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Plankton diversity and dynamics in a polluted eutrophic lake, Ranchi

B. Mukherjee*, M. Nivedita and D. Mukherjee

Section of Environmental Biology, P.G. Department of Zoology, Ranchi College, Ranchi - 834 008, India

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Abstract: *The species diversity of a cultural eutrophic lake at Ranchi was studied in relation to external variables (forcing functions) and internal or state variables. The lake receives daily detergent inputs in the form of washings of a variety of objects. A model was constructed for the estimation of detergent inputs from the increase in the phosphate concentration, and from changes in the concentration of inorganic carbon. Nutrients such as inorganic carbon, nitrates, phosphates, sulphates were found to be high in contrast to natural unpolluted systems. The DOM, COD and BOD were also found to be high suggesting organic pollution of the system with an organic carbon load of 5.4 m moles* l^{-1}*. The growth and development of the plankton constituents was studied in this regime. The natural planktonic rhythm was found to be modified by the polluted condition existing in the lake. The phytoplankton exhibited four peaks in March, May, August, and November while, the zooplankton showed three peaks in February, July and October. The abundance of zooplankton during the annual cycle oscillated with that of the phytoplankton. There was much more evenness in the zooplankton population in comparison to the phytoplankton. Analysis of both, the zooplankton as well as the phytoplankton population was done using the Bray-Curtis dissimilarity index, importance value index and Shannon-Weaver diversity index. The importance value index was found to provide a better evaluation of the plankton community than the diversity index. The phytoplankton population showed no correlation with nutrient availability as indicated by the correlation-regression analysis and the planktonic rhythm was not in tune with normal unpolluted conditions. The lake was classified as meso-polysaprobic using biological and chemical indices (Pantle and Buck index:3.5, BOD:60; DOM:9.3 and COD:130).*

Key words: *Blooms, Cluster analysis, Eutrophic, Importance value index, Species diversity, Saprobity, Ranchi lake*
PDF of full length paper is available online

Introduction

We addressed the question how cultural eutrophication modifies the lake environment, and the diversity and dynamics of the plankton population. This was a part of our effort to develop a model for planning management strategies, and classification of such systems based on the saprobity index.

The word eutrophy is generally taken to mean "nutrient rich". Natural eutrophication of lakes is a slow process involving geologic time scale. The process has been greatly accelerated by cultural eutrophication. The cultural (man-made) eutrophication of freshwater ecosystems is one of the most prevalent environmental problems responsible for water quality degradation on a world-wide scale (Vollenweider, 1968; Harper, 1992; Vezjak *et al.*, 1998; Biggs, 2000; Wetzel, 2006). Cultural eutrophication relates to the rapidly increasing amount of phosphorus and nitrogen normally present at relatively low concentrations. Of the two, phosphorus is considered to be the major cause of eutrophication, as it is a growth-limiting factor for algae in freshwaters.

At Ranchi lake the entry of nutrients was due to the use of detergents and the influx of sewage water from surrounding areas. In order to assess the deterioration of water quality and characteristics of planktonic community. Our studies were concentrated on the estimation of the increase of nutrients due to the influx.

*** Corresponding author:** bm_ebag@rediffmail.com

Materials and Methods

Ranchi lake (Fig. 1a) has an area of about 0.157 km^2, a depth of about 6 m and is one of the oldest water bodies in the city.

Samples were collected twice each month from five stations (Fig. 1b). The plankton samples were preserved in 5% neutralized formalin and Lugol's iodine after collection. Preserved samples (1 ml) were used for species identification and counting on a Sedgwick-Rafter cell at 45x and 100x magnification.

Three types of indices were used for the study of the plankton community. The Shannon-Weaver diversity index was used for the estimation of community diversity (Azeiteiro *et al*., 1999; 2000; Morgado *et al*., 2003). Cluster analysis was done using the Bray-Curtis dissimilarity index (1957). To determine the relative importance of the various phytoplankton species in the community the 'Important Value Index' (IVI) was adopted, a method developed by Curtis and McIntosh (1950) to assess the dominance of forest species. This method was applied to water samples to produce a comparable IVI (importance value index) for each phytoplankton species by combining the standardized abundance, frequency and biovolume with respect to the sum total of that attribute of all the species of the sample, and a relative value was obtained (Jayatissa *et al.,* 2006). The method was found to be more reliable for the assessment of the dominance of different phytoplankton species in comparison to the diversity analysis.

Parameters such as light, temperature, pH, oxygen, inorganic carbon, nitrates, sulphates, phosphates, dissolved organic matter and BOD were monitored at regular monthly intervals. Chemical analysis of phosphates, nitrates, sulphates, BOD and COD was done using standard methods (APHA, 2006).

After qualitative analyses of plankton Tonapi (1980), Ward and Whipple (1945), and estimation of their abundance, the Pantle - Buck saprobity index was determined (Pantle and Buck, 1955). Ortendorfer and Hofrat's list of indicator species was used for determination of water quality (Ortendorfer and Hofrat, 1983). Most of the indices were transformed on the basis of Felfoldy (1987) and Turoboyski (1979) to determine the category of saprobity (Imre, 2004; Dulic *et al.*, 2006).

System design: Ranchi lake is a predominantly eutrophic lake with high nutrient content as exhibited by the concentration of various parameters (Table 1). The system receives a daily detergent input through washings of a variety of objects as well as sewage material from the surrounding drainage systems. Generally there is a chemical rhythm in unpolluted systems in tune with the photosynthesis and respiration of the biota however, in the lake under study, the influx causes a disruption in the chemical rhythm of the lake and it is difficult to asses the changes in the parameters due to the activity of the biota and the entry of pollutants.

Now the problem before us was how to differentiate between the changes in inorganic carbon due to photosynthesis and respiration and that due to the entry of detergents and subsequent precipitation as calcium carbonate, because the detergents contain a large amount of sodium carbonate in the form of fillers.

A mathematical model that could account for the changes in inorganic carbon due to photosynthesis and respiration, and due to addition and precipitation. Table 2 gives the symbols and definitions used in the equation. The model is based on established chemical principles and provides an accurate evaluation as tested earlier (Mukherjee *et al.*, 1993, 2002, 2007, 2008).

Simulation studies were conducted in the laboratory to assess the input of detergents by introducing known amounts of detergents and studying the changes in pH, alkalinity, total inorganic carbon, and phosphates (Table 3) and regression equations were formulated:

$DI\ mg\ l^{-1} = 145\ TA\ meq\ l^{-1} + 122.06$ ....Eq. 2

$DI\ mg\ l^{-1} = 278.81\ PO_4\text{-}P\ mg\ l^{-1} - 38.21$ ....Eq. 3

$DI\ mg\ l^{-1} = 253.98\ \Sigma C_t\ m\ moles\ l^{-1} - 334.74$ ....Eq. 4

Thus addition of parameters to the model (based on regression equations) provides model output for the various parameters. The correlation between detergent input and the three parameters are well approximated (r: ranging from 0.87-0.987: p<0.001). Fig. 2 shows the correlation between the entry of detergents and the increase in the concentration of phosphates as observed in laboratory simulation studies.

Results and Discussion

The detergent input at the site of entry was calculated to be about 437 mg l^{-1} and the simultaneous nutrient loading resulted in an increase in the concentration of phosphates, nitrates, and inorganic carbon. The values were 1.705 mg l^{-1}, 0.50 mg l^{-1} and 3.95 m moles l^{-1} respectively. Thus there was a daily increase in all the nutrients. Analysis of the plankton constituents and its relationship with the chemical environment was studied in this regime.

Phytoplankton:

Laboratory analysis: Fig. 3 shows the annual mean abundance of the various groups of phytoplankton. The percentage of the various classes in a descending order are as follows Cyanobacteria > Bacillariophyceae > Chlorophyceae > Euglenophyceae > Chrysophyceae > Xanthophyceae. As is expected the Cyanobacteria forms the dominant members in these culturally eutrophic waters indicating organic pollution.

In general a bimodal peak is the usual pattern with a spring peak and an autumn peak occurring in February – March, and October - November respectively coinciding with peak nutrient availability. In our study we found four peaks (Fig. 4) in the month of

Table - 1: Showing the mean chemical environment of Ranchi lake, Ranchi (2007-2008)

Parameters	Concentration
pH	9.11
Temperature (°C)	25.9
Oxygen (mg l^{-1})	9.9
Alkalinity (meq l^{-1})	6
Total inorganic carbon (m moles l^{-1})	5.47
Phosphate (mg l^{-1})	2.37
Nitrate (mg l^{-1})	3.7
Sulphate (mg l^{-1})	81.5
Chloride (mg l^{-1})	184.8
BOD_5 (mg l^{-1})	60
COD (mg l^{-1})	130
DOM (mg l^{-1})	9.3
Organic carbon m moles l^{-1}	5.4
Conductivity (μ mhos)	827

BOD = Biological oxygen demand, COD = Chemical oxygen demand, DOM : Dissolved organic matter

Table - 2: Symbols and definitions used in the equations

ΣC_t	:	Total inorganic carbon
$\Delta\Sigma C_t$	:	Change in total inorganic carbon
α_0	:	Fraction of total inorganic carbon as free carbon dioxide
α_1	:	Fraction of total inorganic carbon as bicarbonates
α_2	:	Fraction of total inorganic carbon as carbonates
K_1	:	First dissociation constant of carbonic acid: 4.3×10^{-7}
K_2	:	Second dissociation constant of carbonic acid: 4.8×10^{-11}
$[H^+]$	:	Hydrogen ion concentration = 10^{-pH}
TA	:	Carbonate alkalinity
dA	:	Change in A
$d[H^+]$	:	Change in $[H^+]$

Table - 3: Converting table for investigated parameters into a numerical saprobity grade and evaluating the saprobic status of Ranchi lake (Felfoldy, 1987)

Saprobity grade	Pantle and Buck index	Indices (O_2 mg l^{-1}) COD ($K_2Cr_2O_7$)	BOD
Oligosaprobic	0.5-1.3	< 2	< 2
Oligo-beta Mesosaprobic	1.31-1.8	2-6	2-3
Beta-mesosaprobic	1.81-2.3	6-10	3-5
Alpha-beta Mesosaprobic	2.31-2.8	10-20	5-7
Alpha-mesosaprobic	2.81-3.3	20-70	7-20
Meso-polysaprobic	3.31-3.8	70-200	20-120
Polysaprobic	3.81-4	> 200	> 120
Ranchi lake	3.5	130	68

COD : Chemical oxygen demand, BOD : Biochemical oxygen chemical

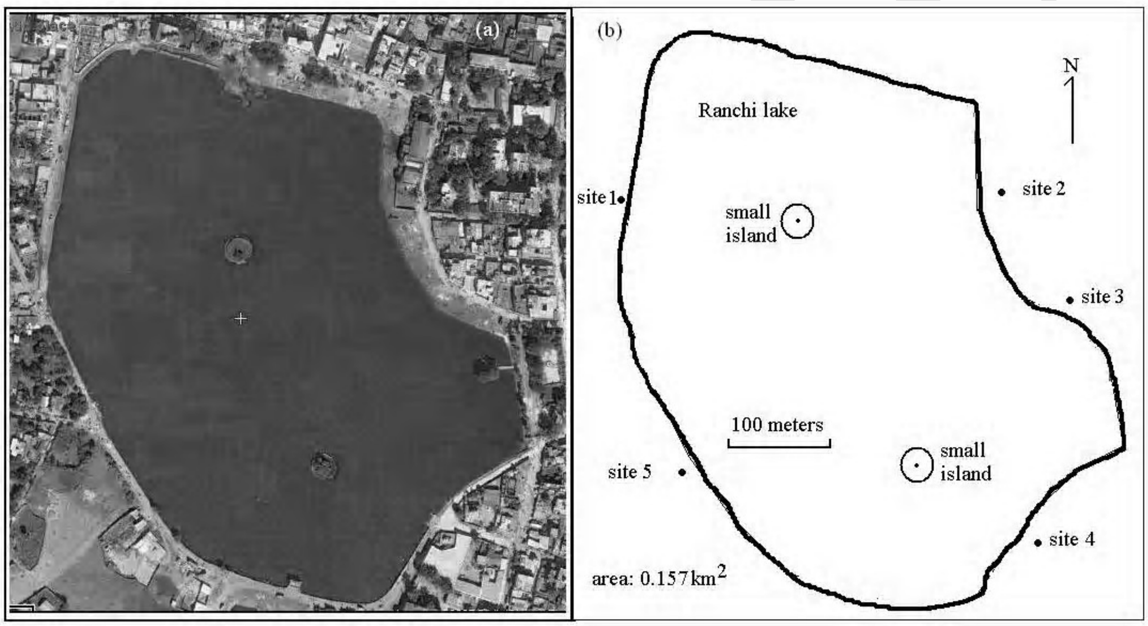

Fig. 1(a): Showing an aerial view of Ranchi lake, (b) The various sites at Ranchi lake from which samples were collected

March (P-1), May (P-2), Aug (P-3) and Nov (P-4). P-1 is contributed by cyanobacteria, bacillariophyceae, chlorophyceae and xanthophyceae; P-2 by bacillariophyceae, chlorophyceae and xanthophyceae; P-3 by bacillariophyceae and xanthophyceae, while P-4 by cyanobacteria, bacillariophyceae, chlorophyceae and chrysophyceae. In contrast to the usual pattern, we found the November peak (P-4) to be higher in contrast to the other three peaks and was dominated by *Gleocapsa punctata, Microcystis flos-aquae, Asterionella formosa, Nitzschia acicularis*, *Scenedesmus arcuatus, Nautococcus sp.* and by filamentous algae.

Regression, diversity, cluster analysis and importance value index: As can be seen in Fig. 5a, there is practically no correlation between the concentration of nitrates and phosphates (r = - 0.37) and the abundance of phytoplankton. In fact at times a positive correlation is exhibited instead of a negative relation because of the

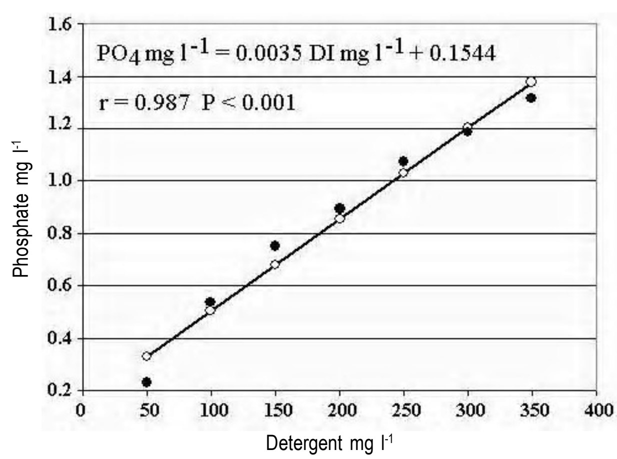

Fig. 2: Correlation between detergent input and increase in the concentration of phosphates in a simulated system

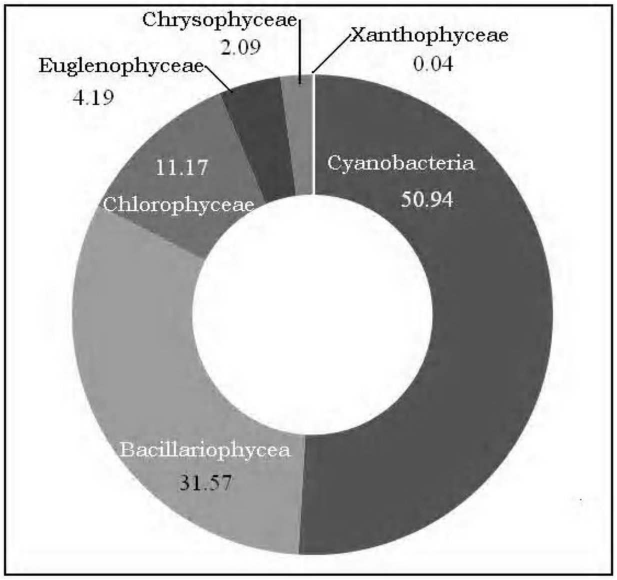

Fig. 3: The mean annual abundance of the various groups of phytoplankton

continuous entry of phosphates and inorganic carbon through the use of detergents, nitrates and organic carbon from sewage material.

Species diversity calculated by the Shannon - Weaver diversity index showed that the maximum diversity (2.5) was in October decreasing slightly in November but, increasing again in the month of December (Fig. 5b). The minimum diversity (0.5) occurred in August. In tune with this rhythm the minimum dominance was in October and the maximum in August. This was the period of abundance of bacillariophyceae, especially *Nitzschia*. Throughout the rest of the year the species diversity fluctuated from 1 to 1.5.

Calculation of the Importance value index showed that the most dominant species of phytoplankton within the community was *Nitzschia* followed by *Microcystis, Gleocapsa, Spirulina inflata* and *Euglena gracilis* (Fig. 6).

The phytoplankton communities of the four peaks were analyzed to assess the relative contribution of the various species towards the blooms. The peak in March showed two clusters (Fig. 7a). Cluster 1 consisted of *Fragilaria virescens*, *Vaucheria*

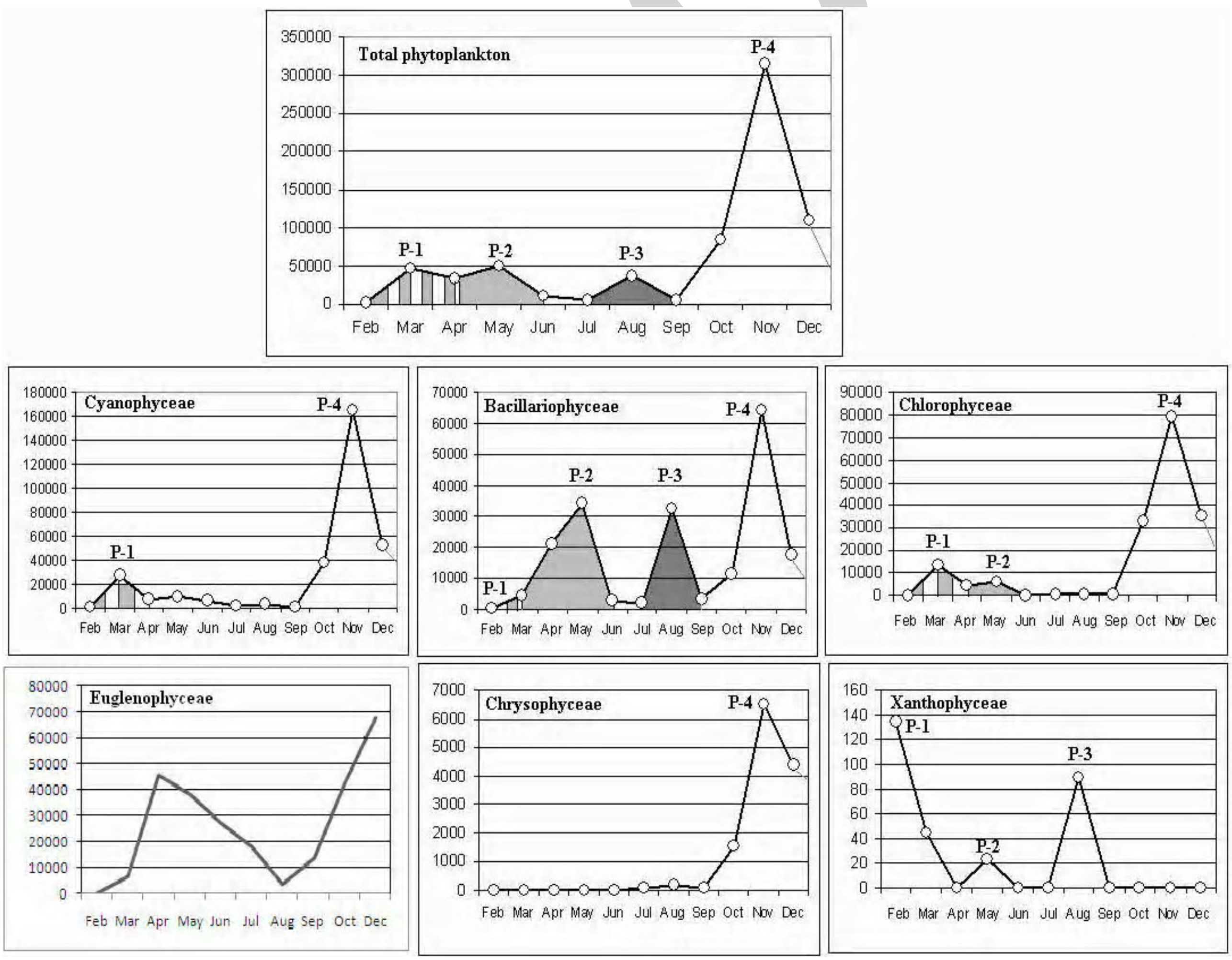

Fig. 4: The various phytoplankton peaks during an annual cycle and the major contributors

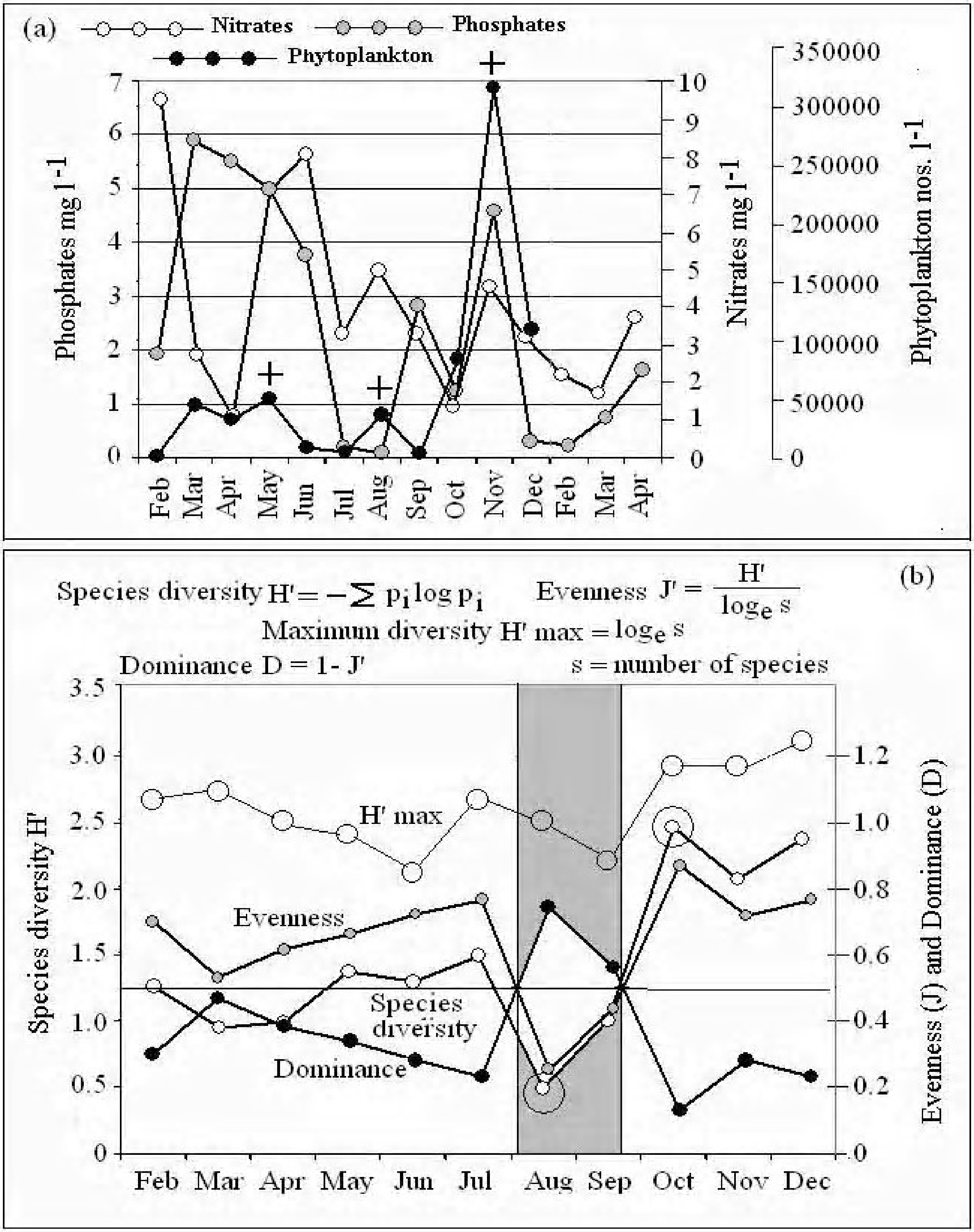

Fig. 5: (a) The seasonal changes in nutrient concentration and the abundance of phytoplankton, (b) The annual changes in phytoplankton species diversity relative to the maximum obtainable

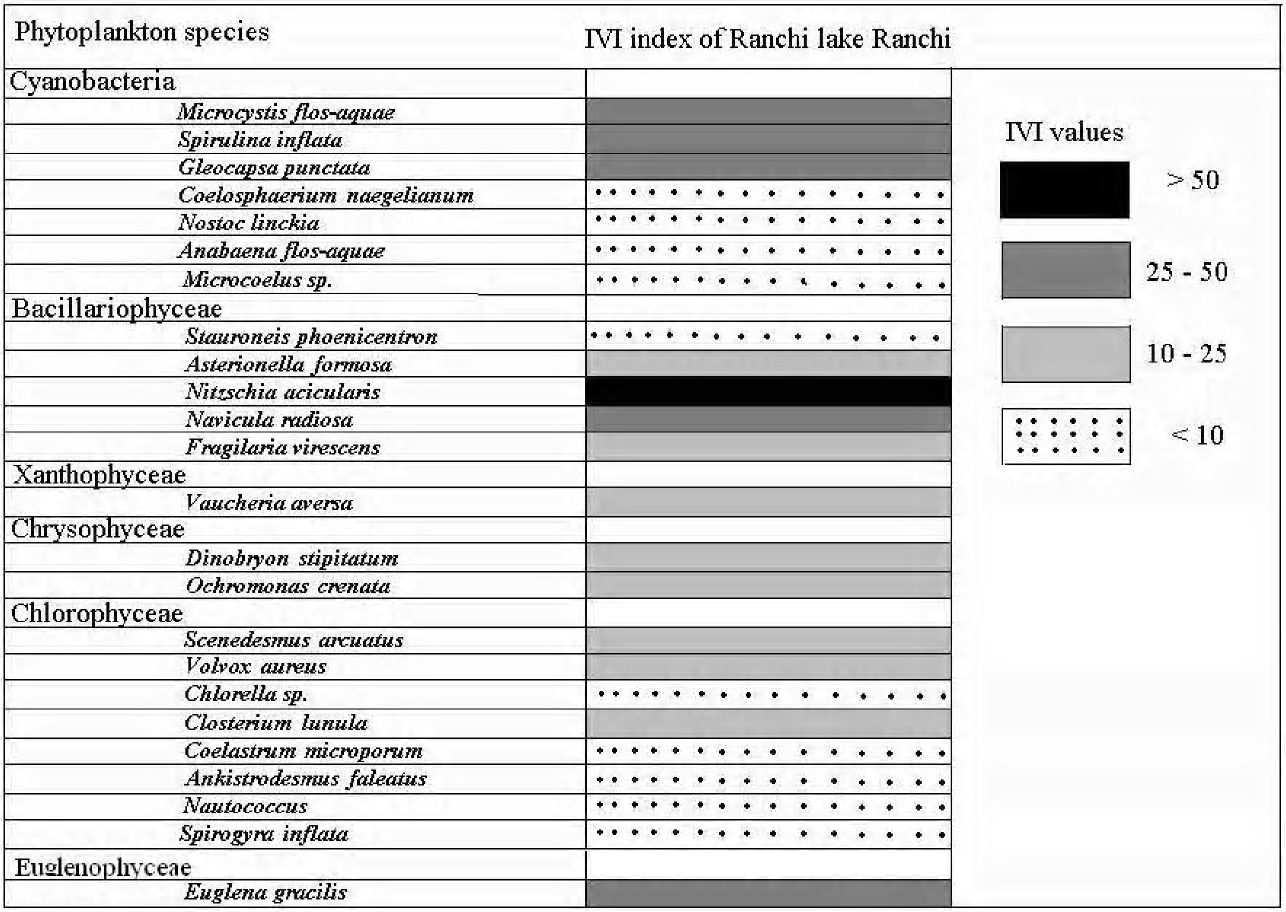

Fig. 6: The importance value index of the phytoplankton community at Ranchi lake. *Nitzschia* appears to be the most important in the community structure followed by *Microcystis, Gleocapsa, Spirulina* and *Euglena,* IVI = Importance value index

aversa and *Spirulina* but, these contributed little towards the peak. Clusters 2 consisted of *Euglena, Microcystis and Nitzschia* and were the main participants of the spring bloom. *Euglena* and *Microcystis* dominated the event.

The bloom in the month of May (Fig. 7b) had two clusters. Cluster 1 still contained *Fragilaria* and *Vaucheria* but, *Spirulina* was replaced by *Spirogyra*. In cluster 2, the major contributors of the event were *Euglena*, *Microcystis*, *Nitzschia*, and two others now join the cluster, they are *Navicula radiosa* and *Spirulina*. *Nitzschia* outnumbered all the other genera in this cluster.

The monsoon bloom in August has three clusters. In cluster 1, *Fragilaria* and *Spirogyra* are replaced by *Navicula* and *Ochromonas crenata* while, *Vaucheria* remains in the cluster (Fig. 7c). *Euglena* and *Microcystis* remains in cluster 2 however, *Spirulina* now enters cluster 2 in place of *Nitzschia*. We now have a third cluster consisting entirely of *Nitzschia*, which out-competes all the other species in the community. Schelske *et al.* (1986), states that diatom growth is dependent on supplies of available silica, which tends to decrease with phosphorus enrichment. Thus, the high concentrations of *Nitzschia* during July – August are favoured by the relatively low concentrations of phosphates. Diversity within the community so far is moderate and moves towards the autumn bloom. As already discussed the maximum diversity was found in October, decreasing slightly in November. However this decrease is compensated by the abundance. In November we have three clusters (Fig. 7d). Cluster 1 consists of *Ochromonas* , *Coelastrum microporum*, *Vaucheria* and *Fragilaria* now disappear. Cluster 2 has *Spirulina*, *Ankistrodesmus sp.*, *Nautococcus sp.*, *Dinobryon stiptatum*, *Closterium lunula*, *Navicula* and *Volvox aureus.* Apart from *Spirulina* and *Navicula* all others appear for the first time in this cluster. The third cluster created by *Nitzschia* during August is now occupied by *Asterionella formosa*, *Microcystis*, *Gleocapsa* and *Nitzschia*. *Gleocapsa* out competes all others in the cluster.

Zooplankton :

Laboratory analysis: Fig. 8a shows the annual mean abundance of the various groups of zooplankton and the species composing the community. The percentage of the various classes in a descending order are as follows Rotifera > Copepoda > Ostracoda > Branchiopoda. In comparison to the phytoplankton, the zooplankton population is lower by a factor of 1.77×10^2. The zooplankton population shows two peaks in the months of February

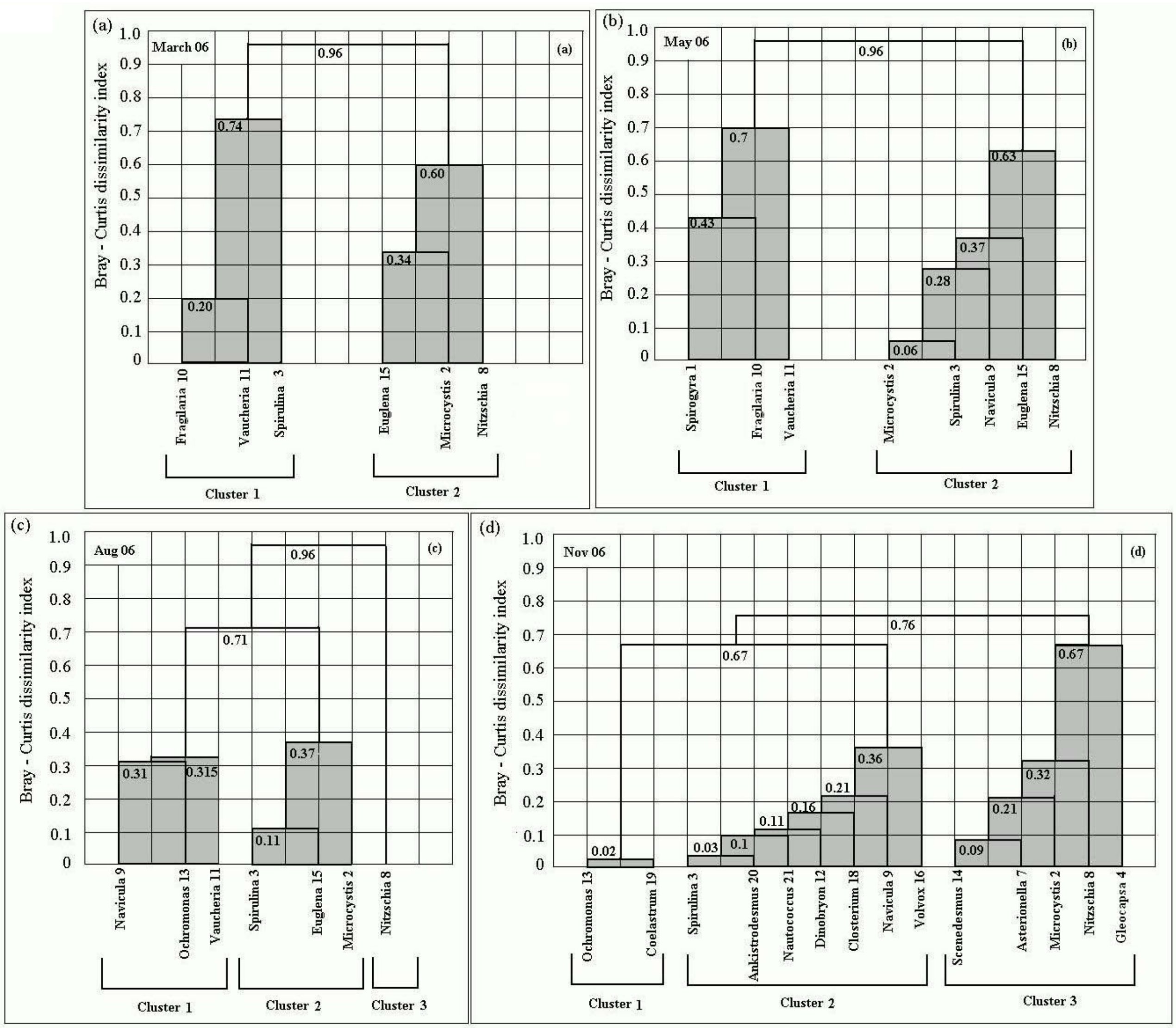

Fig. 7: Cluster analysis of the phytoplankton population during (a) March. (b) May, (c) August and (d) November

and July, with a small peak in October (Fig. 8b). The abundance of zooplankton during the annual cycle oscillated with that of the phytoplankton but with a time lag. There is a time lag of about a month between the phytoplankton and zootoplankton peaks. Interestingly, this time lag of 30-45 days represents the time taken by the zooplankton to develop from their eggs.

Regression diversity, cluster analysis and importance value index: The regression calculated between the zooplankton and phytoplankton population with the introduction of a time lag gives a good negative correlation ($r = -0.81$; $p < 0.01$) and is shown in Fig. 9a.

That is, the zooplankton peak alternates with the phytoplankton peak using a time lag sequence of about 30 to 45 days. Interestingly, although the phytoplankton does not show any relation with nutrient availability but, the zooplankton shows a moderately good negative correlation (Fig. 9b) with phosphates. Jeppesen *et al.* (2002, 2005, 2007) in their studies have reported a similar corelation betwen the abundance of zooplankton and the concentration of phosphates.

Species diversity is high in March and August and is realized just after the peaks in February and July (Fig. 10a). Maximum dominance is in July when *Brachionus* is found in great numbers and the minimum in June and September. Zooplankton is completely absent in November while in October it is represented by a single species of *Rattulus*.

Calculation of the Importance value index showed that the most dominant genera of zooplankton within the community were *Brachionus calcyflorus* and *Mesocyclops leuckarti*, followed by *Heliodiaptomus viduus*, *Cypris subglobosa*, *Keratella procurva* and

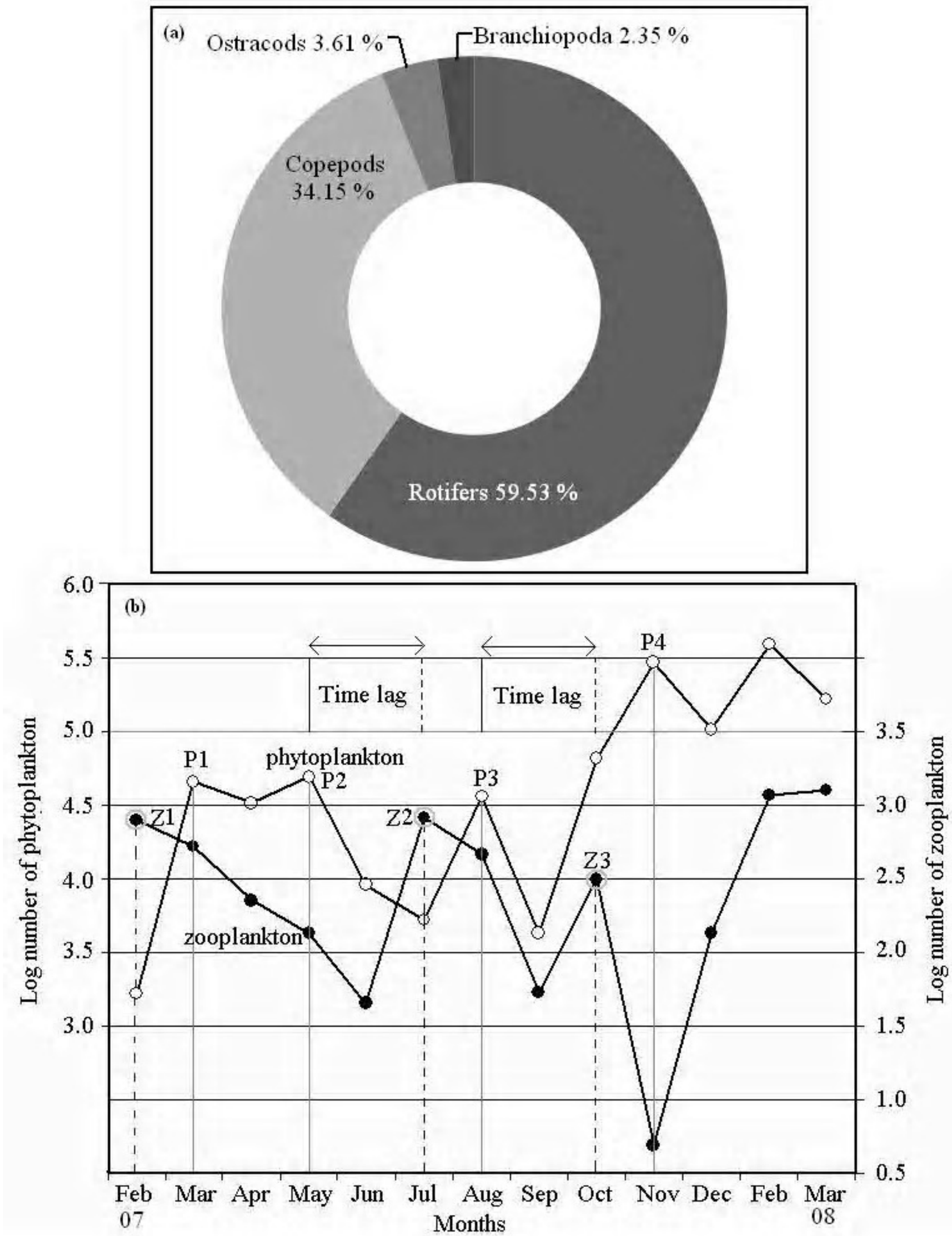

Fig. 8: (a) The mean annual abundance of the various groups of zooplankton, (b) The zooplankton peaks at Ranchi lake during an annual cycle

Rattulus longiseta (Fig. 10b). The others showed short term occurrences increasing the community diversity for short periods.

Cluster analysis of the zooplankton was done for the two peaks, February and July to assess the relative contribution of the various genera. The peak in February (spring peak) shows three clusters (Fig. 11). Cluster 1 consists of *Cypris subglobosa*, *Brachionus calcyflorus* and *Keratella procurva* and all these species show moderate abundance. Cluster two consists of *Moina dubia*, *Hydatina sp.* and *Rattulus longiseta*, these are the least abundant within the clusters. Clusters 3 consist of *Mesocyclops leuckarti, Mesocyclops hyalinus* and *Heliodiaptomus viduus* and are the predominant species in this peak.

The July peak or monsoon peak also has three clusters. In cluster 1, *Cypris* and *Brachionus* are replaced by *Hydatina* (which has increased in numbers during this period) and *Hexarthra* while, *Keratella* remains in this cluster with moderate abundance. *Mesocyclops* decreases in abundance and moves into cluster two along with two new species in the cluster; they are *Filinia longiseta* and *Epiphanes clavulata*. *Brachionus* shows a bloom and forms a separate cluster, now becoming the most dominant species in the zooplankton community as seen earlier in diversity analysis.

Plankton species composition and abundance are functions of interactions with environmental conditions including salinity, temperature, light, nutrients, turbulence, and water depth in addition

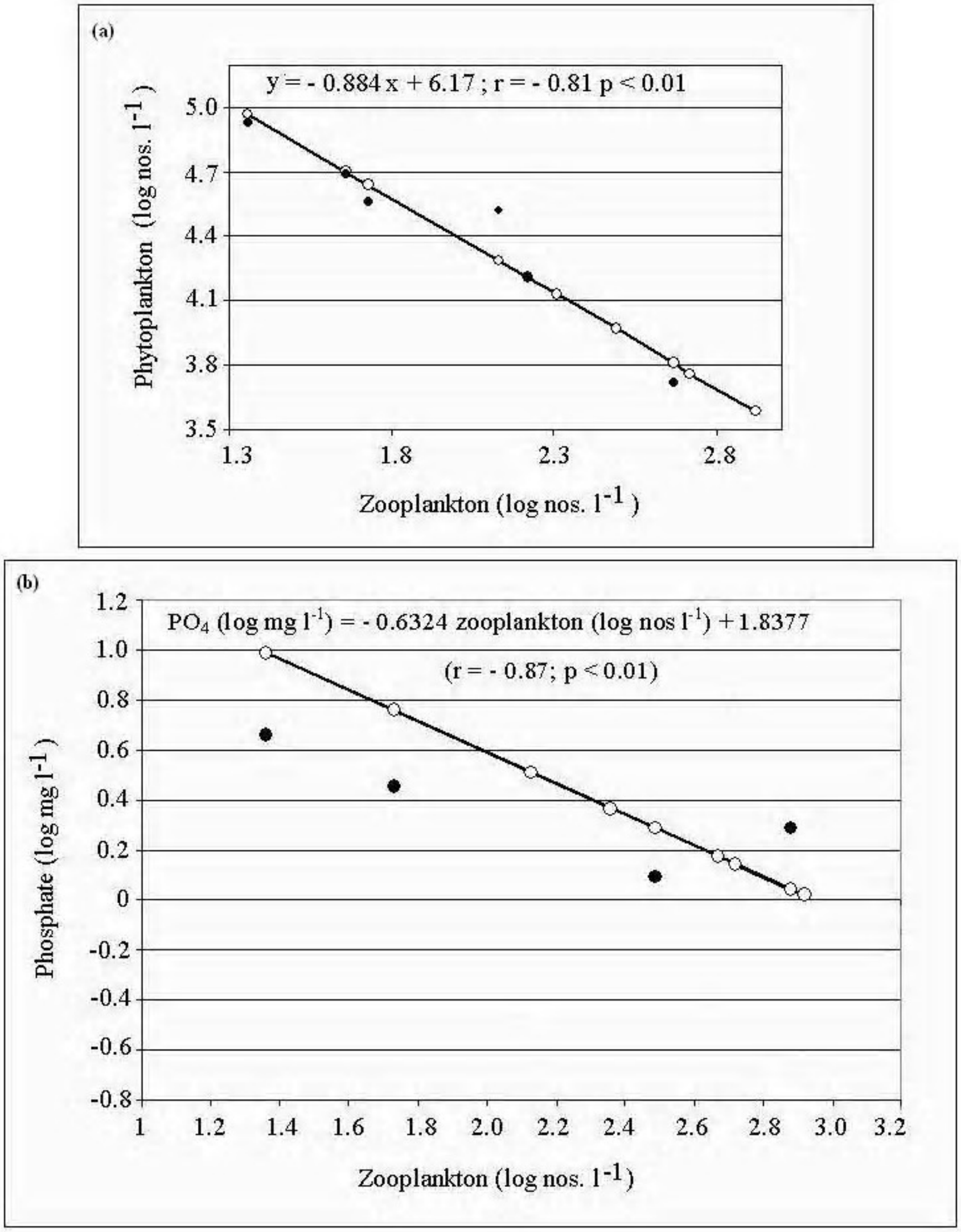

Fig. 9: (a) Correlation between the abundance of phytoplankton and zooplankton, (b) Correlation between the abundance of zooplankton and phosphate concentration of surface waters

to grazing, competition, and disease. Hutchinson and Bowen (1947) stated that it is a well known fact that the total quantity of plankton present in the waters of a lake may undergo marked and rapid variation, so that in the course of a year a number of pulses may succeed each other.

The planktonic community rhythm at Ranchi lake shows a wide displacement from those occurring in natural unpolluted water bodies. Reports of annual planktonic rhythm and peak concentration for Indian fresh waters have been given by Ganpati and Chacko (1951), Chacko and Krishnamurthy (1954), Das and Srivastava (1956), Das (1957, 1959) and Michael (1968). In general a bimodal peak (spring peak and monsoon peak) occurring in February – March and July-August respectively is the usual pattern in India. The spring peak is usually greater than the monsoon peak. However small scale departures usually occur due to specific changes. Michael (1968) reported a single but prolonged peak lasting from January to April. Similarly, Mukherjee *et al.* (1993,1995) in their studies of a polluted pond reported a single peak of phytoplankton (other than cyanobacteria) from February to April while the cyanobacteria exhibited two peaks: one in June and the other in October-November.

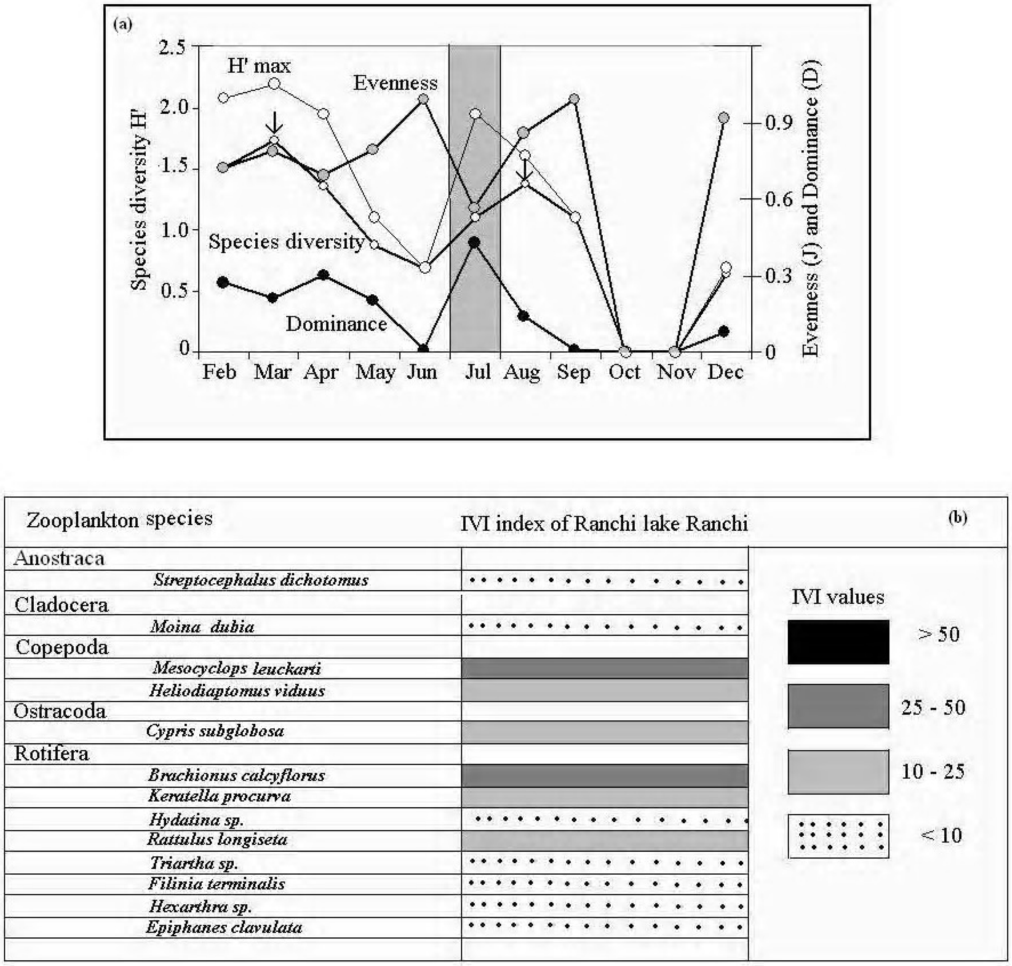

Fig. 10: (a) The annual changes in species diversity in the zooplankton community, (b) The importance value index of different zooplankton at Ranchi lake, Ranchi, IVI = Importance value index

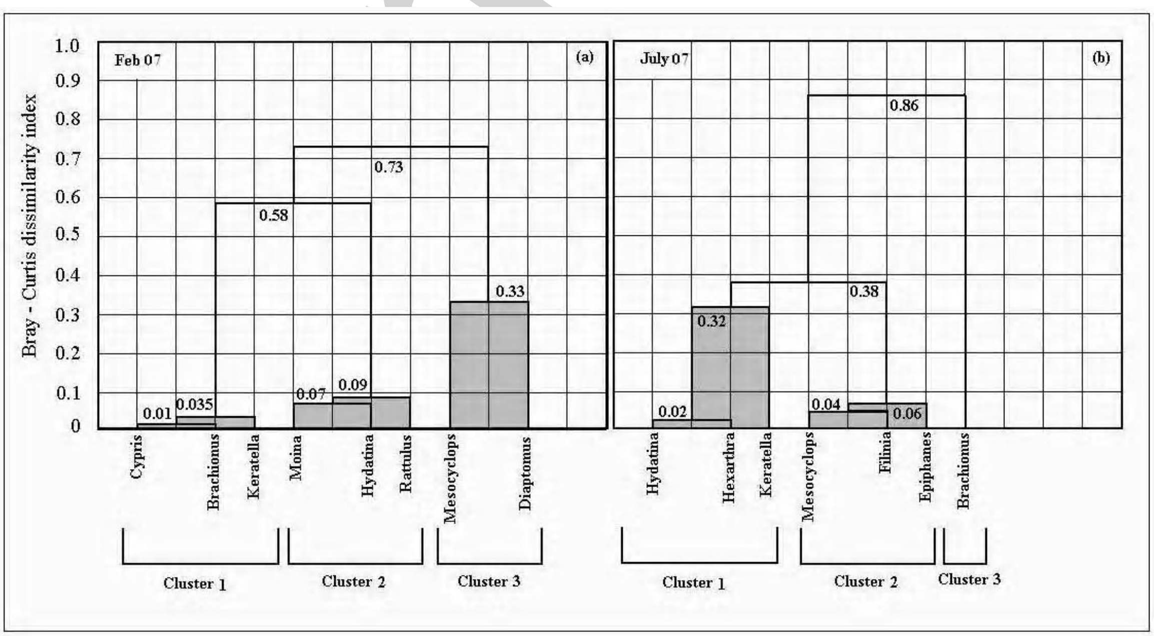

Fig. 11: Dendrogram showing the cluster analysis of the two zooplankton peaks in February and July

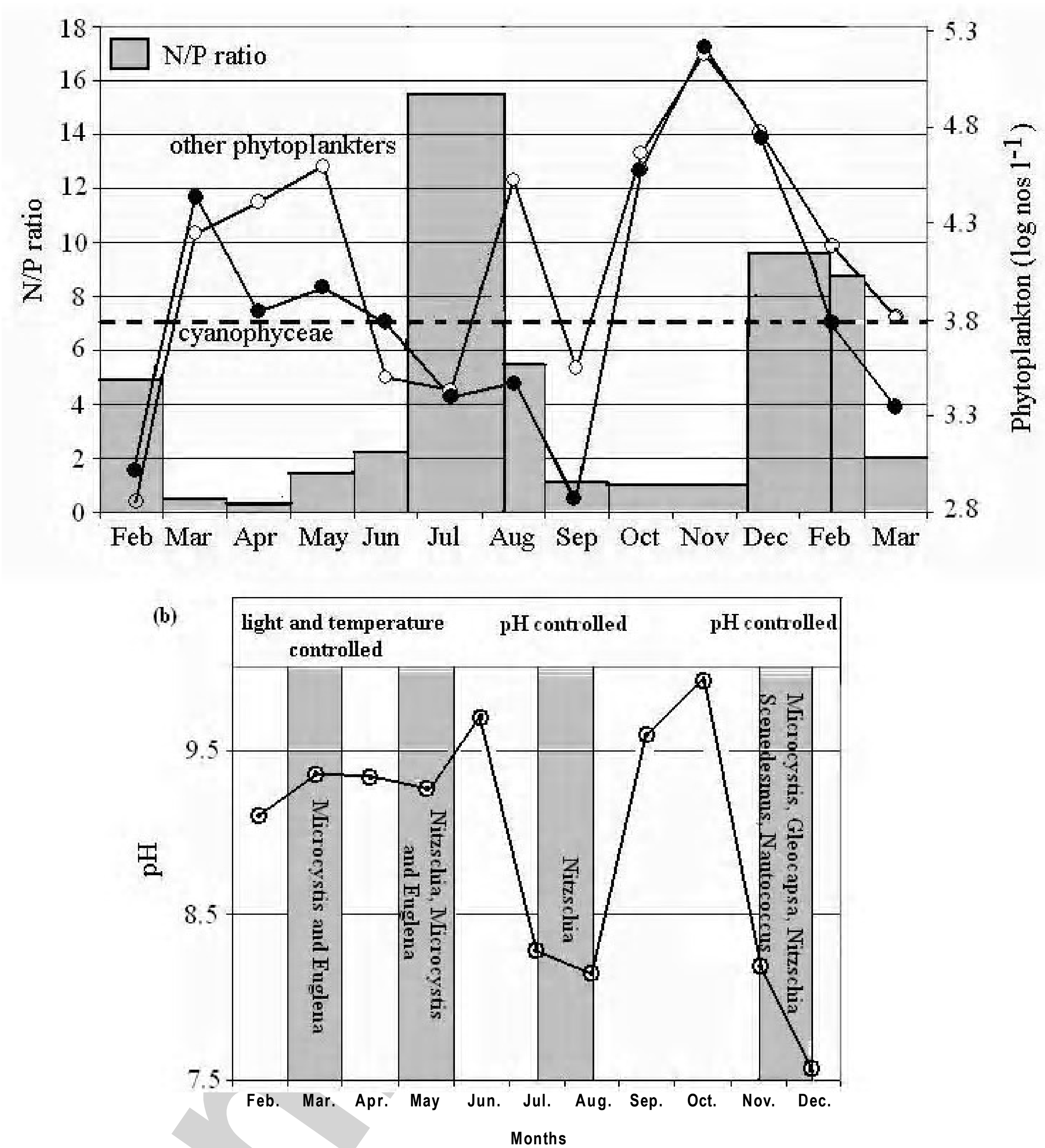

Fig. 12: (a) The N/P ratio and the abundance of cyanophyceae and other phytoplankters, (b) The different factors controlling the plankton dynamics at Ranchi lake

The phytoplankton community at Ranchi lake shows a complete departure from normal conditions. The first three peaks in March, May and August are relatively small while, the November bloom is the highest and is contributed by all the phytoplankton groups. This is in contrast to normal conditions where the spring bloom is more important. *Microcystis* blooms are primarily warm-water phenomenon and the range for optimum growth is 28.8-30.5°C (Kruger and Elhoff, 1978) especially in organically polluted waters. However in Ranchi lake the species shows peak abundance during November at a temperature of 22.8°C. Ranchi lake with high concentration of organic matter thus show an abundance of *Microcystis and Gleocapsa* while the elevated concentrations of nitrates and phosphates favour the development of diatoms.

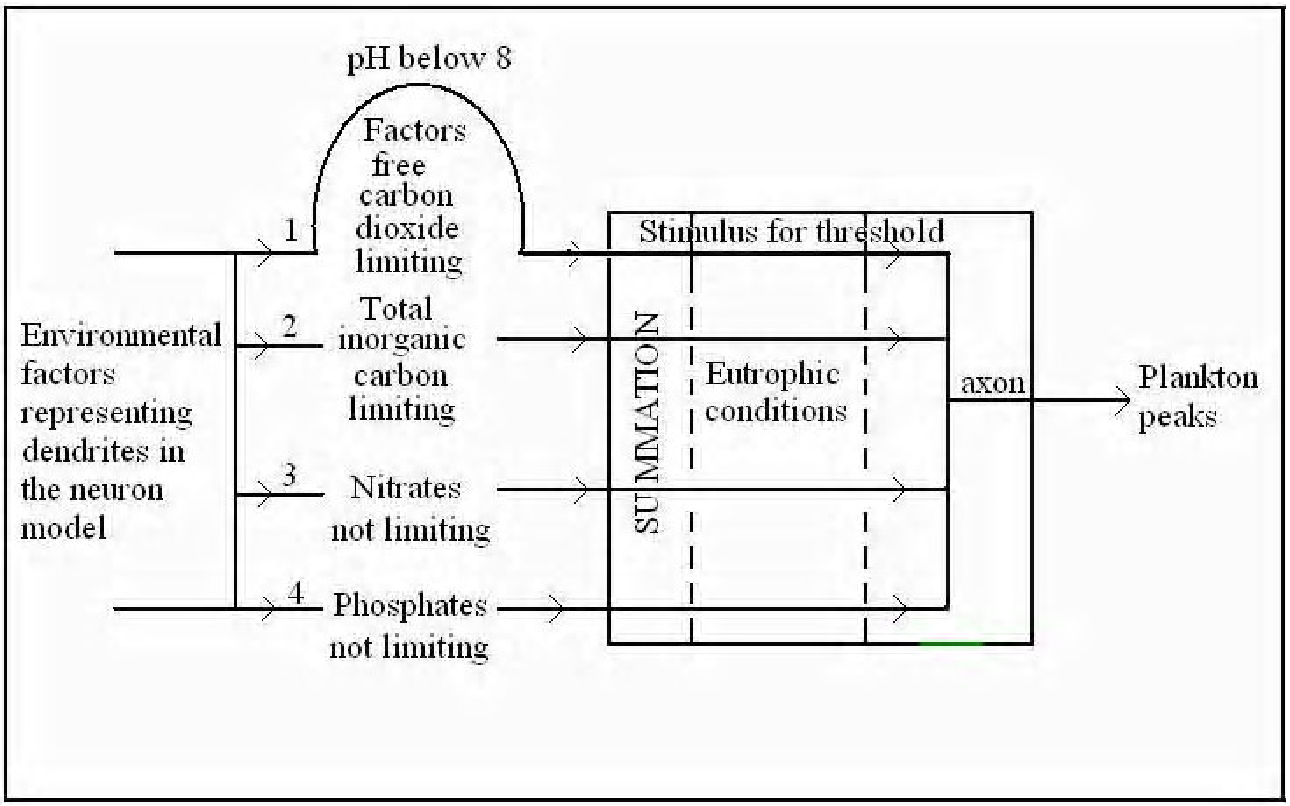

Fig. 13: The neural network model of Ranchi lake depicting the stimulus that triggers the bloom

Juday and Birge (1931) noted that such rises in the phytoplankton might occur without reducing the phosphate content of the water and that on occasions both phosphate and plankton might rise together. Statistical analysis of our data shows that there is little if any correlation between phytoplankton abundance and the concentration of phosphates and nitrates. Similarly, the bloom of cyanobacteria as well as the other plankters during November cannot be explained both on the basis of chemical and biotic analysis. Nutrients such as nitrates, phosphates, inorganic and organic carbon are comparatively high creating a discordant note in the normal planktonic rhythm and what combination of environmental parameters triggers this abnormal bloom is a matter of further research. Schelske *et al.* (1986), states that diatom growth is dependent on supplies of available silica, which tends to decrease with phosphorus enrichment. Thus, the high concentrations of *Nitzschia* during July-August are favoured by the relatively low concentrations of phosphates.

Berthon *et al.*, 1996 states that blooms of cyanobacteria are due to a drop in the N/P ratio below 7, which is the threshold level for algae. When the ratio reaches below 5, the algae collapse giving way to the cyanobacteria which accept a low N/P ratio. In our studies (Fig. 12a) we found that the N/P ratio is not the only factor controlling the dominance of these two groups at Ranchi lake especially in non-limiting conditions.

Although the pattern is consistent with the boom-bust ecological characteristic (Sheil *et al.*, 2006) but, the timing of peaks in zooplankton diversity does not coincide with peaks in phytoplankton diversity as reported by Costelloe *et al.* (2005), rather it occurs with a time lag. This may be due to the grazing intensities of both the zooplankton and fishes and the time that most of the zooplankters require to develop, as discussed earlier. Kuentzel (1969) states that one of the key factors in non-limiting conditions is a bacterial bloom before the algal bloom to provide enough free carbon dioxide to support the phenomenon. Surely the system has more than sufficient organic matter for decomposition by the bacterial population and release of free carbon dioxide. This is also supported by the studies of King (1970). Only in November and December the pH is low (7.5-8.5; Fig. 12b) increasing the availability of free carbon dioxide that triggers the bloom (Fig. 13). Therefore, in these waters free carbon dioxide may be considered as a limiting factor.

Thus the lake can be considered to be eutrophic with mesosaprobic conditions. The phytoplankton community is dominated by cyanobacteria and bacillariophyceae, and the combination of factors that trigger the blooms cannot be accurately predicted at present There is no limiting nutrient as such in the lake to control the growth of organisms. One of the reasons to define such dynamics is the low availability of free carbon dioxide (pH above 9).

Acknowledgements

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References

APHA: Standard methods for the examination of water and wastewater, 21st Edn. APHA,AWWA,WPCF, Washington, DC, USA (2006)

Azeiteiro, U.M., J.C. Marques and P. Re: Zooplankton annual cycle in the Mondego river estuary (Portugal). Arquivos do Museu Bocage, *Nova Series*, **3**, 239-263 (1999).

Azeiteiro, U.M., J.C. Marques and P. Re: Zooplankton assemblages in a shallow seasonally tidal estuary in temperate Atlantic Ocean (Western Portugal: Mondego estuary). Arquivos do Museu Bocage. *Nova Series,* **3**, 357-376 (2000).

Berthon, J.L., J. Devaux, L. Aleya, H. Giraudet and F. Restituito: Impact of eutrophication in Grangent reservoir (Loire, France): Study of the nutrient loads, the dynamics of phytoplankton populations and phyto-zooplankton relations in 1990-1991. *Hydroecol. Appl.*, **8**, 99-125 (1996).

Biggs, B.J.F.: Eutrophication of streams and rivers: Dissolved nutrient-chlorophyll relationship for benthic algae. *J.N. Am. Benthol. Soc.*, **19**, 17-31 (2000).

Bray, T.R. and J.T. Curtis: An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr.*, **27**, 325-349 (1957).

Chacko, P.I. and K. Krishnamurthy: On the plankton of three freshwater ponds in Madras. Symposium on marine and freshwater plankton. Indo-Pacific Council Bangkok. pp. 103-107(1954).

Costelloe, J.F., J. Powling, R.J.W. Reid, R.J. Sheil and P. Hudson: Algal diversity and assemblages in arid zone rivers of the lake Eyre basin, Australia. *River Res. Appl.*, **21**, 337-349 (2005).

Curtis, J.T. and R.P. McIntosh: The interrelationship of certain analytic and synthetic phytosociological characters. *Ecol.*, **31**, 434-455 (1950).

Das, S.M. and V.K. Srivastava: Quantitative studies on freshwater plankton II. Correlation between plankton and hydrological factors. *Proc. Nat. Acad.Sci., India,* **26**, 243-254 (1956).

Das, S.M.: Studies on the ecology of freshwaters of India. 1. Some physical, chemical and biological inter-relations. *Proc. Nat. Acad. Sci., India*, **27**, 150-161 (1957).

Das, S.M.: Studies on freshwater plankton, III: Qualitative composition and seasonal fluctuations in plankton components. *Proc. Nat. Acad. Sci., India*, **29**, 174-189 (1959).

Dulic, Z., V.M. Tutundzic, Z. Markovic and I. Zivic: Monitoring water quality using zooplankton organisms as bioindicators at the Dubica fish farm, Serbia. *Arch. Biol. Sci., Belgrade*, **58**, 245-248 (2006).

Felfoldy, L.: The biological classification of water quality (4th Revised edition) (A biologiai vízminýsítés (4. javított és bývített kiadás)),Vízügyi Hidrobiológia. 16, VGI, Budapest. pp. 1-225 (1987).

Ganpati, S.V.: The ecology of a temple tank containing a permanent bloom of *Microcystis aeruginosa*. *J. Bombay Natural Hist. Soc.*, **42**, 65-67 (1940).

Ganpati, S.V. and P.I. Chacko: Investigation on plankton production and limnology of four fish ponds in Madras. *Proc. Int. Assoc. Theorit. Appl. Limnol.,* **11**, 111-112 (1951).

Harper, D.: Eutrophication of freshwaters. Chapman and Hall, London (1992).

Hutchinson, G.E. and V.T. Bowen: A direct demonstration of the phosphorus cycle in a small lake. *Proceedings Nat. Acad. Sci.*, **33**, 148-153 (1947).

Imre, A.: Comparison of saprobical analyses using plankton in the tributaries of the upper Tisa, Hungary in 2001-2002. *Oceanol. Hydrobiol. Stud.,* **XXXIII**, 63-75 (2004).

Jayatissa, L.P., E.I.L. Silva, J. McElhiney and L.A. Lawton: Occurrence of toxigenic cyanobacterial blooms in freshwaters of Sri Lanka. *System Appl. Microbiol.*, **29**, 156-164 (2006).

Jeppesen, E., J.P. Jensen and M. Sondergaard: Response of phytoplankton, zooplankton and fish to re-oligotrophication: An 11-year study of 23 Danish lakes. *AEHM*, **5**, 31-43 (2002).

Jeppesen, E., M. Sondergaard, N. Mazzeo, M. Meerhoff, C. Branco, V. Huszar and F. Scasso: Lake restoration and biomanipulation in temperate lakes: relevance for subtropical and tropical lakes. *In*: Restoration and management of tropical eutrophic lakes (*Eds*.: M.V. Reddy). Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi. pp. 331-349 (2005).

Jeppesen, E.: Lake responses to reduced nutrient loading – An analysis of contemporary long-term data from 35 case studies. *Freshwater Biol.*, **52**, 1747-1771 (2007).

Juday, C. and E.A. Birge: A second report on the phosphorus content of Wisconsin lake waters. *Trans. Wis. Acad. Sci. Arts Lett.*, **26**, 353-382 (1931).

King, D.L.: The role of carbon in eutrophication. *J. Wat. Pollut. Control Fed.*, **42**, 2035-2051 (1970).

Kruger, G.H. and J.N. Elhoff: The effect of temperature on specific growth rate and activation energy of *Microcystis* and *Synnechococcus* isolates relevant to the onset of natural blooms. *J. Limnol. Soc. S. Afr.*, **4**, 9-20 (1978).

Kuentzel, L.E.: Bacteria, carbon dioxide, and algal blooms. *J. Water Pollut. Control Fed.*, **41**, 1737-1747 (1969).

Michael, R.G.: Studies on the zooplankton of a tropical fish pond. *Hydrobiol.*, **31**, 47-48 (1968).

Morgado, F.M., C. Antunes and M.R. Pastorinho: Distribution and patterns of emergence of suprbenthic and pelagic crustaceans in a shallow temperate estuary (Ria de Aveiro, Portugal). *Acta Oecologica*, **24**, 205-217 (2003).

Mukherjee, B., S. Sinha Roy, S. Mahanty, P. Mazumdar, G.V.N. Pankajakshi and R. Mishra: Estimation of detergent influx and impact assessment in freshwaters. *Stoten*, **136**, 301-318 (1993).

Mukherjee, B. and G.V.N. Pankajakshi: The impact of detergents on plankton diversity in freshwaters. *J. Environ. Biol.*, **16**, 211-218 (1995).

Mukherjee, B., P.N. Pandey and S.N. Singh: Mathematical modelling and system analysis of inorganic carbon in the aquatic environment. *Ecol. Model.*, **152**, 129-143 (2002).

Mukherjee, B., D. Mukherjee, A. Prasad and M. Nivedita: The transfer rates of inorganic carbon and budgetary analysis in a simulated aquatic system. *Ecol. Model.,* 204, 16, 279-288 (2007).

Mukherjee, B., D. Mukhrjee and M. Nivedita: Modelling carbon and nutrient cycling in a simulated pond system at Ranchi. *Ecol. Model.*, **213**, 437-448 (2008).

Ortendorfer, J.L. and W. Hofrat: Wasser und Abwasser. Beitrage zur Gewasserforschung XII, Band 26, Wien (1983).

Pantle, R. and H. Buck: Die biologische Uberwachung der Gewasser und die Darstellung der Ergebnisse. *Gas und Wasserfach.*, **96**, 604-607 (1955).

Pentecoste, A.: An introduction to freshwater algae. Richmond Publication. Co. Richmond (1984).

Schelske, C.L. and E.F. Stoermer: Eutrophication, silica and predicted changes in algal quality in Lake Michigan. *Sci.*, **173**, 423-424 (1971).

Shannon, C.F. and W. Weaver: The mathematical theory of communication. University of Illinois Press, Urbana (1963).

Sheil, R.J., J.F. Costelloe, J.R.W. Reid, P. Hudson and J. Powling: Zooplankton diversity and assemblages in arid zone rivers of the lake Eyre basin. *Australia. Mar. Fresh. Res.*, **57**, 49-60 (2006).

Tonapi, G.T.: Freshwater Biology. National Book Trust of India, New Delhi. p. 341 (1980).

Turoboyski, L.: Technological hydrobiology (Hydrobiologia techniczna) – PWN, Warszawa, 1-444 (1979).

Vezjak, M., T. Savsek and E.A. Stuhler: System dynamics of eutrophication processes in lakes. *Euro. J. Oper. Res.*, **109**, 442-451 (1998).

Vollenweider, R.A.: Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD, Paris. Tech. Rpt. DA 5/SCI/68.27 (1968).

Ward, A.C. and G.C. Whipple: Fresh water biology. John Wiley and Sons, New York (1945).

Wetzel, R.G.: Limnology, 3rd Edn. Academic Press, New York (2006).