Factors influencing phytoplankton density and diversity in Thirumeni Lake, Tamil Nadu, India.

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Abstract

Phytoplankton productivity, density and diversity and factors influencing them were studied in Thirumeni lake, Thiruvarur district, Tamilnadu, India. The Chlorophyceae has been found to dominate the phytoplankton in all the seasons of study. Important taxa of phytoplankton recorded in the present study include *Oscillatoria, Spirulina, Chlorella, Closterium, Scenedesmus,* and *Navicula.* There have been marked seasonal effects with regard to phytoplankton productivity with the highest productivity occurring during summer. Turbidity, total dissolved solids, total alkalinity, chlorides, nitrate and phosphate of lake water and phosphorus of bottom soil have been the most important factors that influenced the phytoplankton productivity, density and diversity in the Thirumeni lake.

Key words: diversity, soil parameters, phytoplankton, productivity, water quality

INTRODUCTION

Among the biotic community of aquatic ecosystems plankton are the major contributors to the lake. Several works have been done on the distribution, density, species diversity and ecology of plankton in the water bodies. Important among them are Michael (1968), Palmer (1969), Munawar (1970a,b), Morton *et al.* (1972),

Bose and Bose (1973), Peterson *et al.* (1973), Hawes (1985), Goel *et al.* (1988), Chatterjee and Mohanti (1989), Khatavkar et al. (1990), Giri (1991), Baruah *et al.* (1993) and Munshi and Singh (1993). Changes in season have been reported to influence the physico- chemical condition of aquatic bodies which in turn to influence the plankton dynamics (Sarkar and Sen, 1975; Bhowmick, *et al.,* 1993). A number of studies have been done on the seasonal variation of plankton by a number of Indian workers (Ganapati, 1942; George, 1961; Michael, 1969; Saha *et al.,* 1971; Khan and Siddique, 1974; Kohli *et al.,* 1982; Sarkar *et al.,* 1985; Bhowmick, 1987; Wishard and Malhotra, 1988 and Dutta and Chutia, 1990).

The phytoplankton (microscopic algae) occur as unicellular, colonial or filamentous forms. The phytoplankton are primary producers in the aquatic community and, as such are at the base of aquatic food chains. Many are grazed upon by zooplankton and other aquatic organisms. According to Dwivedi and Pandey (2002) phytoplankton constitute the very basis of nutritional cycle of an aquatic ecosystem as they form a bulk of food for zooplankton, fishes and other aquatic organisms and play a key role in maintaining proper equilibrium between a biotic and biotic components and the biodiversity of the aquatic eco system.

The structure of the phytoplankton population in aquatic ecosystems is a dynamic one and is constantly changing in species composition and biomass distribution. Changes in species composition and biomass of phytoplankton may affect photosynthetic rates, assimilative efficiencies, rates of nutrient utilization, grazing rates, and so on. Because of their short life cycles, plankton respond quickly to environmental changes, and hence their standing crop and species composition are more likely to indicate the quality of the water in which they are found. Furthermore phytoplankton encountered in the water body reflects the average ecological condition and therefore, they may be used as indicator of water quality (Bhatt *et al.,* 1985, 1999; Har ikrishnan *et al.,* 1999; Saha *et al.,* 2000). In fact Plankton, particularly phytoplankton, long have been used as indicators of water quality (Rawson, 1956; Palmer, 1969). Some species of plankton flourish in highly euntrophic waters while others are very sensitive to organic and or chemical wastes. Some species of plankton develop

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noxious blooms, sometimes creating offensive tastes and odors (Prescott, 1962) or anoxic or toxic conditions resulting in animal death and human illness (Carmichael, 1981). In a very practical sense they are parts of water quality (APHA, 1995).

Phytoplankton productivity depends on the changes in environmental factors such as temperature, meteorological, hydrological, nutritive and biological characteristics. Significant correlations have been established between phytoplankton density and physico-chemical parameters of water (Gujarathi and Kanhere, 1998). There have been correlations between phytoplankton groups with one or other parameters of water, as per earlier observations of Zafar (1964), Munawar (1970a,b, 1974), Saha and Choudhary (1985), Kanungo *et al.* (1985), Chatterjee (1990), Sharma (1993) and Verma and Mohanty (1995). Saha (1980) has reported inverse relationship between nitrate and phytoplankton during the summer and monsoon while direct relationship between the two during the winter. The author has also found an inverse relationship between nitrate and zooplankton. Thus it may be concluded that the density of phytoplankton is dependent on different abiotic factors either directly or indirectly.

This paper evaluates the influence of water quality and bottom soil quality parameters on the density and diversity of phytoplankton in Thirumeni lake, Thiruvarur District, Tamilnadu, India..

STUDY AREA

The Thirumeni Lake

Thirumeni lake is one of the major freshwater habitats and resources of old Thanjavur District, Tamil Nadu, Southern India (Fig. 1). After trifurcation of the old Thanjavur District it now comes under the Thiruvarur District. The lake extends from 10° 33′ 28″ to 10° 34′ 30.9″ N and from 79° 26′ 17.7″ to 79° 27′ 54.1″ E (Fig. 2).

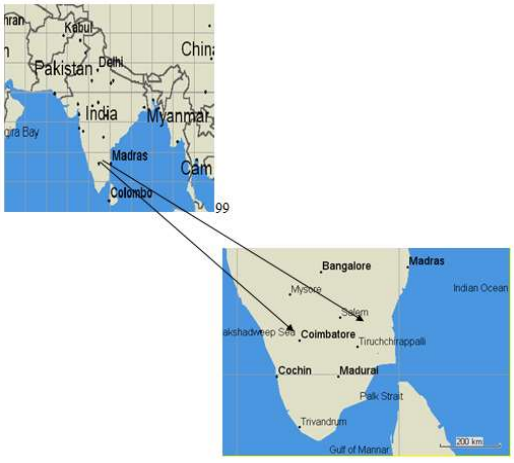


Fig. 1. Map showing the location of Thirumeni Lake

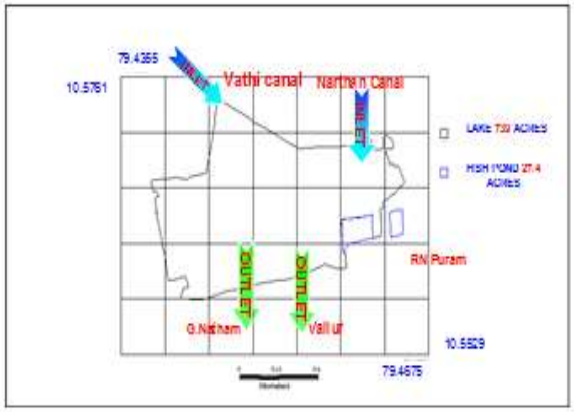


Fig. 2. Sketch map of Thirumeni Lake (G.Natham = Govindhanatham Village, R.N. Puram = Rathanarasimmapuram)

Sampling Stations

For recording periodically the various physico-chemical and biological fluctuations in the lake, three stations were selected. The stations were located nearby the villages Thirumakkottai, Painganadu and Paravakkottai, respectively.

Station I : (10° 33′ 46.44″ N; 79° 27′ 18.36″ E) was at the southern part of the lake near Thirumakkottai.

Station II : (10° 34′ 17.4″ N; 79° 27′ 5.4″ E) was at the Northern side of the lake near Painganadu.

Station III : (10° 34′ 0.48″ N; 79° 26′ 40.56″ E) was at the western part of the lake near Paravakkottai.

METHODS

Study Period

Data were collected from October 2000 to May 2001 and November 2001 to April 2002, during three seasons *viz.*, Monsoon (October, November and December) and Post Monsoon (January, February and March) and Summer (April and May) of two successive years (during the months in an year when water was available in the lake which varied depending on the variations on water inflow from the feeder canals and rains). Data were collected on calm, sunny days and days with high wind, heavy rain and dense fog were avoided.

Measuring Water Quality Variables

The following water quality factors were measured once in a week from the three stations. Sample collections and preservation were as per the specifications of APHA (1995).

Physical Factors

Surface water temperature was measured at 8.00 a.m. It was measured in centigrade (°C) with a LCD-portable digital Multi-Thermo meter with external sensor probe in all the three stations 0.1m below the water level (Danel1 and Sjoberg, 1982) with 0.1°C accuracy. Turbidity was measured by using the Nephelometer and expressed as NTU. Total dissolved solids were measured using Standard TD Scan I pocket TDS tester (10-1990 ppm range).

Chemical Factors

Fifteen chemical factors *viz*., pH., dissolved oxygen, total alkalinity, carbonate alkalinity, bicarbonate alkalinity, total hardness, calcium hardness, magnesium hardness, chloride, iron, ammonia, nitrite, nitrate, sulphate and phosphate were assessed. The water samples were collected from the three stations in pre-cleaned separate water cans (1-2 L capacity) and were analyzed separately (Murphy *et al.,* 1984). The water samples were collected and preserved for later analyses as per the procedures described in APHA (1995). The methods used to measure the water chemistry variables were as follows.

pH of the water samples were determined by portable pen type electronic pH meter. The pH meter was immersed in the water and pH values were read directly from the digital screen (Nagarajan and Thiyagesan, 1996). The dissolved oxygen content was estimated by the standard volumetric Winkler method. (Nagarajan and Thiyagesan, 1996). The alkalinity of water sample was estimated by Acid-Base titrimetric method (Trivedy *et al.,* 1987). Hardness was measured by the complexometric titration using EDTA (Trivedy and Goel, 1986). Calcium was estimated by the complexometric titration using EDTA (Trivedy and Goel, 1986) Magnesium hardness was calculated as follows : Magnesium Hardness = Total Hardness - Calcium Hardness. Estimation of chloride was by following Trivedy and Goel (1986). Iron was estimated by the Phenanthroline method (APHA, 1995). Ammonia was estimated by the Nesslerization method described by Trivedy and Goel (1986).The nitrite content was estimated by the colorimetric Griess – Ilosvay method described by Klein (1973). Determination of nitrate was based on the phenol disulfonic acid colorimetric method described by Trivedy and Goel (1986). Sulphate level was estimated by the barium chloride Turbidimetric method (Trivedy and Goel, 1986). The determination of phosphate was made by the colorimetric method of Trivedy *et al.,* (1987).

Plankton Studies

Sampling

The plankton samples were collected once in a fortnight by filtering 50 litres of surface water at different sites using a standard plankton net (No.20) and were fixed and preserved in modified Lugol's solution (Pandit, 1980) and also in 4% formalin for later identification (Michael, 1986). The plankton sample was also allowed to settle overnight in a measuring cylinder and the sedimented volume was taken to calculate the volume of plankton per cubic metre of water. Identification of the plankton organisms was done out by referring to relevant works (Desikachary 1959a,b; Ward and Whipple 1959; Philipose 1967; Sreenivas and Duthie 1973; Adoni *et al*., 1985; Battish, 1992).

Counting

For counting the plankton, a modification of Lackey drop method (Lackey, 1938) was used. It is a simple method of obtaining counts of considerable accuracy with samples containing dense planktonic populations (APHA, 1995). The plankton was quantified with the help of the formula given by Welch (1952).

i.e., Organisms / l = (N*A/V)/L

A = Number of organisms per drop

L = Volume of original sample

V = Volume of one drop

N = Total volume of the sedimented sample

In the text, quantity of plankton has been expressed as number per cubic meter (APHA, 1995). Unicellular algae were counted as individuals while filamentous Cyanophyceae (100 mm lengths of the filaments) were taken as the equivalents. Similarly, the filamentous Chlorophyceae were recorded as cells while in the colonial forms like Microcystis, Volvox etc., the counting unit was a colony (Jumppanen, 1976).

Bottom Soil Analysis

Bottom samples were collected at three different stations in each region in each month by using Petersen grab. It was towed slowly for a distance of one foot (Wetzel and Likens, 1979; Nagarajan and Thiyagesan, 1996).

Soil Textural Analysis

Soil textural analysis was done at the Tamilnadu Agricultural University, Soil Testing Laboratory, Aduthurai. Soil analyses were by mechanical analysis as per the international pipette method (Piper, 1966).

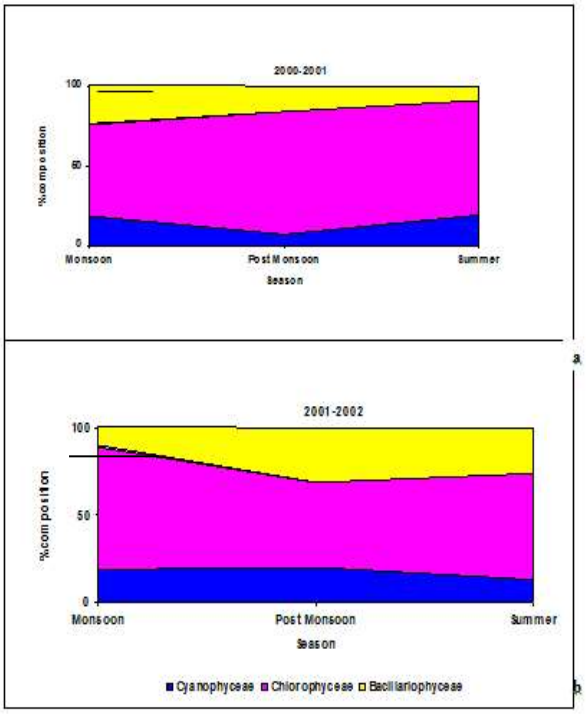


Fig. 3. Seasonal variations in the class-wise phytoplankton composition in Thirumeni lake during a) First Year (2000-2001) and b) Second Year (2001-2002) of the study period.

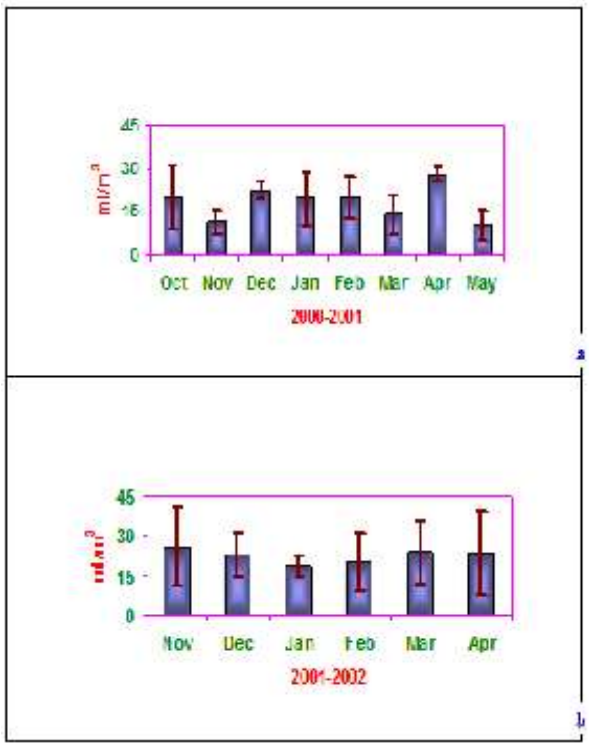


Fig. 4. Monthly variations in the volume of phytoplankton in Thirumeni lake during a) First Year (2000-2001) and b) Second Year (2001-2002) of the study period. Values are X±1SD

Table 1. Phytoplankton genera recorded in Thirumeni lake during the study period

S.No.	Cyanophyceae	Chlorophyceae	Bacillariophyceae
1	*Anabaena*	*Actinastrum*	*Amphiroa*
2	*Aphaniocapsa*	*Ankistodesmis*	*Bacteriastrum*
3	*Aphanothece*	*Chaetophora*	*Cyclotella*
4	*Calothrix*	*Characium*	*Coconeies*
5	*Gloeotrichia*	*Chlamydomonas*	*Denticula*
6	*Gloeocapsa*	*Chlorella*	*Epithemia*
7	*Hapalosiphon*	*Cladophora*	*Gomphonema*
8	*Lyngbya*	*Closterium*	*Navicula*
9	*Merismopedia*	*Cosmarium*	*Nitzschia*
10	*Microcystis*	*Coleochaete*	*Stauroneis*
11	*Nostoc*	*Enteromorphia*	*Synedra*
12	*Oscillatoria*	*Geminella*	
13	*Phormidium*	*Hydrodictyon*	
14	*Rivularia*	*Kirchneriella*	
15	*Spirulina*	*Pediastrum*	
16	*Sympoea*	*Scenedesmus*	
17	*Synechocystis*	*Spirogyra*	
18		*Spondylomorum*	
19		*Stigeoclonium*	
20		*Vaucheria*	

Soil Macronutrient Analysis

For the estimation of the level of soil macronutrients like nitrogen, phosphorus and potassium, soil pH and soil electrical conductivity, the soil samples collected were sent to the Tamilnadu Agricultural University Soil Testing Laboratory, Aduthurai and the results were obtained directly from them.

Data Analysis

Diversity Index

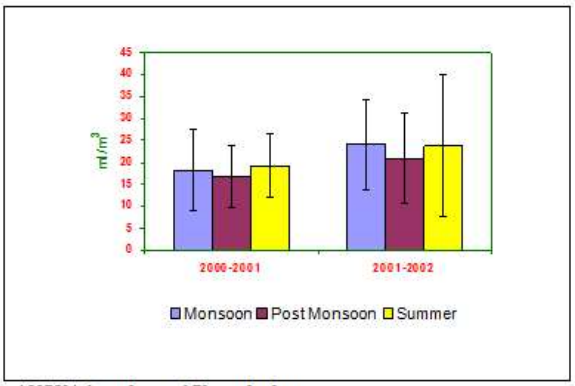
The species-diversity (H') was calculated using the Shannon Weiner index (Shannon and Weiner, 1949).

$$H = -\sum_{I=1}^{S} pi \ln ip$$

Where pi = ni/N; ni = proportion of individual in each category; N=total number observed and s=number of categories).

Statistical Analyses

Basic statistics *viz.*, arithmetic mean, standard deviation and standard error were calculated for all the replicate variables and are given as $\overline{X} \pm 1$ SD or $\overline{X} \pm 1$ SE. Statistical analyses were performed by using



ANOVA for volume of Phytoplankton

Source	DF	SS	MS	F	P
Year	1	379.96	379.96	4.43	0.040
Season	2	17.46	8.73	0.10	0.903
Year*Season	2	115.89	57.95	0.68	0.514
Error	51	4377.43	85.83		

Significant values are indicated by bold types

Fig. 5. Seasonal variations in the volume (ml/m^3) of phytoplankton in Thirumeni lake during the study period. Values are $\overline{X}$±1SD.

Window based statistical packages *viz.*, Microsoft Excel, MINITAB (Ryan *et al.*, 1992) and SPSS (Statistical Package for Social Science; Nie *et al.*, 1975). Mainly parametric tests *viz.*, Analysis of Variance (ANOVA), Cluster Analysis, and Multiple Regression equations were used to test hypothesis. Appropriate data transformations were made wherever needed. For hypothesis testing $P < 0.05$, $P < 0.01$ and $P < 0.001$ were considered and these levels of significance were indicated at appropriate places. Statistical inferences were made by following Sokal and Rohlf (1995) and Zar (2003).

RESULTS

Phytoplankton

Forty eight genera of phytoplankton belonging three classes of algal were recorded in the Thirumeni Lake during the present study period (Table – 1).

i) Cyanophyceae : 17 genera

ii) Chlorophyceae : 20 genera

iii) Bacillariophyceae : 11 genera

The Chlorophyceae members were dominant during all the seasons of both the years of study (Figs. 3a and b).

Volume of Phytoplankton

Month – wise variations in phytoplankton volume (ml/m^3) in the Thirumeni lake during the study period have been shown in Figs. 4a and b. The phytoplankton productivity was highest during April and lowest during November and May in the first year (2000 – 2001) of study (Fig. 4a). In the second year of study (2001 – 2002), there was a declining trend in the phytoplankton

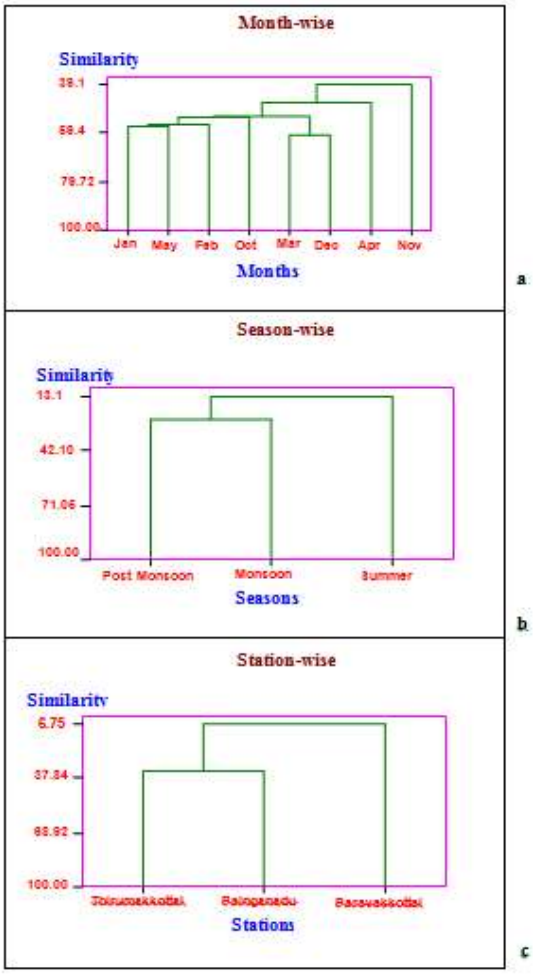


Fig. 6. Dendrograms to show the similarities among the **a)** months and **b)** seasons of the study period and **c)** sampling stations of the lake with regard to volume of phytoplankton.

volume from November to January and thereafter an increasing trend was noticed up to April (Fig. 4b).

The season – wise pattern of phytoplankton productivity was similar in both the years of study with summer season having higher values, the post monsoon season with the least and the monsoon season in between (Fig. 5). The phytoplankton productivity was higher during the second year in all the seasons when compared to that of the first year (Fig. 5) which was also statistically significant (ANOVA; $F_{1,51} = 4.43$; $P<0.05$).

A cluster analysis revealed that the months, April and November were unique in phytoplankton productivity as they were highly dissimilar to other months in this regard (Fig. 6a). Among the seasons, the post monsoon and monsoon were similar with regard to phytoplankton productivity, while the summer season differed from the other seasons in this regard (Fig. 6b). The stations of Thirumakkottai and Painganadu were similar in phytoplankton

Table 2 . Multiple regression equation model to predict the influence of water quality parameters and soil characteristics on the volume (ml / m^3) of phytoplankton.

Variables Model F Model P and R2	Predictor	Coefficient	Standard Deviation	t	P
Phytoplankton volume (ml/m3) F=13.17 P<0.001 R2 = 65.3%	Constant	78.3	15.79	4.96	0
	Total Dissolved Solids	-0.032323	0.008273	-3.91	0
	Total Dissolved Solids^2	0.00006823	0.00000921	7.41	0
	Total Dissolved Solids^3	-0.00000005	0.00000001	-7.18	0
	Total Alkalinity	-0.8709	0.2991	-2.91	0.005
	Total Alkalinity^2	0.0053	0.001841	2.88	0.006
	Total Alkalinity^3	-0.00001009	0.00000352	-2.87	0.006
	Phosphorus	-0.9234	0.3399	-2.72	0.009

productivity, while Paravakkottai station was unique in its phytoplankton productivity during the present study period (Fig. 6c).

Factors Influencing Phytoplankton Productivity

The water quality variables *viz.*, total dissolved solids, total alkalinity and the level of phosphorus in the bottom soil, influenced the phytoplankton productivity, as they explained 65.3 percent of the total variations in the phytoplankton productivity in the lake. Total solids and total alkalinity had cubic relation with volume of phytoplankton whereas phosphorous had linear relationship. The model was highly significant (F=13.17; P<0.001; Table 2).

Density of Phytoplankton

Density of phytoplankton was higher during the monsoon months *i.e.* October to December (October recording the highest value) during the first year (2000 – 2001) and was declining thereafter from January to May (Fig.7a).

In the second year (2001 – 2002), the density of phytoplankton was higher during December, which got declined to the lowest value of the year in February

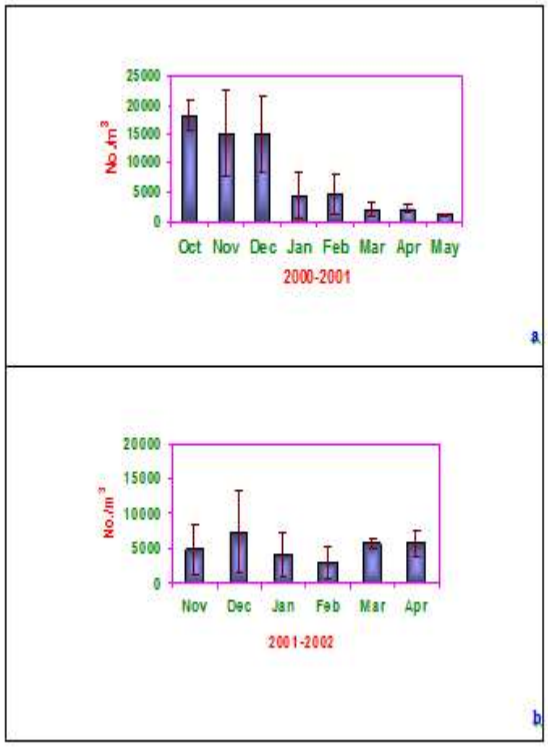
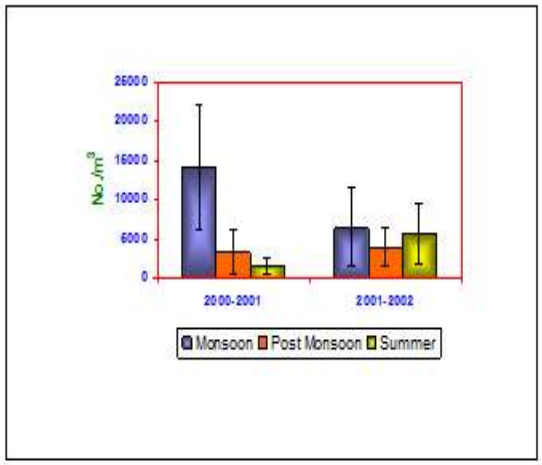


Fig.7. Monthly variations in the density (No./m^3) of phytoplankton in Thirumeni lake during a) First Year (2000-2001) and b) Second Year (2001-2002) of the study period. Values are $\overline{X}$±1SD.



ANOVA for Phytoplankton density

Source	DF	SS	MS	F	P
Year	1	1322.8	1322.8	5.09	0.028
Season	2	4766.0	2383.0	9.17	0.000
Year*Season	2	2839.0	1419.5	5.46	0.007
Error	51	13260.0	260.0		

* Significant values are indicated by bold types

Fig.8. Seasonal variations in the density (No./m^3) of phytoplankton in Thirumeni lake during the study period. Values are $\overline{X}$±1SD.

Table 3 : Multiple regression equation model to predict the influence of water quality parameters and soil characteristics on the density (No./m^3) of phytoplankton.

Variables Model F Model P and R2	Predictor	Coefficient	Standard Deviation	t	P
Phytoplankton density (No./m3) F=9.18 P<0.001 R2 = 71.4%	Constant	35.29	32.06	1.1	0.277
	Total Alkalinity	0.5454	0.1683	3.24	0.002
	Total Alkalinity^2	-0.0017145	0.0004746	-3.61	0.001
	Chlorides	-0.8737	0.3231	-2.7	0.01
	Chlorides^2	0.003005	0.00122	2.46	0.018
	Chlorides^3	-0.00000305	0.0000014	-2.18	0.035
	Nitrate	2008.8	310.3	6.47	0
	Nitrate^2	-33249	5240	-6.35	0
	Nitrate^3	111563	18477	6.04	0
	Phosphate	-2.7915	0.7024	-3.97	0
	Phosphate^2	0.15578	0.03665	4.25	0
	Phosphate^3	-0.0017832	0.0004276	-4.17	0
	Potassium	0.1842	0.04803	3.84	0

Table 4. : Multiple regression equation model to predict the influence of water quality parameters and soil characteristics on the diversity (H′) of phytoplankton.

Variables Model F Model P and R2	Predictor	Coefficient	Standard Deviation	t	P
Phytoplankton diversity (H′) F=6.09 P<0.001 R2 = 37.4%	Constant	0.5506	0.3578	1.54	0.13
	Turbidity	-0.17142	0.03705	-4.63	0
	Turbidity^2	0.008458	0.002076	4.07	0
	Turbidity^3	-0.00012121	0.00003314	-3.66	0.001
	Total Alkalinity	0.011334	0.004129	2.74	0.008
	Total Alkalinity^2	-0.00003101	0.00001148	-2.7	0.009

before showing an increasing trend in March and April (Fig. 7b).

The season – wise variations in the phytoplankton density are shown in Fig. 8. The phytoplankton density varied seasonally in both the years of study and the year-wise and season-wise variations in the phytoplankton density were statistically significant (ANOVA; year $F_{1, 51} = 5.09$; season $F_{1, 51} = 9.17$; $P<0.05$).

Cluster analysis revealed that the months October, November and December were different in their phytoplankton density when compared to other months and were unique in this aspect (Fig. 9a). The phytoplankton density during the monsoon season was highly dissimilar to the other seasons (Fig. 9b).

The Thirumakkottai station was unique with phytoplankton density during the study period, when compared to the other two stations *viz.*, Painganadu and Paravakkottai, which showed similar phytoplankton density variations (Fig. 9 c).

Factors Influencing Phytoplankton Density

Total alkalinity, chlorides, nitrates and phosphates of water and potassium of bottom soil accounted for 71.4% of the variations in the phytoplankton density in Thirumeni lake during the study period. Among the five variables chlorides, nitrates and phosphates had cubic relationship, total alkalinity had quadratic and potassium had positive linear relationship. The model is highly significant ($F = 9.918$; $P<0.001$) (Table 3).

Phytoplankton Diversity

During the first year of study (2000 – 2001) the phytoplankton diversity (H′) was highest in October, which got declined to the lowest value during December (Fig.10a). Then it showed an increasing trend upto February before once again declining upto April and increasing again during May (Fig. 10 a). On the other hand the phytoplankton diversity (H′) was almost similar in all the months of second year (2001 – 2002) except April (Fig. 10 b).

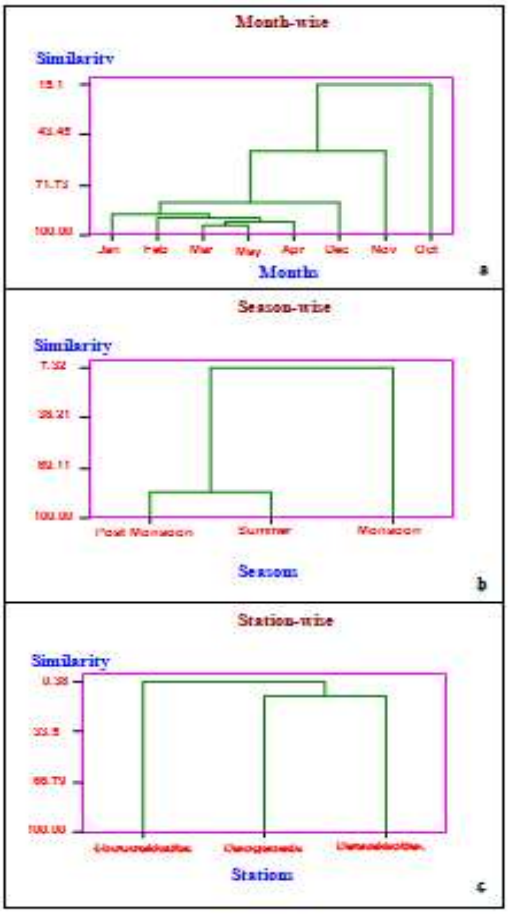


Fig. 9. Dendrograms to show the similarities among the **a)** months and **b)** seasons of the study period and **c)** sampling stations of the lake with regard to density of phytoplankton.

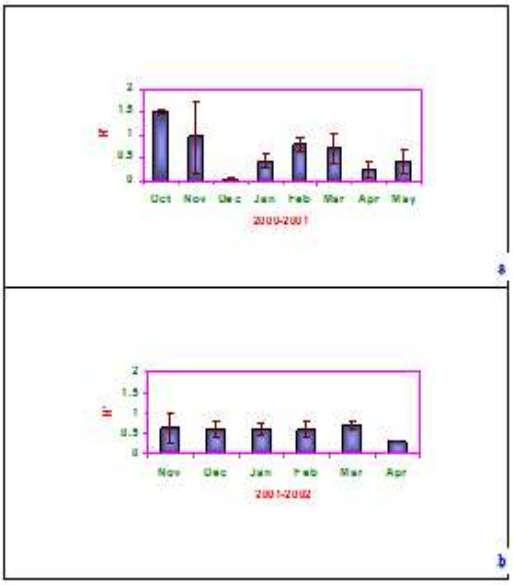
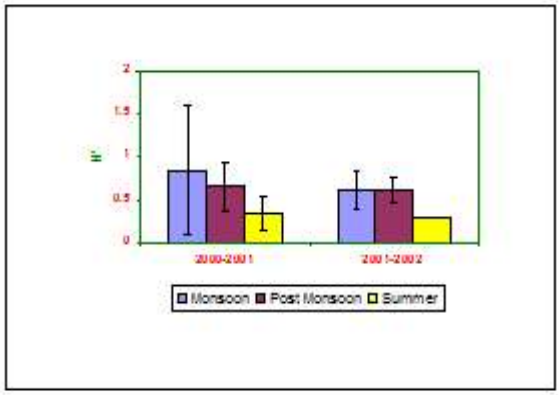


Fig. 10. Monthly variations in the diversity (H′) of phytoplankton in Thirumeni lake during a) First Year (2000-2001) and b) Second Year (2001-2002) of the study period. Values are $\overline{X}$±1SD.



ANOVA for diversity of Phytoplankton

Source	DF	SS	MS	F	P
Year	1	0.1525	0.1525	1.07	0.307
Season	2	1.2774	0.6387	5.15	0.009
Year*Season	2	0.1075	0.0539	0.43	0.651

* Significant values are indicated by bold types

Fig.11. Seasonal variations in the diversity (H′) of phytoplankton in the Thirumeni lake during the study period. Values are $\overline{X}$±1SD.

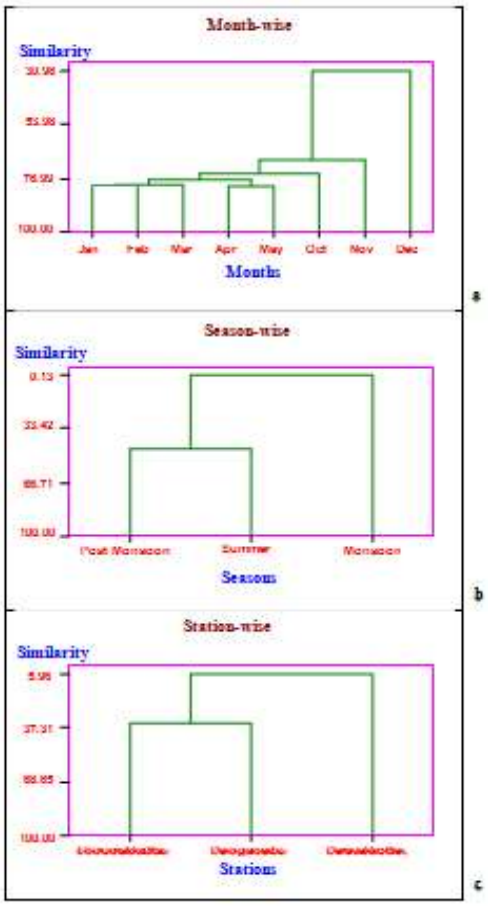


Fig. 12. Dendrograms to show the similarities among the **a)** months and **b)** seasons of the study period and **c)** sampling stations of the lake with regard to diversity of phytoplankton.

With regard to seasons, there was a declining trend in phytoplankton diversity as the season progressed from monsoon to summer across the post monsoon season in the first year (2000 – 2001), while it was almost similar during the monsoon and post monsoon seasons of the second year (2001 – 2002) with a drop during the summer season of that year (Fig.11). The season wise variations in phytoplankton diversity were statistically significant (ANOVA; $F_{1, 51} = 5.13$; $P<0.05$).

The month December was unique in phytoplankton diversity as evidenced from the dendrogram resulting from a cluster analysis (Fig. 12a). The phytoplankton diversity was highly dissimilar in monsoon season as compared to the other two seasons *viz.,* post monsoon and summer (Fig. 12b). The stations Thirumakkottai and Painganadu were similar with regard to phytoplankton diversity while the Paravakkottai station was unique in its phytoplankton diversity (Fig. 12c).

Factors Influencing Phytoplankton Diversity

Turbidity and total alkalinity of lake waters entered into the multiple regression model developed to predict the phytoplankton diversity (H′) in Thirumeni lake as they explained 37.4% of the variations. Both variables had non-linear relationship with phytoplankton diversity and the model was highly significant ($F = 6.09$; $P<0.001$; Table 4).

DISCUSSION

Phytoplankton Composition

The Chlorophyceae has been found to dominate the phytoplankton in all the seasons of both years of study (vide Figs. 3 a and b). Kumar and Gupta (2002) have also found Chlorophyceae to be the most dominant group among the phytoplankton in the freshwater ecosystems of Santal Pargana, Jharkand, India. On the other hand, Patnaik and Sarkar (1976) have found the Bacillariophyceae to be the dominant group in the Chilka lake and Chatterjee and Mohanty (1989) in the Nandankaran lake, Orissa, India. However, the increase in the proportion of nutritionally inferior algae like Chlorophyceae is considered to be a sign of racing eutrophication (Rawson, 1956; Davis, 1954; Jumppanen, 1976; Pandit, 1980; Pandit and Kaul, 1981; Pandit, 1999).

Important taxa of phytoplankton recorded in the present study include Oscillatoria, Spirulina, Chlorella, Closterium, Scenedesmus, and Navicula. According to Pendse et al. (2000), the presence of taxa like Oscillatoria, Spirulina, Chlorella, Closterium, Scenedesmus, Navicula, Euglena and Trachelomonas are indications of organic pollution. Earlier, Palmer (1969) has also shown that the genera like Euglena, Oscillatoria, Scenedesmus, Navicula, Nitzschia and Microcystis are the species found in organically polluted waters. Similar observations have also been made by Hosmani and Bharathi (1980), Goel *et al.* (1986) and More and Nandan (2000).

Seasonal Variations in Phytoplankton

In the present study, it has been found that there have been marked seasonal effects with regard to phytoplankton productivity with the highest productivity occurring during summer (vide Fig. 5). The cluster analyses have also revealed that the phytoplankton production is under the influence of month and season (vide Fig. 4 ,5 and 6). The higher phytoplankton production during summer has been attributed to high intensity of light and high temperature (Prasad and Nair, 1963; Sreenivasan, 1964, 1969; Williams and Mardroch, 1966; Khan and Siddiqui, 1974; Rajyalakshmi and Premswarup, 1975; Purushothaman and Bhatnagar, 1976). Kumar and Gupta (2002) have stated that the summer peak in phytoplankton growth might be due to increase in high transparency and water temperature and decrease in water volume. Butcher (1946), Singh (1960) and Sharma (1983) have also found higher atmospheric or water temperature along with bright sun shine to be an important factor in the periodicity of phytoplankton. Baruah *et al.* (1993) have also reported the phytoplankton to be dominant in summer in the Kewar lake, India, mainly due to favourable thermal condition and high nutrient level during this season.

Interestingly, on the otherhand, the density and diversity of phytoplankton have been found to be higher during monsoon (vide Figs. 8 and 11). Mishra and Tripathi (2000) have attributed the higher phytoplankton density in winter to high turbidity, and more water coverage with rains. However, a review of literature reveals that there exists a considerable variation in the growth periods of phytoplankton. Earlier reports suggest that the maximum growth of phytoplankton is during summer and minimum in winter (Philipose, 1960; Kumar and Dutta, 1991). Kumar (1990) has reported the density of phytoplankton to be greater during summer, post monsoon and winter and lowest in monsoon. Saha and Choudhury (1985) have obtained maximum density of phytoplankton during July and minimum during January. Verma and Mohanty (1995) have recorded three peaks (March, July and January) in phytoplankton at Dhanmukun pond, India, while at Malyanta pond, India, it was maximum in winter months. Thus, it may be inferred that the seasonal variations in phytoplankton density may vary according to different localities. Further,

the higher density and diversity of phytoplankton in monsoon and a higher phytoplankton volume in summer that have been observed in the present study have indicated that few forms dominated the summer months, while a variety of smaller forms occurred in high numbers during the monsoon months.

Water Quality Factors Influencing Phytoplankton

Turbidity, total dissolved solids, total alkalinity, chlorides, nitrate and phosphate of lake water and phosphorus of bottom soil have been the most important factors that influenced the phytoplankton productivity density and diversity in the Thirumeni lake (vide Tables 2-4).

According to Mishra and Tripathi (2000) high turbidity affects phytoplankton density. A positive correlation between total dissolved solids and Cyanophyceae and Chlorophyceae and a negative correlation with Bacillariophyceae has been reported by Dwivedi and Pandey (2002) also. Similarly positive relationship between total alkalinity and Chlorophyceae and Cyanophyceae has been established (Dwivedi and Pandey, 2002). Nitrate is an important factor for controlling the occurrence and abundance of phytoplankton (Dwivedi and Pandey, 2002). Phosphate is considered as one of the important nutrients limiting the growth of phytoplankton (Welch *et al.*, 1978). Dwivedi and Pandey (2002) have found a significant relationship between average phosphate and Bacillariophyceae and Chlorophyceae indicating that high phosphate concentration favoured their growth. The chlorides content has been attributed to good planktonic growth by Raina and Voshra (1996). Significant correlations have been established between phytoplankton density and physico-chemical parameters of water by Zafar (1964), Munawar (1974), Saha and Choudhary (1985), Kanungo et al. (1985), Chatterjee (1990), Sharma (1993), Verma and Mohanty (1995) and Gujarathi and Kanhere (1998). Thus it is inferred that the diversity of phytoplankton in Thirumeni lake is dependent on the above different abiotic factors either directly or indirectly.

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