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Full Length Research Paper

Effect of physico-chemical conditions on the structure and composition of the phytoplankton community in Wular Lake at Lankrishipora, Kashmir

Altaf H. Ganai* and Saltanat Parveen

Limnology Research Laboratory,Department of Zoology, A.M.U, Aligarh (U.P.), India.

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The high altitude valley of Kashmir abounds in a vast array of freshwater bodies of lotic as well as lentic nature. Amongst these, lakes play an important role in biodiversity of this region. The present study on Wular Lake, Kashmir was undertaken from March, 2007 to February, 2008 to study abundance and distribution of phytoplankton and their correlation with physico-chemical conditions of water. A total of 64 phytoplankton belonging to bacillariophyceae, chlorophyceae, cyanophyceae and euglenophyceae were identified. Phytoplankton in general, showed two growth periods, one in spring and other in winter. A clear dominance of bacillariophyceae over chlorophyceae, cyanophyceae and euglenophyceae was observed throughout the study period. *Navicula* spp. with population density of 118 no./ml was recorded to be the most abundant species amongst bacillariophyceae at the selected site. Chlorophyceae formed the second most dominant group of phytoplankton with *Chlorella* spp. (112 no./ml) as the most abundant species. *Osillatoria* spp. with population density of 119 no./ml was found to be the most abundant amongst cyanophyceae. Euglenophyceae formed the least represented group of phytoplankton with peak population in spring. Statistically, bacillariophyceae and euglenophyceae showed significant negative correlation (r = -0.855 and r = -0.177) with water temperature, while cyanophyceae showed significant positive correlation (r = 0.745). Chlorophyceae showed non-significant positive correlation (r = 0.325) with water temperature at the selected site. Shannon-Wiener diversity index (H′) value (1.672) was recorded for cyanophyceae, while the highest evenness (J′) value (0.8872) was recorded for euglenophyceae. The value of Berger-Parker index of dominance (0.1859) was highest for bacillariophyceae. Canonical correspondance analysis (CCA) was also carried out to analyze the relationship between the physico-chemical parameters and the phytoplankton. It showed that the most important factors affecting phytoplankton distribution are water temperature, CO_2, chloride, transparency, TDS, alkalinity and dissolved oxygen.

Key words: Biodiversity, freshwater bodies, phytoplankton, Wular Lake.

INTRODUCTION

Lakes form a significant component of inland aquatic resources of India, especially because of their potential for fishery. These lakes also have high conservation values. Despite the ecosystem services they provide and their patrimonial value, their biological diversity has been seldom investigated. Biological diversity or biodiversity is the degree of variation of life forms within a given species, ecosystem, biome or planet. A diversity index

*Corresponding author. E-mail: saltanatparveen@yahoo.com.

is a quantitative measure that reflects how many different types (such as species) are there in a dataset, and simultaneously takes into account how evenly the basic entities (such as individuals) are distributed among those types. The value of a diversity index increases both when the number of types increases and when evenness increases. For a given number of types, the value of a diversity index is maximized when all types are equally abundant.

Neither ecological modeling nor effective protection/-management of these ecosystems will be possible without a comprehensive knowledge of the relationships between the biological diversity they host, and their environmental features. Phytoplankton is a key component of the lake biota in general, because it forms the base of the pyramid of productivity. Assuming that any increase in nutrient inputs leads to enhanced primary productivity, phytoplankton may serve as a relevant indicator of the trophic state in Indian lakes, as in other parts of the world (Szeląg-Wasielewska, 2006).

Phytoplankton is the chief primary producer of the aquatic environment which fixes solar energy by process of photosynthesis, assimilating carbon dioxide and water to produce carbohydrates. Phytoplanktonic species have different physiological requirements and thus show diverse responses to physical and chemical parameters such as light, temperature and nutrient regime. Their sensitivity and variations in species composition are often a reflection of significant alteration in ambient condition within an ecosystem (Devassy and Goes, 1988, 1989). Hence before any utilization of lake resources comes into consideration, plankton study is of primary interest. Earlier studies on lake phytoplankton diversity (Pieterse and Van, 1988; Vaulot, 2001; Pongswat et al., 2004; Kendirim, 2001; Millman et al., 2005; Tiwari and Chauhan, 2006; Sridhar et al., 2006; Tas and Gonulol, 2007; Senthilkumar and Sivakumar, 2008; Ganai et al., 2010) revealed the importance of this type of study. Studies showed that most of the phytoplankton was a great deal sensitive to the varying environment condition. That is to say, a negative change in phytoplankton composing the primary productivity affects all living creatures. Therefore, phytoplankton that is composed of the first ring of food chain should be examined taxonomically and ecologically.

Very few limnological investigations have been published on the plankton populations of freshwaters of Kashmir Himalaya (Kant and Kachroo, 1971; Kaul et al., 1978; Zutshi et al., 1980; Yousuf et al., 1986; Kaul and Pandit, 1998; Pandit, 1998; Sarwar, 1999; Zutshi and Gopal, 2000; Bhat and Pandit, 2003; Ganai et al., 2010).

In the present study, we focused on the abundance and distribution patterns of phytoplankton and its correlations with the physico-chemical properties of water in Wular Lake, Kashmir, which is the largest freshwater lake of India and Asia (A Ramsar site). The lake has now shrinked down from 20,000 to 2400 hectares due to continued silt deposition brought by its various tributaries, exceptionally high human interference in and around this lake in the form of agriculture, industrialization and urbanization. An area of 11, 853 kanal and 14 malras of land has been illegally encroached from Bandipora side alone. About 92 illegal construction shave been raised over the encroached land (Rashid, 2008). According to the renowned environmentalists, Wular has one of the most disturbed ecosystem of India which needs attention of Indian government and from the local population being wetland of international importance (under the Ramsar convention, 1990). Reclamation of large areas for agriculture, large quantities of domestic sewage and agricultural run-off containing the plant nutrients have been the main factors responsible for accelerated aging or eutrophication of the lake. Thus, this situation provides compelling reasons to relate variations in physico-chemical characteristics to biological diversity (here phytoplankton), in order to assess the trophic status of this lake of prime importance. The data obtained would also help in antipollution conservation or conservation strategies, in addition to formulating the diversity of the lake.

MATERIALS AND METHODS

The present study results from limnological investigation undertaken from March, 2007 to February, 2008 on Wular lake, Kashmir (34°15'-34°28' N Latitude and 74°30' - 74° 45' E longitude). The lake is chiefly fed by River Jhelum which flows in the lake on its South-eastern side near “Banyar”, leaving it at its south-western corner near Sopore.

Collection of samples

The sampling was carried out on a monthly basis from March, 2007 to February, 2008 at Lankrishipora (Map 1: sites I, II and III) between 9-10 a.m. The different physico-chemical parameters such as air and water temperature, dissolved oxygen, total alkalinity, pH, transparency, electrical conductivity, total dissolved solid, free carbon dioxide, chloride, total hardness, calcium, magnesium, nitrate-nitrogen (NO_3-N) and inorganic phosphorus were analyzed following the works of Theroux et al. (1943), Trivedy and Goel (1984) and APHA (1998).

Biological analysis

For phytoplankton analysis, monthly samples (500 ml) were collected from the site in wide mouth plastic bottle. 5 ml of Lugol’s iodine solution was added. After keeping it for 24 h, the supernatant was discarded and 20 ml concentrate was obtained. Quantitative analysis of phytoplankton was done by putting one drop of fixed sample (0.02 ml) on the glass slide and studying it under inverted microscope (Metzer). The results were obtained by recording the number of organisms per ml following Welch (1952). For qualitative analysis, the information given in Dippel (1904), Edmondson (1959) and Needham and Needham (1962) were used.

Three indices were used to obtain the estimation of species

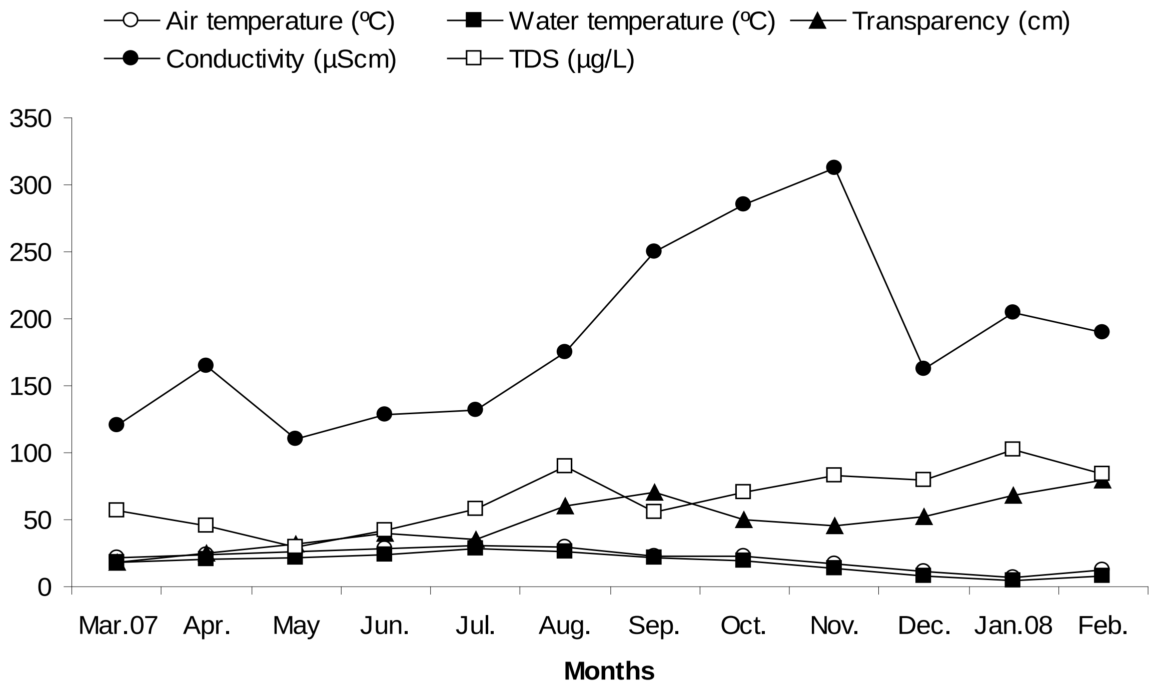


Figure 1. Monthly concentration of air, water, transparency, conductivity and TDS from March, 2007 to February 2008.

diversity, species richness and species evenness:

1. Species diversity was determined following Shannon-Wiener's Index (Ludwig and Reynolds, 1988) using the formula:

$H' = (\Sigma \text{ pi ln pi})$

Where, Pi = n/N

N = No. of individual species, N = total density of all organisms.

2. Species dominance was calculated using Berger-Parker's Index (Berger and Parker, 1970) formula:

$D = Nmax / N$

Where Nmax = density of most dominant species, N = density of all the species.

3. Evenness was calculated using the formula:

$E1 = H1 / \ln S$ (Pielou, 1975)

Where, H1 = species diversity; S = species richness.

Ordination analysis of phytoplanktonic community

The Version 2 of PAST Software Design was used (window Oyvind Hammer & D.A.T. Harper) for performing multivariate analysis of ecological data by canonical correspondence analysis (CCA) conducted to detect patterns of distribution of phytoplankton groups related to physical and chemical parameters. The results contain the environmental variables plotted as arrows emanating from the center of the graph along with points for the samples and phytoplankton groups. The arrows representing the environmental variables indicate the direction of maximum change of that variable across the diagram. The position of the species points indicates the environmental preference of the species.

RESULTS AND DISCUSSION

Abiotic parameters

Monthly variations in various physico-chemical parameters of the lake at the selected site are given in the Figures 1 to 4. The lake is influenced by a wide array of physico-chemical factors. Fluctuations of these factors affect the biota of the lake. Air temperature ranged from 7°C (January, 2008) to 31°C (July, 2007) whereas water temperature ranged between 5°C (January, 2008) and 28°C (July, 2007).

Lower water temperature was due to cold, low ambient temperature and shorter photoperiods. Water temperature influences aquatic life through metabolic rates and concentration of dissolved gases like carbon dioxide, oxygen and chemical solute. For transparency, values ranged between 0.45 (November, 2007) and 1.70 m (March, 2007).

Transparency remained high during winter which can be related to lower rate of decomposition and less human activities during winter. Transparency showed positive significant correlation with TDS (r = 0.656). Concentration of

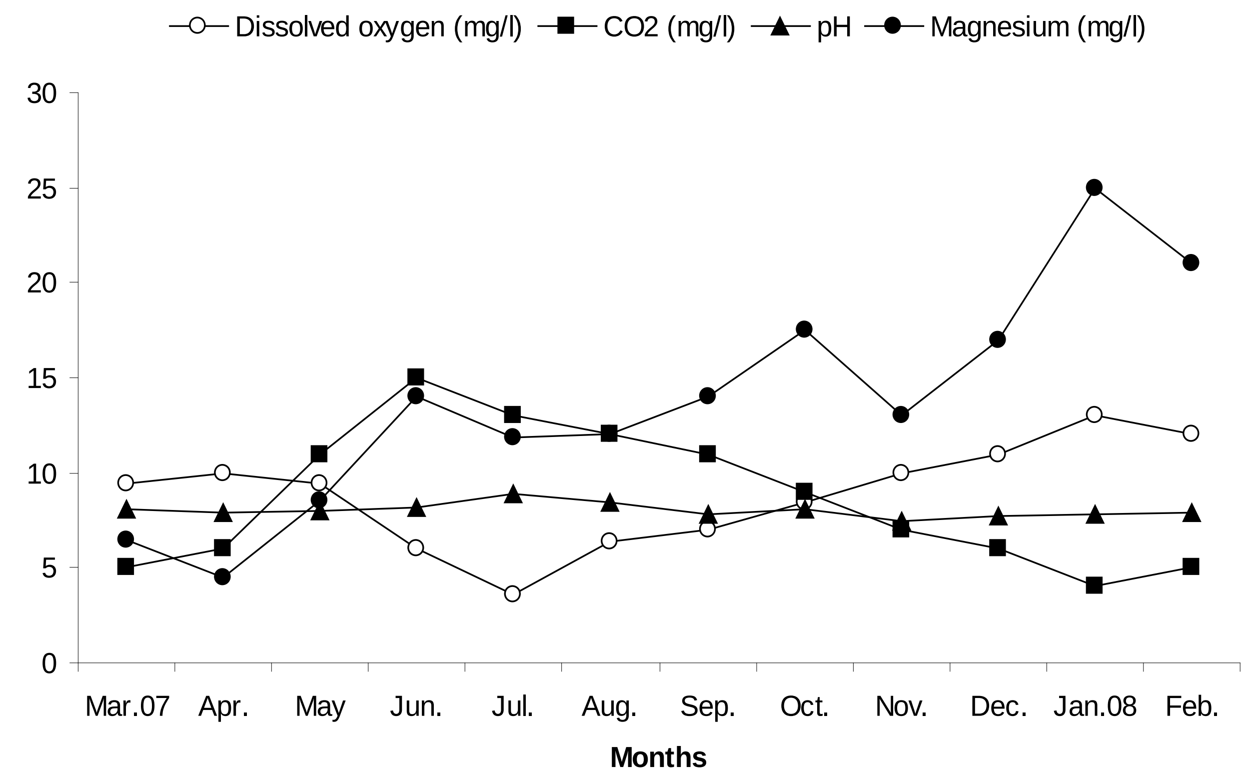


Figure 2. Monthly concentration of dissolved oxygen, CO_2, pH and magnesium from March, 2007 to February 2008.

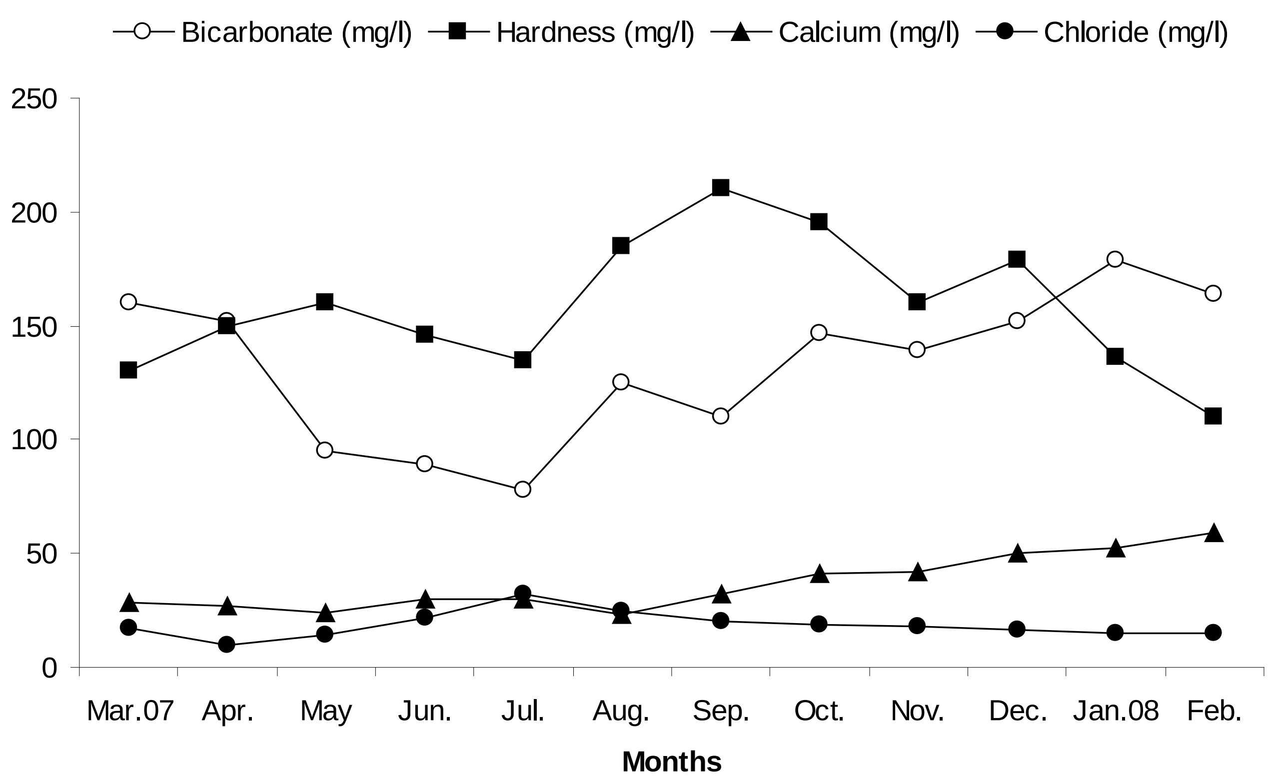


Figure 3. Monthly concentration of bicarbonate, hardness, calcium and chloride from March, 2007 to February 2008.

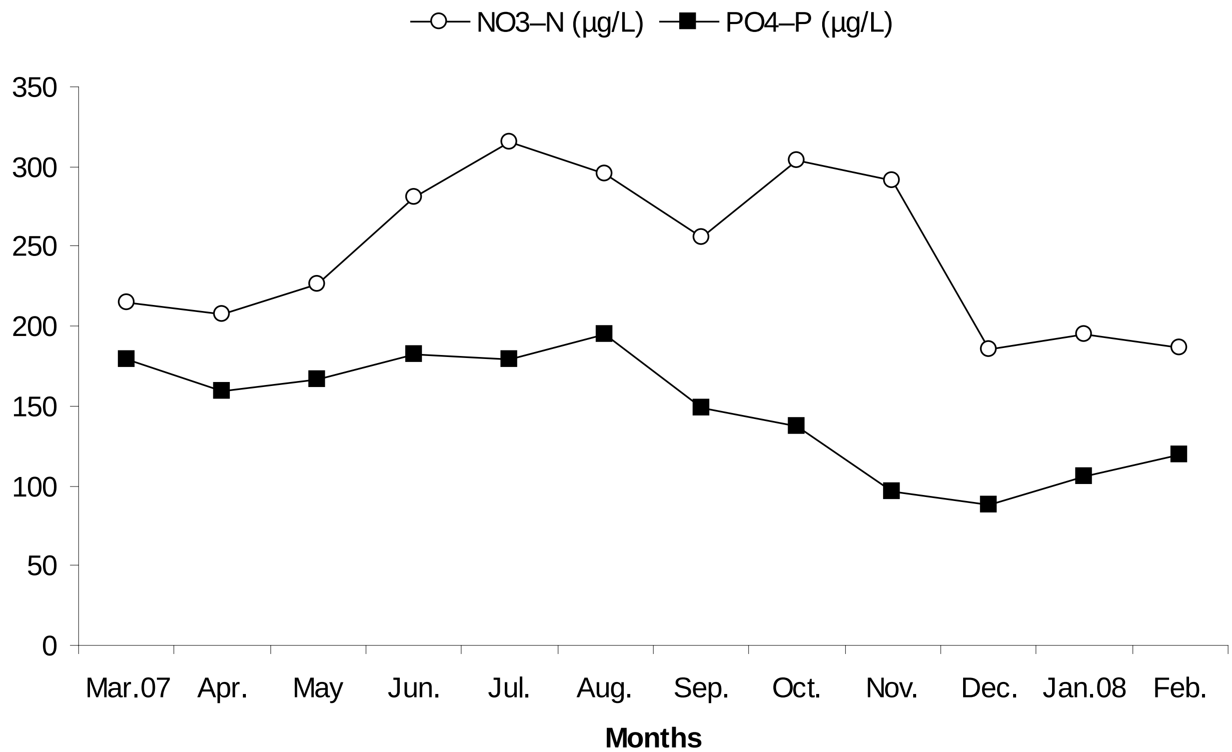


Figure 4. Monthly concentration of NO_3-N and PO_4-P from March, 2007 to February 2008.

conductivity varied from 110.0 (May, 2007) to 312.0 mg/l (October, 2007). Low values of electrical conductivity were recorded in spring and summer which could be related to locking of nutrients during seasons. Concentration of TDS varied from 42 (August, 2007) to 162.0 mg/l (February, 2008). Lower values of TDS were recorded during summer which is due to their utilization by plankton and other aquatic plants. Dissolved oxygen plays a crucial role in regulating the aquatic life. With regard to the dissolved oxygen variable, values fluctuated between 3.60 (July, 2007) and 13.0 mg/l (January, 2008). The higher values recorded for dissolved oxygen in solution in the winter period can be attributed to lower rate of decomposition, low respiratory demand and the capacity of water to hold high oxygen concentration at low temperature. Dissolved oxygen showed significant negative correlation with water temperature (r = -0.904) and significant positive cor-relation with pH (r = 0.811). For carbon dioxide, values fluctuated between 4.0 (January, 2008) and 15.0 mg/l (June, 2007). High values of free CO_2 were recorded during summer which can be attributed to higher decomposition rate and enhanced respiratory activities of plants and animals. pH remained on alkaline side throughout the period of investigation and ranged between 7.5 (November, 2007) and 8.9 (July, 2009). pH between 6.5 and 9.0 can support good fishery as such lake water is favorable from fisheries point of view. Statistically, pH showed positive significant correlation with alkalinity (r = 0.926). Alkalinity was of bicarbonate type only and varied from 78 (July, 2007) to 179 mg/l (January, 2008). Decline in conductivity values in spring and summer could be related to increase in phytoplankton and macrophyte population leading to increase in the uptake of nutrients. Hardness concentration in present study ranged between 110 (February, 2008) and 210 mg/l (September, 2007). High values of total hardness were recorded during autumn which can be related to inflowing sewage and high anthropogenic activities in and around the lake. Calcium values fluctuated between 23.0 (August, 2007) and 59.0 mg/l (February, 2008) whereas values of magnesium varied from minimum of 4.50 (April.2007) to maximum of 25.0 mg/l (January, 2008). Decline in values of calcium and magnesium were recorded in spring and summer which might be related to its active utilization by plankton and their uptake by aquatic vegetation and sedimentation. Values of chloride concentration ranged between 10 and 32.5 mg/l. The higher values of chloride were recorded in summer which is attributed to presence of large amount of organic matter of allocthonus and autochthonus origin and its concentration due to high ambient temperature.

According to Mc Caul and Crossland (1974), the most important factor responsible for eutrophication of fresh water lakes is PO_4-P and NO_3-N. In the present study, NO_3-N ranged between 186 (December, 2007) and 315 µg/l (July, 2007). High values were recorded during summer which could be attributed to decomposition of organic matter at higher temperature and entry of nitrogen fertilizers from catchment areas. Statistically, NO_3-N showed significant negative correlation with phytoplankton at the selected site. PO_4-P varied from 88 (December, 2007) to 195 µg/l (August, 2007). High values of PO_4-P were recorded in summer which can be related to decomposition of organic matter at high temperature, and decrease in water level leading to increase in concentration. Statistically, PO_4-P showed negative and non significant correlation with phytoplankton (r = -0.057).

Phytoplankton composition

Phytoplankton communities do not respond only to natural changes into the lakes, but may also present variations as a consequence of human interventions affecting the water body, either directly or through activities carried on in the basin as a whole. These influences affecting the lakes result in modifications to the structure and composition of the phytoplankton, which may take the form of changes in the taxa of which the algal associations are composed, in the abundance of each taxa, the richness and diversity of the associations, and other community parameters. Finally, due to the interdependence existing between the different organisms of which systems are composed, these variations in the phytoplankton communities translate to changes in the trophic chain and the productivity of the lakes. The biological spectrum of the lentic fresh water bodies are multidimensional where phytoplankton is useful in biomonitoring the ecological disturbance caused by a number of physico-chemical factors, sewage pollutants and other anthrogenic factors.

Limnological charac-teristics of Wular Lake in different seasons are related to the hydrological conditions of the River Jhelum and other inflowing streams also. This influence is reflected in the physico-chemical characteristics and the plankton communities of water in different seasons in present study. Seasonal variations in phytoplankton diversity were very pronounced.

This study however, documented very less number of phytoplankton when compared with the past studies as many of the species might have disappeared due to the heavy pollution. A total of 64 phytoplankton species (Table 1), belonging to four speciose groups, documented in this study indicate diverse nature of phytoplankton in general as well as that of Wular Lake in particular, of which 33 belong to bacillariophyceae, 21 to chlorophyceae, 8 to cyanophyceae and 2 to euglenaphyceae. The order of dominance was: Bacillariophyceae > Chlophyceae > Myxophyceae > Euglenophyceae.

The presence and absence of phytoplankton at the selected site is given in Table 1. Bacillariophyceae (33 species) constituted the most dominate speciose group of phytoplankton. The monthly percent contribution of bacillariophyceae in terms of population density at the selected site is given in Figure 5. Monthly percent contribution of bacillariophyceae varied from minimum of 7.1% (October, 2007) to a maximum of 82.9% (September, 2007). The population density of bacillariophyceae varied from a minimum of 16 no./ml in the month of July, 2007 to a maximum of 394 no./ml in the month of January, 2008 (Figure 7). The most abundant species in terms of population density were *Amphora* sp., *Cyclotella* spp., *Epithemia* spp., *Fragilaria* spp., *Longissima elongatum*, *Meriodion* spp*. Navicula* spp. and *Nitzchia* sp. *Navicula* spp. was recorded to be the most dominant species amongst the bacillariophyceae.

With respect to the phytoplankton communities, bacillariophyceae or diatom group remained dominant in the lake during winter in the present investigation which could be attributed to the fact that they are able to grow under the condition of weak light and low temperature which are less suitable for other algae and low concentration of nutrients (NO_3-N and PO_4-P) in the winter (December- January). The findings are in conformity with the findings of Munawar (1974) and Ganai et al. (2010). Statistically, bacillariophyceae showed negative correlation (r = -0.855) with water temperature at the selected site.

Chlorophyceae (21species) formed the second most speciose group at the selected site. The monthly percent contribution of chlorophyceae in terms of population density amongst different phytoplankton groups at the selected site is given in Figure 5. Monthly percent contribution of chlorophyceae varied from minimum of 7.4% (February, 2008) to a maximum of 64.8 (April, 2007). The number of chlorophyceae varied from a minimum of 21 no./ml in June, 2007 to a maximum of 326 no./ml in the month of May, 2007 at the selected site (Figure 7). The most abundant species in terms of population density were *Chlorella* spp., *Pediastrum* spp., *Spirogyra* spp*.* and *Volvox* spp*.*). Amongst chlorophyceae, *Chlorella* spp. was found to be the most dominant species at the selected site.

Chlorophyceae in present study depicted unimodal spring peak which could be related to increasing temperature in addition to increased phosphorus and nitrate concentration. Kant and Kachroo (1977) and Ganai et al. (2010) also reported a single chlorophycean peak in summer in Kashmir Himalayan lakes. Statistically, chlorophyceae depicted positive but non-significant correlation (r = 0.325) with water temperature at the selected site.

Cyanophyceae formed the third most speciose group of phytoplankton (8) at the selected site. Cyanophyceae are more efficient in utilizing CO_2 at high pH level and low light availability and thus, their abundance indicate the

Table 1. Monthly variations in population density (no./m)of phytoplankton in Wular Lake at Lankrishipora, Kashmir from March 2007 to February 2008 (+ = presence; - = absence).

Genera \ Month	Mar07	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan08	Feb
Bacillariophyceae	-	-	-	-	-	-	-	-	-	-	-	-
Achananthes lanceolata	-	-	-	-	-	-	-	-	+	+	+	-
Amphora spp.	+	-	-	-	-	-	-	-	+	-	+	+
Amphora ovalis	-	-	-	-	-	-	-	-	-	-	-	-
Asterionella formosa	-	-	-	-	-	-	+	-	-	-	+	+
Ceratoneis arcus	-	-	-	-	-	-	-	-	-	-	+	+
Cyclotella spp.	+	+	-	-	-	-	-	-	+	+	+	+
Cymbella cistula	-	+	+	-	-	-	-	-	-	+	+	+
Closteriopsis longissima	+	+	-	-	-	-	+	-	-	+	+	+
Cocconeis placentula	-	-	-	-	-	-	-	-	-	-	+	+
Diatoma spp.	+	+	-	-	-	-	-	-	-	+	+	+
Diatoma vulgare	-	-	+	-	-	-	-	-	-	+	+	+
Epithemia spp.	+	+	-	-	+	+	-	-	-	+	+	+
Eunotia spp.	-	+	-	-	-	-	-	+	-	-	+	+
Frustulia spp.	-	+	+	-	-	-	-	-	-	+	+	+
Fragilaria spp.	-	-	+	-	-	-	-	-	-	+	+	+
Fragilaria capucina	-	-	-	-	-	-	-	-	-	-	-	-
Gomphonema spp.	+	-	-	-	+	+	-	-	-	+	+	+
Gomphonema gracile	-	-	-	-	-	-	-	-	-	-	+	+
Gomphonema germinatum	-	-	+	-	+	-	-	-	-	-	+	-
Longissima elongatum	-	+	+	-	-	-	-	-	-	+	+	+
Melosira spp.	-	-	-	-	-	-	-	+	-	-	+	+
Meridion circulare	-	+	+	-	-	-	-	-	-	-	-	-
Meridion spp.	+	-	-	-	-	-	-	-	+	+	+	+
Navicula spp.	+	+	+	-	-	+	+	+	-	+	+	+
Navicula americana	+	+	+	-	-	-	-	-	-	-	+	+
Nitzchia spp.	+	+	+	-	-	-	-	+	-	+	+	+
Nitzchia vermicularis	-	-	-	-	-	-	-	-	+	+	+	-
Stauroneis spp.	+	+	+	-	-	+	-	-	-	+	+	+
Surirella spp.	+	-	-	-	-	-	-	-	-	-	+	+
Synedra ascus	-	-	-	-	-	+	-	+	-	-	+	+
Synedra radiana	+	-	-	-	-	-	-	-	-	-	+	+
Synedra ulna	+	-	-	-	-	-	+	-	-	+	+	-
Tabellaria spp.	-	-	+	-	-	-	-	-	-	+	+	+
Chlorophyceae												
Actinastrum spp.	+	+	+	-	-	-	+	-	-	-	-	-
Ankistrodesmus spp.	+	+	+	-	-	-	+	-	+	+	-	-
Ankistrodesmus falcatus	-	+	+	-	-	-	-	+	-	-	-	-
Chlorella spp.	+	+	+	-	+	-	+	+	-	+	+	+
Coelastrium sphaericum	+	+	+	-	-	-	-	+	-	-	-	-
Chlamydomonas	-	+	+	-	-	+	-	-	+	+	-	-
Cosmarium spp.	+	+	+	-	+	+	+	-	-	-	-	-
Closterium spp.	+	+	+	-	-	-	+	-	+	+	-	-
Closterium leibleinii	+	+	+	-	-	-	-	-	-	-	+	-
Closterium setaceum	+	+	-	-	+	+	-	-	-	-	-	-
Eudorina spp.	+	+	+	-	-	+	-	-	-	-	-	-
Oedogonium spp.	-	+	+	-	+	+	-	-	-	-	-	-
Pediastrum spp.	+	+	+	-	-	+	+	+	+	-	-	-

Table 1 Contd.

Scenedesmus spp.	-	+	+	+	+	-	-	-	-	-	-	-
Selenastrum spp.	+	+	+	-	-	-	+	-	-	+	+	+
Selenastrum gracile	+	+	+	+	-	-	+	-	-	-	-	-
Spirogyra spp.	+	+	+	-	+	-	-	+	+	-	+	+
Tetraspora spp.	+	+	+	-	+	-	-	-	-	-	-	-
Ulothrix zonata	+	+	+	+	-	-	-	-	-	+	+	-
Volvox spp.	+	+	+	-	+	-	-	+	-	-	+	+
Zygnena spp.	+	+	-	-	+	+	+	-	-	+	-	-
Cyanophyceae												
Anabaena spp.	-	+	+	+	+	+	+	+	-	-	+	+
Lyngbya spp.	-	-	-		+	+	+	+	-	-	-	+
Microcystis spp.	+	-	-	+	+	+	-	-	-	-	+	+
Merismopedia spp.	-	+	-	+	+	+	-	-	+	-	-	-
Nostoc spp.	-	-	+	+	+	-	-	-	+	-	+	+
Oscillatoria spp.	-	+	+	+	+	+	+	+	+	-	-	+
Phormedium spp.	-	-	+	+	+	-	-	+	-	-	+	+
Rivularia spp.	+	+	-	-	+	+	-	+	+	-	+	+
Euglenophyceae												
Euglena ascus	+	+	+	-	-	-	-	-	-	+	+	+
Phacus spp.	+	+	+	-	-	-	-	-	-	-	+	+

eutrophic nature of water body (Lin, 1972).

The monthly percent contribution of cyanophyceae in terms of population density amongst different phytoplankton groups is given in Figure 5. Monthly percent contribution of cyanophyceae varied from minimum of 0.0% (December, 2007) to a maximum of 82.5% (June, 2007). The population density of cyanophyceae varied from minimum of 6 no./ml in the month of march 2007 to a maximum of a 110 no./ml in July, 2007 (Figure 7). The most abundant species in terms of population densities were *Anabaena* spp., *Lyngbya* spp.) and *Oscillatoria* spp. The presence of *Merismopedia* and *Oscillatoria* spp. in the present study indicate the eutrophic nature of water body. Statistically, cyanophyceae showed positive correlation (r = 0.745) with water temperature at the selected site.

Blue-green algal (cyanophyceae) abundance was found to be the major portion in the phytoplankton community during autumn at the selected site. The reasons behind this result may be the moderate temperature, alkaline pH, low water volume and bright sunlight which created favourable condition for better propagation of this group of phytoplankton.

Euglenoid algae form a relatively large and diverse group but few species are truly planktonic (Wetzel, 1983). They are facultative heterotrophs and generally abundant in waters rich in organic matter. Euglenophyceae in the present study formed the least represented group of phytoplankton (2 species), which were represented by only two genera, *Euglena ascus* and *Phacus* spp. The monthly percent contribution of euglenophyceae in terms of population density amongst phytoplankton is given in Figure 5. Monthly percent contribution of euglenophyceae varied from minimum of 0.0% (June, July, August, September, October and November, 2007) to a maximum of 7.2 (April, 2007). *E. ascus* with population density of 72 no./ml was found to be the most abundant species amongst two genera. The number of euglenophyceae were found to vary from a minimum of 6 no./ml in December, 2007 to a maximum of 36 no./ml in May, 2007 (Figure 7). Statistically, euglenophyceae showed negative correlation (r = -0.535) with water temperature at the selected site of the lake.

With respect to the phytoplankton communities, euglenophyceae in the present study started emerging in winter and showed their higher proportion in the phytoplankton community in spring, 2007. Increasing temperature and accumulation of organic loads from surface run-off, autothonous and allocthonus organic load, sewage and clear sun-shine may be the reasons for the dominance of euglenophyceae in spring.

Unni (1993) who analyzed the data from a large number of studies, observed that the species diversity (50 to 100 species) of hypertrophic reservoirs is higher

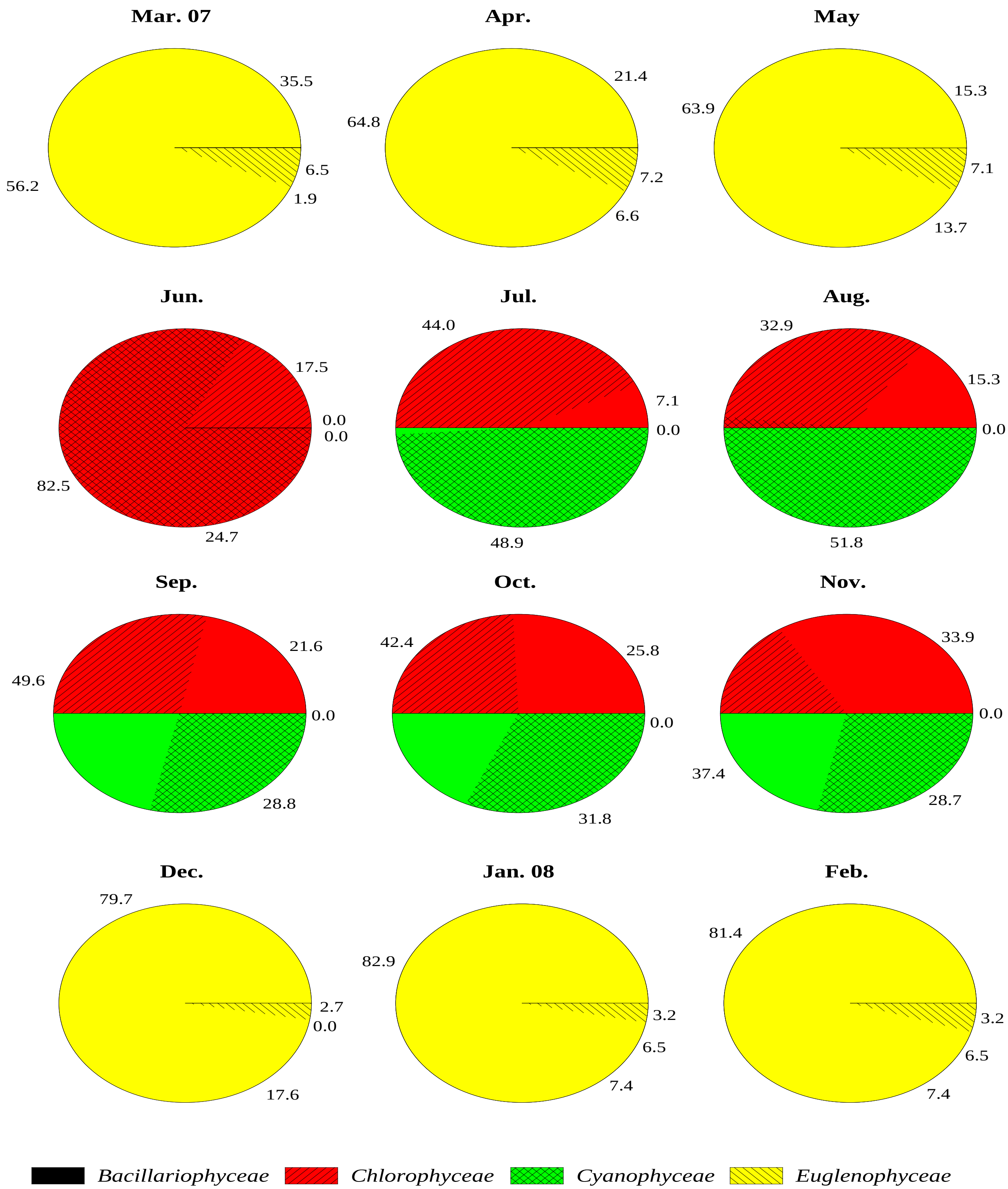


Figure 5. Monthly percent contribution of different phytoplankton groups in Wular Lake at Lankrishipora, Kashmir.

(and similar to that of tropical lakes in Southeast Asia) than that of the oligotrophic reservoirs (about 15 species). In a short term comparative study of nine south Indian reservoirs (between 9_270 and 11_480 N and 240 to 2300 maltitude), Uhlmann et al. (1982) also observed surprisingly large number of phytoplankton taxa (mostly

Table 2. Variation of diversity indices of different groups of phytoplankton in Wular lake, Kashmir during March, 2007 to February, 2008.

Group	Shannon_H	Evenness_e^H/S	Dominance_D
Bacillariophyceae	1.945	0.6355	0.1859
Chlorophyceae	2.094	0.6763	0.1616
Cyanophyceae	2.206	0.8251	0.1252
Euglenophyceae	1.672	0.8872	0.2032

green and blue-green algae) even in waters deficient in orthophosphates.

A number of workers have reported many algal species as indicators of water quality (Naik et al., 2005; Nandan and Aher, 2005; Zargar and Ghosh, 2006). Zargar and Ghosh (2006) in a study on Kadra reserviour of Karnataka listed several algal forms belonging to Chlorophyceae, Cyanophyceae, Euglenophyceae and Bacillariophyceae as indicators of water pollution. The Wular Lake is subjected to pollution due to addition of industrial effluents, fertilizers from agricultural lands and domestic sewage. Progressive enrichment of water with nutrients leads to mass production of algae, which in turn leads to the increased productivity and other undesirable biotic changes.

Nandan and Aher (2005) has shown the algal genera, Euglena, *Oscillatoria, Scenedesmus, Navicula, Nitzschia* and *Microcystis* which are the species found in organically polluted waters. Palmer (1969) has shown that genera like *Schenedesmus, Oscillatoria, Microcystis, Navicula, Nitzschia* and *Euglena* are the species found in organically polluted waters supported by More (1997). Similar genera were recorded in the present investigation thereby showing that lake is organically polluted. The epilethic and epiphytic algae are excellent indicators of water pollution (Round, 1965). In the present study, occurrence of *Oscillatoria, Phormidium, Lyngbya* and *Ulothrix* as epilethic algae and certain diatoms like *Gomphonema, Cymbella* and *Navicula* as epiphytic were recorded. Thus, algal communities can be used as indicators of pollution for assessing the water quality of this lake of international importance. The algae like *Microcystis aeruginosa* was used as the best single indicator of pollution and it was associated with the highest degree of civic pollution (Nandan and Aher, 2005). In the present study, *Microcystis* was also recorded in the selected site. The occurrence of *Oscillatoria* in the present study indicates pollutants of biological origin which agreed with the observations of Gadag et al. (2005).

It is reported that excessive growth of certain algal genera, viz., *Scenedesmus*, *Anabaena, Oscillatoria* and *Melosira* indicate nutrient enrichment of aquatic bodies (Kumar, 1990; Zargar and Ghosh, 2006).The present study on Wular Lake also support the findings. Studies show that the dominant phytoplankton and their seasonality are highly variable in different water bodies according to their nutrient status, age, morphometry and other locational factors (Gopal and Zutshi, 1998).

The study revealed that the water quality parameters such as temperature, pH, nitrate and phosphate play a very important role in altering the phytoplankton distribution. The human anthropogenic are the main causative agents in the increase of the nutrients in this lake of international importance.

Diversity indices

An important application of diversity indices in phytoplankton studies is their usage in the assessment of pollution. Species diversity is a function of species richness and evenness with which the individuals are distributed in these species (Margalef, 1958). Highest values of Shannon-Wiener Index were recorded for cyanophycece (2.206, Table2) and lowest for euglenophyceae (1.672, Table 2). For Indian lakes, the Shannon-Weiner diversity index proposed as diversity index greater than (> 4) is clean water; between 3-4 is mildly polluted water and less than 2 (< 2) is heavily polluted water (Shekhar et al., 2008). Since, the Shannon-Weiner diversity index in the present study ranged between 1.672 - 2.206 in the selected water body, therefore, this water body oscillates between moderately polluted to highly polluted. Maximum evenness values were recorded for euglenophyceae (0.8872, Table 2), being less speciose and evenly distributed and minimum for bacillariophyceae (0.6355). The present results indicate consistently higher phytoplankton even-ness with broadly identical values (Table 2).This reflects equitable abundance of various species throughout the study period. Highest values for species dominance were recorded for eulenophyceae (0.2032) and lowest for cyanophyceae (0.1252, Table 2). Phytoplankton groups indicate lower dominance with concurrent values.

Canonical correspondence analysis (CCA)

For CCA ordination, the group environmental bi-plot (Figure 6) shows the relations of the groups and

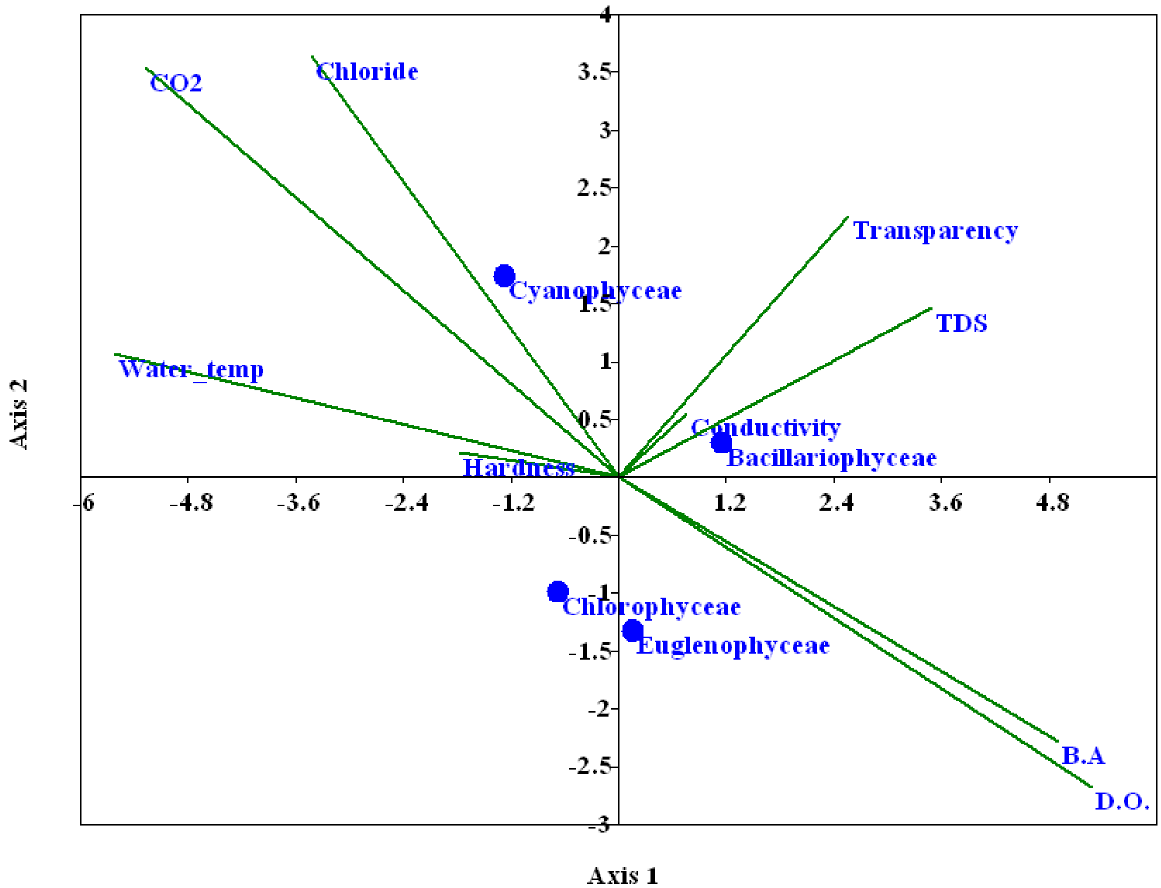


Figure 6. Canonical correspondence analysis (CCA) ordination diagram with 4 phytoplankton groups (Bacilariophycea, Chlorophycea, Euglenophyceas and Cyanophycea) and 9 quantitative environmental variables (lines). The environmental factors are: D.O, water temperaature, bicarbonate alkalinity, hardness, transparency, TDS, choloride, CO_2 and conductivity.

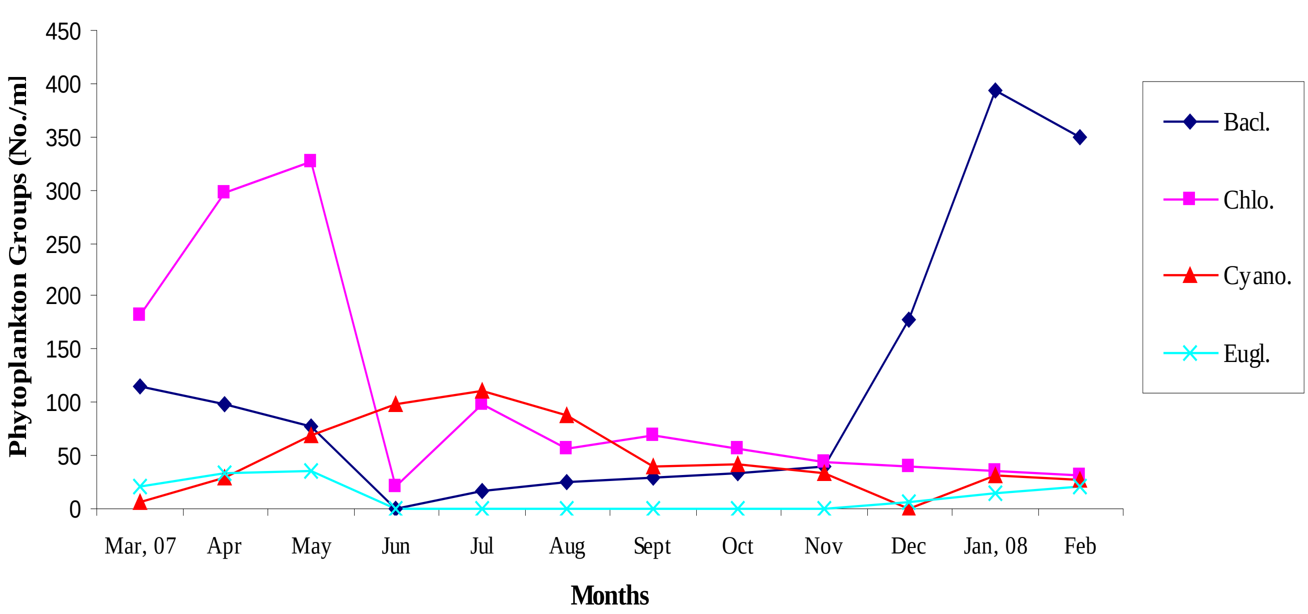
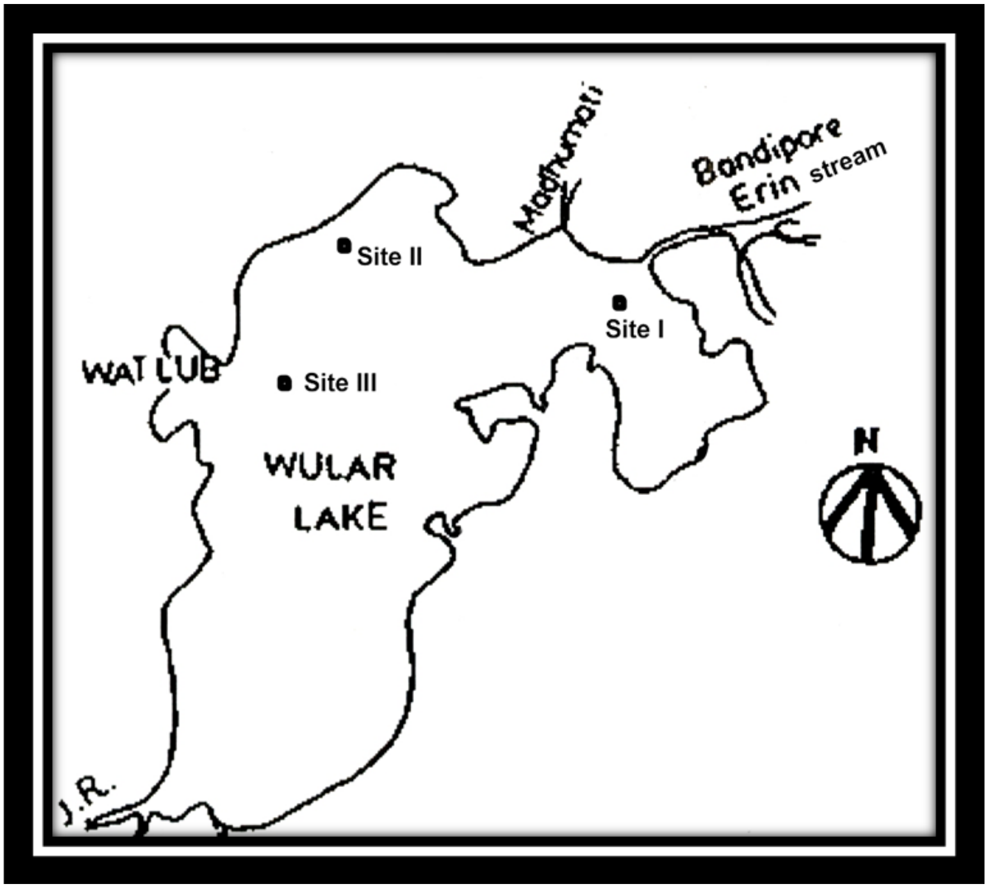


Figure 7. Monthly variations in phytoplankton groups during March, 2007 to February 2008.



Map 1. Wular Lake showing sampling stations. Site 1 (Lankrishipora).

environmental variables with the ordination axis. In the graph, environmental factors are indicated by the line, length of line represents the degree of relationship between sample plots, the distribution of phyto-plankton and environmental factors. The length of the arrow indicates the relative importance of the environ-mental variable in determining the axis. The positions of the group's centers (points) along the ordination axis represent their respective optima along the environ-mental gradient. The group-environmental correlation with axis 1 was 0.39. It correlated well with D.O, water temperature, bicarbonate alkalinity, transparency, TDS, chlorides and CO_2. The bacilariophyceae has the highest values on this axis. Group with lowest corre-lation with this axis was euglenaphyceae. In addition, the analysis make vertical lines connecting a particular group with the line of environmental factors closer to the connecting point near the line of environ-mental factor showing strong positive correlation.

Further, the most important factors affecting phyto-plankton distributions are water temperature, CO_2, chloride, transparency, TDS, alkalinity and dissolved oxygen (Figure 6). However, conductivity, hardness has lesser influence on the distribution of phytoplankton groups. Bacillariophyceae and cyanophyceae showed positive correla-tion with TDS and chloride, respec-tively.

Conclusions

Phytoplankton and its constituent group's speciose reflected the definite periodicity. Bacillariophyceae was the most dominant speciose and eulenophyceae was recorded to be the least speciose. In the current discussion on which index should be used, if any, it is shown that, the diversity index used here can give only a numerical value of the relation between species richness and species evenness. The ecological impor-tance of each species is not included. Until the ques-tion is answered, if a high or low number of indivi-duals, biomass, productivity, etc., make species more or less important in a community, diversity indices re-main just mere numbers.

Further, from CCA, it was concluded that the most important factors affecting the phytoplankton distribu-tion are water temperature, CO_2, chloride, transpa-rency, TDS, alkalinity and dissolved oxygen. However, conductivity and hardness has lesser influence on the distribution of phytoplankton groups.

Recommendation

Based on the seasonal variation of various physico-chemical properties of water and phytoplankton population, an integrated management approach combining capture and culture fishery (subject to provision of infrastructure by Government) during different seasons of the year in this lake of international importance could be taken up for augmenting fish production to a great extent. Further, the lake is facing extinction and as such international community should come to the rescue of this dying lake, before it is too late.

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