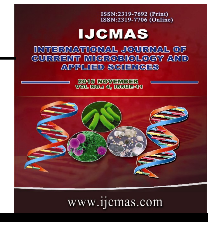

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Original Research Article

Seasonal Changes in Phytoplankton Community of Lake Ramgarh, India

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A B S T R A C T

The seasonality of primary productivity, phytoplankton density and species diversity of Lake Ramgarh was studied together with physico-chemical factors for one year on the basis of monthly sampling. Correlation between various physico-chemical parameters, productivity and plankton groups were also calculated according to Karl Pearson's formula. The gross and net primary productions were recorded high (1.99 and 1.47 $gCm^{-3}h^{-1}$ respectively) during summer while relatively low (0.62 and 0.42 $gCm^{-3}h^{-1}$ respectively) during the winter season. The phytoplankton community of the lake belonged to three major groups and according to their density these groups ranked *Bacillariophyceae (43.58%) > Chlorophyceae (33.41%) > Cynophyceae (23%). Nitzschia*, *Synedra* and *Navicula* were the main contributors in density of *Bacillariophyceae.* Group *Chlorophyceae* was dominated by *Closterium* and *Chlorella* while *Spirulina*, *Anabaena* and *Microcystis* were the most common genera of *Cynophyceae*. These dominant forms also exhibited a clear seasonal succession. The phytoplankton number, represented by 32 species, also fluctuated seasonally, but tended to increase (20) in the summer period. At the same time the temperature (31.3^{o}C) and concentration of dissolved O_2 (9.5 mgL^{-1}) and nutrients (Nitrate 10.8 mgL^{-1}, Nitrite 1.8 mgl^{-1}, Phosphate 0.12 mgL^{-1}, Sulphate 20.7 mgL^{-1}) were also found higher. These results suggest that temperature, dissolved O_2 and nutrients play a crucial role in the primary production and phytoplankton dynamics for Lake Ramgarh.

K e y w o r d s

Lake Ramgarh, Phytoplankton, Primary production, Nutrients, Seasonal succession

Introduction

Phytoplanktons are single celled organisms, physiologically similar but microscopically smaller as compared to land plants. Like land plants, phytoplankton fix solar energy and carbon through photosynthesis, making it available for higher trophic levels (Gliwicz, 2002; Auer *et al.*, 2004). Evolutionarily, they are the descendants of the ancestors which gave rise to both animals and plants more than 500 million years ago (Keeling *et al.*, 2004). Phytoplanktons are regarded as the chief primary producers, forming an important link between the abiotic factors and the biota in any aquatic environment (Hulyal and Kaliwal, 2008). The magnitude and dynamics of phytoplankton are increasingly considered as bioindicators to assess the trophic status of an aquatic ecosystem (Baruah and Das, 2001; Shashi Shekhar *et* *al.,* 2008). Phytoplankton standing crop exhibits definite seasonal patterns in aquatic ecosystems, based on several factors (Temponeras *et al,* 2000; Khuantrairong and Traichaiyaporn, 2008). The supply levels of major nutrients, light, grazing, water mixing regimes, basin morphometry and drainage from catchment area, for example, are known to influence the seasonal variations of phytoplankton abundance and primary production (Kagami *et al.,* 2006).

Rajasthan in spite of being a recognized state of arid condition is characterized by large number of water bodies both natural and manmade. These water bodies of arid and semi arid region are characterized by very low precipitation largely confined to the rainy season and extremely hig temperature. Jamwa Ramgarh Lake is an important water body of Jaipur, Rajasthan, India.it also source of potable water in addition to irrigation and pisciculture. But this water body is under constant threat due to scanty rains and increased human activities. It is therefore, essential to manage scientifically this water body to tap it maximum potentiality. So in the present study, an attempt was made to examine the seasonal variation of phytoplankton community and primary productivity of Lake Ramgarh with special reference to physical and chemical parameters of lake water.

Materials and Methods

Study area

Ramgarh Lake is situated 3 km from Jamwa Ramgarh village and about 30 km. away from Jaipur city in the northeast direction. It lies between 27°32′ N latitude and 75°32′ E longitude at an elevation of 132.5 m above MSL. It is a huge artificial lake which was created by constructing a high bund amidst tree covered hills for drinking water supply to Jaipur city. The catchment area of 769 km^2 drains mostly the Aravalli hill ranges. At full reservoir level, reservoir covers 1260 ha and has a maximum length of 7 km. The capacity of the reservoir is 59 million m^3, the maximum and mean depths being 12.0 m and 10.2 m respectively. It has a shoreline of 22.8 km and the shoreline development is 1.81.

Sample collection and estimations

The studies were continued for a period of one year from October, 2005 to September, 2006. The water and plankton samples were collected during morning hours on monthly basis from five different locations (1-5) of Ramgarh Lake in Jaipur (Fig. 1). For physico-chemical studies, water samples were collected in 500 ml plastic bottles. The water temperature was recorded by mercury thermometer for each site under study. Dissolved oxygen (DO_2) was fixed on the spot in biological oxygen demand (BOD) bottles, brought to laboratory and analyzed by modified Winkler's method (APHA, 1995). Various parameters like free carbon dioxide (free CO_2), alkalinity, salinity, hardness, total solids (TS), biological oxygen demand (BOD) and chemical oxygen demand (COD) were estimated according to APHA (1995). Nitrate (inorganic) and phosphate (ortho) were estimated by the spectrophotometric method (Systronics 119).

For the study of phytoplankton, the water samples were transferred to 500 ml polyethylene bottles. Then, 5 ml Lugol's iodine solution and 10-15 ml 4% formalin were added to it for fixation and preservation of planktonic cells. The organisms were identified under a microscope using specialized literatures (Edmondson, 1965; Needham and Needham, 1978; APHA, 1995). One ml of plankton sample was drawn and transferred to the Sedgwick Rafter counting cell for quantitative analysis. Each sample was counted five to eight times and average was taken for calculation. Density of plankton was calculated at each site, and expressed in No x 10^8 L^{-1}.The frequency of occurrence of different phytoplankton species is represented as: dominant (50% or more), common (between 10% and 50%) and rare (below 10%).

Primary productivity (GPP=Gross Primary Productivity and NPP= Net Primary Productivity) was measured following dark and light bottle method (Gaarder and Gran, 1927). For this study 250 ml corning glass bottles were employed. The dark bottles were painted and further covered with cloth bag of black colour to prevent entry of sun light. Bottles used for incubation were suspended horizontally in the surface water for three hours. Before and after the incubation the dissolved oxygen was fixed in the field itself and estimated by the Winkler's method. These oxygen values were converted to carbon values by multiplying with the factor of 0.375 (Sreenivasan, 1964). The results were computed in gC m^{-3} h^{-1} for GPP, NPP and respiration. The correlation of various physico-chemical parameters, phytoplankton groups and primary production were tested using Pearson Product- Moment Correlation (Pearson, 1920).

Results and Discussion

Phytoplankton density, diversity and productivity

The physico-chemical factors were varied from season to season as shown in table 1. During the present study, water temperature varied between 16.0 and 31.3°C. Salinity values varied from 3.1 to 39.1 mgL^{-1} and the pH ranged between 7 and 8.7. The maximum and minimum values for hardness were 100.4 mgL^{-1} and 127.2 mgL^{-1} respectively. Nitrate and phosphate content ranged between zero to 10.8 mgL^{-1} and 0.04 to 0.12 mgL^{-1}respectively. Water temperature, pH, dissolved O2, alkalinity, total hardness and nutrient concentrations showed maximum values during summer due to high temperature which enhanced evaporation of water resulting concentration of the salts (Nasar and Sharma, 1980). But total solids and salinity showed maximum values during monsoon. This may be due to inflow of soil and agriculture waste from the catchment area.

The phytoplankton community of the lake belonged to three major groups and ranked Bacillariophyceae (diatoms) > Chlorophyceae (green algae) > Cyanophyceae (blue green algae) during the study period. It is apparent from Table 2 that out of 32 species reported, 12 belonged to Chlorophyceae, 11 to Bacillariophyceae and 9 to Cyanophyceae. The total density of phytoplankton recorded varied between 174.0 cells x 10^8 L^{-1} in January and 510.6 cells x 10^8 L^{-1} in June 06 as shown in figure 2. The observation indicates that numerically Chlorophyceae dominated during March to June. Bacillariophyceae was dominated for 7 months from July to August and from October to February while in the month of September Cyanophyceae was the dominant group.

Observations on the seasonal distribution of different groups of phytoplankton with respect to their species number and density are presented in the figure 3. It is apparent from these figures that species diversity and total density was maximum in summer. It may be suggested that nutrient enrichment enhances the growth of phytoplankton in summer season (Chun *et al.*, 2007). Increasing phytoplankton population utilizes these nutrients by active absorption, resulting lower concentration of nutrient in monsoon season (Sommer, 1987; Reynolds, 1997; Naselli-Flores, 2000). A drop in nitrate level to complete absence in October may be due to consumption by algae (Temponeras *et al.*, 2000). Inter-annual variability in nutrient resources can also play an important role in the determination of phytoplankton distribution and abundance (Naselli-Flores, 2000).

It is further apparent from the data that the minimum number of species of phytoplankton was recorded during the rainy season, while the total density of phytoplankton was found to be minimum during winter. It is known that during winter, low algal growth is due to low water temperature. Increasing illumination with the onset of summer followed by high availability of nutrients and water column turbulence strongly support the development of phytoplankton in summer months as reported by Naselli- Flores and Barone (2000), Garg *et al.* (2009) and Mukherjee *et al.* (2010).

Correlation between various physico-chemical parameters and different plankton groups of Ramgarh Lake is shown in table 3. Total phytoplankton density showed a positive correlation with temperature ($r = 0.76$; $p<0.01$), dissolved O_2 ($r = 0.67$; $p<0.05$), alkalinity ($r = 0.59$; $p<0.05$) and nitrate ($r = 0.62$; $p<0.05$).

A significant positive correlation between dissolved O_2 and phytoplankton density may be due to its evolution from the latter through photosynthesis. The individual preference of different phytoplankton groups indicates that the low dissolved oxygen is accompanied by higher density of Bacillariophyceae in winter (Millman *et al.*, 2005; Khuantrairong and Traichaiyaporn, 2008). Whereas the occurrence of Chlorophyceae and Cyanophyceae during summer at high concentration of dissolved oxygen indicates that these groups prefer oxygenated waters (Albay and Akcaalan, 2003).

The relationship of CO_2 with phytoplankton density is insignificant in the present study. It is said that the availability of free CO_2 is primarily a need for photosynthesis and whenever, CO_2 is not available it is obtained by breaking down of bicarbonates (Sharma and Sharma, 1881). In this case, it is felt that the higher bicarbonate alkalinity is the determining factor for the phytoplanktonic picture in Ramgarh Lake. Laskar and Gupta (2009) have also reported a positive correlation between phytoplankton density and alkalinity value.

The density of phytoplankton showed three peaks; peak of summer, monsoon and winter in which summer peak was more prominent than the other two. The summer peak, recorded in the month of June, was dominated by Chlorophyceae. Both the monsoon peak of August and the winter peak, of November, were dominated by Bacillariophyceae. Tarar and Bodhke (2002) found that winter months were more favourable for multiplication of diatoms. The growth of diatoms in lake is governed by many factors such as thermal stratification and sedimentation, light intensity and carbon availability (Round *et al.*, 1990, Kristov *et al.*, 2003), low flow and water body mixing (Kim *et al.*, 2007). Low density of Bacillariophyceae in summer season may be due to the influences of temperature and grazing behaviour of zooplankton on diatoms because zooplankton density was found very low in winter at Ramgarh Lake (Paulose and Maheshwari, 2008).

The monsoon peak of Bacillariophyceae was mainly composed of *Nitzschia palea* while the winter peak was of *Synedra ulna*. The summer peak of Chlorophyceae was dominated by *Closterium setaceum.*

The percentage composition of algal groups differed throughout the study period. Bacillariophyceae was found the dominant group and its contribution ranged between 23.0% and 64.0% of the total phytoplankton depending upon season. *Nitzschia*, *Synedra* and *Navicula* were the main contributors in density of Bacillariophyceae. Other genera of Bacillariophyceae were *Cyclotella, Diatoma, Campylodiscus, Fragilaria, Achnanthes, Cymbella, Amphora* and *Coscinodiscus.*

Chlorophyceae ranked second in position contributing 21.0% to 49.0% towards the total phytoplankton density with 12 genera. The dominant genera of Chlorophyceae were *Closterium* and *Chlorella* whereas *Clostridium, Chlamydomonas, Volvox, Scenedesmus, Ankistrodesmus, Ophiocytium, Richterella, Pediastrum, Spirotaenia,* and *Ulothrix* were comparatively lesser in number during the study period.

This group showed a direct relationship with temperature ($r = 0.58$; $p<0.05$), alkalinity ($r = 0.68$; $p<0.05$), nitrate ($r = 0.65$; $p<0.05$) and phosphate ($r = 0.60$; $p<0.05$). The highest value of phosphate and nitrate coinciding with higher density of Chlorophyceae during summer season (June) indicate that these nutrients regulate the growth of green algae (Kwang-Guk *et al.*, 2003).

The contribution of Cyanophyceae was varying between 8.0% and 45.0% of the total density. In Cyanophyceae *Spirulina*, *Anabaena* and *Microcystis* were the most common genera while *Aphanocapsa, Phormidium, Gloeothece, Nostoc, Merismopedia* and *Synechocystis* were found occassionally.

It showed positive correlation with temperature ($r = 0.77$; $p<0.01$), pH ($r = 0.71$; $p<0.01$), dissolved O_2 ($r = 0.82$; $p<0.01$) and alkalinity ($r = 0.62$; $p<0.05$).

The dominant forms of three phytoplankton groups exhibited a clear seasonal succession. *Chlorella* was dominant during monsoon season while *Closterium* during summer. Out of the three genera of Bacillariophyceae, *Synedra* showed their maximum frequency during winter and early summer, *Navicula* during late summer and *Nitzschia* during monsoon. Among Cyanophyceae, *Anabaena* dominated during early summer, *Microcystis* during late summer and *Spirulina* during monsoon.

The species composition of Ramgarh Lake was coincided with nitrate content of the water. When nitrate concentration was maximum in summer, phytoplankton population was dominated by *Closterium sp*. Nitrate content reached its lowest value during monsoon, followed by a high contribution of *Nitzschia sp*. to the total phytoplankton density. The drop in nitrate level to almost complete depletion in winter is accompanied by an increase in density of *Synedra sp.* It can be assumed that the species dominance in a lake is determined by competition for nutrients (Gligora *et al.*, 2007). The species of *Synedra* was competitively superior for phosphorus at a low concentration of nitrogen and it becomes more productive in winter.

Table.1 Mean monthly values of various physico-chemical parameters during 2005-2006 at five stations in Ramgarh Lake, Jaipur

Parameters	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.
Water Temperature (°C)	29.0 ±0.01	23.0±0.03	20.0±0.02	16.0±0.01	22.0±0.03	24.0±0.01	29.8±0.01	30.0±0.01	31.3±0.02	27.2±0.01	31.2±0.03	29.9±0.01
Air temperature (°C)	32.0±0.12	28.0±0.01	25.2±0.30	20.5±0.03	26.8±1.00	28.0±0.98	33.0±0.35	33.6±0.10	34.5±1.60	32.6±1.02	33.0±0.85	32.8±0.45
pH	7.5±0.02	7.4±0.03	7.2±0.04	7.1±0.02	7.8±0.03	8.1±0.03	8.2±0.02	8.3±0.01	8.7±0.04	8.5±0.08	8.5±0.03	8.6±0.01
Dissolved O_2 (mg L^{-1})	3.8±0.73	2.9±0.70	6.5±0.68	2.9±0.85	1.2±0.20	8.7±0.14	9.5±0.43	9.1±0.40	8.6±0.22	7.8±0.20	9.3±0.16	7.8±0.15
Free CO_2 (mg L^{-1})	4.2±0.38	4.3±0.46	5.5±0.35	8.8±1.43	0.0±0.0	0.0±0.0	4.4±0.0	4.4±0.0	4.4±0.0	8.8±0.0	5.7±0.88	9.6±0.53
Alkalinity (mg L^{-1})	120.0±4.06	132.0±5.83	138.0±3.16	150.0±3.16	150.0±2.44	155.0±5.32	180.4±3.60	180.0±2.80	200.0±2.00	172.0±10.1	172.0±4.89	182.0±3.74
Total hardness (mg L^{-1})	110.0±0.97	113.0±1.49	115.0±2.80	118.0±3.28	124.0±2.19	115.0±0.48	124.0±1.02	125.2±3.04	127.2±1.95	112.4±2.40	102.0±7.23	100.4±0.40
Salinity (mg L^{-1})	3.3± 0.34	12.5±0.77	13.8±0.53	12.2±0.44	12.2±0.43	15.4±0.44	15.2±0.57	15.6±0.54	18.9±0.71	21.4±1.35	23.3±0.70	42.4±
TS (mg L^{-1})	9.65±150.0	150.0±7.85	152.2±5.25	210.8±10.2	220.0±9.95	365.0±10.9	156.0±8.94	187.6±7.56	380.4±12.9	475.8±14.51	642.0±13.7	635.9±9.69
Nitrite (mg L^{-1})	0.04±0.0	0.035±0.0	0.034±0.0	0.04±0.0	0.06±0.0	0.06±0.0	0.09±0.02	0.08±0.02	1.8±0.32	1.06±0.10	1.20±0.50	0.83±0.24
Nitrate (mg L^{-1})	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	1.2±0.43	1.6±0.65	10.8±4.60	6.1±2.36	3.46±1.15	1.0±0.70
Phosphate (mg L^{-1})	0.04±0.0	0.04±0.0	0.05±0.01	0.06±0.02	0.04±0.01	0.08±0.01	0.08±0.02	0.04±0.0	0.12±0.06	0.06±0.01	0.09±0.02	0.06±0.02

Values are mean±standard deviation and average of five sites

Table.2 Species composition of various phytoplankton groups at Ramgarh Lake

Name of species	Oct	Nov	Dec	Jan.	Feb	March	April	May	June	July	Aug	Sept
BACILLARIOPHYCEAE												
Synedra ulna	+	+++	++	++	++	++	++	+	+	+	+	+
Nitzschia palea	+	+	+	+	+	+	+	+	+	++	+++	++
Navicula pseudocuspidata	+	+	+	+	++	+	+	+++	++	+	+	+
Cyclotella sp.	-	-	-	-	-	-	+	+	+	+	-	-
Diatoma sp.	+	+	+	-	-	-	-	-	-	-	-	-
Campylodiscus sp.	-	-	-	-	-	-	-	-	-	+	+	-
Fragilaria sp.	-	-	-	-	-	+	+	+	+	+	-	-
Achnanthes	-	-	-	-	-	-	-	-	+	+	-	-
Cymbella sp.	+	+	+	-	-	-	-	-	+	+	-	-
Amphora sp.	-	-	+	+	+	+	+	-	-	-	-	-
Coscinodiscus sp.	-	+	+	+	-	-	-	-	-	-	-	-
CHLOROPHYCEAE												
Closterium setaceum	+	+	+	++	+	++	++	+++	+++	+	+	+
Chlamydomonas sp.	-	-	-	-	-	+	+	-	-	-	-	-
Volvox sp.	+	-	-	-	-	-	-	-	-	+	+	+
Chlorella vulgaris	+	+	+	++	-	-	-	-	+	++	+++	++
Scenedesmus sp..	+	+	+	-	-	-	-	-	-	+	-	-
Ankistrodesmus sp.	-	-	-	+	+	+	+	+	-	-	+	+
Ophiocytium sp.	-	-	+	+	-	-	-	-	-	-	-	-
Richterella sp.	-	-	-	-	-	+	+	-	-	-	-	-
Pediastrum sp.	+	+	-	-	-	-	-	-	-	-	-	-
Spirotaenia sp.	+	+	-	-	-	-	-	-	-	-	-	-
Clostridium sp.	+	+	+	+	+	+	+	+	+	-	-	-
Ulothrix sp.	-	-	-	-	-	+	+	+	+	-	-	-

Cont.

Name of species	Oct	Nov	Dec	Jan.	Feb	March	April	May	June	July	Aug	Sept
CYANOPHYCEAE												
Spirulina sp.	-	-	-	+	+	+	+	+	+	+	++	+++
Anabaena sp.	+	+	+	+	+	++	+++	+	+	+	+	+
Phormidium sp.	-	-	-	-	-	-	-	-	+	+	-	-
Gloeothece sp.	-	-	-	-	-	-	-	-	-	+	-	-
Nostoc sp.	+	+	+	+	-	-	-	-	-	-	-	-
Microcystis sp.	+	+	+	+	+	+	+	+++	+++	+	+	+
Aphanocapsa sp.	-	-	+	+	+	+	+	+	+	+	+	+
Merismopedia sp.	+	+	+	+	-	-	-	+	+	+	+	+
Synechocystis sp.	-	-	-	-	+	+	+	+	+	+	-	-

+++ = Dominant
++ = Common
\+ = Rare
\- = Absent

Table.3 Correlation matrix (r) between various physico-chemical parameters and phytoplankton groups at Ramgarh Lake

Temp.	pH	D. O_2	Free CO_2	Alkalinity	Salinity	Hardness	TS	Nitrate	Nitrite	Phosphate	Parameters
0.76**	0.53	0.67*	-0.06	0.59*	-0.04	0.14	0.12	0.62*	0.40	0.44	Total phytoplankton
0.58*	0.53	0.56	-0.06	0.68*	-0.02	0.54	0.04	0.65*	0.37	0.60*	Chlorophyceae
0.77**	0.71**	0.82**	0.23	0.62*	0.46	-0.25	0.55	0.39	0.44	0.54	Cyanophyceae
0.34	-0.05	-0.14	-0.25	-0.31	-0.44	-0.14	-0.23	0.26	0.06	-0.20	Bacillariophyceae

(*indicates significant at $p < 0.05$ and ** indicates significant at $p < 0.01$ level)

Table.4 Correlation (r) matrix between various limnological parameters and productivity of Ramgarh Lake

NPP	GPP	Parameters
0.66*	0.65*	Temperature
0.59*	0.76**	pH
0.74**	0.85**	D. O_2
0.10	0.16	Free CO_2
0.78**	0.87**	Alkalinity
0.37	0.39	Salinity
0.23	0.24	Total hardness
0.57*	0.58*	TS
0.58*	0.70**	Nitrate
0.67*	0.68*	Nitrite
0.96**	0.88**	Phosphate
0.58*	0.60*	Total phytoplankton
0.65*	0.71**	Chlorophyceae
0.61*	0.66*	Cyanophyceae
-0.20	-0.12	Bacillariophyceae

(*indicates significant at $p < 0.05$ and ** indicates significant at $p < 0.01$ level)

Fig.1 Map of Ramgarh Lake, Jaipur showing different sampling sites

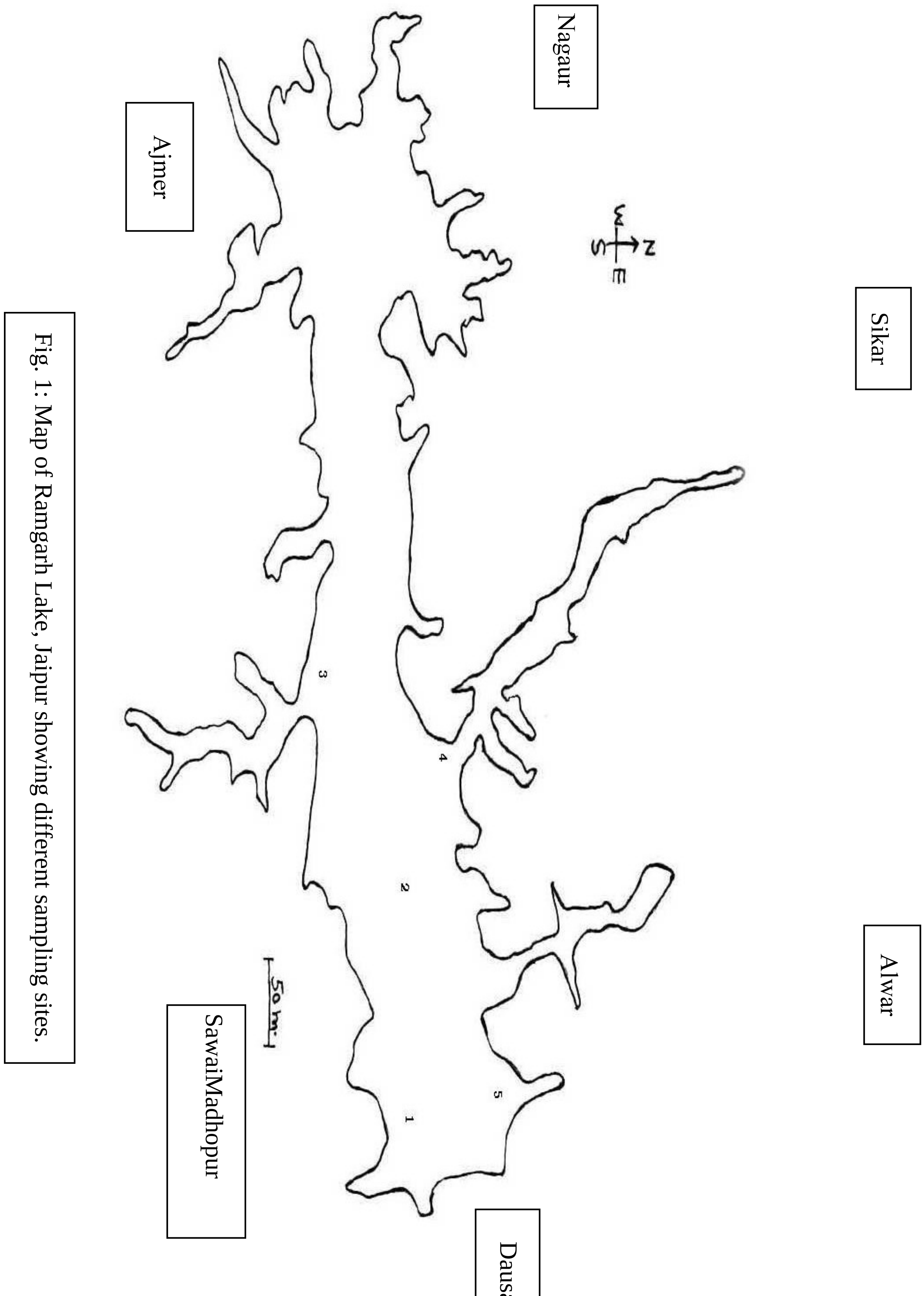
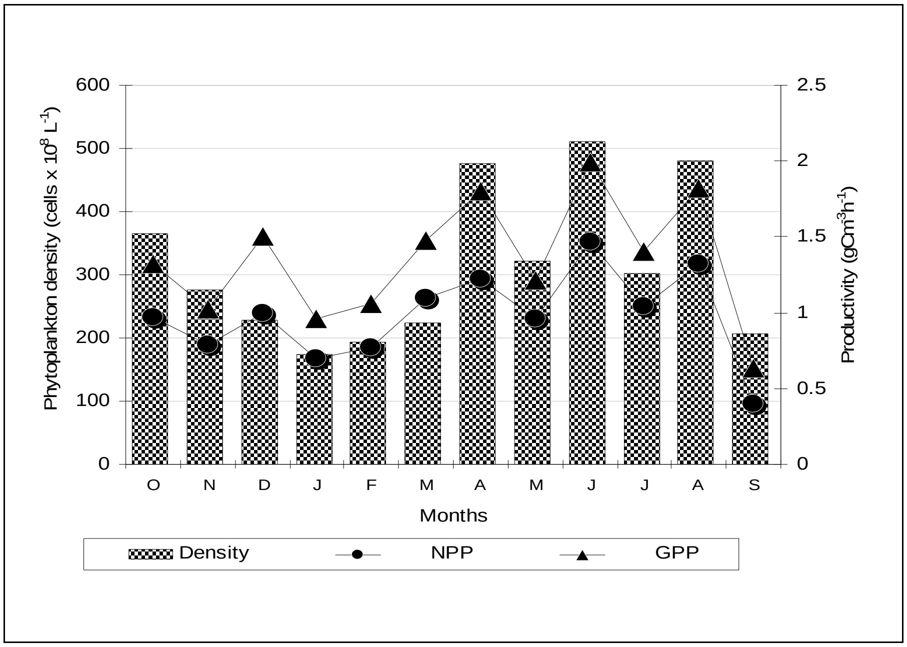
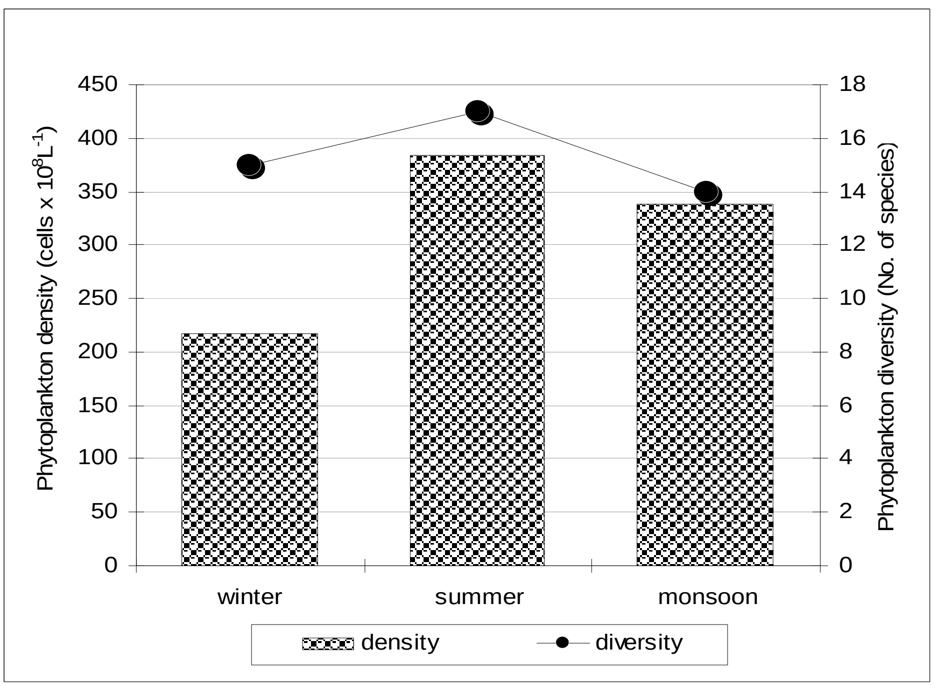


Fig.2 Annual trend of phytoplankton density and productivity during 2005-2006 in Ramgarh Lake,Jaipur



(NPP= Net Primary Productivity, GPP= Gross Primary Productivity)

Fig.3 Seasonal variations in phytoplankton density and diversity during 2006 of Ramgarh Lake, Jaipur



This ability gives a significant advantage to these organisms in monsoon. It was able to compete for phosphorus and reach dominance as long as *Closterium* and *Nitzschia sp*. were excluded by nitrogen depletion (Lampert and Sommer, 1997).

Observations on the monthly gross and net primary productions in phytoplankton community at Ramgarh Lake are presented in the figure 2. It is evident from the data that both gross and net production was maximum during the month of June 06 and minimum in the month of September 06. Maximum primary productivity was observed in summer and minimum was found in winter.

Washing, bathing, dumping of wastes as well as other anthropogenic activities and surface water runoff into the lake water during monsoon months enormously deposit organic matter to lake sediments increasing the nutrient load Khuantrairong and Traichaiyaporn, 2008). These nutrients are least available to algae and diatom for their growth and development during low light intensity and low temperature (winter months). These probably are responsible for comparatively lower values of primary productivity in winter months (Toman, 1996; Pugnetti and Bettinetti, 1999). However, in summer, the rise in temperature enhances the release of nutrients from sediments through bacterial decomposition. The excessive amount of nutrient along with higher temperature favours the growth of aquatic flora, which ultimately increases the primary productivity (Van Donk *et al.*, 1993; Thillai Rajasekar *et al.*, 2005).

Effect of different limnological parameters on productivity is depicted in table 4. NPP and GPP showed positive correlation with water level, temperature, pH, EC, alkalinity, dissolved O_2, TDS, TS, magnesium hardness, BOD, COD, nutrients and phytoplankton density. Higher summer values of productivity was also explained on this correlation basis. The peak of productivity in month of June may be due to high pH, alkalinity, EC, TS, nutrients and plankton density. Sulabha and Prakasam (2006) reported a direct correlation between alkalinity and primary production throughout their investigation. But Das and Manna (2004) found strong positive correlation of primary production with conductivity and total alkalinity. Phytoplankton is favoured under more alkaline condition, since alkaline system act as a trap for atmospheric carbon di oxide (Lopez-Archilla *et al.*, 2004). Thus the highest primary production levels are encountered in alkaline lake (Melack, 1981).

The present study shows that in the Ramgarh Lake the concentration of nitrate, like that of phosphorus may be important in the determination of phytoplankton dominance. It can be pointed out that the phytoplankton peaks were followed by nutrient peaks. It may be suggested that nutrient enrichment enhances the growth of phytoplankton in summer season. Increasing phytoplankton population utilizes these nutrients by active absorption, resulting lower concentration of nutrient in next season. On the other hand, heavy grazing by zooplankton on phytoplankton may also be responsible for the lower density of phytoplankton during monsoon season.

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