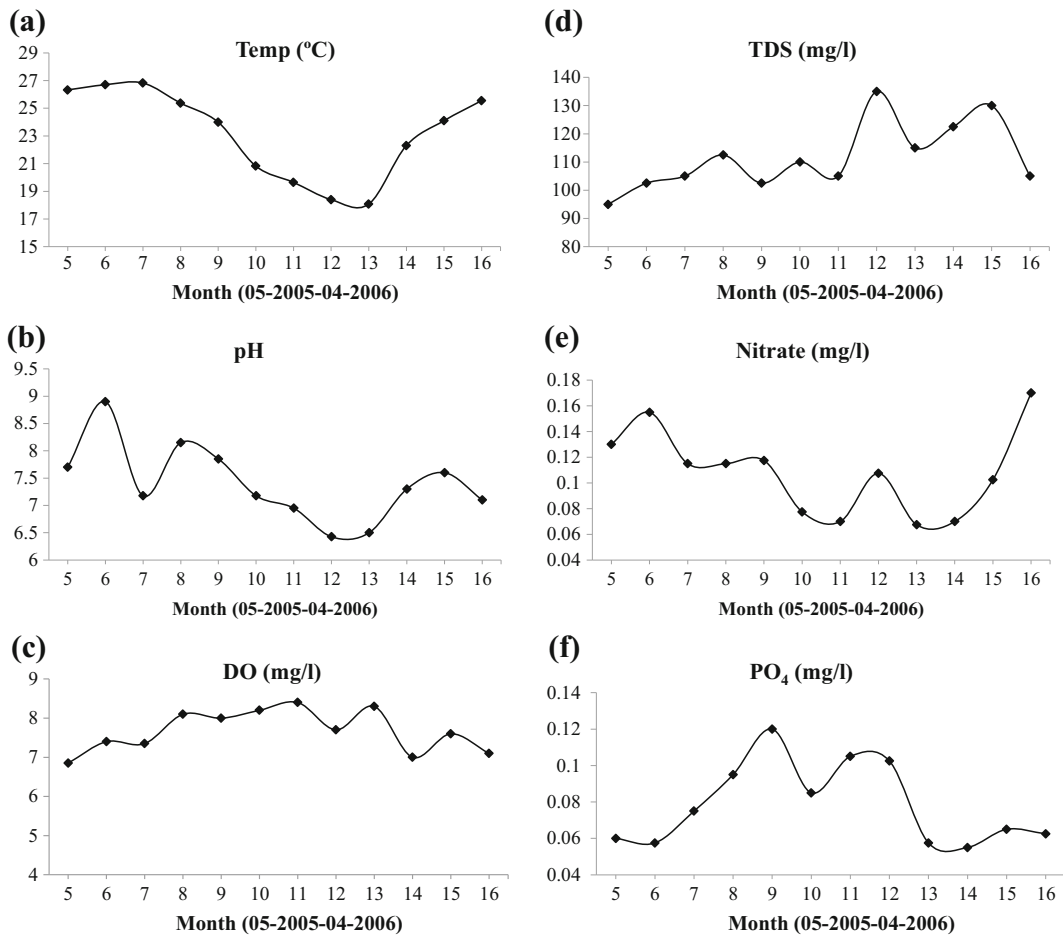
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**Fig. 2** a–f Temporal variability of physicochemical variables in Bhoj wetland (*dots* represent average of four sampling stations)