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Research Article

Temporal Changes in Environmental Characteristics and Diversity of Net Phytoplankton in a Freshwater Lake

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Abstract: Temporal changes in the species composition, seasonal abundance, and diversity of net phytoplankton (NPP) were investigated in relation to some environmental characteristics of the water and sediment of Lake Krishnasayer, an ancient man-made shallow freshwater lake, located at Burdwan, India, between January and December 2003. In all, 43 species and 7 genera were identified from the weekly samples taken from a 1 × 1 × 1-m water column at sites I and II. The most abundant taxa were Cyanophyta (34.8%-37.8%) and Bacillariophyta (34.2%-34.3%), whilst Euglenophyta was the least abundant (4%-5.3%). The relationships (r) were significant ($P < 0.05$) and positive between water temperature and abundance of Euglenophyta, Secchi transparency, and Chlorophyta and Bacillariophyta, dissolved oxygen and Chlorophyta, dissolved chloride, and Cyanophyta and Euglenophyta, phosphate-phosphorus and Cyanophyta, and organic carbon and Bacillariophyta. In contrast, the relationships (r) were significant ($P < 0.05$), but inverse between water temperature and abundance of Bacillariophyta, Secchi transparency and Euglenophyta, dissolved chloride and Bacillariophyta, nitrate-nitrogen and Euglenophyta, and organic carbon and Euglenophyta. Furthermore, regression coefficients (b) indicated a significant ($P < 0.05$) positive relationship between Secchi transparency and overall NPP abundance, and a significant ($P < 0.05$) inverse relationship between silica and overall NPP abundance. The diversity indicated high values with peaks in species abundance in March, May, and September at site I, and in May, September, and November at site II. The seasonal abundance and frequency of occurrence for a few dominant species of Cyanophyta (e.g., *Anabaena circinalis, Nostoc carneum, Oscillatoria formosa, Rivularia haematitis, and Spirula subsalsa*), Chlorophyta (e.g., *Spirogyra communis, Ulothrix tenerrima, and Zygnema pectinum*), Euglenophyta (e.g., *Euglena viridis*), and Bacillariophyta (e.g., *Cyclotella glomerata, Navicula capitata, Nitzschia acicularis,* and *Pinnularia major*) in the surface water of this lake were 3.3%-5.5%, respectively.

Key Words: Freshwater lake, net phytoplankton, composition, diversity, physico-chemical environment, trophic status

Introduction

Net phytoplankton (NPP) are a ubiquitous component of the algal species near the surface water of freshwater lakes and are collected with plankton nets of the appropriate mesh size (Clesceri et al., 1998). They have often been considered the indicator of water quality (Rawson, 1956; Melack, 1979). NPP species are photosynthetic and are grazed upon by zooplankton and other aquatic organisms (Clesceri et al., 1998). NPP sometimes develop noxious blooms, creating an offensive taste, odour, and toxic conditions that may result in animal death and human illness (Carmichael, 1981). NPP occur in unicellular, colonial, or filamentous forms, and because of their short life-cycle respond quickly to slight fluctuations in the physico-chemical environment, resulting in altered population abundance and species composition in the surface water in which they are found. Although some studies of seasonal abundance of phytoplankton, particularly of micro-, nano-, and picophytoplankton, have been conducted in Africa, Europe, and other regions of the world (Bailey-Watts, 1982; Talling, 1993; Harper et al., 1995; Watson et al., 1997; Scheffer, 1998; Çetin, 2000; Talling & Parker, 2002; Squires & Lesack, 2002; Calijuri et al., 2002; Hirose et al., 2003), relatively few studies have been conducted on the diversity and seasonal abundance of NPP, which may constitute a fraction of the total phytoplankton community, are abundant in the surface water of tropical lakes, and play an important role in maintaining the ecology and water quality of freshwater ecosystems (Parker & Hutcher, 1974).

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Nearly all tropical regions of the world abound in shallow man-made lakes and ponds, but limnological studies of NPP, particularly of taste, odour, filter-clogging, and other surface-water species, have as yet not been done. Furthermore, most previous studies of lakes and fish ponds in India, south-east Asia, and elsewhere deal with the limnology of sub-tropical and high altitude impounded water bodies, dry zone small reservoirs and ponds, or temporary rain water pools in which water level recedes quickly according to temperature conditions (George, 1966, 1969; Sreenivasan, 1974; Khan & Siddiqui, 1977; Das & Upadhya, 1979; Hegde, 1990; Singh, 1990; Amarsinghe & Vijverberg, 2002; Calijuri et al., 2002). In contrast, Lake Krishnasayer, which was constructed in 1691 (Chattopadhyay, 1997), receives a lot of rainwater (1100-1200 mm, annually) and the run-off from the surroundings and regions lying along the shore during the south-west monsoon season (June to September). Furthermore, as there is no evident history on record of its occasional drying up under adverse conditions, nor any history of a large amount of water entering into or escaping from this lake, this freshwater lake can be considered a model eutrophic man-made lake that supports a diverse but dense NPP population, with occasional blooms in the surface water. The aims of this study were: i) to examine the relationship between seasonal NPP abundance and a range of physico-chemical factors of the water and sediment, and ii) to correlate these with the changing ecology relevant to the composition and diversity of NPP in this ancient man-made lake.

Study Area

The present study was conducted in Lake Krishnasayer, a perennial, shallow (8-10 m) man-made freshwater lake of approximately 13.5 ha in Burdwan, India (lat 23º16′N, long 87º54′E) between January and December 2003 (Figure 1).

Materials and Methods

Sampling

Six water samples, 4 from water located 3 m away from the edge of the 4 sides of the lake (site I) and 2 from water from the middle of the lake (site II), were taken 3 times a month between 0800 and 0900 IST (Indian Standard Time). Every sample of the lake's surface water was taken with a 1 × 1 × 1-m water column from a small paddle boat manoeuvred with minimal agitation of water. The NPP were randomly collected in a 50-ml glass tube by filtering the above water column in each quadrant with a nylon monofilament conical plankton net of 75-mm mesh with a 0.25-m mouth diameter. Immediately after the samples were taken, net zooplankters (e.g., ciliates, rotifers, copepods, and cladocerans) were segregated and preserved for future community analysis and bioenergetic studies. The remaining NPP were transferred to another 50-ml glass tube and 0.5 ml modified Lugol's solution was added. These were routinely examined and counted in the laboratory a day after the preservation using an inverted compound Olympus microscope at desired magnifications (Wetzel & Likens, 1991).

NPP Count

NPP that settled down at the bottom of the tube were thoroughly mixed and 1 ml of this sample was transferred with a large-bore 1-ml pipette to a Sedgwick-

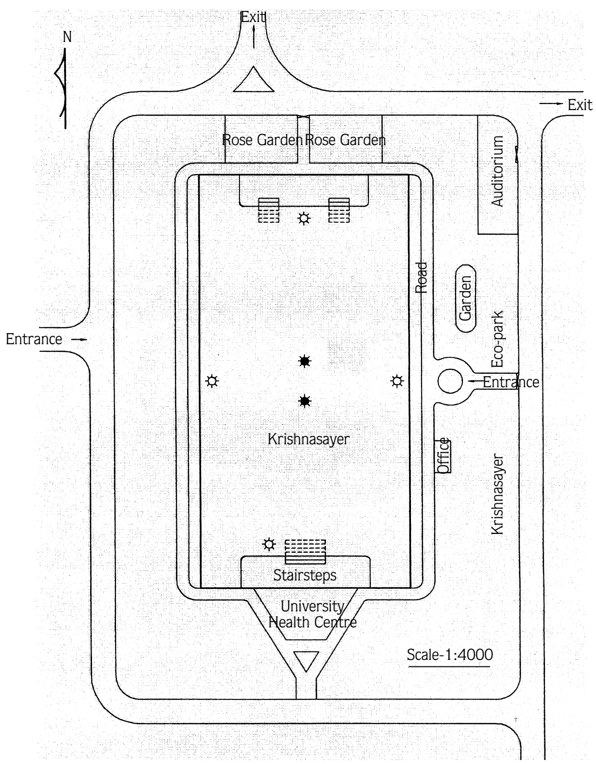

Figure 1. Schematic representation of the location of the NPP sampling sites in Lake Krishnasayer, Burdwan, West Bengal, India (✷ = site I with 4 sampling points located at the 4 sides of the lake, and ☼ = site II with 2 sampling points located in the middle of the lake).

Rafter (S-R) plankton counting cell for determining the number and composition of the sample. The count was made in random fields and repeated 5 times for each sample. The number of NPP (cells, colonies, or filaments) per millilitre was enumerated as follows:

$$\text{No./ml} = \frac{C \times 1000\ \text{mm}^3}{A \times D \times F}$$

where C = number of organisms counted, A = area of field, mm^2, D = depth of a field (S-R cell depth) mm, and F = number of fields counted.

Data obtained for a particular species from site I and site II samples were pooled, except for the seasonal diversity, which was determined by keeping the data (i.e. monthly data from site I and site II) for sites I and II separate.

NPP were identified and recorded across seasons following the methods outlined by Krammer & Lange-Bertalot (1991), Cox (1996), and Wehr & Sheath (2003). A few NPP were enumerated only to genus level as the identification of individuals to species level was impossible or excessively time consuming. Taxa were grouped in classes, as the aim of the present study was a broad overview of NPP composition and diversity rather than an in-depth study of the community structure and succession in the surface water. Furthermore, working with these groups would reduce the complexity (due to a few rare species present in small numbers and a few dominant species present in large numbers) of the seasonal abundance and diversity in this freshwater ecosystem.

Simpson's diversity (D) scores were calculated for all samples counted and analyses compared 2 sites and seasons to determine if any change in NPP diversity could be seen in this lake. The index (Simpson, 1949) was

$$\text{No./ml} = 1 - \sum \left(\frac{n_i}{N}\right)^2 ,$$

where n_i is the proportional numerical abundance of each species i.

Environmental characteristics

Non-depth (> 1 m) water temperature and pH were measured in situ with a certified mercury-filled Celsius thermometer sensitive to 0.1 °C and a digital pH meter (Hanna instruments, Portugal), respectively. Secchi depths were measured once on each sampling date at 1200 IST with a 20-cm diameter black and white Secchi-disc. All water samples for chemical analysis were taken at approximately the same time of the day (i.e. between 0800 and 0900 IST). Water samples for dissolved oxygen, combined carbon dioxide, dissolved chlorides, and silica were analysed following the methods outlined by Wetzel & Likens (1991) and Clesceri et al. (1998). Furthermore, one portion (15-20 ml) of each water sample was filtered through Whatman No. 41 filter paper, and the filtrate was used for determining concentrations of total dissolved nitrate-nitrogen and phosphate (orthophosphorus) using a UV-Vis spectrophotometer (Chemito 2100) with standardised chemicals and procedures (Solorzano & Sharp, 1980; Clesceri et al., 1998). The percentage of organic carbon in the sediment was determined by the method described by Chhatwal et al. (1996).

Data analysis

Means are followed by standard errors throughout. To explore the magnitude and direction of association of the physico-chemical parameters amongst themselves, and the relationship between NPP abundance and the physico-chemical environment of the lake, correlation coefficients (r) were calculated following the procedure described by Zar (1996). The observed (r) values were then compared to the table values at $P < 0.05$ level of significance. Scattergrams, resulting from plotting changes in overall NPP abundance (dependent variable) against corresponding changes in the physico-chemical factors (independent variables), and the fitted regression lines ($y = a + bx$) were computed to predict any change in the quantitative relationship between the dependent and independent variables.

Results

The 43 NPP species identified across seasons (7 identified to genus only) are listed in Table 1. The most abundant groups were Cyanophyta (35.8%; dominated by *Anabaena circinalis, Nostoc carneum, Oscillatoria formosa, Rivularia haematites,* and *Spirulina subsalsa*),

Table 1. NPP species recorded from the surface water of Lake Krishnasayar between January and December 2003 (% by number = contribution of species to the total number of net phytoplankters recorded across seasons, % frequency of occurrence = percentage of plankton nets in which the species was recorded).

Taxa	% by number	% frequency of occurrence
Cyanophyta (16 spp.)	35.8	-
Anabaena circinalis (Rabenhorst) Bornet & Flahault	5.0	100
Komvophoron constrictum (Szafer) Anagnostid & Komorek	0.6	58.3
Calothrix braunii Bornet & Flahault	0.3	50.0
Calothrix sp.	2.4	75.0
Cylindrospermum stagnale (Kützing) Bornet & Flahault	0.4	50.0
Gloeotrichia echinulata (J.E.Smith) P.Richcter	1.3	83.3
Rosenvingiella radicans (Kützing) Rindi, McIvor & Guiry	1.2	83.3
Microcoleus subtorulosus (Brebisson) Gomont	0.6	66.6
Microcystis biformis (A.Braun) Rabenhorst	1.6	75.0
Nodularia spumigena (Mertens) Bornet & Flahault	0.6	59.7
Nostoc carneum (C.Agardh) Bornet & Flahault	5.2	100
Oscillatoria formosa (Bory) Gomont	5.5	100
Oscillatoria limosa (C.Agardh) Gomont	1.4	58.3
Plectonema sp.	1.8	91.6
Rivularia haematites (de Candolle) Bornet & Flahault	3.5	100
Spirulina subsalsa (Oersted) Gomont	4.4	100
Chlorophyta (15 spp.)	24.7	-
Chlamydomonas globosa Snow	3.2	91.6
Chlorococcum infusion (Schnank) Meneghini	1.6	75.0
Gleococcus sp.	0.5	66.6
Hydrodictyon reticulatum (Linnaeus) Lagerheim	0.6	66.6
Mougeotia genuflexa (Dillwin) C.Agardh	0.5	75.0
Pediastrum sp.	1.8	83.3
Schizomeris leibleinii Kützing	0.3	50.0
Spirogyra communis (Hassal) Kützing	3.3	100
Tetraedron limnectum Borge	2.2	66.6
Ulothrix tenerrima Kützing	3.8	100
Ulothrix zonata (Weber & Mohr) Kützing	0.3	50.0
Volvox aureus Ehrenberg	0.2	33.3
Zygnema pectinatum (voucher) Agardh	4.0	91.6
Closterium sp.	1.7	83.3
Desmidium grevilli (Kützing ex Ralfs) de Bary	0.7	75.0
Euglenophyta (2 spp.)	5.3	-
Euglena sp.	0.2	41.6
Eugulena viridis Ehrenberg	5.1	100
Bacillariophyta (17 spp.)	34	-
Asterionella formosa Hassall	1.2	83.3
Cocconeis placentula Ehrenberg	1.5	75
Cyclotella glomelata Bachmann	4.5	100
Denticula pelagica Hustedt	0.3	50.0
Diatoma valgare Bory	2.8	100
Fragellaria construens (Eherenberg) Grunow	0.2	34.7
Gonphonema parvulum (Kützing) Kützing	0.4	50
Aulacoseira granulata (Ehrenberg) Simonsen	1.3	100
Meridion circulare (Greville) C.Agardh	0.5	66.6
Navicula capitata Ehrenberg	4.0	100
Navicula lanceolata Kützing	1.2	58.3
Nitzschia acicularis (Kützing) W.Smith	4.0	100
Nitzschia linearis (Agardh) W.Smith	0.6	66.6
Pinnularia major (Kützing) Rabenhorst	5.2	100
Pinnularia viridis (Nitzsch) Ehrenberg	1.1	58.3
Synedra capitata Ehrenberg	2.7	100
Tabellaria sp.	2.5	91.6

Bacillariophyta (34%; dominated by *Cyclotella glomerata*, *Diatoma* vulgare, *Navicula lanceolata, Nitzschia acicularis Pinnularia major, Synedra capitata*, and *Tabellaria* sp.), and Chlorophyta (24.7%; dominated by *Chlamydomonas globosa, Spirogyra communis, Ulothrix tenerrima*, and *Zygnema pectinatum*). The abundance of Euglenophyta (5.3%), dominated by *Euglena viridis*, was much lower. All this indicates a Cyanophyta-Bacillariophyta-Chlorophyta dominance (94.5%) in the surface water NPP assemblage. Furthermore, Cyanophyta were abundant in May, June, July, August, September, November, and December, whereas Bacillariophyta were abundant in January, February, March, April, and October (Figure 2).

The environmental characteristics of the water and sediment of Lake Krishnasayer differed from season to season (Figure 3). Because of the shallowness of the lake thermal stratification did not occur, and the water temperature reached its high in May (34.5 °C) and its low in January (20 °C). Water temperature in July and August, however, was moderate (28-28.2 °C), probably because of the cooling effect of the water mass that entered the lake after heavy monsoon rains during this period. Secchi transparency peaked in April (27 cm) and was the lowest in July (19 cm), while the lake water was always alkaline and pH varied from 9.8 in April to 7.6 in January. The highest dissolved oxygen content was in April (9.5 mg l^{-1}) and lowest in January (5.6 mg l^{-1}), whereas combined carbon dioxide concentration was highest in September (210.2 mg l^{-1}) and lowest in April (108 mg l^{-1}). In contrast, the highest concentration of chloride was in May (4.5 mg l^{-1}) and lowest was in September (2.2 mg l^{-1}). Concentrations of nitrate-nitrogen and orthophosphate phosphorus were highest in January (0.72 mg l^{-1} and 6.1 µg l^{-1}, respectively) and lowest in July and August (0.34 mg l^{-1} and 4.5 µg l^{-1}, respectively). In contrast, the dissolved silica (mg l^{-1}) and organic carbon content (%) in the sediment were highest in July (14.8 mg l^{-1}) and December (1.9%) and lowest in January (5.8 mg l^{-1}), and July and August (1.2%), respectively (Figure 3).

Simple correlations (r) between water temperature and pH, chlorides, silica, and organic carbon revealed significant differences ($P < 0.05$), while r between the concentration of silica and Secchi transparency, nitrate-nitrogen, and organic carbon revealed significant differences ($P < 0.05$) (Table 2).

Furthermore, r between physico-chemical factors and NPP abundance revealed the following significant differences ($P < 0.05$): between water temperature and Euglenophyta, between Secchi transparency, and

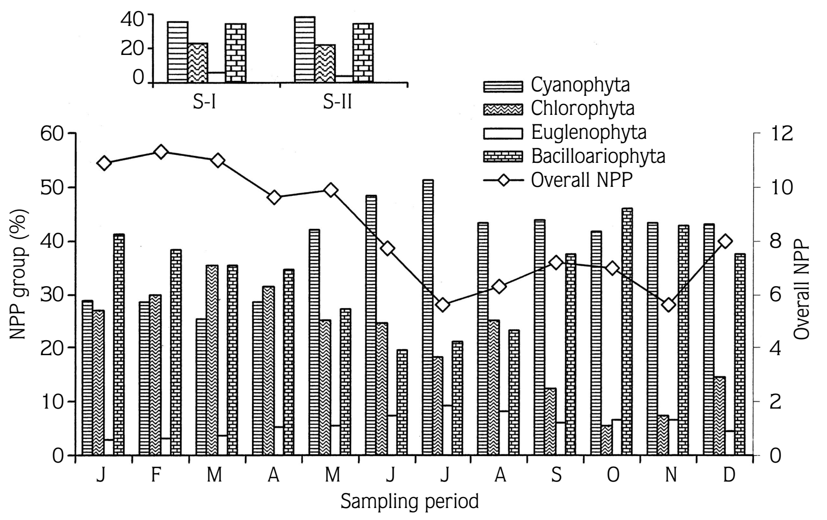

Figure 2. Characteristics of the NPP assemblage across seasons in Lake Krishnasayer surface water [inset: NPP group abundance (%) for site I (S-I) and site II (S-II); for further explanation, see text].

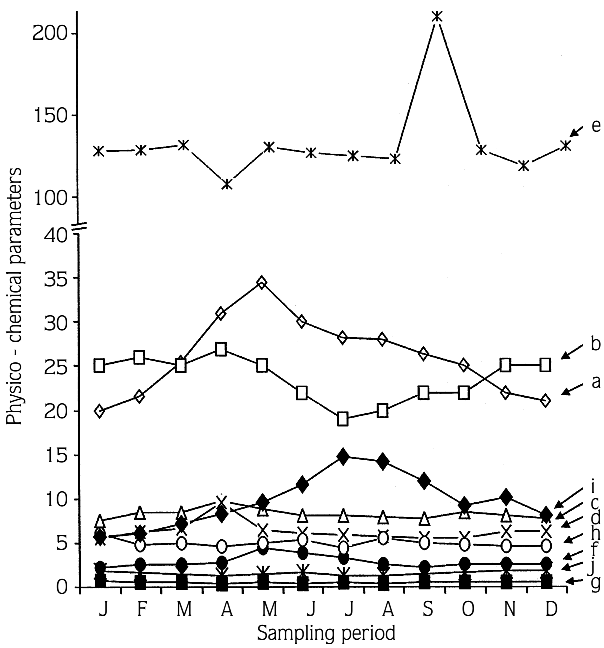

Figure 3. Environmental characteristics of the water and sediment of Krishnasayer across the seasons [a = water temperature (°C), b = transparency (cm), c = pH, d = dissolved oxgen (mg/l), e = combined carbon dioxide (mg/l), f = dissolved chlorides (mg/l), g = nitrates (mg/l), h = phosphates (µg/l), i = silica (mg/l), and j = organic carbon (%)].

Chlorophyta and Bacillariophyta, between pH and Chlorophyta, between dissolved oxygen and Chlorophyta, between combined CO_2 and Cyanophyta, between dissolved chloride, and Cyanophyta and Euglenophyta, between nitrate-nitrogen and Bacillariophyta, between orthophosphate phosphorus and Cyanophyta, between silica and Euglenophyta, and between organic carbon and Bacillariophyta (Table 3). In contrast, r between physico-chemical factors and NPP abundance revealed differences that were significant ($P < 0.05$), but inverse, as follows: between water temperature and Bacillariophyta, between Secchi transparency and Euglenophyta, between pH and Euglenophyta, between dissolved oxygen and Cyanophyta, between dissolved chloride and Bacillariophyta, between nitrate-nitrogen and Euglenophyta, between silica, and Chlorophyta and Bacillariophyta, and between organic carbon and Euglenophyta. Furthermore, scattergrams with fitted regression lines revealed that the relationships between changes in overall NPP abundance and physico-chemical parameters of Lake Krishnasayer between January and December 2003 were linear (Figure 4a-j). The relationship between overall NPP abundance and Secchi transparency was significant ($P < 0.05$), whereas the relationship between overall NPP abundance and silica was significant ($P < 0.05$), but inverse (Figures 4b, i).

Table 2. Correlation coefficients (r) between various physico-chemical parameters of the water and sediment of Lake Krishnasayer between January and December 2003 (n = 36).

	Temperature	Transparency	pH	Dissolved oxygen	Combined CO_2	Dissolved chlorides	Nitrate-nitrogen	Phosphate (Ortho) phosphorus	Silica	Organic carbon
Temperature		–0.22	0.581*	0.282	–0.007	–0.503*	0.013	–0.008	0.473*	–0.76*
Transparency			0.050	0.065	–0.034	–0.017	–0.003	0.010	–0.864*	0.44
pH				0.079	–0.262	–0.176	–0.080	–0.050	–0.156	–0.45*
Dissolved oxygen					–0.188	–0.144	–0.090	–0.060	–0.231	–0.37
Combined CO_2						–0.108	–0.152	–0.168	0.175	–0.04
Chlorides							–0.150	–0.134	0.296	–0.29
Nitrates								–0.116	–0.65*	0.60*
Phosphates									–0.1	0.09
Silica										–0.664*
Organic carbon										

Significant differences are indicated by *($P < 0.05$).

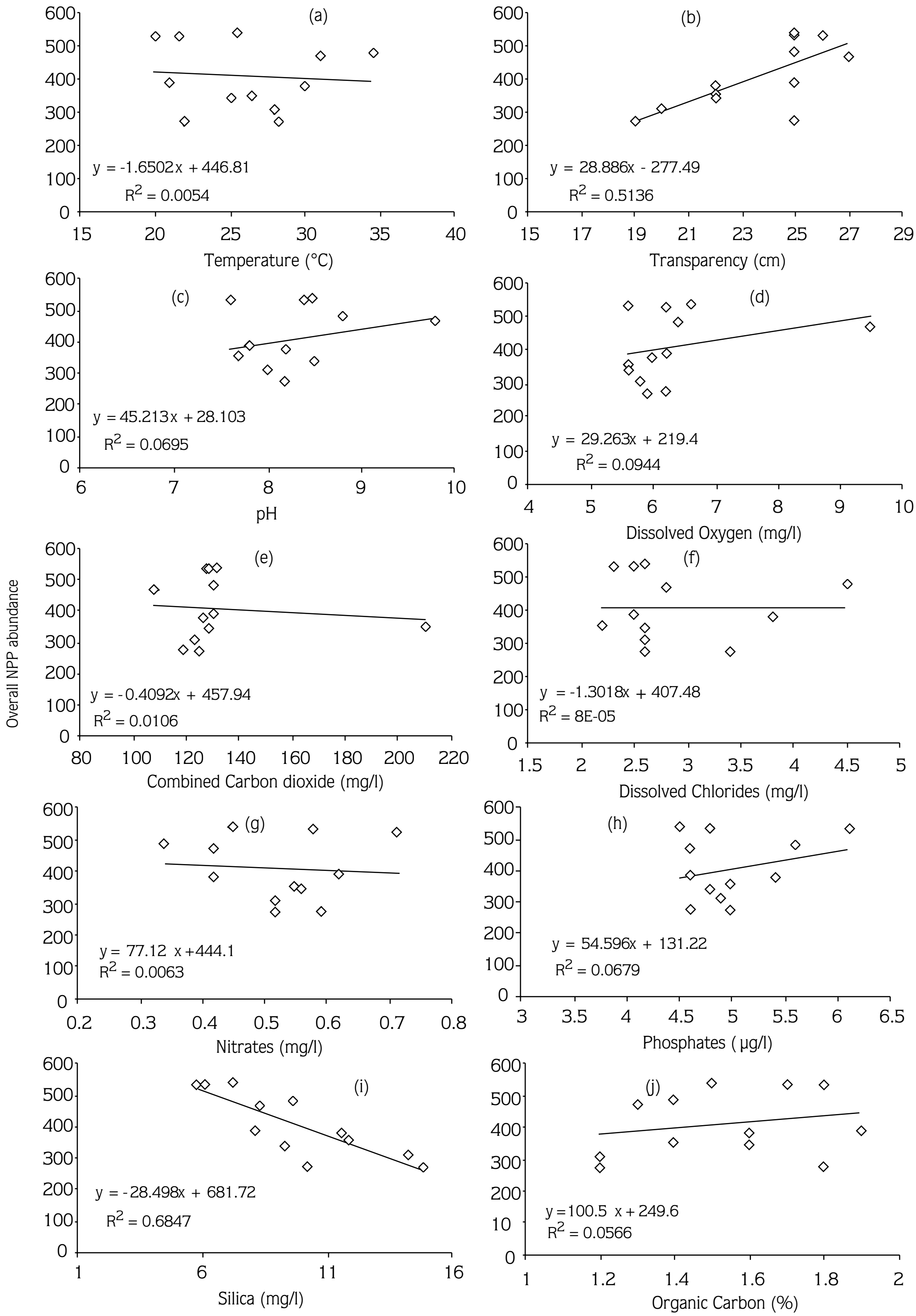

Figure 4. Scattergrams with fitted regression lines showing linear relationships between changes in NPP abundance and physico-chemical parameters of the water and sediment of Lake Krishnasayer between January and December 2003.

The Simpson's scores showed small fluctuations in NPP diversity across seasons (Figure 5). The diversity was greatest in March (0.9993) and lowest in November (0.9976) for site I (Figure 5a), while it was greatest in May (0.9991) and lowest in August (0.9938) for site II (Figure 5b). This suggests that the processes affecting NPP diversity operated almost equally throughout the surface water and across all seasons. Nonetheless, 3 small peaks of NPP diversity were observed in March, May, and September for site I, and in May, September, and November for site II.

Discussion

Freshwater ecosystems are subject to temporal changes that cause uncertainty in phytoplankton composition and assemblage (Çetin, 2000; Calijuri et al., 2002). Changes in the relative abundance and occurrence of the most common NPP species in the studied lake are summarised in Table 1. Comparisons of 43 species and 7 genera identified from samples taken from site I with those identified from samples taken from site II reveal that NPP composition was generally similar for the 2 sites

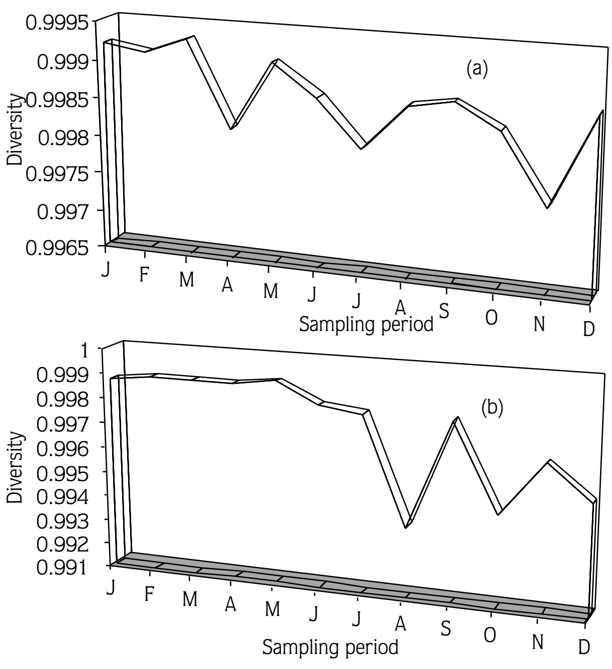

Figure 5. Simpson's diversity of NPP species for site I (a) and site II (b) of Lake Krishnasayer surface water between January and December 2003.

(Figure 2). This was probably because of the similar type of environment and stagnant condition that has prevailed in this shallow freshwater lake for years. On the other hand, competition among NPP for common resources in a confined environment like Lake Krishnasayer may lead some species to face temporary exclusion, as was seen in 2 species of Chlorophyta (*Chosterium* sp. and *Desmidium gravelli*) during October and November, when these were absent from the surface water. In contrast, the abundance of 16 species of Cyanophyta and 17 species of Bacillariophyta was greatest in July (48.8%) and October (46%), and lowest in March (21.7%) and June (19.4%), respectively. As a result, overall NPP abundance showed some dramatic increases and decreases, with little change in species composition in the surface water. In many temperate lakes, the maxima of phytoplankton abundance and blooms were detected in summer (e.g., Maeda et al., 1992), or in spring and summer (e.g., Talling & Parker, 2002), but in Lake Krishnasayer, the extraordinary occurrence of 3 NPP blooms (in February, May, and September) and a relatively high NPP abundance in December were observed (Figure 2). Records for recent decades from shallow lakes furnish evidence that phytoplankton in surface waters have less long-term stability than those in stratified deep lakes, with regard to species composition and seasonal cycles (Bailey-Watts, 1982; Scheffer, 1998). Nevertheless, many of the environmental factors that regulate and give structure to NPP abundance and population cycles in Lake Krishnasayer are probably physical and chemical, sometimes associated in groups or associated in time-sequence with the increase and decrease in water temperature, transparency, pH, dissolved oxygen, dissolved chlorides, silica, and nutrient elements, such as nitrate-nitrogen and phosphate-phosphorus (Table 3). Other factors involved in regulating the structure may be biological (composition and abundance of zooplankton and pathogenic agents), toxic substances, and mixing of water by strong winds during the south-west monsoon season.

Nutrient limitation is also an important factor for phytoplankton abundance in shallow freshwater lakes (Scheffer, 1998; Hubble & Harper, 2002; Hirose et al., 2003). Results of an artificial lake fertilisation experiment demonstrated that phytoplankton abundance was often limited by the concentration of nitrogen rather than by the concentration of phosphorus (Stockner & Shortreed,

Table 3. Correlation coefficients (r) between the abundances of NPP and physico-chemical parameters of Lake Krishnasayer between January and December 2003 (n = 36).

Class	Temperature	Transparency	pH	Dissolved Oxygen	Combined CO_2	Dissolved Chlorides	Nitrate-nitrogen	Phosphate-phosphorus	Silica	Organic carbon
Chlorophyta	0.119	0.556*	0.385*	0.451*	–0.288	0.096	–0.270	0.172	-0602*	-0.06
Cyanophyta	0.280	–0.075	–0.254	–0.378*	0.347*	0.550*	–0.218	0.514*	0.038	0.21
Euglenophyta	0.937*	–0.453*	–0.423*	0.227	–0.049	0.570*	–0.834*	0.062	0.663*	-0.64*
Bacillariophyta	–0.502*	0.753*	0.091	0.163	0.025	–0.458*	0.361*	0.064	-0.942*	0.47*

Significant differences are indicated by * ($P < 0.05$).

1988). However, in Lake Krishnasayer, seasonal increase in the nitrogen-phosphorus ratio corresponded with the increased NPP abundance in the surface water, except in July and August when this relationship was reversed, probably due to the reduced concentration of nitrogen due to monsoon rains. Furthermore, seasonal changes in the concentration of phosphate-phosphorus and overall NPP abundance demonstrated an insignificant ($P > 0.05$) positive relationship (Figure 4h), suggesting that phosphate-phosphorus was the nutrient for growth, but not the limiting one for overall NPP abundance in this lake. In contrast, the seasonal change in the concentration of NO_3-N and overall NPP abundance demonstrated an insignificant ($P > 0.05$) inverse relationship (Figure 4g), suggesting that NO_3-N was also the nutrient for growth and the limiting one for overall NPP abundance in this lake. Apart from this, the effectiveness of the sediment to transfer organic carbon (bottom-up) to supplement NPP growth and abundance under nitrogen- or phosphorus-deficient conditions in this lake was lacking as the organic carbon level was always low, differing only slightly (from 0.1% to 0.7%) from season to season (Figure 3). Contrary to reports of the transfer of atmospheric P to P-deficient upland water (e.g., Gibson et al., 1995), atmospheric NO_3-N in precipitation to N-deficient temperate lake water (e.g., Talling & Parker, 2002), or sediment stocks of P and N to P- and N-deficient lake water (e.g., Pentecost, 1998), results of the present investigation demonstrated little transfer of atmospheric P and N to enhance the concentration of P and N of the studied lake (Figure 3).

Melack (1979) distinguished phytoplankton seasonality in shallow tropical freshwater bodies, and maintained that temporal variations of phytoplankton in lakes corresponded with differences due to rain. Considering that lake Krishnasayer, typical of such aquatic ecosystems, receives significant monsoon rainfall, as well as runoff every June-September resulting in enhanced concentrations of suspended sediment, inorganic particles, and dissolved organic matter, these in turn might have interfered with light penetration and adversely affected seasonal abundance and diversity of net phytoplankters in this lake. Consistent with the data, the seasonal diversity was lowest in July and August for site I (Figure 5a) and site II (Figure 5b), respectively. The diversity peaked in March, May, and September (Figure 5a) and May, September, and November (Figure 5b) corresponded with the abundance of a few species of Cyanophyta (e.g., *Anabaena circinalis*, *Nostoc carneum*, *Oscillatoria formosa, Rivularia haematitis*, and *Spirulina subsalsa*), Chlorophyta (e.g., *Spirogyra communis, Ulothrix tenerrima*, and *Zygnema pectinum*), Euglenophyta (e.g., *Euglena viridis*), and Bacillariophyceae (e.g., *Cyclotella glomerata*, *Navicula capitata, Nitzschia acicularis*, and *Pinnularia major*). As this lake experiences stagnant conditions for years, there is a possibility of demonstrating high scores for species diversity and low scores for species composition amongst NPP.

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