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SEASONAL VARIABILITY OF N:P RATIOS
IN EUTROPHIC LAKES

by

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ABSTRACT.

The ratios of different forms of nitrogen to phosphorus (particulate,total,total dissolved,and dissolved inorganic N:P) from four eutrophic lakes are presented to assess their variability during two subsequent growing seasons.Particulate and total N:P showed the lowest amplitude of fluctuations,while the total inorganic N:P ratios showed the highest.All N:P forms demonstrated substantial variations and seasonal pattern over the growing period April-October.It was the short-lasting spring minima of the N:P ratios,ranging from less than 1:1 to 6:1 ,which triggerred the onset of nitrogen fixing Cyanophyte blooms,while seasonal mean values were as high as 20:1 to 30:1 and misleading in assessing nitrogen limitation.The nitrogen fixation rapidly restored the N:P values to normal levels (TN:TP 15:1 and over).

VARIABILITÉ SAISONNIÈRE DES RAPPORTS N:P DANS LES LACS EUTROPHES.

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RÉSUMÉ

Les rapports des différentes formes d'azote/phosphore (N:P
particulaire, total, dissous total et inorganique dissous) pour
les quatre lacs eutrophes sont présentés de façon à évaluer leur
variabilité au cours de deux saisons de croissance subséquentes.
Les rapports N:P particulaire et total présentaient l'amplitude
minimale des fluctuations tandis que ceux du N:P inorganique
total affichaient l'amplitude maximale. Toutes les formes de N:P
révélaient des variations sensibles et saisonnières au cours de
la période de croissance d'avril à octobre. Ce sont les valeurs
minimales de courte durée au cours du printemps, comprises entre
un peu moins de 1:1 à 6:1, qui ont déclenché les proliférations
de cyanophyte à fixation d'azote, tandis que les valeurs
saisonnières moyennes atteignaient 20:1 à 30:1 et faussaient
l'évaluation de la limitation de l'azote. La fixation de l'azote
a rétabli rapidement les rapports N:P à des niveaux normaux
(NT:PT 15:1 et plus).

MANAGEMENT PERSPECTIVE.

        This study is an invited contribution presented at the
Symposium on Trophic Interactions held in Balatonfured,Hungary,
in   September   1987,and   prepared   for   publication in the
Proceedings.It is based on author's earlier data,collected during
his work in Western & Northern Region.It demonstrates the
importance of N:P ratios in water quality management and provides
a new information on seasonal fluctuations of these ratios.It is
the minimum values that trigger onset of nuisance blue-green
algae blooms,while   seasonal mean values,frequently used in
limnological literature,may be misleading.

ANALYSE DE GESTION

Cette étude a été présentée, sur demande, au Colloque sur
les interactions trophiques tenu à Balatonfured en Hongrie, en
septembre 1987, et préparée en vue de sa publication dans le
compte rendu. Elle est basée sur des données recueillies
antérieurement par l'auteur au cours de ses travaux dans la
région de l'ouest et du nord. Elle démontre l'importance des
rapports N:P dans la gestion de la qualité des eaux et fournit de
nouvelles informations sur les fluctuations saisonnières de ces
rapports. Ce sont les valeurs minimales qui déclenchent la
prolifération des algues bleu-vert nuisibles, tandis que les
valeurs saisonnières moyennes, souvent utilisées dans la
documentation limnologique, peuvent prêter à confusion.

INTRODUCTION.

The concept of nutrient limitation for plant growth and the role of nitrogen to phosphorus ratios has been known since the beginning of modern agriculture (Liebig 1855) and introduced to limnology at its early stage ,especially in relation to algal nutrition and species composition.Because of the normal elemental composition of main building blocks of plankton biomass (proteins,carbohydrates,lipids) and generally accepted proportions of the key nutrients in the algal cells (C:N:P=106:16:1),analyzed recently by Vollenweider (1985), it was assumed that this proportion can be expected in the dissolved form in the water colums also.Forsberg (1979) presented a generalized diagram of trophic states in relation to N:P ratios,with low N:P ratios (less than 10:1) being characteristic of nitrogen-limited eutrophic systems,and high ratios (over 20:1) being typical for the oligotrophic lakes.Smith (1983) provided a summary of data from 17 lakes showing that a N:P ratio of 29:1 (as total N and P) is a borderline under which lakes favour development of N-fixing Cyanophytes , while higher ratios disfavour it.Schindler (1977),Leonardson and Ripl (1980) and Barica et al.(1980) demonstrated experimentally that manipulation of N:P ratios by addition of N (as nitrate or ammonia,or both) leads to substantial changes in phytoplankton composition,with low ratios favouring the Cyanophytes,and the higher ones favouring Chlorophytes or non-fixing blue-greens.

However,there has been no uniformity in the forms used to calculate N:P ratios in the literature.They vary from cellular ratios,considered in Vollenweider (1985),to total ,total dissolved and total inorganic N:P,the latter used in experimental enrichment studies.Average data for growing season (Smith 1983) or seasonal averages,(late winter,Niemi 1979;winter and summer,Allan and Kenney,1978) were used mostly,assuming negligible variation of the ratios within the growing season.

This paper compares different forms of expression of the N:P ratios and demonstrates a significant variability within a growing season,reanalyzing experimental data from 4 eutrophic lakes in Western Canada (Barica 1975).

STUDY AREA AND METHODS.

1.Definition of terms and methodology.

The various forms of nitrogen and phosphorus and their ratios presented in this paper are defined as follows:

Particulate nitrogen (Part.N): analyzed on a portion of a GF/C filter using Carlo Erba elemental analyzer for C and N;
Particulate phosphorus (Part.P):analyzed by ignition and acid digestion on a portion of the GF/C filter.
Part.N : Part.P = ratio of the concentrations (ug/L) by weight.

Dissolved inorganic nitrogen (DIN):The sum of ammonia,nitrite and nitrate nitrogen (ug/L); all measured in filtrate,determined colorimetrically using phenol-hypochlorite method for ammonia and sulphanilamide-naphtylethylene diamine method for nitrite.Nitrate determined in central laboratory using automated procedures (Cd reduction).
Dissolved inorganic phosphorus (DIP) = soluble reactive phosphorus (SRP),determined in filtrate using the acid molybdate-ascorbic acid method.
DIN :DIP =ratio of the concentrations by weight (ug/L).

Total dissolved nitrogen (TDN) and Total dissolved phosphorus (TDP):analyzed as nitrate and SRP respectively on part of filtrate irradiated with UV light.
TDN = DIN + dissolved organic N
TDP = SRP + dissolved organic P
TDN :TDP = ratio of the concentrations by weight (ug/L).

Total nitrogen (TN) = Part.N + TDN
Total Phosphorus (TP) = Part.P + TDP

2.Selected study lakes.

For this study,four small prairie lakes of varying level of eutrophication and algal biomass were selected as being characteristic of a total of about 100 lakes studied during 1971-1983 near Erickson,South-western Manitoba, in Central Canada (Barica 1975).The lakes were monitored at short intervals over a period of several years covering all seasons,but particulate C,N and P values were obtained only between 1971-1974 and later discontinued.The study period for this paper is therefore limited to those years.The lakes are presented according to the advancement of natural eutrophication in the following order:

Lake 885. A true hypereutrophic lake,with heavy Aphanizomenon flos-aquae blooms each year,and their regular massive collapses and resulting fish kills between July and August,with additional partial collapses before and after,including preceding Chrysophytes (Chrysochromulina parva) blooms in May.Maximum

chlorophyll a levels for the study period :211 - 283 ug/L.

Lake 154.A hypereutrophic lake also,but collapses of Aphanizomenon bloom do not occur regularly each year.Partial collapses of Microcystis and Merismopedia blooms in combination with diatoms (Nitzschia,Synedra and Cyclotella) recorded (Kling 1975).Max.chlorophyll a levels for the study period :141 - 280 ug/L.

Lake 302:A eutrophic lake,with no total collapses of algal blooms.The predominant algal species are Microcystis, Anabaena, Cryptomonas, Rhodomonas,and apring blooms of diatoms.The blooms die-off gradually,without causing a total oxygen depletion.Max.chlorophyll a levels for the study period :108-110 ug/L.

Lake 255.The least eutrophic lake of all four,low summerkill risk and no visible algal blooms (maximum chlorophyll a for the study period 19 - 20 ug/l).Phytoplankton composed of Chrysophycae,Diatoms and Cryptomonads.

RESULTS AND DISCUSSION.

1.Variations of N:P ratios during a growing season.
Time series of the various forms of N:P ratios and chlorophyll a during two consecutive growing seasons (April-October) for the four study lakes are presented in Figures 1-4.It can be seen that the true low N:P ratios (less than 5 : 1,referred to in Allan and Kenney, 1979, occur for only a short period of time (few weeks),usually in the spring or fall.The spring minima in lakes 885 and 154 preceded development of Aphanizomenon flos-aquae blooms and may be assumed to trigger the onset of N-fixing species.Then,the lake system seems to adjust its N:P balance to come close to "normal" ratios ,which then persist for the duration of the bloom,and respond to its physiological state (note some decreases during the bloom collapse period).Seasonal mean values of N:P ratios,used often in the literature,are therefore misleading.It is the short-lasting minima of the N:P ratios which characterize the nutrient limitation status of a lake.Considering only the seasonal mean values ,all four study lakes,which are distinctly eutrophic to hypereutrophic,would fall below these categories if using either Forsberg's (1979) or Smith's (1983) boundaries (seasonal mean values of TN:TP, TDN:TDP, and DIN:DIP ratios were higher than 20:1 in most cases).Only Part.N:Part.P ratios show values expected for eutrophic lakes (less than 10:1).At the same time,most of the N:P minimum values in the study lakes were in the range of less than 1:1 to 6:1.

2.Differences between the various forms of N:P ratios.

Statistical evaluation of the experimental data,particularly its minimum,maximum and mean values,standard deviations and coefficients of variability are presented in Tables 1-4.Particulate and total N:P ratios appear to be the most stable forms with the minimal,but significant amplitudes of fluctuation These forms are considered to be closest to the true cellular ratios.TDN:TDP ratios fluctuate more,and the most extreme fluctuations are found in DIN:DIP values.This is understandable,since the extreme fluctuations of water quality are characteristic of hypereutrophic lakes as a result of nutrient oscillations and frequent pulses of regenerated nutrients associated with the collapses of the Aphanizomenon flos-aquae blooms (Barica 1974,Barica et al.1980).DIN:DIP ratios may be useful for N or P enrichment experiments,but their validity for an overall characterization of lakes is questionable.Particulate N:P ratios are elaborate to obtain on a routine monitoring basis,so total N:P ratios appear to be the most practicable.The cellular component in TN:TPs provides a stabilizing factor,as the response to instantanious changes in chemistry of water column is bufferred by physiological processes in the algal cells and creates a considerable time lag.The DIN:DIPs on the other hand reflect the momentary situation in the lake and therefore fluctuate erratically.This measurement cannot be therefore considered to be a reliable indicator of the nutrient limitation.

3.Effect of nitrogen fixation and build-up.

It is noteworthy that the highest amplitudes of fluctuations in all N:P forms and the highest coefficients of variation were found in Lake 255,which does not experience nitrogen-fixing blooms.

Onset of nitrogen fixing species provide necessary supply of nitrogen needed to compensate for the deficit. Brownlee and Murphy (1983) measured the total input of fixed nitrogen to Lake 885 during one month of fully developed Aphanizomenon bloom to be 2.73 kg per hectare.However,the build-up of the nitrogen in the system was not permanenent;on the die-off of the Aphanizomenon bloom,the N:P ratios quickly fell back to spring low levels.This phenomenon was observed also during N-addition experiments (Barica et al 1980) where the accumulated nitrogen was soon removed from the system,presumably through denitrification process.The eutrophic lakes cannot store the added nitrogen for an extended period and cannot carry it over to the next growing season.

ACKNOWLEDGEMENTS

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Tab.1.Some statistical parameters for Lake 885.

atio	Maximum	Minimum	Mean	Std Dev.	Coeff. of Variation
art N/Part P					
1972	26.52	1.82	10.76	7.32	68.0776
1973	30.27	3.02	12.05	8.04	66.7373
N/TP					
1972	89.94	1.27	27.24	22.36	82.104
973	76.87	7.61	24.45	13.96	57.1204
TDN/TDP					
1972	61.87	.4	28.35	16.99	59.9328
973	102.73	2.77	32.62	28.15	86.3026
DIN/DIP					
972	57.9	.63	11.49	13.21	114.936
973	64.5	1.33	17.96	21.06	117.27
hlor A					
1972	283	7.4	81.01	69.03	85.2219
973	211	2	47.72	58.86	123.333

Tab.2.Some statistical parameters for Lake 154.

Ratio	Maximum	Minimum	Mean	Std Dev.	Coeff. of Variation
Part N/Part P					
1972	30	3.66	12.81	8.42	65.7263
1973	14	2.82	7.609	2.75	30.7338
TN/TP					
1972	45.72	11.78	27.33	7.96	29.2163
1973	41.21	12.22	22.70	8.66	38.1471
TDN/TDP					
1972	64.3	3.65	38.60	16.97	43.9655
1973	137.02	14.26	42.5744	33.95	79.7485
DIN/DIP					
1972	192.5	1.07	32.1611	51.54	160.279
1973	113.75	.2	12.9437	27.34	211.293
Chlor A					
1972	280	4	100.755	93.46	92.763
1973	141	3	54.1579	41.25	76.1717

Tab.3.Some statistical parameters for Lake 302.

Ratio	Maximum	Minimum	Mean	Std Dev.	Coeff. o Variatio
Part N/Part P					
1972	14.37	2.85	7.105	3.24	45.7361
1973	16.36	3.9	8.348	3.56	42.7382
TN/TP					
1972	64.74	6.66	26.752	14.18	53.0311
1973	53.81	7.4	23.392	13.81	59.0726
TDN/TDP					
1972	82.02	.78	44.085	25.47	57.7845
1973	120.33	6.52	36.178	28.61	79.0813
DIN/DIP					
1972	227.8	.25	27.072	59.85	221.099
1973	66	.3	10.532	16.04	152.354
Chlor A					
1972	110	1.9	35.811	32.42	90.5362
1973	108.5	3.4	40.366	33.64	1132.
83.3611					

Tab.4 Some statistical parameters for Lake 255.

| Ratio	Maximum	Minimum	Mean	Std Dev	Coeff. of Variation
Part N/Part P					
1972	87.04	12.44	29.71	25.17	84.7284
1973	29	2.7	9.9466	7.63	76.7389
TN/TP					
1972	20.96	.38	8.681	7.63	87.9252
1973	76.85	7.22	26.581	18.68	70.3029
TDN/TDP					
1972	17.64	.75	5.36	6.94	129.527
1973	93	7.18	33.563	24.63	73.4068
DIN/DIP					
1972	263.75	12.11	7094.47	84.22	142.924
1973	18.66	.58	4.525	6.61	146.138
Chlor A					
1972	19	4	10.125	4.82	47.6413
1973	20	2	9.7142	5.62	57.8713

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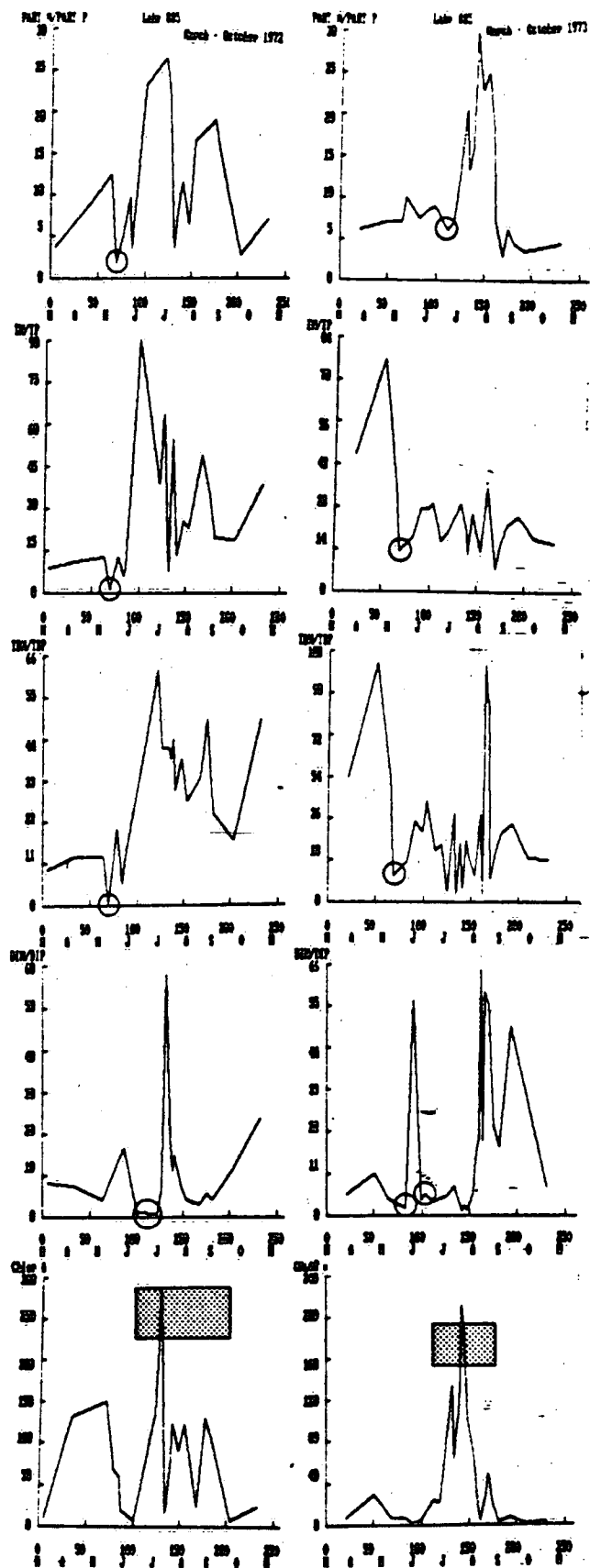
Fig.1.Variations of different forms of N:P ratios and chlorophyll
a in Lake 885 during two growing seasons.Shaded areas indicate
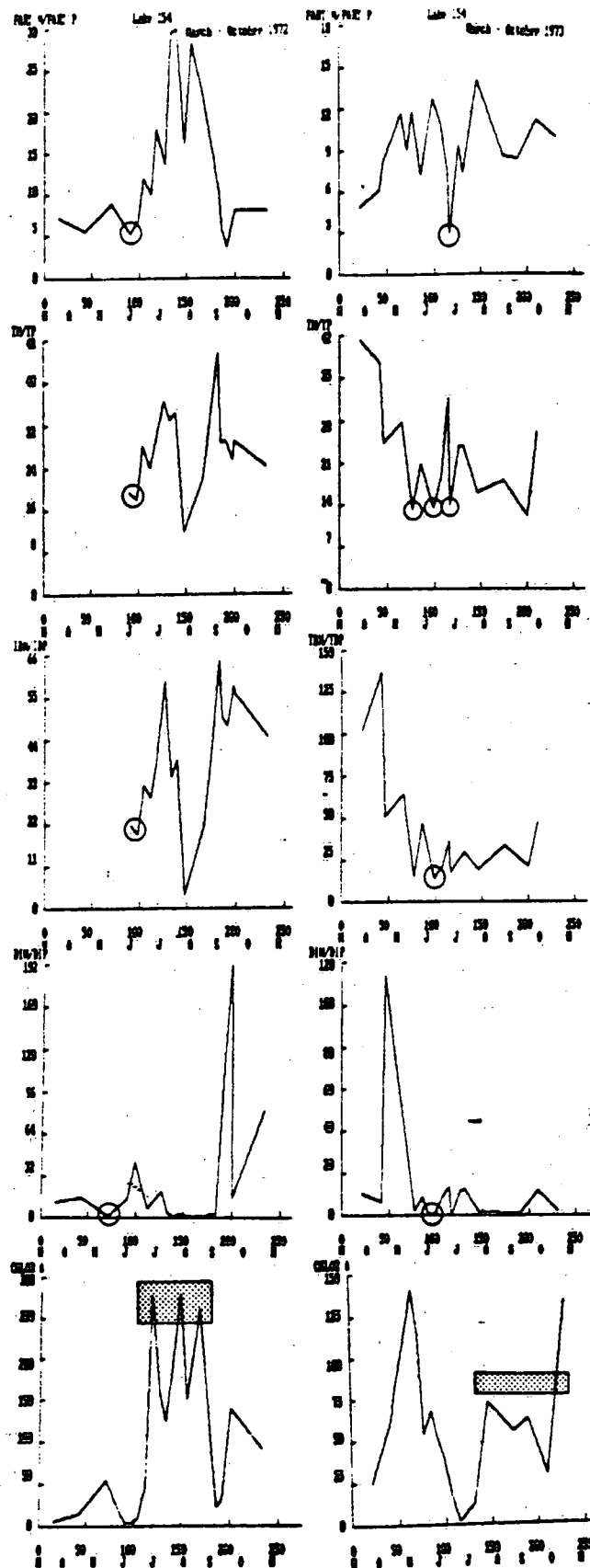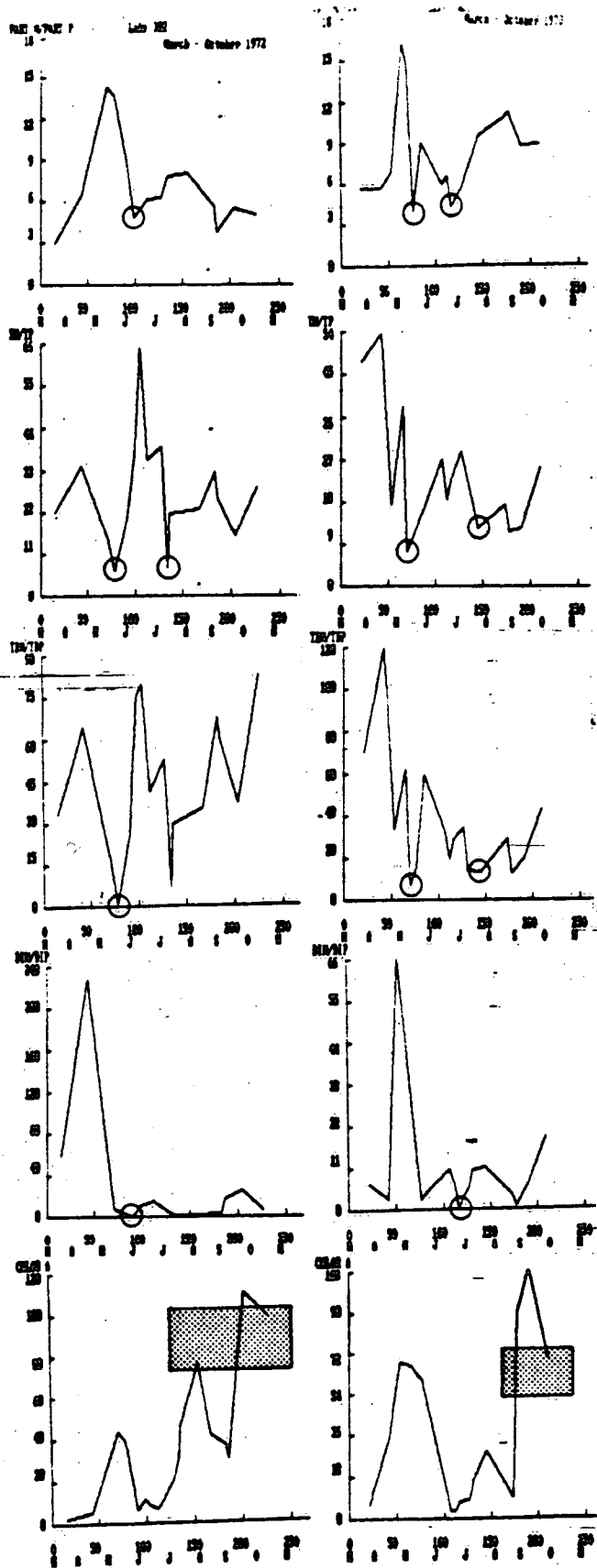Cyanophyte bloom periods;circles show N:P ratios minima preceding
them.

Fig.2.Variations of different forms of N:P ratios and chlorophyll a in Lake 154 during two growing seasons.Shaded areas indicate Cyanophyte bloom periods;circles show N:P ratios minima preceding them.

Fig.3.Variations of different forms of N:P ratios and chlorophyll
a in Lake 302 during two growing seasons.Shaded areas indicate
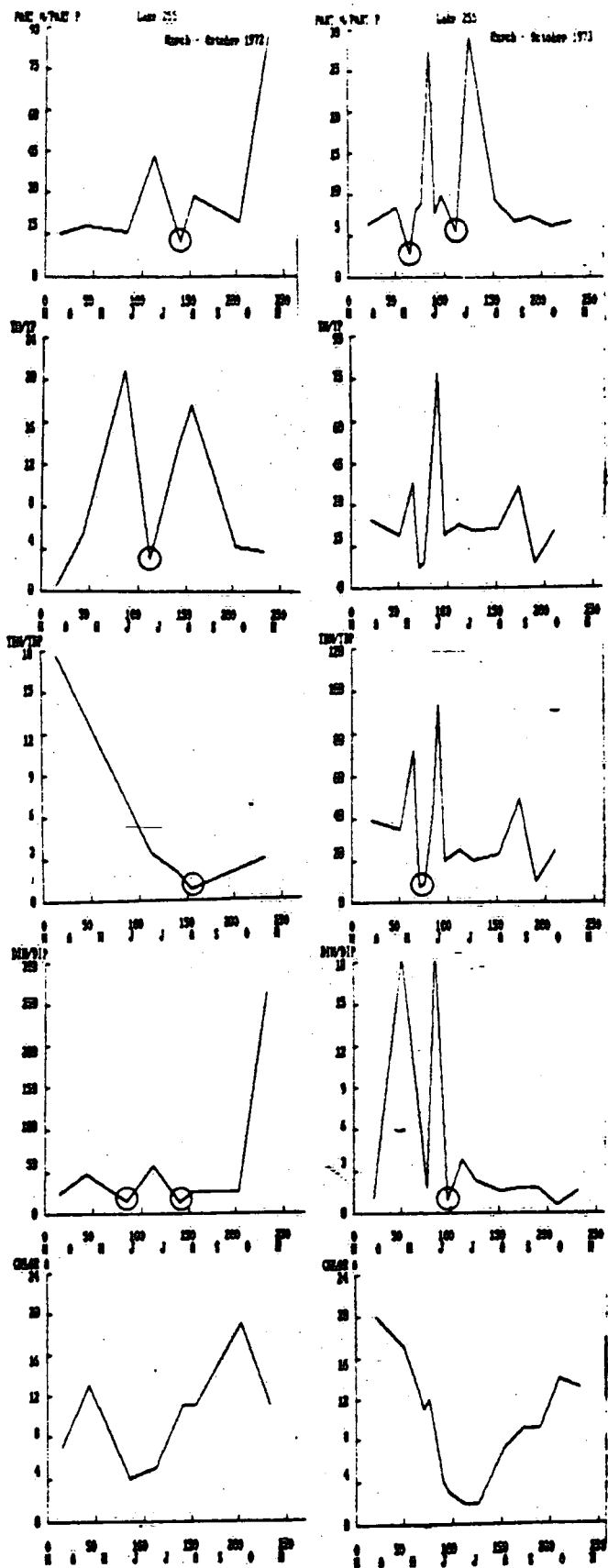Cyanophyte bloom periods;circles show N:P ratios minima preceding
them.

Fig.4.Variations of different forms of N:P ratios and chlorophyll
a in Lake 255 (no Cyanophyte blooms).