Diatoms as Indicators of Lake Trophic Status

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ABSTRACT

Relationships between surface sediment diatom assemblages and lake trophic status were studied in 50 Canadian Precambrian Shield lakes in the Muskoka-Haliburton and southern Ontario regions. The purpose of this study was to develop mathematical regression models to infer lake trophic status from diatom assemblage data. To achieve this goal, however, additional investigations dealing with the evaluation of lake trophic status and the autecological features of key diatom species were carried out.

Because a unifying index and classification for lake trophic status was not available, a new multiple index was developed in this study, by the computation of the physical, chemical and biological data from 85 south Ontario lakes. By using the new trophic parameter, the lake trophic level (TL) was determined:

$$TL = 1.37 \ln[1+(TP \times Chl\text{-}a / SD)],$$ where,

TP=total phosphorus, Chl-a=chlorophyll-a and SD=Secchi depth.

The boundaries between 7 lake trophic categories (Ultra-oligotrophic lakes: 0-0.24; Oligotrophic lakes: 0.241-1.8; Oligomesotrophic lakes: 1.81-3.0; Mesotrophic lakes: 3.01-4.20; Mesoeutrophic lakes: 4.21-5.4; Eutrophic lakes: 5.41-10 and Hyper-eutrophic lakes: above 10) were established. The new trophic parameter was more convenient for management of water quality, communication to the public and comparison with other lake trophic status indices than many of the previously published indices because the TL index attempts to increase understanding of the

characteristics of lakes and their comprehensive trophic states. It is more reasonable and clear for a unifying determination of true trophic states of lakes.

Diatom species autecology analysis was central to this thesis. However, the autecological relationship of diatom species and lake trophic status had not previously been well documented. Based on the investigation of the diatom composition and variety of species abundance in 30 study lakes, the distribution optima of diatom species were determined. These determinations were based on a quantitative method called "weighted average" (Charles 1985). On this basis, the diatom species were classified into five trophic categories (oligotrophic, oligomesotrophic, mesotrophic, mesoeutrophic and eutrophic species groups). The resulting diatom trophic status autecological features were used in the regression analysis between diatom assemblages and lake trophic status.

When the TL trophic level values of the 30 lakes were regressed against their five corresponding diatom trophic groups, the two mathematical equations for expressing the assumed linear relationship between the diatom assemblages composition were determined by

(1) using a single regression technique:

Trophic level of lake (TL) = 2.643 - 7.575 log (Index D)

($r = 0.88$ $r^2 = 0.77$ $P = 0.0001$; $n = 30$)

Where, Index D = (O% + OM% + M%)/(E% + ME% + M%);

(2) using a multiple regression technique:

$$TL=4.285-0.076\ O\%-\ 0.055\ OM\%\ -\ 0.026\ M\%\ +\ 0.033\ ME\%\ +\ 0.065\ E\%$$

$$(r=0.89,\ r^2=0.792,\ P=0.0001,\ n=30)$$

There was a significant correlation between measured and diatom inferred trophic levels both by single and multiple regression methods ($P < 0.0001$, $n=20$), when both models were applied to another 20 test lakes. Their correlation coefficients (r^2) were also statistically significant ($r^2 >0.68$, $n=20$). As such, the two transfer function models between diatoms and lake trophic status were validated. The two models obtained as noted above were developed using one group of lakes and then tested using an entirely different group of lakes.

This study indicated that diatom assemblages are sensitive to lake trophic status. As indicators of lake trophic status, diatoms are especially useful in situations where no local trophic information is available and in studies of the paleotrophic history of lakes.

Diatom autecological information was used to develop a theory assessing water quality and lake trophic status.

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Finally, I would like to dedicate this thesis to my lovely wife Chunfeng Chen, my daughter Hongyan, my parents and other family members for their love and support.

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INTRODUCTION

I. Research background and problems

As early as the 1960s, it was realized that lake eutrophication had become a very serious environmental problem in the world. This stimulated the Organization for Economic Cooperation and Development (OECD) to begin to develop a basis for monitoring and controlling lake eutrophication (Vollenweider 1968). The emphasis of this International Cooperation Program on Monitoring of Inland Water and Eutrophication Control was to quantify the relationship between nutrient loading and lake trophic response (Vollenweider 1968; Dillon 1975; Vollenweider and Kerekes 1980; Vollenweider 1982). Even after completion of the OECD program at the end of the 1970s, eutrophication research interests have continued to this day (e. g. Lambou et al. 1983; Auer et al. 1986; Yoshimi 1986; Henderson-Sellers and Markland 1988; Agbeti and Dickman 1989).

Although the research publications on various aspects of lake eutrophication are voluminous, the value of the results obtained was not what was expected. One of the difficulties has been that researchers have assessed eutrophication in different geographic areas using different standards. Consequently, the OECD report recommends that the results of their report be handled with caution and should not be applied to cases which lie outside the ranges and situations covered by the programs (Henderson-sellers and Markland 1988). One of the most basic aspects, for instance, the question of how to classify lakes with respect to their trophic status still remains largely unanswered to this day (Yoshimi 1987). As a

result, it is my contention that no wholly unifying index and classification for lake trophic status is available.

The major advantage of using biological monitors of water quality is in their ability to integrate the effects of a variety of variables which impact on the receiving waters in which they live (Dickman et al. 1980). This is especially apparent when investigating the environmental history of a lake and attempting to trace its paleoenvironment. The reason for this is that the chemical characteristics of water would be lost over time whereas the messages of this chemical information could be recorded or reflected by some aquatic animals and plants which are preserved in the sediments of lakes as microfossils. During the past several decades, the approaches of biological monitoring for lake eutrophication, especially cultural eutrophication, were most frequently developed by diatom analysis (e.g. Vallentyne 1957; Frey 1964; Stockner 1971; Duthie and Sreenivasa 1972; Haworth 1976; Brugam 1978, 1979; Beaver 1981; Stoermer et al. 1985; Christie 1988; Agbeti and Dickman 1989)

To date, the significance of diatoms as indicators of lake trophic status has been indicated by many studies as summarized by Beaver (1981). The rapid reproduction of diatoms makes them very responsive to changes in water quality. Diatoms are particularly valuable for concentrated studies of environmental analyses because of their ubiquity, diversity, and adaptability. The silicious frustules of diatoms endow them with another useful quality: their taxonomic identification as their taxonomic characteristics are well preserved and readily distinguished especially when compared to other algal classes. In addition, the silicious walls of diatoms are usually preserved well in lake sediments (Stevenson & Lowe, 1984). The documentation about diatom habitat characteristics

has shown that some species are very sensitive to the differing physiochemical characteristics of water from a large range of lakes (Beaver 1981). Diatoms have been used successfully to infer the pH status of numerous lakes (e.g. Nygaard 1956; Smol 1986; Dickman et. al. 1985; Charles 1985).

To develop biological hypotheses and techniques for environmental monitoring, a quantitative correlation between physical and chemical characteristics of water and the biological information about this water body should be first developed and tested. For this reason diatoms as monitors of lake eutrophication were studied because most previous approaches for monitoring lake trophic status of both the present and past times were often done by only using a few indicator species and/or simple taxonomic ratios (e.g. Vallentyne 1957; Frey 1964; Stockner 1971).

Recent developments in this field make it possible to use new statistical methods to correlate diatom assemblages with physical (e.g. Secchi depth value) and chemical (e.g. total phosphorus concentration) parameters of lake trophic status (Christie 1988; Agbeti and Dickman 1989). This approach is still relatively new. Initial attempts to predict trophic status from diatom assemblages have not been fully conclusive (see Literature Review and Discussion). In most cases, the diatom species autecological features that distinguish trophic status have not been sufficiently documented. The predictive capability of the diatom assemblage has not been properly tested.

Thus, when I was encouraged by my supervisor, Dr. Mike Dickman to start my study on this very challenging and very difficult topic, two main problems of this research had to be overcome:

1. A unifying index and classification for lake trophic status was needed in order to determine the relative trophic status of any body of water for any lake in the world. A hypothesis for such an index of lake trophic status must be established before diatom data analysis can be carried out.

2. The autecological relationship of diatom species and lake trophic status has not been as well documented as it has for diatom pH indicator assemblages. It is very important, therefore, to categorize diatom assemblages into several indicator groups which correspond to lake trophic level classes.

II. Hypotheses and research design

Ho: There is no statistical relationship between diatom species composition and lake trophic status.

The aims of this study were:

1. to try to find an assumed linear mathematical relationship between the diatom trophic indicator assemblages in the surface sediments of 30 lakes and the reported trophic status of these same 30 study lakes;

2. to establish a unifying multiple index for classification of lake trophic status based on physical, chemical and biological data of 85 Ontario lakes (using data provided by OME);

3. to document the diatom species autecological features using quantitative methods;

4. to develop a theory which refers to ecological knowledge of diatoms in assessing water quality and lake trophic status.

As discussed above, an additional study for the classification of lake trophic status is indispensable before the diatom analyses can be carried out.

This might be expressed as a metaphor with bridge construction (Fig. 1). This bridge must be started by building two fundamental pillars. To complete these pillars, my study is divided into three portions.

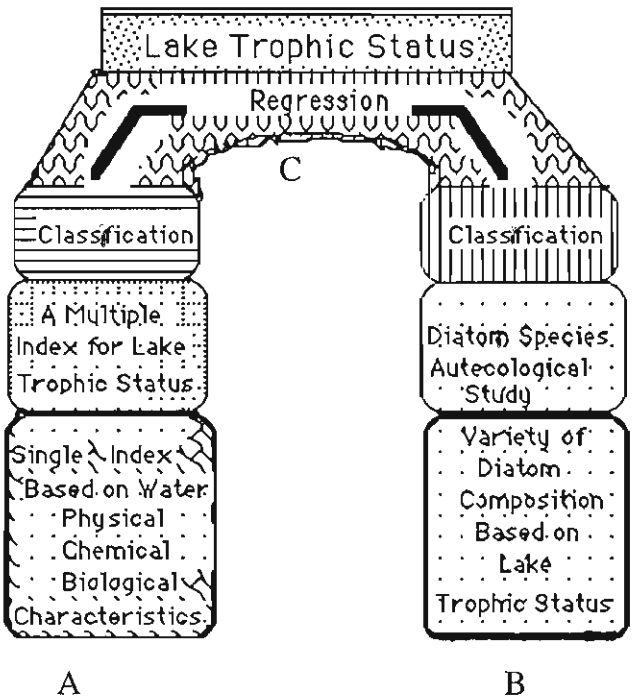


Fig.1. A research metaphor for this study

Part A on the left is especially designed for the study of lake trophic levels in order to obtain a unifying index and classification for lake trophic status with analogous lake pH values for determining water acidity of any lake in the world. For this aspect, all criteria for classification of lake trophic status by previous studies were reevaluated. Among these, some

of the most commonly used single indices were combined into a multiple lake trophic index according to the relationship between the lake productivity and each of these indices.

Part B on the right is concerned with studying diatom species distributions in different lakes. There are three important bases for diatom analysis: 1) Diatom taxonomy, 2) Autecological analyses of trophic characteristics of diatom species, and 3) the statistical analysis of diatom counts.

Diatom species autecological features and lake trophic status were determined by (1) analyzing the frequency of each species' distribution in lakes of different trophic status (2) using weighted means to determine the optimum value of each diatom species on lake trophic level and (3) comparing those weighted averages with published references. Five levels of classification based on diatom trophic feature were recognized.

1. Eutrophic species: Diatom species which are abundant only in eutrophic lakes
2. Mesoeutrophic species: Diatom species which are abundant both in eutrophic and mesotrophic lakes
3. Mesotrophic species: Diatom species which include a) diatoms that were only abundant in mesotrophic lakes, b) diatoms that displayed no apparent trophic preference (i.e. those which were abundant in lakes of all trophic statuses)
4. Oligomesotrophic species: Diatom species which were abundant in both oligotrophic and mesotrophic lakes
5. Oligotrophic: diatom species which were abundant only in oligotrophic lakes

Part C of this study (the bridge between the two pillars in Fig. 1) involved the establishment and testing of a correlation between diatom assemblages, which were classified into one of these five trophic levels and lake trophic status, which was classified by a new multiple trophic parameter. The mathematical regression equation for expressing this correlation was made by analyzing varieties of diatom composition from 30 different trophic status lakes of the Ontario region. To test this hypothesis, the lake trophic value inferred by the diatom assemblages from another 20 lakes of different trophic status but located in the same region was regressed against the trophic level of each lake as calculated from the MOE data. The correlation coefficient for this regression was then obtained.

REVIEW OF THE LITERATURE

A brief discussion of the basic concepts and dynamics of various aspects dealing with lake eutrophication, the research history of lake trophic status and diatom ecological research pertinent to this study will be discussed in this section. This will provide some background, information and support for my thesis studies on the relationship between diatoms and lake trophic status.

I. The dynamics of lake eutrophication

The definition of lake eutrophication has been published by many limnologists since Naumann (1919) first introduced the general concepts of oligotrophy and eutrophy and distinguished them on the basis of phytoplanktonic populations (Wetzel 1983). The general argument for this definition was summarized by OECD as: "Eutrophication is the response to nutrient over-enrichment (primarily phosphorus) and can occur under natural or man-made conditions" (Janus and Vollenweider 1981). Based on an array of attendant conditions associated with increased productivity, Wetzel pointed out that the term eutrophication is synonymous with increased growth of the biota of a lake (Wetzel 1983). Natural eutrophication refers to a natural "aging" process in undisturbed lakes which eventually terminates in the disappearance of the lake itself (Likens 1972). This process may be vastly accelerated by human activity; under this condition it has been called cultural eutrophication (Hasler 1947).

When the results of eutrophication are undesirable to man, eutrophication is often considered a form of pollution (Likens 1972).

Early in the 1960's, it became obvious that a large number of lakes and reservoirs were rapidly changing their trophic characteristics due to the addition of plant nutrients originating largely from human activities. The main nutrient sources identified were municipal and industrial wastes as well as agricultural and urban runoffs (Janus and Vollenweider 1981).

The dynamics and function of the main nutrients causing lake eutrophication have been studied by many researchers. The nutrients studied included Phosphorus (e.g. Vollenweider 1968; Fuhs et al. 1972; Schindler 1974), Nitrogen (e.g. Vollenweider 1968), Carbon (e. g. Allen 1972; Wetzel 1972), Silica (e. g. Schelske and Stoermer 1972) and others.

The nutrient loading concept implies that a relationship exists between the quantity of the nutrients entering a water body and its response to those nutrient inputs (Wetzel 1983). Vollenweider (1968) first formulated definitive quantitative loading criteria for phosphorus and nitrogen and the expected trophic conditions of water bodies. The results from the OECD program and many others (e.g. Auer et al. 1986) have demonstrated very clearly that phosphorus plays a major role in eutrophication. In comparison to other macronutrients required by biota, phosphorus is least abundant and commonly is the first element to limit biological productivity (Vollenweider 1968).

The importance of phosphorus in comparison to nitrogen and carbon has been particularly well documented by Schindler's large scale fertilization experiments (Schindler 1974). The clearest explanation of the key factor relating phosphorus to lake eutrophication could be made from the biochemistry and physiology of phosphorus (Vollenweider 1968). It is

present in the cell material in a variety of compounds, such as DNA, RNA, Vitamins, ADP and ATP, which are indispensable to life activities of aquatic biota (Ibid).

In unproductive oligotrophic lakes, phosphorus availability is often the principal limiting nutrient for plant growth. After the demand of algal production for phosphorus has been met and the lake becomes more productive, nitrogen replaces phosphorus as the limiting factor for algal growth (Fuhs et al.1972; Likens 1972; Wetzel 1983). Increased loading of inorganic nitrogen to lakes frequently results from agricultural activity, sewage, and atmospheric pollution by man (Wetzel 1983).

Inorganic carbon is a major nutrient of plant metabolism. Some studies in the early 1970s (e.g. Kerr et al. 1972) provided examples of carbon limitation in the phytoplankton of lakes. In a soft water eutrophic lake, the increased inorganic carbon content of water may result in the high and sustained phytoplankton primary productivity rates (Allen 1972).

However, the limitation of inorganic carbon did not prevent a large algal bloom from occurring (Hobbie 1972, cited from Allen 1972). Thus phosphorus and nitrogen limit photosynthesis more frequently than does inorganic carbon which occurs in much greater abundance (Wetzel 1983).

Schelske and Stoermer observed that the process of eutrophication results in lower concentrations of silica in the lake. With continued depletion of silica, diatoms will be replaced in the phytoplankton by nonsilicous forms, such as blue-green and green algae (Schelske and Stoermer 1972).

A relationship between dissolved oxygen content and lake trophic status has been described by many researchers, where the dissolved

oxygen content is negatively correlated with the degree of lake eutrophication (e.g. Cornett and Rigler 1979, 1980; Edmondson 1980). In eutrophic lakes, epilimnetic oxygen concentration can vary markedly on a diel basis. In oligotrophic lakes such variation is minimal (Henderson-sellers and Markland 1988). Oxygen affects the solubility and availability of many nutrients and, therefore, the productivity of the lake (Edmonton 1980). However, the dissolved oxygen is not a limiting nutrient to lake eutrophication. The dynamics of oxygen distribution in lakes are governed by a balance between inputs from the atmosphere and photosynthesis, and losses due to chemical and biotic oxidations (Wetzel 1983).

II. The classification of lake trophic status

The concept of lake trophic status requires the assignment of one of a set of discrete categories to the water body in question to provide a qualitative description of its trophic status. This occurs despite the fact that the process of eutrophication continues smoothly from a nutrient poor (oligotrophic) condition to a nutrient rich (eutrophic) condition (Henderson-sellers and Markland 1988). Carlson also recognized the fact that "all trophic classification is based on the division of the trophic continuum into a small number of discrete stages, termed trophic states. Traditional systems divide the continuum into three classes: eutrophic, high productivity; mesotrophic, medium productivity; and oligotrophic, low productivity. There is often no clear delineation between these divisions" (Carlson 1977).

Based on an array of attendant conditions associated with increased productivity, Wetzel (1983) commented that "Trophy of a lake refers to the rate of primary production occurring within a lake. Trophy then, is an expression of the combined effects of limiting nutrients such as phosphorus and nitrogen supplied to the lake per unit time and their rate of uptake".

Numerous methods have been proposed and used to measure the trophic status of lakes. These range from measuring a single nutrient such as phosphorus or nitrogen, or measuring a single physical parameter such as Secchi disk transparency, to measurements of increasingly complex sets of parameters to provide trophic indices (TSIs) employing multiple parameter measurements, loading models and dynamic simulation models (Lambou et al 1983). These TSIs for lakes have been proposed for three

main purposes: management of lake quality, communication to the public and comparisons of water quality between different lakes (e.g. Carlson 1977; Reckhow 1981; Lambou et al 1983; Yoshimi 1987).

1. Single parameter measures of trophic status

(1) a physical method, Secchi disk depth transparency values

An approximate evaluation of the transparency of water to light was devised by an Italian scientist, Secchi, who observed the point at which a white disk lowered into the water was no longer visible (Wetzel 1983). Because it is inexpensive and easy to use, it has been widely employed for over a century as a tool to measure water transparency (Ladewski and Stoermer 1973; Tilzer 1977). Secchi depth is to a great extent a function of light attenuation which depends on the inherent optical properties of the water (Tilzer 1977).

Secchi depth has been frequently correlated with phytoplankton chlorophyll a concentrations. Thus, algal biomass suspended in the water column will be correlated with Secchi transparency (e.g. Canfield and Hodson 1983; Lind 1986). The vanishing depth of the Secchi disc will vary inversely with algal population densities. Therefore, Secchi transparency has been used to estimate compensation depth, phytoplankton standing crop and nutrient concentrations and has been suggested as one measure of approximate primary productivity, which in turn reflects the lake trophic status (Ladewski and Stoermer 1973). The data obtained for Secchi transparency were used by the OME and the OECD to categorize the trophic conditions in the lakes (Table 1).

Table 1. The comparison of the Secchi depth boundaries presently used by the MOE and OECD to classify lakes into their respective trophic states

Trophic State	MOE (1982) (m)	OECD (1979) (m)
Ultraoligotrophic		> 9.9
Oligotrophic	> 5	4.2-9.9
Mesotrophic	3 - 5	2.45 - 4.2
Eutrophic	0 - 3	1.5-2.45
Hypereutrophic		< 1.5

However, it must be noted that Secchi depth correlations suffer from a number of limitations such as the presence of dissolved colour and turbidity associated with suspended inorganic material and non-algal organic matter (Tilzer 1977, Lind 1986). Therefore, it might be expected that Secchi transparency will give erroneous values in humic lakes or lakes that contain a high amount of non-algal particulate matter (Forsberg and Ryding 1980; Agbeti 1987). Carlson (1977) also pointed out that Secchi transparency is very sensitive to biomass changes at low concentrations but becomes insensitive at high biomass levels (concentrations).

(a) Total phosphorus concentration

Accurate indices of lake trophic status based on total phosphorus are based on the assumption that phosphorus is the major limiting factor for algal growth and that the concentration of all forms of phosphorus present are a function of algal biomass (Schindler 1974). Since phosphorus is considered as the most important nutrient associated with eutrophication and the first element to limit biological productivity, it has been most frequently used to quantify the primary productivity of lakes, and therefore has been used as one frequent measure of lake trophic status (e. g. Rast and Lee 1978; Vollenweider 1979 and others). The advantage of the phosphorus index is that it is relatively stable through the year (Carlson 1977). An arbitrary boundary line for total phosphorus and lake trophic status was adopted by the OECD (Janus and Vollenweider 1981) to categorize the trophic conditions in the lakes (Table 2).

Table 2. The comparison of the boundaries for total phosphorus, Total nitrogen and hypolimnetic oxygen depletion rate to classify lakes into their respective trophic states. Modified from Janus and Vollenweider (1981) and Henderson-sellers and Markland (1988)

Trophic State	Total phosphorus ($ug\ l^{-1}$)	Total Nitrogen ($mg\ l^{-1}$)	Hypolimnetic Oxygen Depletion Rate ($mg\ m^{-3}day^{-1}$)
Ultraoligotrophic	< 2.5	< 661	-
Oligotrophic	2.5 - 8	661-753	< 25
Mesotrophic	8 - 25	753-1875	250-550
Eutrophic	25 - 80	>1875	> 550
Hypereutrophic	> 80	-	-

(b) Total nitrogen concentration

Nitrogen is also an important nutrient in lake eutrophication and is an especially important factor in causing blue-green algal blooms. Since the function of nitrogen to primary productivity of lakes can not be ignored, it has been used as one of the major indices which together with phosphorus was used to determine lake trophic status by the OECD program (Vollenweider 1979; Wetzel 1983). The classification of lake trophic status based on total nitrogen concentration is given by

Vollenweider (1979, Table 2). Compared to the phosphorus index, however, this index is not as frequently adopted.

(c) Hypolimnetic oxygen depletion rates

As eutrophication proceeds, oxygen depletion of hypolimnetic water increases. The measure of its depletion rate has been used as a measure of trophic status as it has a low short term variability (Henderson-sellers and Markland 1988). Its value was used to quantify trophic condition (Table 2). However, Charlton (1980) cautions that this measure should not be used as a surrogate for productivity without reference to hypolimnion thickness and water temperature. Burns and Ross (1972) also observed that a high oxygen depletion in Lake Erie was caused by the loss of the oxygen from night time algal metabolism together with the activity of the large bacterial populations in the lake.

(3) Biological analysis methods

(a) Chlorophyll-a concentrations

Chlorophyll-a concentration has been used for many years as a direct indication of trophic status (Sakamoto 1966; Rast and Lee 1978; Henderson-sellers and Markland 1988). The positive relationship between phosphorus concentration and chlorophyll-a concentration in lakes has been documented by many researchers (e.g. Sakamoto 1966; Dillon and Rigler 1974; Vollenweider 1979). Trophic status boundaries as defined by

seven different boundary levels of chlorophyll-a of lakes are summarized in Table 3.

trophic status	Sakamoto (1966)	NAS (1973)	Dobson et al. (1974)	USEPA (1974)	Rast & Lee (1978)	MOE (1982)	OECD (1981)
ultra-oligotropic	< 0.3	-	-	-	-	-	< 0.7
oligotrophic	0.3-2.5	0-4	0-4.3	< 7	0-2	0-2	0.7-2.1
mesotrophic	1-15	4-10	4.3-8.8	7-12	2-6	2-4	2.1-6.25
eutrophic	5-140	> 10	> 8.8	> 12	> 6	> 4	6.25-19.2
hyper-eutrophic	>140	-	-	-	-	-	> 19.2

Table 3. Trophic boundaries in lakes, as determined from chlorophyll-a mean concentration in lakes (mg m^{-3}). Modified from Henderson-sellers and Markland (1988).

(b) Mean primary productivity and phytoplankton biomass

This method uses radioactive carbon assimilation to estimate the rate of primary productivity, as all photosynthetic organisms require relatively large quantities of carbon (Likens 1972). This classification relates the rates of carbon assimilation and phytoplankton biomass to trophic status of lakes (Table 4). The validity of this criterion, however, depends upon the assumption that organic matter inputs from the littoral and allochthonous sources are small relative to those of the phytoplankton (Wetzel 1983).

Trophic State	Mean primary productivity ($mgC\ m^{-2}day^{-1}$)	Phytoplankton Density ($cm^3\ m^{-3}$)	Phytoplankton Biomass ($mgC\ m^{-3}$)
Ultraoligotrophic	< 50	< 1	< 50
Oligotrophic	50-300	1 - 3	20-100
mesotrophic	300-1000	3 - 5	100-300
Eutrophic	>1000	5 -10	>300
Hypereutrophic	-	> 10	-

Table 4. The primary productivity of phytoplankton as related to lake trophic status. Modified from Wetzel (1983).

(c) Phytoplankton abundance

Phytoplankton abundance is one of the parameters used to estimate lake trophic status (Wetzel 1983). Lambou and his collaborators (Lambou et al. 1983) compared 29 trophic state measurements and concluded that most methods for measuring trophic state are much more effective in ranking lakes when nutrients (as measured by TP levels) are used as the ranking criteria than when the biological manifestations of eutrophication (as measured by chlorophyll levels) are used as the ranking criteria. Many of the standard methods are not very effective in ranking lakes against chlorophyll-a; methods based upon the distributional patterns and/or

community structure of phytoplankton populations appear to be ineffective in discriminating between a lake's trophic rank (Lambou et al. 1983).

2. The relationship between single parameters

The relationship between certain pairs of trophic variables has been examined by many studies which show both good and poor correlations (e.g. Carlson 1977; Lambou et al. 1983; Yoshimi 1987; Henderson-sellers and Markland 1988).

Carlson (1977) found that Secchi transparency correlated best with total phosphorus: SD = 64.9/TP (r^2=0.79, n=61)

The correlation between chlorophyll-a and total phosphorus or Secchi depth wasn't linear; the nonlinear elements in the relationship necessitated a log-log transformation of these data. The resulting equations were: lnSD = 2.04 - 0.68lnChl-a (r^2=0.86, n=147); lnChl-a = 1.449lnTP - 2.442 (r^2=0.73, n=43)

Carlson also mentioned in the same paper that the correlation may be poor during spring and fall overturn when algal production tends to be limited by temperature or light (Carlson 1977). This means that the relationship is not stable in the different seasons.

It also should be noticed that the correlation among trophic variables in different regions has different correlation coefficient values (Table 5).

TP & Chl-a	TP & SD	Chl-a & SD
$\ln Chl\text{-}a = 1.449 \ln TP - 2.442$	$SD = 64.9/TP$	$\ln SD = 2.04 - 0.68 \ln Chl\text{-}a$
$(r^2=0.73,\ n=43)^1$	$(r^2=0.79,\ n=61)^1$	$(r^2=0.86,\ n=147)^1$
$Chl\text{-}a = 0.0731 TP^{1.449}$	$\log TP = 0.818 - 1.307 \log SD$**	$SD = 8.7/(1+0.47 Chla)$*
$(r^2=0.90,\ n=55)^2$		
	$\log TP = \log 1.53 - 0.96 \log SD$	$\log SD = 0.961 - 0.606 \log Chl\text{-}a$**
$Chl\text{-}a = 0.776 TP^{0.64}$	$(r^2=0.53,\ n=21)^4$	
$(r^2=0.36, n=757)^3$		$\log Chl\text{-}a = \log 0.84 - 1.06 \log SD$
$Chl\text{-}a = 0.28 TP^{0.96}$ *	$SD = 4.27 - 0.045 TP$	$r^2=0.44,\ n=22)^4$
$Chl\text{-}a = 0.087 TP + 2.32$	$(r^2=0.14,\ n=85)^+$	
$(r^2=0.30, n=85)^+$		$SD = 4.9 - 0.36 Chl\text{-}a$
$Chl\text{-}a = 0.3 TP - 1.03$	++	$(r^2=0.23,\ n=85)^+$
$(r^2=0.94, n=20)^4$		++

Table 5 The relationship between single trophic parameters such as chlorophyll-a, total phosphorus concentration and Secchi transparency. The data cited from: 1. Carlson (1977); 2. Henderson-sellers and Markland (1988)(values from Sakamoto 1966 and compiled by Dillon and Rigler 1974); 3. cited from Henderson-sellers and Markland (1988) (values from the National Eutrophication Survey in the USA); 4. Agbeti (1987); * Vollenweider (1982); ** USEPA, cited from Henderson-sellers and Markland (1988); $^+$ values from this research lakes in central Ontario region; $^{++}$ Christie (1988).

From Table 5, it was concluded that the correlation between pairs of trophic variables certainly exists, but the degree of correlation relationship differs in different regional lakes and times. Therefore, there

is no universal linear model existing between pairs of trophic variables. Although each criterion changes from oligotrophy to eutrophy, the changes do not occur at sharply defined points, nor do they all occur at the same rate. Thus, no one parameter can be used alone. The regression equation which is obtained from a certain region and time when applied to another region and/or time must be done with caution (Yoshimi 1987).

III. Non-diatom Algae as Indicators of Lake Environments

Algae are ancient organisms, extending back about 3.1 billion years into the Precambrian epoch of earth's history (Bold & Wynne, 1978). Freshwater algae have been frequently used as the major biological monitor of environmental characteristics of lakes and rivers (Ibid). In the absence of historical limnological data, paleolimnologists have inferred past lake water condition changes using fossil remains of algal assemblages because the rapid reproductive rate of the algae makes them very responsive to changes in water quality (e.g. Stoermer 1975; Frederick 1977; Crisman 1978; Dickman et al. 1983; Bradbury et al. 1981; Battarbee 1984; Charles 1984; Xiun and Wu 1986). Fossil records of the algae have been reported by many scientists, and these provide us with the basic information to indicate and/or reconstruct ecological environments both for present and past environments (Lowe et al. 1972). Diatoms are still by far the most valuable group of algae for paleoenvironmental analyses because their taxonomic characteristics are well preserved and readily distinguished, especially when compared to heteromorphic algae (Stevenson & Lowe, 1984). When it comes to algae which do not contain silica, a majority of the palaeolimnological publications have been based on

the distribution of several genera of green algae. Although many other taxa can be recognized from Holocene deposits, they can't be utilized as good indicators of paleoenvironment because the documentation about their habitat characteristics lacks sufficient detail to be used as a sensitive correlate with the physiochemical characteristics of water.

1). Paleoecological indicators of non-silica algae

The remains of non-diatom and non-chrysophyte algae may be abundant in lacustrine sediments. For example, Frederick (1977) identified 106 taxa from postglacial cores. Although many taxa can be recognized from sediments, the majority of palaeolimnological interpretation utilizing non-diatom non-chrysophyte algal assemblages have been based on several genera. Those are included as: a). Spores of Zygnemataceae which include the genera of *Mougeotia, Spirogyra, Debarya* and *Zygnema* (Van Geel and Van Der Hammen, 1978); b). Fossilized forms of green algae including genera *Pediastrum, Gloeotrichia, Botryococcus* and *Staurastrum* have been described (Bradbaury et al. 1981; Crisman 1978; Xiun and Wu 1986), and *Cosmarium, Oedogonium* and *Trachelomonas* (Frederick 1981); c). Fossil oogonium of Charophyta, the major genus in Holocene deposits include *Chara, Tolypella, Lychnothamnus* and *Nitella* (Wang et al., in press).

The stratigraphic and paleoecological research of *Pediastrum* is most frequently reported from Holocene sediments (Yang, unpublished). The occurrence of this genus can indicate high productivity in past lacustrine environments (Bradbury et al. 1981; Crisman 1978; Xiun et Wu 1986; Pollingher 1986).

The occurrence of some taxa also corresponds to the trophic history of a lake. Oligotrophic status is reflected in occurrence of oligotrophic indicators (i.e. *Cosmarium variolatum, Staurastrum orbiculare). Cosmarium formosulum, Pediastrum boryanum, P. simplex Staurastrum dejectum* and *S. oaradokum*) are good indicators of eutrophic status of lakes (e.g. Hutchinson 1967, Frederick 1981; Bradbury et al. 1981). The abundance of spores of Zygnemataceae including *Mougeotia, Spirogyra, Debarya* and *Zygnema* (Hoshaw 1968; Van Geel and Van Der Hammen 1978), fossil oogonium of Charophyta including *Chara, Tolypella, Lychnothamnus* and *Nitella* (Wang et al., in press) can indicate a low water level or shallow lake environment. The abundance of planktonic forms of *Pediastrum, Botryococcus, Staurastrum,* and *Cosmarium* on the other hand can indicate a relatively deep lake environment. The changes in the ratio of these two types of fossil algae in sediment cores may indicate changes in climate (Yang, unpublished).

Data presented here demonstrate the importance of non-diatom and non-chrysophyte algae in paleolimnology. Nevertheless, caution must be exercised in basing paleolimnological reconstructions on only one parameter. When combined with diatoms, pollen and several other parameters, both the validity and potential of algal assemblages in paleolimnology are strengthened (Yang 1988 unpublished paper).

2). Chrysophyte as indicators of lake environment

Freshwater Chrysophytes are commonly found to be an important phytoplankton in temperate, oligotrophic lakes (Hutchinson 1967; Siver and Chock 1986). Chrysophytes are well represented in lacustrine

sedimentary records by their silicified resting stages, known as statospores (Nygaard, 1956), and by the siliceous scales characteristic of the family Mallomonadaceae (Smol 1986).

The stratigraphic distribution of scales has been used to trace patterns of lake eutrophication (e.g. Battarbee et al. 1980; Smol 1980; Smol et al. 1983; Haworth 1984).

However, a more common application of fossil chrysophytes is to infer the lake's acidification history (Smol et al. 1984; Smol 1986; Steinberg and Hartmann 1986; Siver 1987; Dixit et al. 1989a). The results of these investigations have indicated that the distribution of some Mallomanadaceae taxa are closely related to lake water pH, and therefore the past changes in lake acidity can be reconstructed by analyzing their changes in assemblage species composition (Smol et al. 1984; Smol 1986; Steinberg and Hartmann 1986; Siver 1987; Dixit et al. 1989a).

The most recent developments in this area employed the method of canonical correspondence analysis (CCA) to examine the relationship between chrysophyte assemblages and environmental variables (Dixit et al. 1989b). By using CCA, environmental variables based on chrysophyte assemblages were identified. Lake water pH was the most important variable influencing the distribution of chrysophyte scales, and the second most important environmental factor was metal iron concentrations (Ibid). A calibration model between pH and chrysophyte taxa using CCA proved to be far superior to traditional regression methods (Ibid). This study provided compelling evidence that CCA offers great promise in surface sediment calibration and paleolimnological reconstruction studies.

V. Diatom Analysis and Environmental Reconstruction

1. A research history overview

Although virtually all algal groups can be studied using paleolimnological techniques, diatoms are still the most intensively studied (Smol 1989). Diatoms have been recorded and classified for over two centuries (Yang and Qi, in press). In the late nineteenth century the systematic and taxonomic investigations of modern and fossil diatoms was nearly complete and scientists began to pay attention to aspects of distribution ecology (Cleve-Euler, 1951-1955). By far the most common algal microfossils are diatom frustules (Round 1964; Bradbury 1975; Yang 1988).

Because of the ubiquity, diversity, and adaptability of diatoms, they are particularly valuable for concentrated studies of environmental analyses (Stevenson & Lowe, 1984). Identification of diatom species is easier than with other groups of algae because taxonomic characteristics are easily preserved and readily distinguishable, especially when compared to heteromorphic algae. This is also valuable in Paleolimnological studies because the silicious walls of diatoms make them resistant to decomposition, and they are usually preserved well in sediments (Stockner 1971; Renberg and Hellberg 1982; Stevenson and Lowe, 1984). The significance of diatoms as indicators of various characteristics of the freshwater environment has been indicated by many studies (Lowe 1974; Beaver, 1981; Dickman et al. 1983).

Environmental inferences using diatoms have their origins about 50 years ago when F. Hustedt (1938-1939) published a system of ecological

preference of diatom categories based on his ecological and geographic observations. As noted by Smol (1989), major quantitative advantages in Hustedt's system were made by several Scandinavian researchers between 1950s and 1970s, resulting in the development of powerful transfer functions that could be used to infer past pH levels from diatoms.

During the past two decades, numerous approaches to diatom analysis both for monitoring current lake environments and for making paleolimnological reconstructions have been made. Such studies have dealt with **1):** lake eutrophication, especially cultural eutrophication processes (Vallentyne 1957; Frey 1964; Stockner 1971; Duthie and Sreenivasa 1972; Haworth 1976; Brugam 1978, 1979, 1983; Beaver 1981; Stoermer 1985; Christie 1988; Agbeti and Dickman 1989); **2):** lake pH history (Nygaard,1956; Dickman et. al. 1984; Dickman and Thode 1985; Charles 1985); **3):** lake ontogeny and the glacial history of lake related climate change (e.g. Round 1960; Alhonen 1967; Patrick 1970; Sreenivasa and Duthie 1973; Haworth 1977; Stoermer 1977; Brugam 1980; Hickman et al. 1984; Stoermer et al. 1987; Stabell 1987). **4).** tracing the effects of human activity on north American lakes (e.g. Brugam 1978, Davis and Norton 1978, Munch 1980; Stoermer et al. 1985).

2. Research history: A review of diatoms as indicators of Lake Acidity

To date, the most intensively and successfully studied relationship between diatoms and environmental variables is the correlation between diatom assemblages and lake water acidity. For this reason, a special

literature survey of this aspect was made in order to obtain some insight into the relationship between diatoms and lake trophic status.

1). Hustedt's diatom categories and lake pH.

As early as the 1930s, Hustedt identified and enumerated the diatoms in over 650 samples from Java, Bali and Sumatra which have a wide variety of habitats and cover a large range of environmental conditions. He concluded that the hydrogen ion concentration of the water had the greatest influence on the diatom flora (Hustedt 1937-1939). He was the first scientist to quantify the diatom species and place them into five pH categories which are expressed as follows:

1. alkalibiontic (alkb): diatom species occur at pH values > 7;
2. alkaliphilous (alkf): occurring at pH about 7 with widest distribution at pH > 7;
3. indifferent (ind): equal occurrences on both sides of pH 7;
4. acidophilous (acf): occurring at pH about 7 with widest distribution at pH < 7;
5. acidobiontic (acd): occurring at pH < 7, optimum distribution at pH = 5.5 and/or less.

Hustedt's classification was the fist comparatively systematic document for diatom autecological information on pH to indicate lake water acidity (Foged 1953, 1955, 1958, 1964). He also provided a basis for further quantitative analysis and linear regression analyses between diatom assemblages and lake water pH (Jorgensen 1948; Nygaard 1956; Merilainen 1967; Renberg and Hellberg 1982).

2). Diatom indices

From the 1940s to the 1960s, diatomists had been studying to search for more reliable pH results by the introduction of the quantitative concept into Hustedt's ecological system (Jorgensen 1948; Nygaard 1956; Merilainen 1967).

Based on Hustedt's pH classification of diatoms, Nygaard established a methodology on pH reconstruction using diatom assemblages (Nygaard 1956). The indices that he proposed were assigned by analyzing the relative frequencies of acid and alkaline diatom categories which included:

Index a = (acid units)/ (alkaline units)

= (acf% + 5 x acb%)/(alkf + 5 x alkb%)

Index w = (acid units)/ number of acid species

Index E = (alkaline units)/ number of alkaline species

Although Nygaard's indices did not successfully complete a direct model between diatom assemblage and lake water pH, his achievements pointed the way towards a quantification of the techniques of pH reconstruction (Battarbee and Smol 1986).

In 1967, Merilainen evaluated the usefulness of Nygaard's indices with respect to 12 Finnish lakes (Merilainen 1967). Merilainen paid particular attention to the strengthening of the diatoms-pH calibration system. Comparing two other indices, he found that Index a can more naturally reflect water pH values. After the values of Index a were transformed to logarithms they were found to be grouped about a straight line described by the equation :

log Index a = -1.08X + 7.16, where X = pH value (P.57. Ibid). Thus, the inferred lake water pH values can be related to the following equation:

pH = 6.63 - 0.93 log Index a

A further improvement of the Nygaard /Merilainen system was proposed by Renberg and Hellberg (1982). In order to avoid values of infinity they modified the Nygaard index a by including indifferent (circumneutral) taxa in the equation. They then calculated the coefficient for each diatom assemblage by using multiple regression analysis and this was used to formulate an index B:

Index B=(ind% + 5 acf% + 40 acb%)/(ind% + 3.5 alk% +108 alb%)

Index B was also transformed to logarithms in order to get a linear model to correspond to pH values. When plotted against the values of pH from 30 lakes in Sweden, Finland and Norway, the equation of the linear function was:

pH = 6.40 -0.85 log Index B (r^2 = 0.91 SE = $\pm$ 0.30)

This method has been widely used for lake paleo-pH reconstructions in many countries of the world (Davis 1987), the publications using this method are voluminous. Its usefulness is especially apparent in situations where local surface sediment diatom assemblage data are absent since the data classification used in the equation are based on information available in the literature (Battarbee 1986).

Despite these advantages there have been few developments in understanding the ecology of diatoms in acidic ecosystems (Battarbee 1986). With the emphasis on sediments and on tightening the link between diatom habitat and ecology, understanding the ecology of diatoms in acidic ecosystems has been neglected. Until we know more about the specific response of individual species to environmental changes brought about by lake acidification we will not be able to realize the full potential of the sediment record (Ibid).

3). Recent developments

The increase in studies of lake acidification has been a driving force in the development of methods of pH reconstruction, including:

1) Multiple regression analysis of various pH indicator diatom assemblages (e.g. Charles 1985; Dixit 1986).

2) Multiple regression of principle components of diatom taxa and multiple regression of taxonomic clusters (Davis and Anderson 1985).

These two methods have also been used for calibration with limited success (Davis and Anderson 1985). Due to regional differences, these calibration relationships may not be transferable from one lake region to another (Ibid).

3) Diatom-based pH reconstruction of lake acidification using canonical correspondence analysis (Stevenson et al. 1989).

3. Research history: A review of diatoms as indicators of lake trophic status

Although the origins of studies on the relationship between diatoms and lake trophic status can be traced back to the latter part of the nineteenth century, the more intensive research occurred between 1960 and 1980 when the increase in the seriousness of the global eutrophication problem was a driving force in the development of nutrient-related diatom studies (e.g. Vallentyne 1957; Frey 1964; Smith 1966; Stockner and Benson 1967; Stoermer and Yang 1969, 1970; Stockner 1971; Duthie and Sreenivasa 1972; Haworth 1976; Brugam 1978, 1979).

With the recognition that acidification was an important environmental problem in the 1980s, most research resources in North America and western Europe were focused on reconstructing past pH levels (Smol 1989). Meanwhile, problems dealing with past production and trophic dynamics continued to be investigated, (e.g. Beaver 1981; Engstrom et al. 1985; Stoermer 1985; Christie 1988; Agbeti and Dickman 1989), but at a much slower pace than acidification work (Smol 1989). It also appears that the diatom-trophy relationship is much more complex than that of diatom-pH (personal communication with Dickman and Stoermer, 1989). For these reasons, quantitative correlations between diatom assemblages and lake trophic status were not developed.

The methodology of diatoms-trophy studies has been developed through a number of stages, in which trophic status has been inferred in three ways:

1). by some indicator species;

2). by ratios of diatom taxonomic group;

3). by trophic indices with single regression or multiple regressions.

1). Inferring trophic status from diatom indicator species

The classification of diatom species on lake trophic levels can be traced back to as early as 1919, when Naumann introduced the general concepts of oligotrophy and eutrophy and distinguished them on the basis of phytoplankton (Naumann 1919 as cited in Wetzel 1983). The earlier period of the publications on nutrient-diatom relationships can be found from Kolbe (1932); Hustedt (1936); Patrick (1943, 1954); Foged (1954);

Hutchinson et al. (1956), those cited from Patrick (1968); Smith (1966) and others.

In 1966, Smith provided the framework for a systematic relationship between diatom species and nutrient levels (Smith 1966):

Eutrophic species: occur in water with high nutrient concentrations;

Mesotrophic species: occur in water with moderate nutrient concentrations;

Oligotrophic species: occur in water with low nutrient concentrations;

Dystrophic species: occur in water rich in humic materials.

This modification was widely adopted until today, and the increase in studies on the diatom-nutrient relationship has improved the understanding of diatom autecology and lake trophic status (Lowe 1974; Beaver 1981). The presence of some individual diatom species has been used to indicate trophic state. For example, *Stephanodiscus hantzschii*, and to a lesser extent *Melosira granulata* are both well-known species of eutrophic lakes (Guillizzoni et al. 1986). *Cyclotella bodanica*, *C. stelligera* and *C. ocellata* are commonly considered oligotrophic indicators (Stockner and Benson 1967). *Asterionella formosa*, *Fragilaria crotonensis* and *Tabellaria fenestrata* are considered to be indicative of nutrient-rich or disturbed watersheds (Ibid). This traditional species-indicator method for tracing the trophic history of lakes can still be found in the literature of the 1980s (e.g. Olive and Price 1978; Brugam 1983; Engstrom et al. 1985; Stoermer et al. 1985; Yang 1986; Battarbee 1986; Luttenton et al. 1986; Earle et al. 1988).

2). Inferring trophic status by ratios of diatom taxonomic groupings

In the attempts to quantify and reconstruct the trophic status and productivity of lakes, a number of phytoplankton indices have been developed (Nygaard 1949; Shannon and Weaver 1963; Pielou 1966; Palmer 1969). However, some feel that these indices are ineffective at trophically ranking lakes (Lambou et al. 1983). Furthermore, Nygaard's indices assumed a degree of uniformity with various phytoplankton taxonomic groups that extensive phytoplankton analyses have not substantiated (Hern et al. 1979; Lambou et al. 1979, 1983; Morris et al. 1979; Williams et al. 1979; Taylor et al. 1979). Lammbou and his collaborators pointed out that methods based upon the distribution patterns and/or community structure of phytoplankton populations appear to have a low correlation with trophic levels in their trophically ranked lakes (Lambou et al. 1983).

The trophic indices were based on ratios or quotients for species groups of diatom families [i.e.. Centricaceae to Pennate, C : P (Nygaard 1949) and Araphidineae to Centricaceae, A : C (Stockner and Benson 1967)]. Based on the observation of the distribution ratios of centric and pennate diatoms in lakes as they relate to different trophic levels, Nygaard found that these ratios could be used as a trophic index (TSI):

TSI = number of centrics/number of pennate

Nygaard's index seems more useful than only using some indicator to trace trophic levels. However, Stockner argued that the presence or

absence, or a change in the relative abundance of some species cannot be attributed to changed trophic condition alone, because biological interactions such as parasitism, predation or competition may also be contributing factors (Stockner and Benson 1967; Stockner 1972).

Based on sediment and plankton samples from temperate lakes, Stockner found that the ratio of different diatom taxonomic groups, Araphidinids (A) to Centrics (C), tended to reflect the lake trophic status. Araphidinid diatoms were often abundant in eutrophic lakes, whereas centric diatoms were usually abundant in oligotrophic lakes (Stockner and Benson 1967). The ratio of Araphidineae to Centrales was therefore proposed as an index of trophic status (Ibid).

Stockner (1971) noted that in a number of lakes that had become eutrophic as a result of human disturbances, core samples showed an increase in the planktonic diatom tribe Araphidineae, whereas representatives of the Centrales decreased. From this observation, a classification scheme was developed and three categories were recognized: oligotrophic (A / C = 0.0 - 1.0), mesotrophic (A / C =1.0 - 2.0) and eutrophic (A / C > 2.0) (Stockner 1971).

This index seems to be a much more reliable indicator than the C/P ratio index and has been applied to many studies for tracing paleotrophic history of lakes (e.g. Stockner 1972, 1975; Bailey and Davis 1978; Brugam 1978; Culver et al. 1981). However, a number of critical comments about the disadvantages of the Stockner ratio were also given in these and other publications (e. g. Duthie and Sreenivasa 1971; Stockner 1972; Brugam 1979; Wetzel 1983).

According to Stockner (1971), his ratio was only meant to be applied to deep lakes which were greater than 3 m in depth.

On the other hand, the mechanism of diatom distribution corresponding to lake trophic status does not appear at high taxonomic levels. Any category or classification of diatom ecology must be based on the similarity of species and their autecological features (Hustedt 1937-1939, Lowe 1974; Beaver 1981). Not all species of the Centric or Araphidineae can be abundant in the same trophic conditions.

3). Using the diatom index with single regression analysis

Almost all approaches for monitoring lake trophic status and tracing paleotrophy were done using some indicator species and/or simple taxonomic ratios (e.g. Vallentyne 1957; Frey 1964; Stockner 1971) until 1985 when Agbeti started to adapt the quantitative method developed for pH and diatom indices in order to established his diatom-trophy index (DITI):

$$\mathbf{DITI = (E + O\text{-}M + M + M\text{-}E) / (O + O\text{-}M + M + M\text{-}E)}$$

Where, E represents eutrophic indicator species, O-M oligo-mesotrophic indicator species, M mesotrophic indicator species M-E meso-eutophic indicator species and O oligotrophic indicator species (p.65, Agbeti 1987).

By using a simple regression technique, diatom assemblage index DITI was correlated with three common trophic parameters; Secchi transparency, total phosphorus and chlorophyll-a values. The calibrated equation model between diatom assemblages and each of the trophic parameters were obtained (Ibid):

DITI = 0.12 Chl-a + 0.34 (r=0.74, r^2=0.55, n=29, P < 0.01)

DITI = 0.04 TP + 0.18 (r=0.77, n=29, P < 0.05)

DITI = 1.36 - 0.12 SD (r= -0.60, r^2=0.36, n=29, P < 0.01)

Two years later, the models were modified (Agbeti and Dickman 1989) by using both single regression and multiple regression methods after logarithm transformation had been carried out:

Linear regression, **logDITI=0.68 logChl-a - log0.40**

(r=0.91, n=29, SE=+0.17, P<0.00001)

log DITI=0.87 logTP - log1.1

(r=0.84, n=29, SE=+0.22, P<0.00001)

Multiple regression; **logTP = log0.84 - 0.13 logol + 0.31 logme + 0.12 logeu**

(r = 0.85, n = 29, SE = 0.12, P< 0.00001)

log chl-a = -log0.15 - 0.15 logol + 0.55 logme + 0.16 logeu

(r = 0.87, n = 29, SE = 0.27, P<0.00001)

One disadvantage of this approach was that the autecological feature of each diatom species, whether an oligotrophic or eutrophic indicator, was based on the literature and not on an autecological study of its distributions in the study lakes. Autecological features of many diatom species described by Agbeti as they relate to lake trophic status have not been documented. Even where documentation can be found, many contradictions exist in the different published research papers (Lowe 1974; Beaver 1981).

Whether inferred trophic levels were significantly correlated with observed trophic levels remained unclear. Nevertheless, this was the first investigation using quantitative methods to correlate diatom assemblages and lake trophic status. This approach pointed the way for further research.

A similar approach was completed by Christie in 1988. The diatom assemblages from 39 southeastern Ontario lakes were used to calibrate three common trophic parameters; Secchi transparency, total phosphorus and chlorophyll-a values using multiple regression methods (Christie 1988). Three calibration equations were used:

Inferred chl-a = 3.8 - 0.11 groupI- 0.026 groupII - 0.001 groupIII- 0.0004 groupIV +0.05groupV (r^2=0.9, n=39)

Inferred TP = 39.9 - 0.37group - 0.14groupII- 0.23groupIII - 0.14groupIV + 0.064groupV (r^2=0.56, n=39)

Inferred TP = 4.5-0.06groupI - 0.02groupII - 0.013groupIII - 0.002groupIV + 0.023groupV (r^2=0.54, n=39)

In this study, the autecological features of dominant diatom species were determined by analyzing the frequency distribution of each of dominant diatom species on lakes of different trophic status. However, the five categories (Group I-V) obtained by the calculation of species weight averages did not give a clear definition of each group in each corresponding lake of different trophic level. For example, the diatom group I in the above equation representing an oligotrophic species group is unclear. What is the boundary relationship between values of species

weight average and each of the three trophic parameters? In addition, both development and testing of the hypothesis in the Christie's approach was carried out by using data from the same set of lakes. This results in a circular argument or tautology which may nullify the test of the null hypothesis.

DESCRIPTION OF THE RESEARCH LAKES

The study lakes are situated in a sparsely populated region of the Muskoka and Haliburton districts in central Ontario, Canada (Fig. 2, Table 6 and Appendix I). The lake beds consisted of Precambrian Shield rock and Late quaternary lacustrine sediments, the geologic characteristics of this region (Chapman 1975). The formation of lakes in this region was associated with glacial activity during the Late Pleistocene and Early Holocene (Chapman 1975, and Dillon et. al. 1978). A northern forest that was dominated by hemlock and pine covers the watershed of many of these lakes (Chapman 1975).

According to Dillon, lakes in this region have a low to moderate acid-neutralizing capacity (Dillon et. al. 1978). The Precambrian Shield bedrock and the variable covering of till offers little buffering capacity and consequently many of the lakes in this region are believed to have been affected by anthropogenic acidification from long range transport of atmospheric pollution. Many lakes exhibit a summer eplimnetic pH of <5.5 (Taylor et al. 1986). The relationship between diatom assemblages and lake water pH was studied by Taylor, Duthie and Smith (Taylor et. al. 1986, 1987).

In order to decrease the ecologic variables between different lakes, such as nutrient loading and acid rain, that could effect the lakes, research was carried out only in Muskoka and Haliburton districts in central Ontario in order to keep the geologic and geographic background of the study lakes as similar as possible.

Fig. 2. Location of the study area. After Taylor et al. 1986.

The characteristics of the water in each of the 86 research lakes were made available to me by the Ontario Ministry of the Environment (Table 6). The information concerning the trophic status of each of the study lakes was taken from the published literature (OME 1985, 1988a-d). The designation of the literature-derived trophic status was based on total phosphorus (TP), chlorophyll-a (Chl-a) and Secchi depth transparency (SD).

Total phosphorus was the best correlate with the trophic status of the study lakes compared to other criteria (e.g. chlorophyll-a and Secchi disk transparency). Lakes were selected in order to represent a wide range of trophic variation ranging from oligotrophic to eutrophic conditions. In this lake set, Trading Bay (Lake of Bay) displayed the lowest TP (2 $\mu g\ l^{-1}$) and Baxter Lake displayed the highest TP (75 $\mu g\ l^{-1}$).

The lake trophic status of these 86 lakes was re-evaluated in this study by using a new trophic multiparameter in order to avoid the reliance on the single parameter approach. Among these 86 lakes, 50 were chosen for surface sediment diatom sampling.

Table 6. The geographic and water environmental information of 86 Study lakes.

#	Lake	Long.	Lat.	Township	Ward	TP	Chl-a	SD
1	Fawn	45o10'N	79°15'W	Huntsville	Stephenson	68	8.7*	1.2
2	Moot	45o09'N	79°10'W	Lake of Bays	McLean	43	7.8	1.5
3	Brandy	45°06'N	79°32'W	Mustoka Lakes	Medora	55	7.3	1.95
4	Hesners	45°01'N	79°39'W	Mustoka Lakes	Wood	32	12.7	3.2
5	Riley	44°50'N	79°11'W	Gravenhust	Ryde	48	5.6	2.7
6	Nine Mile	45°57'N	79°35'W	Mustoka Lakes	Wood	56	4.4	2.6
7	Long	45°12'N	79°21'W	Mustoka Lakes	Wood	13	2.5	1.75
8	Black	45°00'N	79°34'W	Lake of Bays	Wood	35	3	1.9
9	Leech	45°03'N	79°06'W	Bracebrige	Oakley	47	4.13	4.63
10	Bass	45°07'N	79°42'W	Gravenhust	Ryde	12	6.2	2.3
11	Ricketts	45°09'N	79°45'W	Mustoka Lakes	Medora	13	4.7	2
12	Gullfeather	45°06'N	79°01'W	Bracebrige	Oakley	17	4.7	2.9
13	Ril	45°10'N	79°00'W	Lake of Bays	Ridout	9	6.2	2.7
14	Little Leech	45°02'N	79°01'W	Bracebrige	Oakley	16	3.5	3
15	Long Turtle	44°54'N	79°27'W	Mustoka Lakes	Wood	17	3.8	3.7
16	Medora	45°04'N	79°39'W	Mustoka Lakes	Medora	12	5.6	4.4
17	Grevenhurst Bay	45°03'N	79°29'W	Gravenhust	Ryde	11	5.3	4
18	Spence	45°00'N	79°17'W	Bracebrige	Draper	11	3.9	3.25
19	North Muldew	44°54'N	79°27'W	Mustoka Lakes	Wood	13	2.4	3.8
20	Prospect	44°57'N	79°08'W	Bracebrige	Draper	11	2.7	4.5
21	Clearwater	44°48'N	79°14'W	Gravenhust	Morrison	8	2.3	2.8
22	Loon	44°27'N	78°59'W	Mustoka Lakes	Wood	10	2.6	4.5
23	Little long	45°15'N	79°31'W	Mustoka Lakes	Wood	7	3.2	4.08
24	Wood	45°01'N	79°05'W	Mustoka Lakes	Wood	10	2.1	4.8
25	Pine	45°04'N	79°07'W	Bracebrige	Oakley	5	3.1	3.9
26	Clear	45°02'N	79°01'W	Bracebrige	Oakley	14	1.9	7.2
27	Leonard	45°04'N	79°27'W	Mustoka Lakes	Monck	10	1.6	6.1
28	Heeney	45°08'N	79°06'W	Lake of Bays	McLean	5	1.7	4.2
29	Trading Bay	45°15'N	79°00'W	Lake of Bays	Ridout	5	1.6*	5
30	Muskoka	45°01'N	79°36'W	Mustoka Lakes	Medora	6	1.4	4.5
31	Kahshe	44°50'N	79°18'W	Gravenhust	Morrison	18	5.8	3.5
32	Ben	44°53'N	79°12'W	Gravenhust	Ryde	15	3.7	4.5
33	Ryde	44°54'N	79°15'W	Gravenhust	Ryde	34	4.4	1.6
34	Weismuller	44°54'N	79°15'W	Bracebrige	Ryde	25*	5.9*	3**
35	Pine	44°57'N	79°27'W	Gravenhust	Wood	17	4	4
36	Sosseau	45°07'N	79°31'W	Gravenhust	Ryde	14	3.2	2.25
37	Ada	45°05'N	79°38'W	Mustoka Lakes	Medora	21	5.4	1.6
38	Mckay	45°03'N	79°10'W	Bracebrige	Draper	11	2	4.3
39	Gull	44°55'N	79°21'W	Gravenhust	Musloka	13	1.5	5.2
40	Clear	45°12'N	79°14'W	Bracebrige	Oakley	18	4.4	5
41	Menominee	45°12'N	79°09'W	Bracebrige	Oakley	14	2.9	1.5
42	Wildcat	45°11'N	79°02'W	Lake of Bays	Ridout	6	2.8	2.5
43	Simoce	44°10'N	79°30'W	Boundary		20	2.6*	7
44	Gold city	45°01'N	79°05'W	Huntsville	Stisted	27	7.2	2.5**
45	Baxter	45°19'N	79°25'W	Georgian Bay	Baxter	46	3.2	3.5
46	Healey	45°05'N	79°11'W	Bracebrige	Macaulay	12	4	1.5

Table 6 Continued

#	Lake	Long.	Lat.	Township	Ward	TP	Chl-a	SD
47	Henshaw	45°06'N	79°35'W	Mustoka Lakes	Medora	9	4.7	5.3
48	Hammel Bay	45°10'N	79°27'W	Mustoka Lakes	Watt	22	3.7	2.3
49	Waseosa	45°01'N	79°05'W	Mustoka Lakes	Wood	9	4.7	2.81
50	Horseshoe	44°52'N	78°24'W	Lake of Bay	Ridout	6	2.4	3.5
51	St. Nora	45°09'N	78°50'W	Lake of Bay	Ridout	5	1.4	5.8
52	Little hawk	45°09'N	78°43'W	Lake of Bay	Ridout	5	1.5	6.7
53	High	45°15'N	79°30'W	Mustoka Lakes	Watt	5	2.6	5.5
54	Wolfkin	45°14'N	79°06'W	Lake of Bay	Ridout	5	3.7	4.5
55	Hardy	45°00'N	79°32'W	Mustoka Lakes	Medora	6	4.1	3.9
56	Stewart	45°08'N	79°46'W	Georgian Bay	Medora	6	2.6	2.7
57	Seyer's	44°48'N	78°37'W	Lake of Bay	Ridout	6	2.1	3.8
58	Pencil	45°01'N	78°21'W	Lake of Bay	Ridout	6	1.6	4.2
59	Bitter	45°10'N	78°35'W	Lake of Bay	Ridout	7	1.5	6.8
60	Two Island	45°04'N	78°22'W	Lake of Bay	Ridout	7	1.8	6.1
61	Fairy	45°20'N	79°11'W	Huntsville	Brunel	7	2.1	2.7
62	Oxtongue	45°22'N	78°55'W	Huntsville	Brunel	8	2.3	2.7
63	Peninsula	45°20'N	79°06'W	Huntsville	Brunel	8	1.6	3.5
64	Kashagawigmog	44°59'N	78°36'W	Lake of Bay	Ridout	9	3.3	4.6
65	Camel	45°10'N	79°25'W	Mustoka Lakes	Watt	9	4	2.9
66	Lipsy	45°10'N	78°38'W	Lake of Bay	Ridout	9	4.7	5.3
67	Long(Large)	45°00'N	79°39'W	Mustoka Lakes	Medora	9	1.9	4.6
68	Bella	45°27'N	79°02'W	Lake of Bay	Sinclair	10	2.1	4.8
69	Mary	45°15'N	79°15'W	Huntsville	Brunel	10	1.6	2.8
70	Wilbermere	45°00'N	78°13'W	Lake of Bay	Ridout	11	1.7	4.8
71	Vernon	45°20'N	79°17'W	Huntsville	Ststed	11	1.7	2.6
72	Oudaze	45°27'N	79°11'W	Huntsville	Chaffey	11	3.9	2.3
73	Buck	45°25'N	79°23'W	Lake of Bay	Sinclair	11	2.6	1.3
74	Sunny	44°55'N	79°18'W	Gravenhust	Morrison	11	4.5	4.4
75	Longline	45°15'N	78°59'W	Lake of Bay	Ridout	12	2.6	4.6
76	Young	45°13'N	79°33'W	Mustoka Lakes	Watt	12	2.3	4.1
77	Otter	45°18'N	79°10'W	Huntsville	Brunel	14	5.7	3
78	Bonnie	45°08'N	79°15'W	Bracebrige	Oakley	14	1.9	7.2
79	Sparrow	44°47'N	79°24'W	Gravenhust	Morrison	15	2.6	2.6
80	Oakley	45°02'N	79°01'W	Mustoka Lakes	Wood	16	3.6	3
81	Penfold	45°18'N	79°17'W	Huntsville	Syephenson	17	7.5	1.5
82	Pine-wood	45°21'N	79°35'W	Mustoka Lakes	Watt	17	4	4
83	Jessop	45°12'N	79°45'W	Huntsville	Syephenson	18	7	1
84	Perch(fish)	45°27'N	79°14'W	Huntsville	Chaffey	19	8	1
85	Clark	45°24'N	79°18'W	Huntsville	Chaffey	21	3.1	.5
86	Fox	45°22'N	78°21'W	Huntasville	Stisted	10	2.1	4.8

*: From MOE 1985 **: Measured during field work.

MATERIALS AND METHODS

I. Field work

Surface sediment samples were collected during the summer period of 1989 (from July 2 to July 17). Three replicate samples were taken from 3 different points in the profundal zone of most of the lakes using a K-B Gravity Corer. The profundal zone consisted of exposed fine sediments free of vegetation. For some shallow lakes, such as Wildcat, Hesners, Golden City and Ricketts, sediment cores were collected from the lower infralittoral zone where submersed rooted or adnate macrophytes were rare or from the transitional littoriprofundal zone which was occupied by scattered algae and mosses.

The K. B. gravity corer was carefully inserted into the sediments to take about 20 cm from the top of the mud-water interface. Before raising the corer out of the water, a corer cover was placed at its base. The top 2 mm of core sediment sample was extracted into a plastic whirlpack bag using a small plastic pipe. In this way, the diatom assemblage represented over an estimated one to five year period of deposition was obtained.

The three replicate core samples taken from different locations in each lake were combined into one homogeneous sample for each of the 50 study lakes. In this way the diatom assemblages in the core better reflected the diatom composition of each lakes.

Once samples were taken and coded, a brief note about the geographic information, sample location, water color, terrestrial vegetation, aquatic plants and Secchi disk depth were made for each lake.

II. Laboratory analysis

All samples were analyzed in the Limnology Laboratory in the Biology Department at Brock University. The procedures for diatom cleaning, mounting and counting corresponded to those of Battarbee (1986) and Yang (1988).

A. Diatom cleaning

The procedures for diatom cleaning were as follow:

1. Samples were homogenized using a glass stirring rod. The volume of each sample was then measured, and 3 ml of the homogeneous mixture was removed and placed into a 60 ml test tube.
2. Approximately 3 times the sample volume of H_2O_2 (30%), an oxidizing agent, was added to the beaker. After about 6 hours, a microspatula of $KMnO_4$ was added, initiating an exothermic reaction which oxidized most of the remaining organic matter in the test tube.
3. When the solution containing the sample had cooled, 5 ml of HCl (35.4%) was added in order to clean out the remaining calcite in the sample.
4. After one day, the sample was put into a 500 ml beaker with 450 ml of distilled water. Each sample was washed three times with distilled water. The settling time between the 2 washings was 6 hours.
5. The cleaned diatom sample was poured into a Battarbee dish in which 4 coverslips had been placed. After the material had

air-dried, the four coverslips were removed and mounted on glass microscope slides using Hyrax mounting media (Patrick & Reimer 1966).

B. Diatom taxonomy

In order to identify diatom taxa correctly, all diatom samples were studied under a scanning electron microscope at the Nanjing Institute of Geology and Paleontology, Academia Sinica of Nanjing, China. The SEM photos of common diatom species (Plates 1-10) were made and added to the appendix of this paper. The references used in the identification of diatoms include Hustedt (1930), Cleve-Euler (1951-1955), Patrick & Reimer (1966, 1975), and Germain (1981). Identification of some unusual diatom taxa were discussed with Professor Stoermer, Dr. Kociolek in Great Lakes Research Division, the University of Michigan as well as my supervisor, Professor Dickman.

C. Diatom counting

Before diatom counting began, each lake sample was coded to obtain an unbiased count. Coding reduced the chance of unconscious bias during the enumeration procedure. The prepared slides were next examined at 1000X magnification with a Leitz Research Microscope, and all diatoms were identified to species and/or variety. Diatom valves were enumerated row by row until a total of approximately 600 frustules (1200 valves) had been counted from each replicate slide sample. For the counting of diatom fragments, those greater in size than half a full valve were also counted as

one unit and those smaller than half this size were ignored.

III. Data analysis

The diatom counting data were intered a Macintosh SE Computer equipped with Statview 512 in order to calculate diatom percentage abundance, weight averaging value of diatom species on lake trophic status, diatom index of lake trophic status (Index D) and the regression analyses between Index D and lake trophic value which was based on the data of total phosphorus (TP), chlorophyll-a (Chl-a) and Secchi disk transparency (SD).

A. Choosing lake trophic status parameters

To determine the trophic status of the central Ontario Lakes, a new trophic state index was developed and used in this research.

Traditionally, the total phosphorus, chlorophyll-a and Secchi transparency are the most commonly used parameters for determining lake trophic status (Lambou et al. 1983). However, the contradictions among these three traditionally single parameters were considerable in the data set supplied to me by the OME. Thus a lake classified as eutrophic based on its total phosphorus might be mesotrophic based on its Secchi transparency and total chlorophyll. Similar observations on other data sets were made by Carlson and Lambou and others (Carlson 1977; Lambou et al. 1983; Yoshimi 1987; Henderson-sellers and Markland 1988). That is to say that some lakes may be considered oligotrophic according to one criterion and mesotrophic or even eutrophic by another.

In order to resolve this problem, a new multiple trophic parameter index of trophic status was introduced which combined these three single parameters according to the principle relationship between lake productivity and each of the three variables (TP, Chl-a and SD):

1. lake trophic status was positively correlated with total phosphorus;
2. lake trophic status was also positively correlated with mean annual chlorophyll-a concentration;
3. lake trophic status was negatively correlated with Secchi transparency in lake water;

Thus, the combination of these three parameters was used to develop a new multiple trophic status index for the lake trophic status which was referred to here as the MTSI index.

4. MTSI was positively correlated with (TP x Chl-a / SD)

MTSI = TP x Chl-a / SD

The MTSI value of lakes calculated from the above equation ranged from ultraoligotrophic to hypereutorphic. In order to make a new classification of lake trophic status for easier communication and application, a new definition of the term; "trophic level" (TL) was proposed here for quantifying trophic status of lakes into a simple range of degree between 0 (ultraoligotrophic lakes) to 10 (hypereutrophic lakes) based on the mathematical calculation:

$$TL = 1.37 \ln[1 + MTSI]$$

$$= 1.37 \ln[1+(TP \times Chl\text{-}a / SD)]$$

The value of the lake trophic level, therefore, was obtained from the computation based on three distinct parameters (TP, Chl-a and SD). The standard of five categories of lake trophic level were quantified by the new parameter and are shown in Table 6, where they are compared with trophic boundaries defined by other authors who relied on single parameters.

Trophic State	TP ($\mu g\ l^{-1}$)	Chl-a ($\mu g\ l^{-1}$)	SD (M)	Trophic Level
ultraoligotrophic	< 2.5	< 0.7	> 9	< 0.24
oligotrophic	2.5 - 8.0	0.7 - 2.1	6.01 - 9	0.24 -1.8
mesotrophic	8.01- 25	2.11 - 6.25	3.01 - 6	1.81- 5.4
eutrophic	25.01-80	6.26-19.20	1.51 - 3	5.41 - 10
hypereutrophic	> 80	> 19.2	0 - 1.5	> 10

Table. 7 The comparison of the boundaries for total phosphorus, chlorophyll-a, Secchi transparency and relative trophic status to classify lakes according to their respective trophic states. The literature source for standards of total phosphorus (TP) and chlorophyll-a (Chl-a) are from Janus and Vollenweider 1981, and standard of Secchi disk transparency (SD) are from Vollenweider 1979.

B. Diatom Autecology and Lake Trophic Status

Because autecological features of some diatom species are not well documented, it is impossible to do good regression analysis of diatom

assemblages and lake trophic status without accurate diatom autecolgical information.

To solve these problems, I designed my research to examine the different trophic status lake diatom assemblages from 30 study lakes in the central Ontario region. Diatom species autecological features and lake trophic status were determined by analyzing the frequency of each species' distribution in different trophic status lakes and using the weighted average (WA) technique (Charles 1985).

The weighted mean of diatom species characteristics was determined from the following formula; $X = \sum P_i (X_i) / \sum P_i$ Where:

X = the mean of the relative trophic status of each diatom species

P_i = the percentage occurrence of the diatom species in sediment of lake i

X_i = the value of the relative trophic status in lake i.

Five catalogues of classification based on diatom trophic feature were employed.

1. Eutrophic species: Diatom species which are abundant only in eutrophic lakes, WA value larger than 5.4
2. Mesoeutrophic species: Diatom species that were abundant both in eutrophic and mesotrophic lakes, WA value between 4.21 and 5.4
3. Mesotrophic species: Diatom species which are mainly abundant in mesotrophic lakes, WA value between 3.01 and 4.2
4. Oligomesotrophic Species: Diatom species which are abundant both in oligotrophic and mesotrophic lakes, WA value between 1.8 and 3.0
5. Oligotrophibiontic: Diatom species which are abundant only in oligotrophic lakes, WA value smaller than 1.8.

C. Regression Analysis

The results of autecological features of common diatom species which were classified into the five diatom trophic catalogues were obtained from studies of 30 central Ontario region lakes. The relative trophic status in this set of lakes ranged from 1.2 (oligotrophic lake) to 8.4 (eutrophic lake).

The five categories of surface sediment diatom relative abundance of each of the 30 study lakes were used to regress against the values of trophic level of the corresponding lakes, by using two methods:

(1) The multiple regression analysis:

The values of trophic level were directly regressed against the relative abundance values of these five catalogues of diatoms using multiple regression technique. A multiple regression equation of diatom inferred trophic status was obtained.

(2) The single regression with diatom trophic index (DTI)

The diatom trophic indices (Index D) proposed here were obtained by analyzing the relative frequencies of five diatom trophic categories which included: **Index D = (O% + OM% + M%)/(E% + ME% + M%)**

Where;

O = oligotrophic species; OM = oligomesotrophic species; M = mesotrophic species; E = eutrophic species and ME = mesoeutrophic species.

Then, the Index D values obtained from the above equation were regressed against the values of trophic level by using the single regression

technique. A single regression equation of diatom inferred trophic status was then obtained

D. Tests of the Hypothesis

The main hypothesis of the thesis (see introduction) cocerns the possiple relationship between diatom assemblages and lake trophic status. To test this hypothesis, both the values of trophic level inferred by the diatom assemblages from another 20 lakes of different trophic status in the same region were correlated against the observed TL values which were calculated from the OME data set (OME 1988). The correlation coefficient of this regression was then obtained. Thus, a relationship between sediment diatom assemblages and lake trophic status was established. The reason for using another set of lakes for this purpose was to avoid the difficulties associated with formulating a circular argument by using the same set of lakes for formulating and testing the regression equations (Dickman, personal communications).

RESULTS

Part A: Characteristics of study lake trophic status

1). The literature derived trophic variables

The values for total phosphorus (TP), chlorophyll-a (Chl-a) and Secchi depth (SD) of the 86 study lakes were based on the data obtained from the MOE (Table 6, from MOE 1988). In order to check whether the value of a trophic variable (such as Chl-a) was strongly influenced by another variable such as TP, the relationship among TP, SD and Chl-a was investigated. The annual mean Chl-a concentration was positively correlated with the annual mean total phosphorus concentration (Fig. 3). The annual mean values of SD were negatively correlated with both TP and Chl-a (Figs. 4 & 5). The correlation coefficients for these relationships were relatively low (TP vs Chl-a, r^2=0.30; SD vs TP, r^2=0.14 and SD vs Chl-a, r^2=0.23).

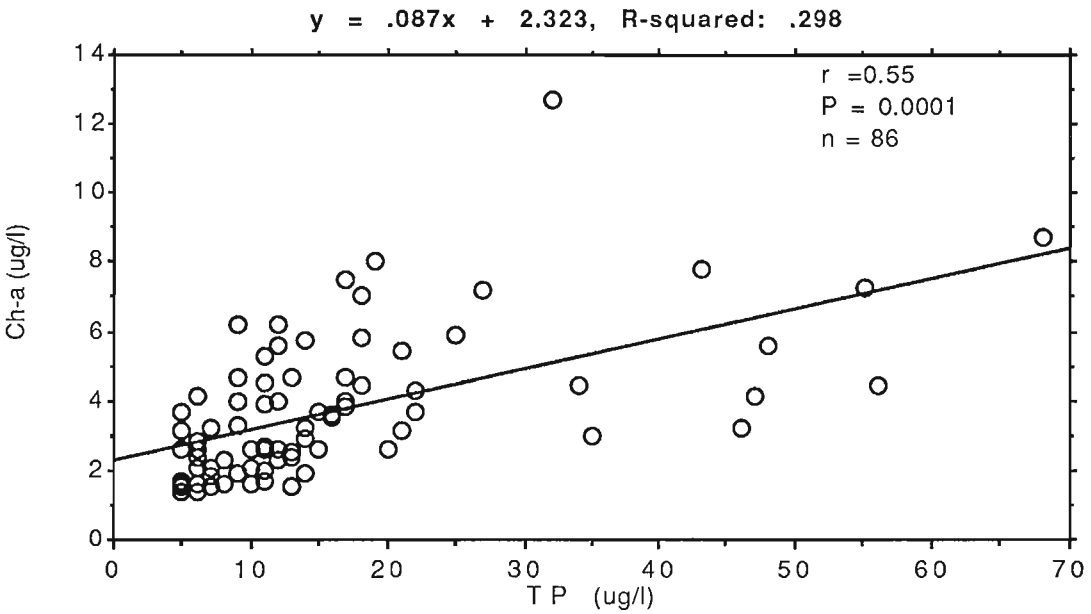


Fig.3: Annual phosphorous concentrations (μg l^{-1}) versus annual chlorophyll-a concentrations (μg l^{-1}) for the 86 study lakes.

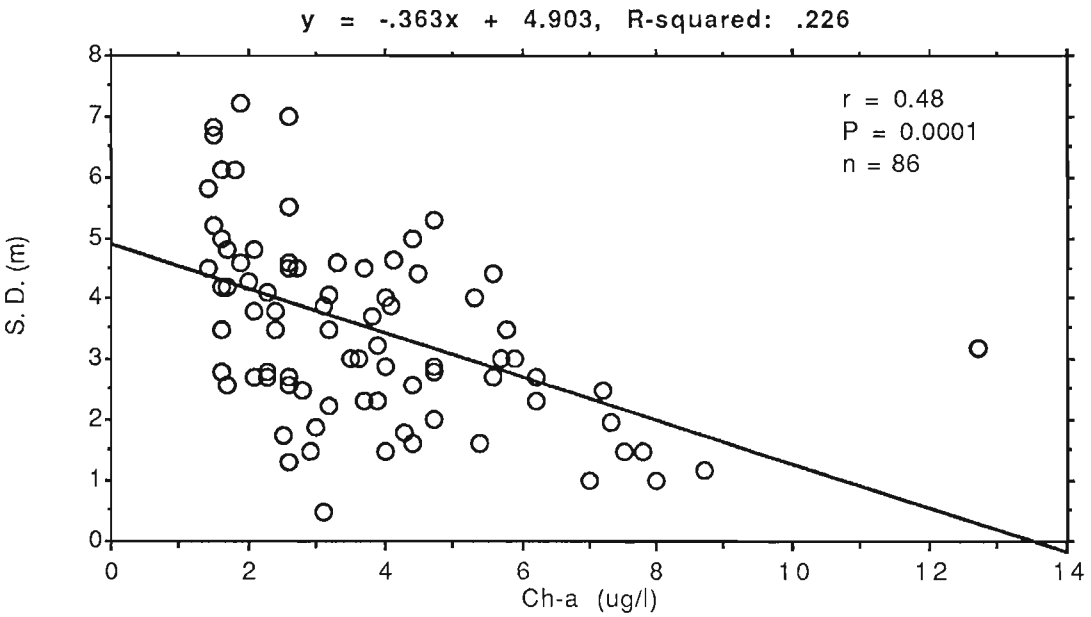


Fig.4: Annual mean values of Secchi depth (m) versus the annual chlorophyll-a concentration (μg l^{-1}) for the 86 study lakes.

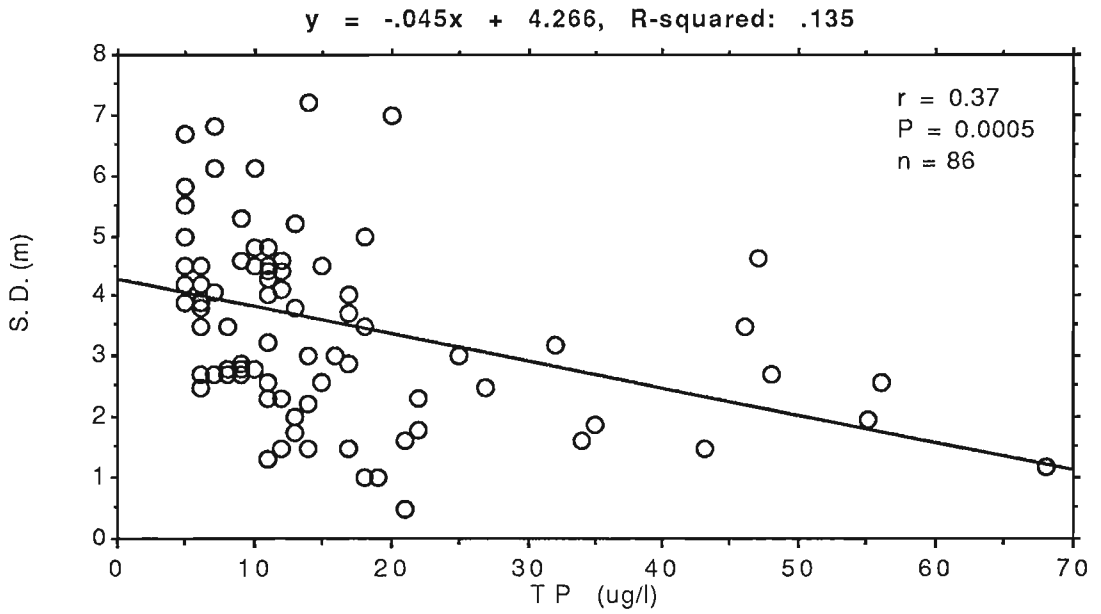


Fig.5: Annual mean values of Secchi depth (m) versus annual total phosphorus concentration ($\mu g\ l^{-1}$) for the 86 study lakes.

Because the relationship between some of these variables appeared to be a log relationship, the method of logarithmic transformation was used to improve the correlation coefficient. However, the results of the logarithmic transformation only improved the data a little. The correlation coefficient value between Log TP, Log Chl-a and Log SD were still low. Thus, there was no strong relationship among the values of TP, Chl-a and Secchi transparency in this lake set of 86 study lakes.

2). The classification of lake trophic status

The classification of lake trophic status is based on a qualitative description of 5 categories which range from nutrient poor and low primary productivity (ultraoligotrophic) to nutrient rich and high primary productivity (hypereutrophic; Henderson-sellers and Markland 1988).

Traditional systems divide the above named continuum into five classes: ultraoligotrophic; oligotrophic; mesotrophic; eutrophic and hypereutophic lakes (Table 6). In the published literature, mesotrophic lakes are often further broken down into three subcategories; oligomesotrophic, mesotrophic and mesoeutrophic (e.g. Agbeti 1987). However, there are no clear boundaries between these 3 mesotrophic subclassifications (Agbeti 1987).

In this study, the classification of trophic status of the study lakes which was based on the computation of TP, Chl-a and SD values was defined as trophic level (TL). The range of mesotrophic values based on TP, Chl-a, SD and TL was divided into three equivalent subranges respectively. Clear boundaries among oligomesotrophic, mesotrophic and mesoeutrophic were obtained (Table 8)

Trophic State	TP ($ug\ l^{-1}$)	Chl-a ($ug\ l^{-1}$)	SD (m)	TL
ultraoligotrophic	< 2.5	< 0.7	> 9	< 0.24
oligotrophic	2.5 - 8.0	0.7 - 2.1	6.01 - 9	0.241-1.8
oligomesotrophic	8.01 - 14	2.11 - 3.50	5.01- 6	1.81 -3.0
mesotrophic	14.01-19	3.51-4.86	4.01-5	3.01-4.20
mesoeutrophic	19.01-25	4.86-6.25	3.01-4	4.20-5.40
eutrophic	25.01 - 80	6.25 -19.2	1.5 - 3	5.41 - 10
hypereutrophic	> 80	> 19.2	0 - 1.5	> 10

Table 8. The comparison of the boundaries for total phosphorus, chlorophyll-a, Secchi transparency and trophic level (TL). These boundaries were used to classify the lakes into their respective trophic states. The literature source for standards of TP and chl-a are from Janus and Vollenweider 1981, and standard of SD is modified from Vollenweider 1979. The rationale for the boundaries for the three subdivision of mesotrophic lakes is described in the text.

The application of a new classification scheme for lake trophic status was carried out using the MOE data for 86 study lakes in central Ontario. The comparison of the results of this group of lakes was carried out by using this new method and three other traditional methods (TP, Chl-a and SD) were made (Table 9). By using boundary guidelines of the new method to describe the trophic status of these lakes, 14 of the lakes were classified as eutrophic, another 14 lakes as mesoeutrophic, 18 as mesotrophic, 29 as oligomesotrophic and only 10 of the lakes were classified as oligotrophic. The trophic levels of the 86 study lakes ranged from 1.0 (Little Hawk, Lake# 52) to 8.4 (Fawn, Lake#1). There were no ultraoligotrophic or hypereutrophic lakes among the study lakes (Table 9).

Table 9: Values of total phosphorus (TP), chlorophyll-a (Chl-a), Secchi depth (SD) and the trophic level (TL) for 86 study lakes with their corresponding trophic categories. The fifty lakes above the dashed line were chosen for sediment diatom sampling.

#	Lake	TP (μgl^{-1})	categ..	Ch-a (μgl^{-1})	categ..	SD (m)	categ..	TL	categ..
1	Fawn	68	E	8.7	E	1.2	E	8.4	E
2	Moot	43	E	7.8	E	1.5	E	7.4	E
3	Brandy	55	E	7.3	E	1.95	E	7.3	E
4	Hesners	32	E	12.7	E	3.2	ME	6.6	E
5	Riley	48	E	5.6	ME	2.7	E	6.3	E
6	Nine Mile	56	E	4.4	M	2.6	E	6.2	E
7	Lon	13	OM	2.5	OM	1.75	E	4	M
8	Black	35	E	3	OM	1.9	E	5.5	E
9	Leech	47	E	4.13	M	4.63	M	5.1	ME
10	Bass	12	OM	6.2	ME	2.3	E	4.8	ME
11	Ricketts	13	OM	4.7	M	2	E	4.7	ME
12	Gullfeathe	17	M	4.7	M	2.9	E	4.6	ME
13	Ril	9	OM	6.2	ME	2.7	E	4.2	M
14	Little Leech	16	M	3.5	M	3	ME	4.1	M
15	Long Turtl	17	M	3.8	M	3.7	ME	4	M
16	Meddra	12	OM	5.6	ME	4.4	M	3.8	M
17	Grevenhurst Bay	11	OM	5.3	ME	4	M	3.7	M
18	Spence	11	OM	3.9	M	3.25	ME	3.6	M
19	North Muldew	13	OM	2.4	OM	3.8	ME	3	OM
20	prospect	11	OM	2.7	OM	4.5	M	2.8	OM
21	Clearwater	8	OM	2.3	OM	2.8	E	2.8	OM
22	Loon	10	OM	2.6	OM	4.5	M	2.6	OM
23	Little long	7	O	3.2	OM	4.08	M	2.5	OM
24	Wood	10	OM	2.1	OM	4.8	M	2.3	OM
25	Pine	5	O	3.1	OM	3.9	ME	2.2	OM
26	Clear	14	M	1.9	O	7.2	O	2.1	OM
27	Leonard	10	OM	1.6	O	6.1	O	1.8	O
28	Heeney	5	O	1.7	O	4.2	M	1.5	O
29	Trading Bay	5	O	1.6	O	5	OM	1.3	O
30	Muskoka	6	O	1.4	O	4.5	M	1.4	O
31	Kahshe	18	M	5.8	ME	3.5	ME	4.7	ME
32	Ben	15	M	3.7	M	4.5	M	3.5	M
33	Ryde	34	E	4.4	M	1.6	E	6.2	E
34	Weismuller	25	E	5.9	ME	3	ME	5.3	ME
35	Pine	17	M	4	M	4	M	3.9	M
36	Sosseau	14	M	3.2	OM	2.25	E	4.1	M
37	Ada	21	ME	5.4	ME	1.6	E	5.8	E
38	Mckay	11	OM	2	O	4.3	M	2.5	OM
39	Gull	13	OM	1.5	O	5.2	OM	2.2	OM
40	Clear Water	18	M	4.4	M	5	OM	3.8	M
41	Menominee	14	M	2.9	OM	1.5	E	4.5	ME

Table 9 continue

#	Lake	TP (μgl^{-1})	categ..	Ch-a (μgl^{-1})	categ..	SD (m)	categ..	TL	categ..
42	Wildcat	6	O	2.8	OM	2.5	E	2.8	OM
43	Simoce	20	ME	2.6	OM	7	O	4.2	ME
44	Gold city	27	E	7.2	E	2.5	E	5.9	E
45	Baxter	46	E	3.2	OM	3.5	ME	5.1	ME
46	Healey	12	OM	4	M	1.5	E	4.8	ME
47	Henshaw	9	OM	4.7	M	5.3	OM	3	OM
48	Hammel Bay	22	ME	3.7	M	2.3	E	4.9	ME
49	Waseosa	9	OM	4.7	M	2.81	E	3.8	M
50	Horseshoe	6	O	2.4	OM	3.5	ME	2.2	OM
51	St. Nora	5	O	1.4	O	5.8	OM	1.1	O
52	Little hawk	5	O	1.5	O	6.7	O	1	O
53	High	5	O	2.6	OM	5.5	OM	1.6	O
54	Wolfkin	5	O	3.7	M	4.5	M	2.2	OM
55	Hard	6	O	4.1	M	3.9	ME	2.7	OM
56	Stewart	6	O	2.6	OM	2.7	E	2.6	OM
57	Seyer's	6	O	2.1	O	3.8	ME	2	OM
58	Pencil	6	O	1.6	O	4.2	M	1.6	O
59	Bitter	7	O	1.5	O	6.8	O	1.3	O
60	Two Island	7	O	1.8	O	6.1	O	1.5	O
61	Fairy	7	O	2.1	O	2.7	E	2.5	OM
62	Oxtongue	8	OM	2.3	OM	2.7	E	2.8	OM
63	Peninsula	8	OM	1.6	O	3.5	ME	2.1	OM
64	Kashagawigmog	9	OM	3.3	OM	4.6	M	2.7	OM
65	Camel	9	OM	4	M	2.9	E	3.5	M
66	Lipsy	9	OM	4.7	M	5.3	OM	3	OM
67	Long(Large)	9	OM	1.9	O	4.6	M	2.1	OM
68	Bella	10	OM	2.1	OM	4.8	M	2.3	OM
69	Mary	10	OM	1.6	O	2.8	E	2.6	OM
70	Wilbermere	11	OM	1.7	O	4.8	M	2.2	OM
71	Vernon	11	OM	1.7	O	2.6	E	2.9	OM
72	Oudaze	11	OM	3.9	M	2.3	E	4.1	M
73	Buck	11	OM	2.6	OM	1.3	E	4.3	ME
74	Sunny	11	OM	4.5	M	4.4	M	3.4	M
75	Longline	12	OM	2.6	OM	4.6	M	2.8	OM
76	Young	12	OM	2.3	OM	4.1	M	2.8	OM
77	Otter	14	M	5.7	ME	3	ME	4.5	ME
78	Clear	14	M	1.9	O	7.2	O	2.1	OM
79	Sparrow	15	M	2.6	OM	2.6	E	3.8	M
80	Oakley	16	M	3.6	M	3	ME	4.1	M
81	Penfold	17	M	7.5	E	1.5	E	6.1	E
82	Pine-wood	17	M	4	M	4	OM	3.9	M
83	Jessop	18	M	7	E	1	E	6.6	E
84	Perch(fish)	19	ME	8	E	1	E	6.8	E
85	Clark	21	ME	3.1	OM	0.5	HE	6.6	E
86	Fox	22	ME	4.3	M	1.8	E	5.4	ME

3). The relationship between TL and each of TP, Chl-a and SD.

The relationship between TL values and each of the TP, Chl-a and SD values for the 86 study lakes was statistically significant (Figs. 6-9). Their correlation coefficient values were relatively high. The regression coefficient of TL vs Chl-a (r^2=0.64) was a littler higher than TP (r^2=0.63) and SD (r^2=0.52).

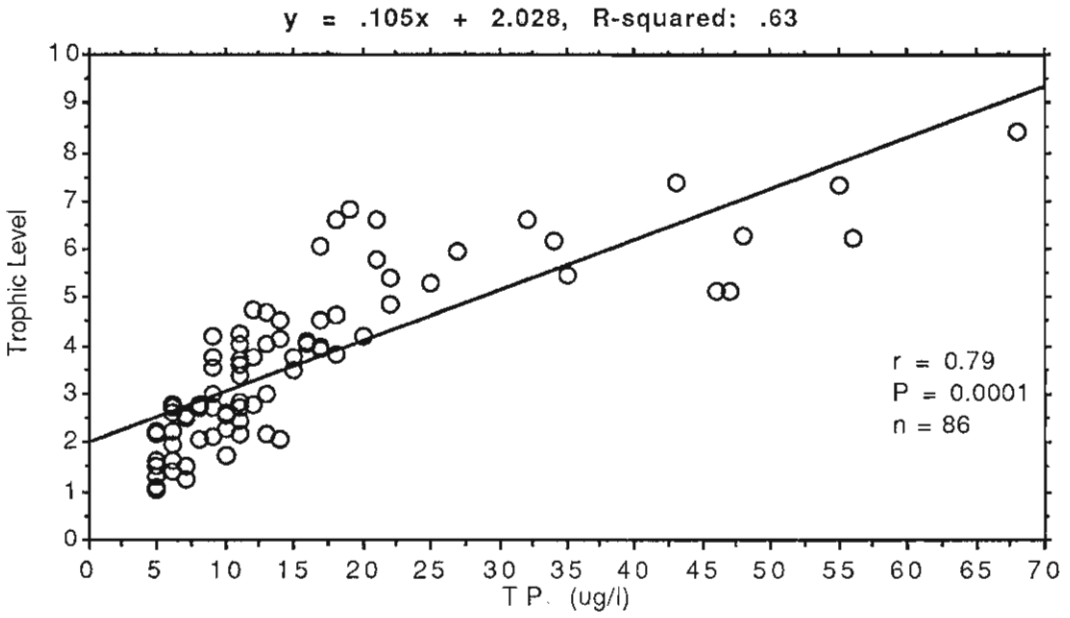


Fig.6: The trophic level versus the annual mean of total phosphorus ($\mu g\ l^{-1}$) concentration for the 86 study lakes.

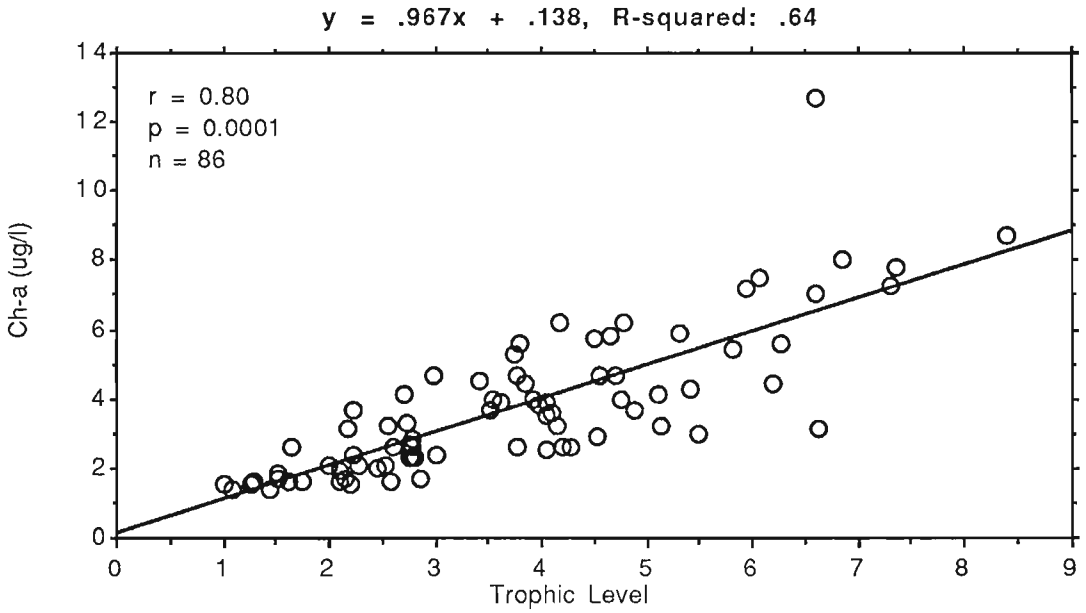


Fig.7: The trophic level versus the annual mean of chlorophyll-a ($\mu g\ l^{-1}$) concentration for the 86 study lakes.

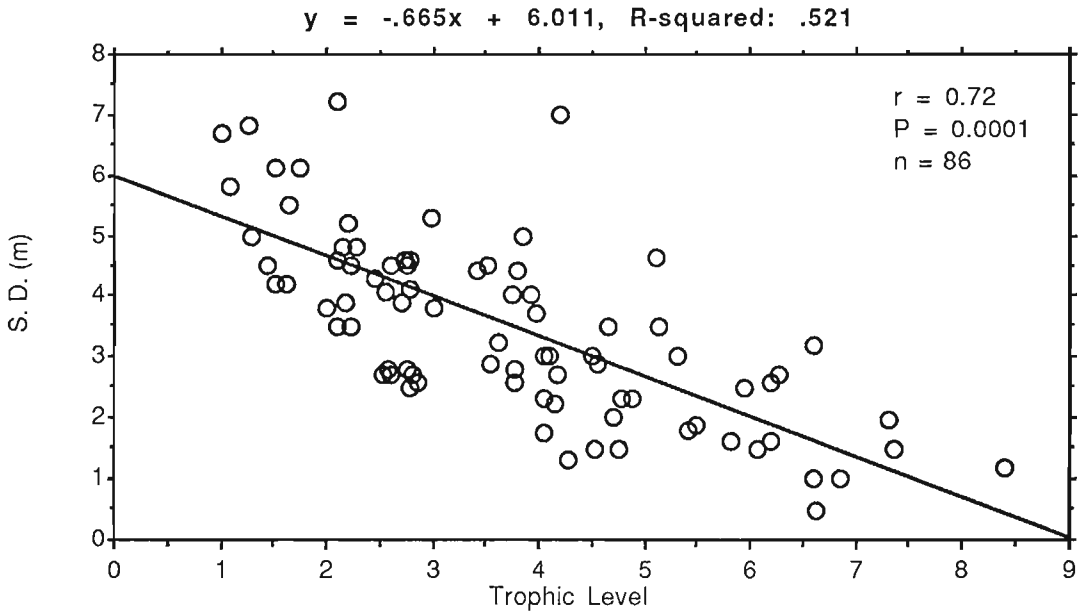


Fig.8: Trophic level versus the annual mean of Secchi transparency (m) for the 86 study lakes.

Part B: Diatom Species and Their autecological characteristics

1. Observations of diatom species

A total of 251 diatom species belonging to 38 genera were observed (Table 10) in the 50 study lakes examined during this thesis research undertaking (Appendices 1-4). The lakes chosen for the diatom study are listed in corresponding number (1-50) in Table 8.

The diatom flora of the Muskoka region is typical of oligomesotrophic to eutrophic habitats, and is similar to that found in other regions which are undergoing lake eutrophication such as southern Ontario (Stockner 1971, Christie 1988), northeastern Minnesota (Bright 1968), Adirondack Lakes (Charles 1986) and other Canadian lakes (Agbeti and Dickman 1989).

Thirty species which were present in at least 5 study lakes with relative abundances of at least 5% in one lake were defined as dominant species. The percentage abundance of these 30 species was plotted against TP, Chl-a, SD and TL to determine how individual species were influenced by each of these environmental variables (Fig. 9-12).

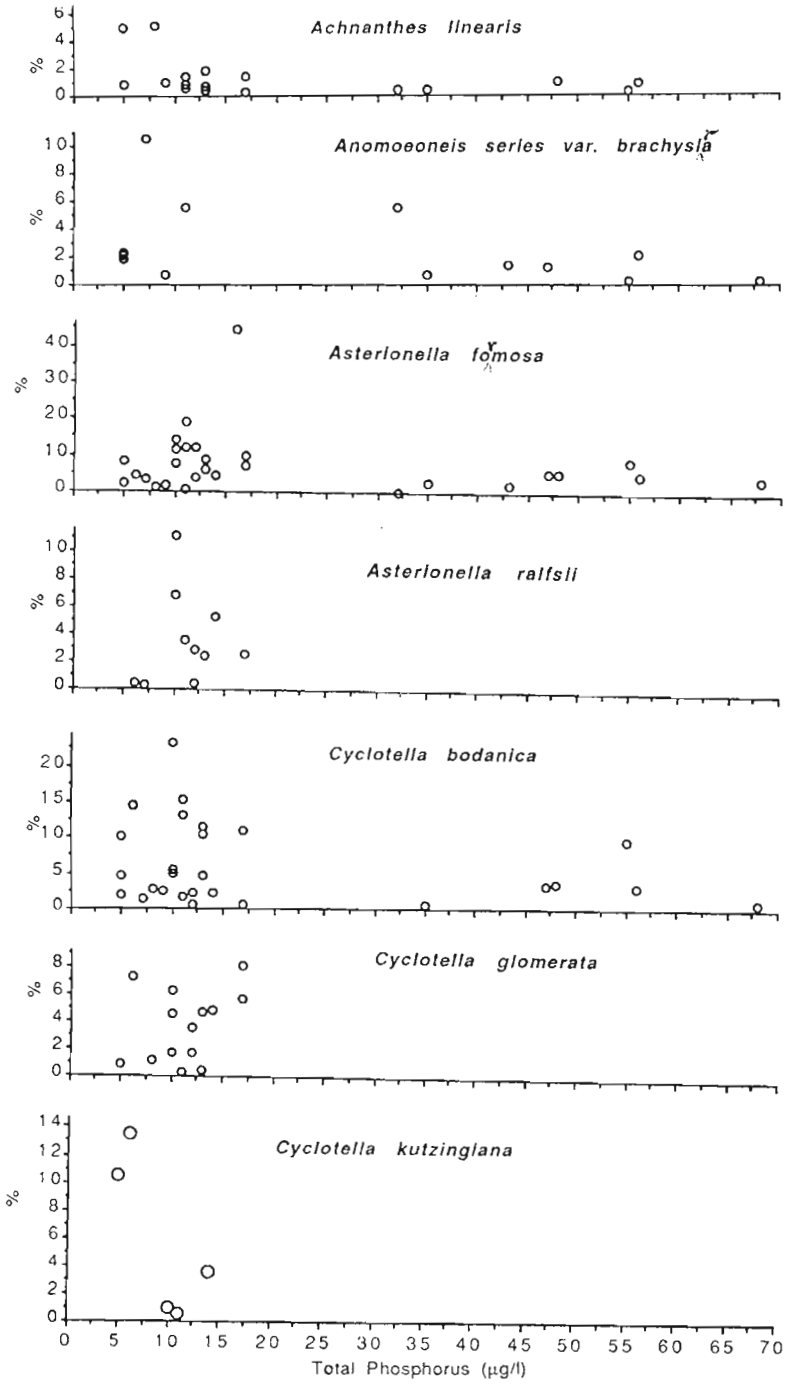
Table 10: List of diatom taxa recorded in the 50 study lakes.

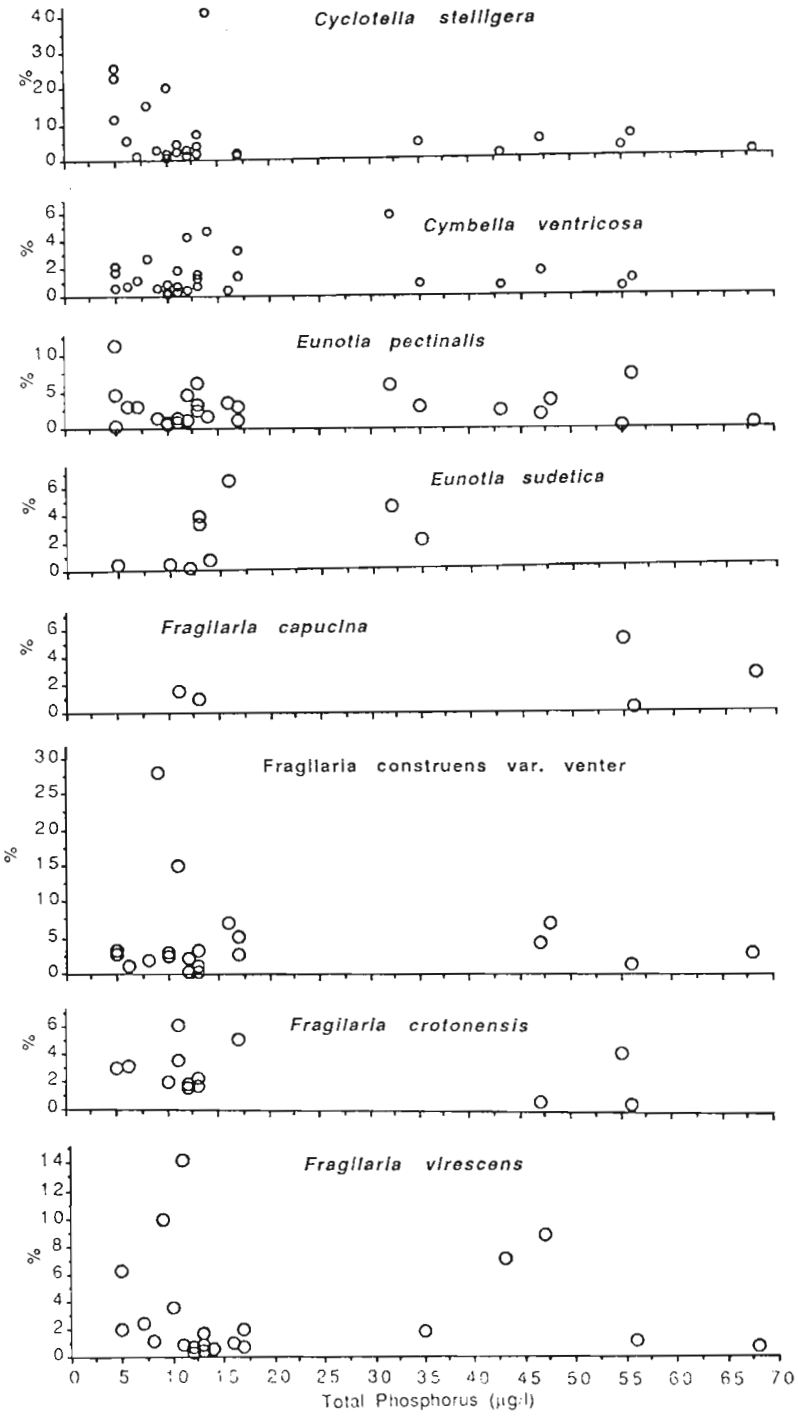
Achnanthes affinis	*Cymbella acuticuscula*	*Eunotia nelgelii*
A. biasolettiana	*C. amphicephala*	*E. parallela*
A. conspicua	*C. brehmii*	*E. pectinalis*
A. dispar	*C. cesati*	*E. pectinalis var. ventralis*
A. exigua	*C. cistula*	*E. praerupta var. bidens*
A. gibberula	*C. cuspidata*	*E. praerupta var. inflata*
A. lanceolata	*C. hauckii*	*E. robusta*
A. lanceolata var. elliptica	*C. hybridica*	*E. septenottrionalis*
A. linearis	*C. hustedtii*	*E. sudetica*
A. marginulata	*C. lunata*	*E. sudetica var. bidens*
A. ostrupii	*C. microcephala*	*E. tautoniensis*
A. peragallii	*C. naviculiformis*	*E. tenella*
Actinella punctata	*C. pusilla*	*E. trinacria*
Amphicampa hemicyclus	*C. sotica*	*E. valida*
Amphora nomanii	*C. ventricosa*	*E. vanheurckii var. intermedia*
A. ovalis	*Diatoma elongatum*	*Fragilaria affinis*
A. perpussila	*D. vulgare*	*F. brevistrata*
Anomoeoneis exilis	*Diploneis elliptica*	*F. capucina*
A. follis	*D. marginestriata*	*F. construens*
A. serians	*D. oculata*	*F. construens var. binodis*
A. serians var. brachysira	*D. ovalis*	*F. construens var. venter*
A. vitrea	*D. paella*	*F. crotonensis*
Asterionella formosa	*Epithemia argus*	*F. magocsyi*
A. ralfsii	*E. intermedia*	*F. pinnata*
Caloneis alpestris	*Eucocconeis flexella*	*F. undata*
C. bacillum	*Eunotia alpina*	*F. vancheriae*
C. schumaniana	*E. arcus*	*F. virescens*
C. silicula	*E. bidentula*	*Frustulia rhomboides*
Ceratoneis arcus var. linearis	*E. biggiba var. pumila*	*F. vulgare*
Cocconeis disculus	*E. curvata*	*Gomphonema acuminatum*
C. pediculus	*E. diodon*	*G. angustatum*
C. placentula	*E. elegans*	*G. bohemicum*
Cyclotella bodanica	*E. exigua var. compacta*	*G. constricta var. capitata*
C. commensis	*E. faba*	*G. gracile*
C. glomerata	*E. flexuosa*	*G. gravei*
C. kuetzingiana	*E. incisa*	*G. longiceps*
C. meneghiniana	*E. indica*	*G. parvulum*
C. michiganiana	*E. kochielenensis*	*G. subtile*
C. ocellata	*E. lunaris*	*G. truncutum var. capitatum*
C. stelligera	*E. lunaris var. capitata*	*Gyrosigma accuminatum*
Cyclostephanos dubius	*E. leochelinensis*	*G. attenuatum*
Cymatopleura elliptica	*E. monodon*	*G. obscusum*

Table 10 continued.

Gyrosigma. strigile
G. wansbeckii
Hantzschia amphioxys
Mastogloia smithii
Melosira ambigua
M. distans
M. distans var. alpigena
M. granulata
M. granulata var. angustissima
M. islandica
M. italica
M. lirata
M. perglabra
Meridion circulare
Navicula amphibola
N. bacillum
N. bicapitallata
N. cocconiformis
N. cryptocephala
N. cuspitata
N. disjuncta
N. exigua
N. fragilarioides
N. gastrum
N. grimmei
N. gysingensis
N. hustedtii
N. jarnefelti
N. lanceolata
N. lapidosa
N. laevissima
N. maculata
N. placentula
N. protracta
N. pseudoscutiformis
N. pupula
N. radiosa
N. scutiformis
N. simlex
N. simula
N. sovereigae
N. subhamulata var. undulata
Neidium affine
N. alpinum
N. bisculcatum var. subundatum
N. dilatatum
N. iridis
N. productum
Nitzschia acuta
N. angustata
N. apiculata
N. dissipata
N. frustulum
N. gracilis
N. hantzschia
N. ignorata
N. lacunarum
N. linearis
N. lorenziana
N. nomanii
N. obtusa
N. palea
N. recta
N. romana
N. spectabilis
N. subtilis
N. vermiculare
Opephora matyi
Pinnularia abaujensis
P. acrosphaeria
P. accuminata
P. appendiculata
P. biceps
P. borealis
P. braunii
P. cardinalis
P. esoxa
P. fasciata
P. formica
P. gentlis
P. gibba
P. interrupta
P. macilenta
P. major
Pinnularia. mesolepta
P. microstauron
P. nodosa
P. polyonca
P. stomatophora
P. subcapitata
P. sublinearis
P. viridis
Rhopalodia gibba
Stauroneis anceps
S. legumen
S. livinstonii
S. parvula
S. phoenicenteron
S. smith
S. staurolineata
Stenopterobia intermedia
Stephanodiscus hantzschia
S. niagarae
Surirella angustata
S. biseriata
S. delicatissima
S. linearis
S. moelleriana
S. ovalis
S. ovata
S. robusta
S. striatula
S. tenera
Synedra acus
S. amphicephata
S. affinis
S. alpina
S. nana
S. parastica
S. rumpens
S. tabulata
S. ulna
Tabellaria binalis
T. fenestrata
T. flocculosa

Fig. 9A. Total phosphorus ($\mu g\ l^{-1}$) vs. the relative abundance of 15 dominant diatom taxa.


Achnanthes linearis
Anomoeoneis series var. brachysira
Asterionella formosa
Asterionella ralfsii
Cyclotella bodanica
Cyclotella glomerata
Cyclotella kutzingiana
%
Total Phosphorus (µg/l)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Cymbella ventricosa
Eunotia pectinalis
Eunotia sudetica
Fragilaria capucina
Fragilaria construens var. venter
Fragilaria crotonensis
Fragilaria virescens
%
Total Phosphorus (µg/l)

Fig. 9B. Total phosphorus ($\mu g\ l^{-1}$) vs. the relative abundance of 15 dominant diatom taxa.

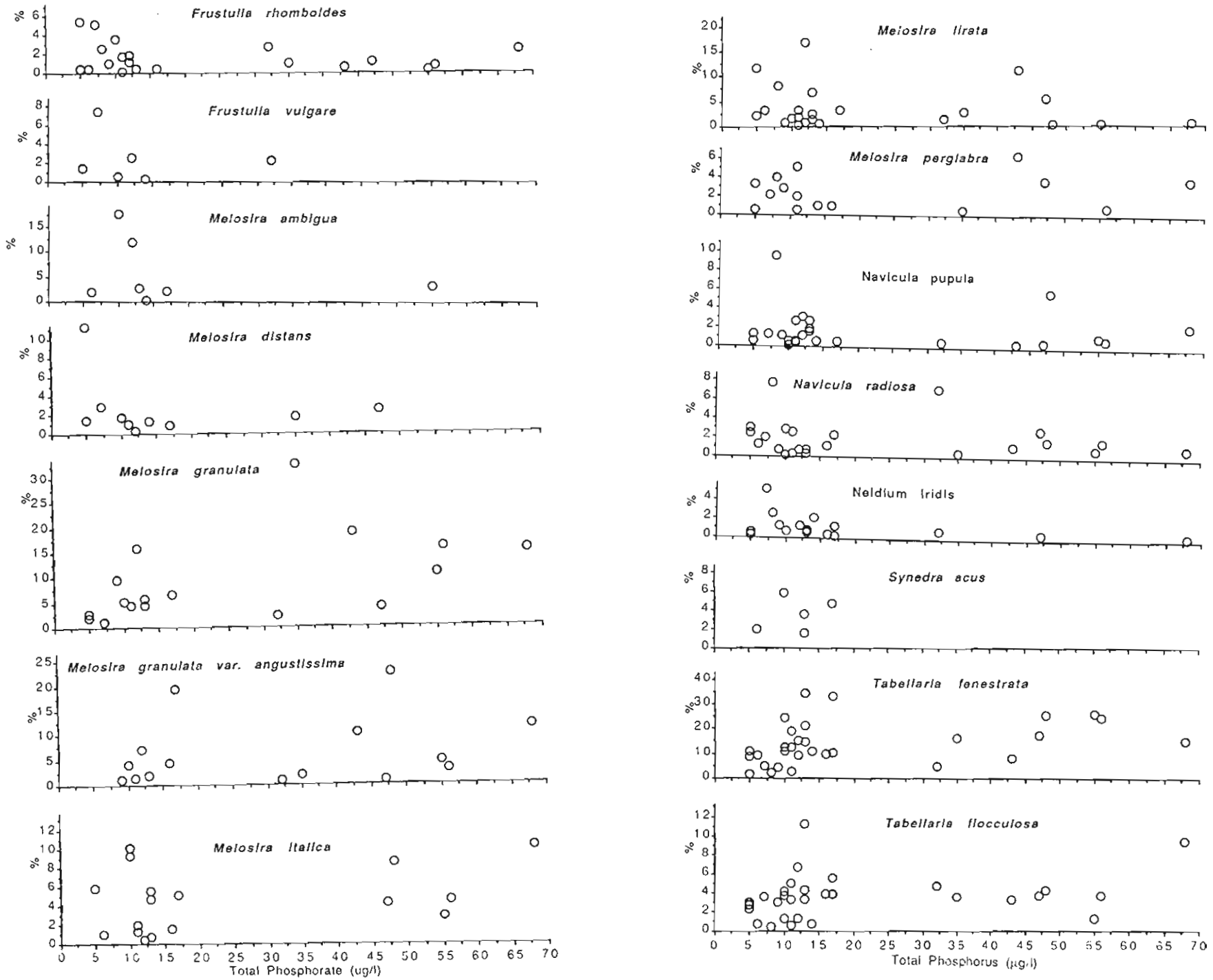
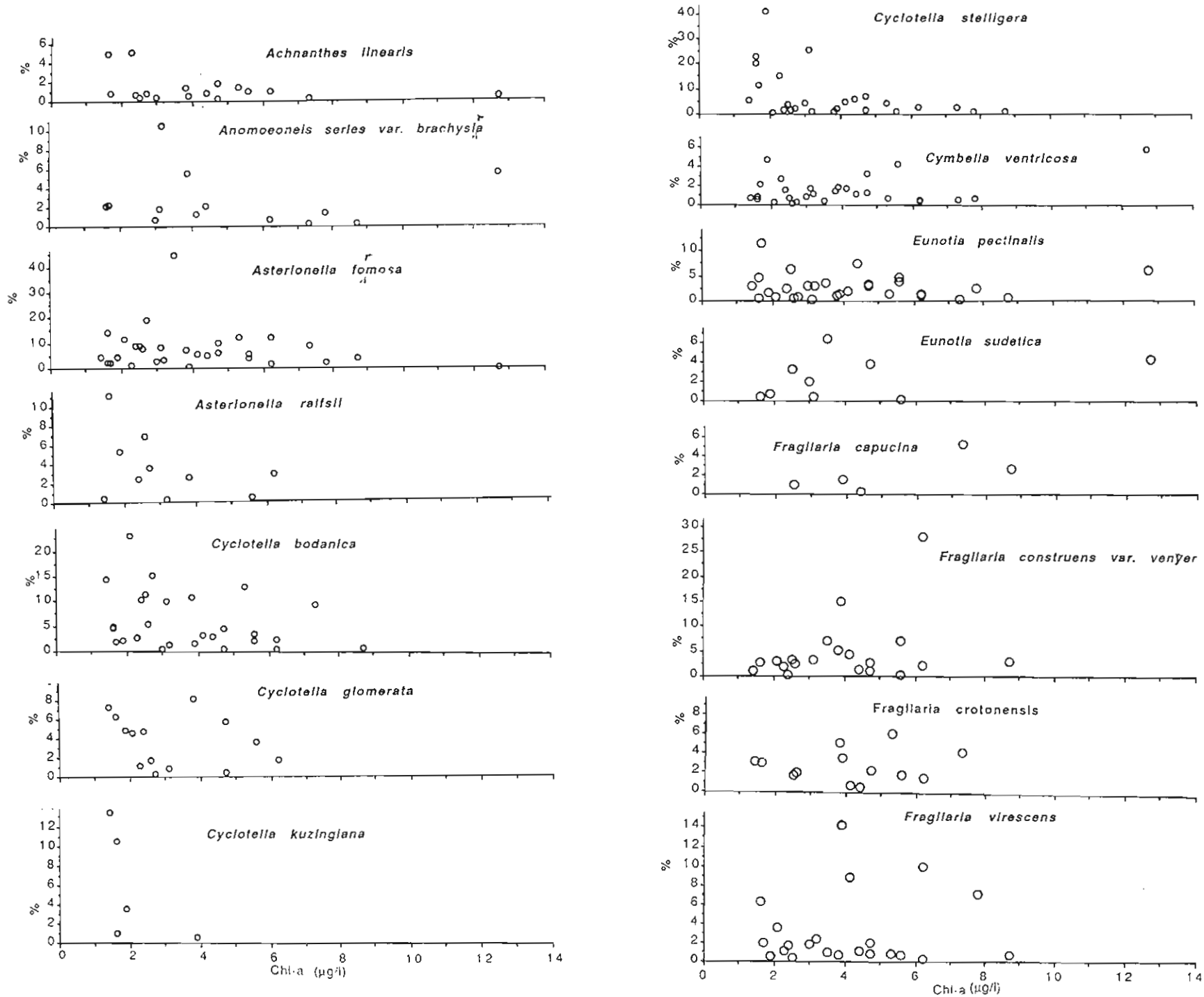

Frustulia rhomboides
Frustulia vulgare
Melosira ambigua
Melosira distans
Melosira granulata
Melosira granulata var. angustissima
Melosira italica
Melosira lirata
Melosira perglabra
Navicula pupula
Navicula radiosa
Neidium iridis
Synedra acus
Tabellaria fenestrata
Tabellaria flocculosa
%
Total Phosphorate (ug/l)
Total Phosphorus (µg/l)

Fig. 10A. Chlorophyll-a ($\mu g\ l^{-1}$) vs. the relative abundance of 15 dominant diatom taxa.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Anomoeoneis series var. brachysira
Asterionella formosa
Asterionella ralfsii
Cyclotella bodanica
Cyclotella glomerata
Cyclotella kuzingiana
Cyclotella stelligera
Cymbella ventricosa
Eunotia pectinalis
Eunotia sudetica
Fragilaria capucina
Fragilaria construens var. venter
Fragilaria crotonensis
Fragilaria virescens
%
Chl-a (µg/l)

Fig. 10B. Chlorophyll-a ($\mu g\ l^{-1}$) vs. the relative abundance of 15 dominant diatom taxa.

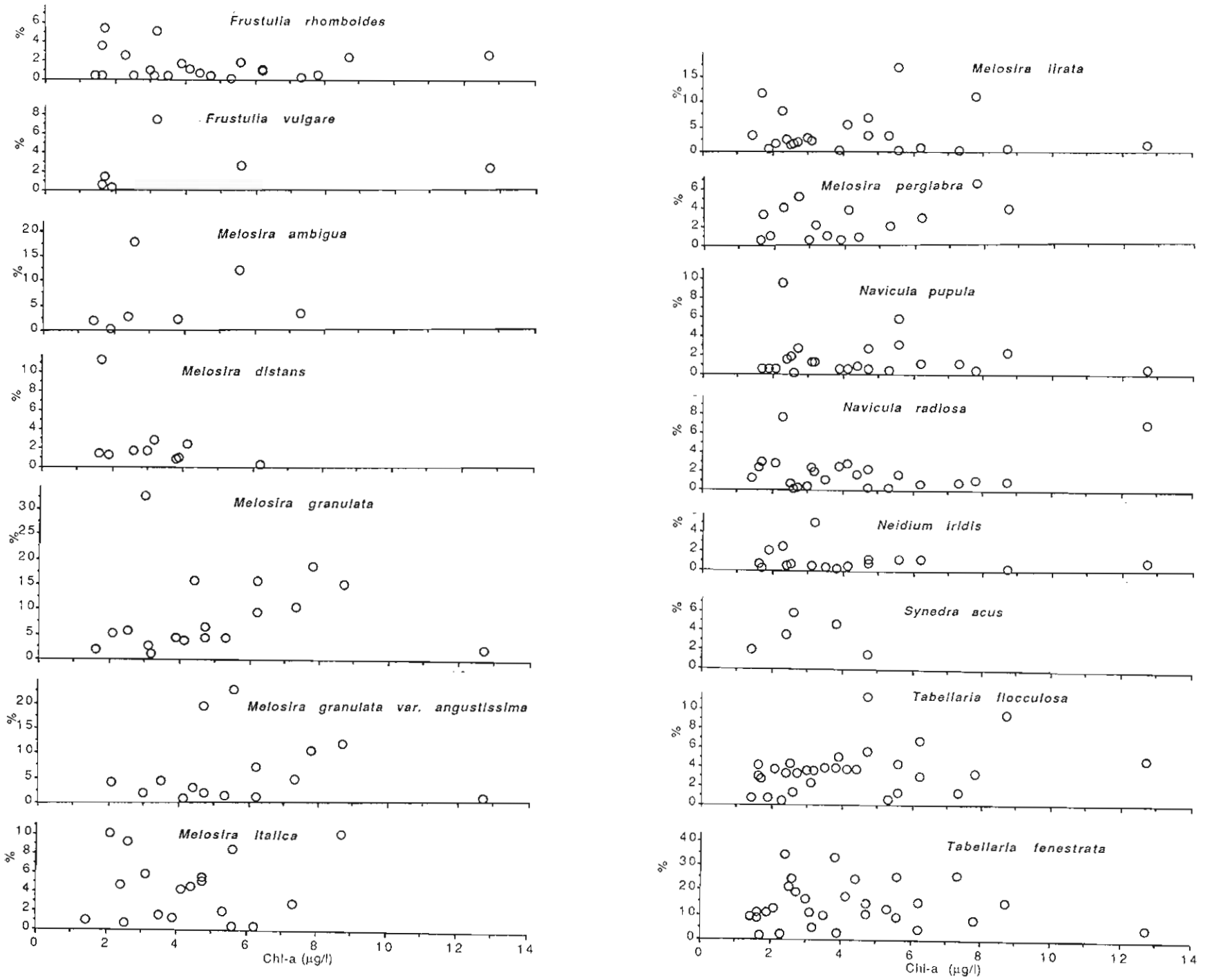
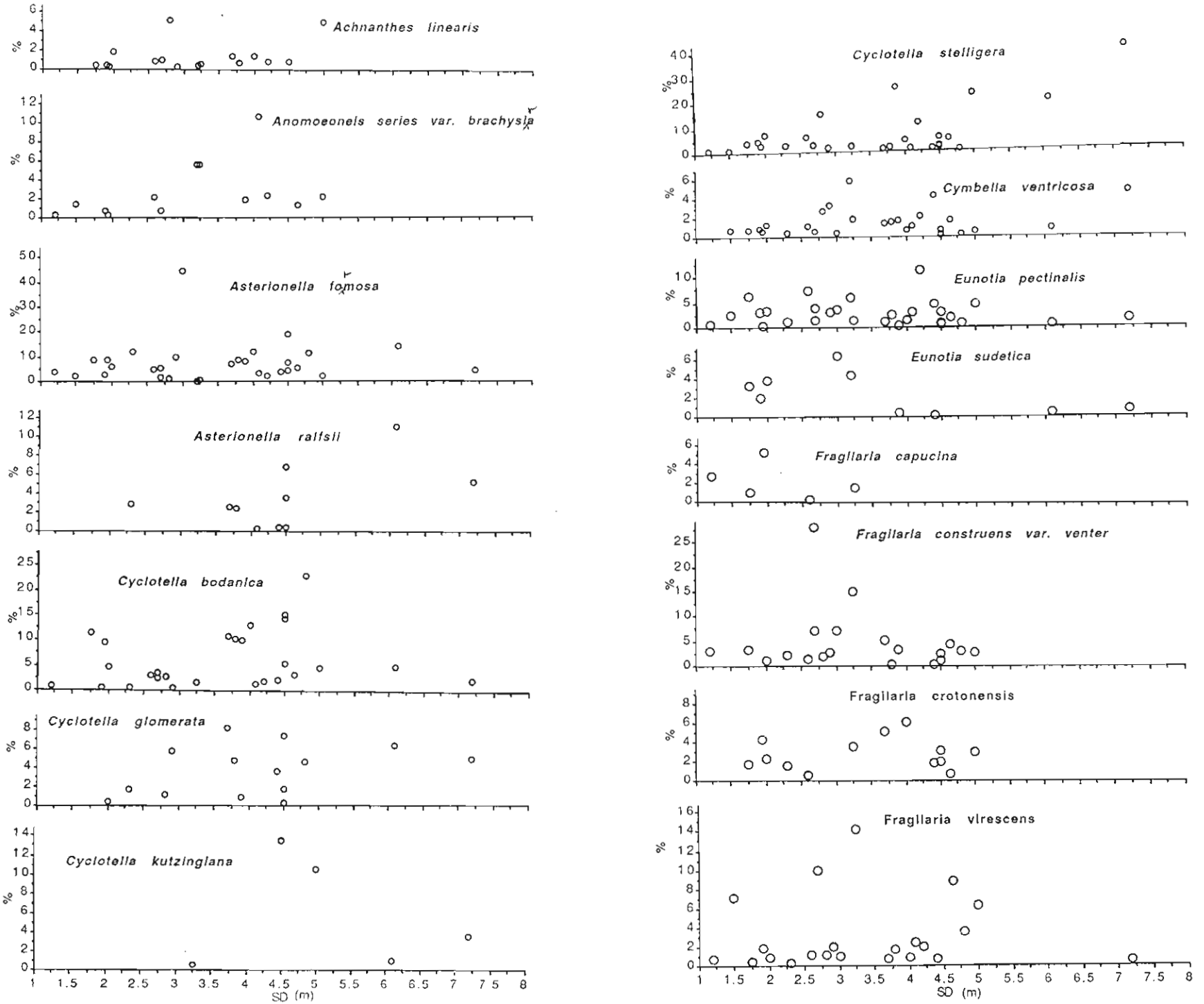

Frustulia rhomboides
Frustulia vulgare
Melosira ambigua
Melosira distans
Melosira granulata
Melosira granulata var. angustissima
Melosira italica
Melosira lirata
Melosira perglabra
Navicula pupula
Navicula radiosa
Neidium iridis
Synedra acus
Tabellaria flocculosa
Tabellaria fenestrata
%
Chl-a (µg/l)

Fig. 11A. Secchi transparency (m) vs. the relative abundance of 15 dominant diatom taxa.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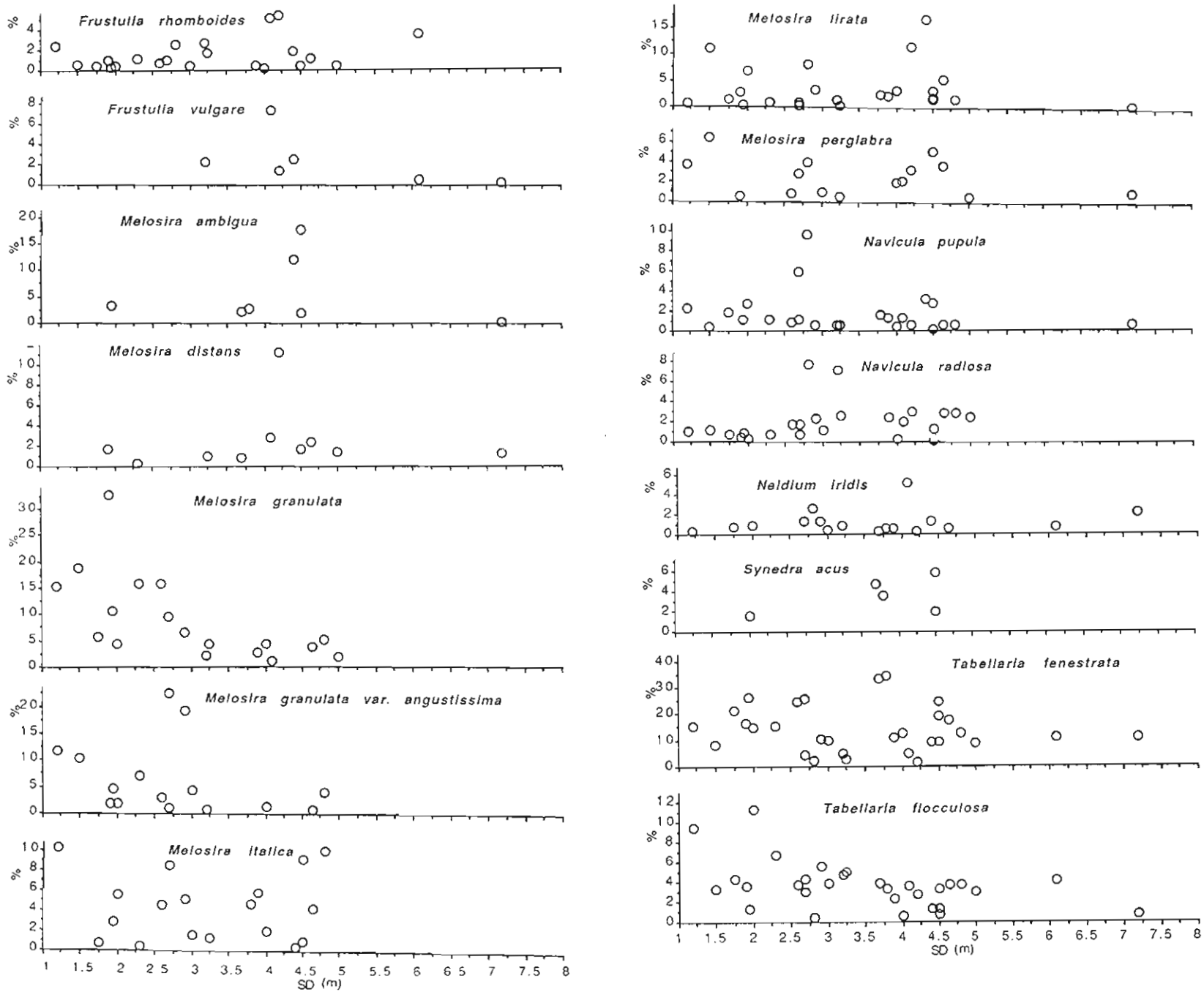
Anomoeoneis series var. brachysira
Asterionella formosa
Asterionella ralfsii
Cyclotella bodanica
Cyclotella glomerata
Cyclotella kutzingiana
Cyclotella stelligera
Cymbella ventricosa
Eunotia pectinalis
Eunotia sudetica
Fragilaria capucina
Fragilaria construens var. venter
Fragilaria crotonensis
Fragilaria virescens
%
SD (m)

Fig. 11B. Secchi transparency (m) vs. the relative abundance of 15 dominant diatom taxa.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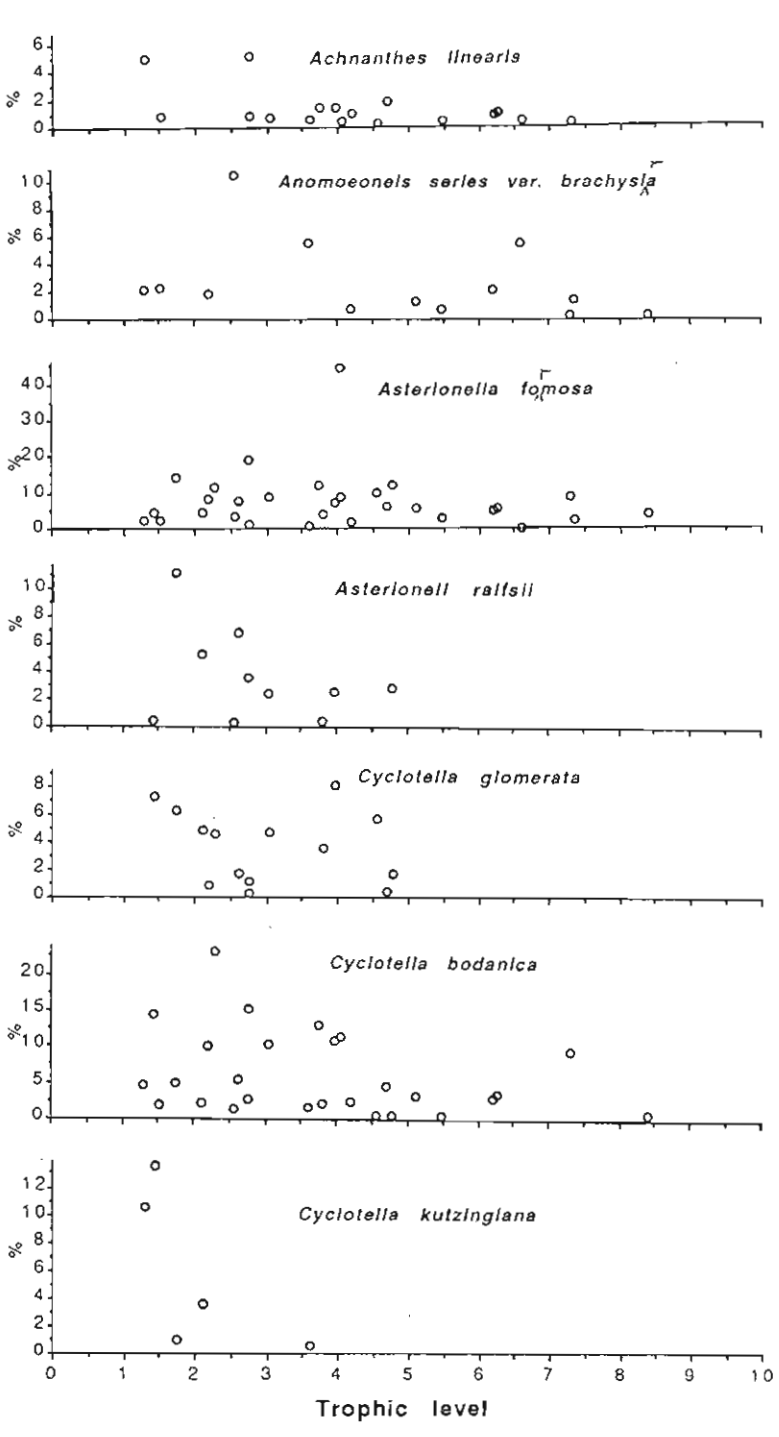
Frustulia vulgare
Melosira ambigua
Melosira distans
Melosira granulata
Melosira granulata var. angustissima
Melosira italica
Melosira lirata
Melosira perglabra
Navicula pupula
Navicula radiosa
Neidium iridis
Synedra acus
Tabellaria fenestrata
Tabellaria flocculosa
%
SD (m)

Fig. 12A. Trophic level vs. the relative abundance of 15 dominant diatom taxa.


Achnanthes linearis
Anomoeoneis series var. brachysira
Asterionella formosa
Asterionell ralfsii
Cyclotella glomerata
Cyclotella bodanica
Cyclotella kutzingiana
%
Trophic level

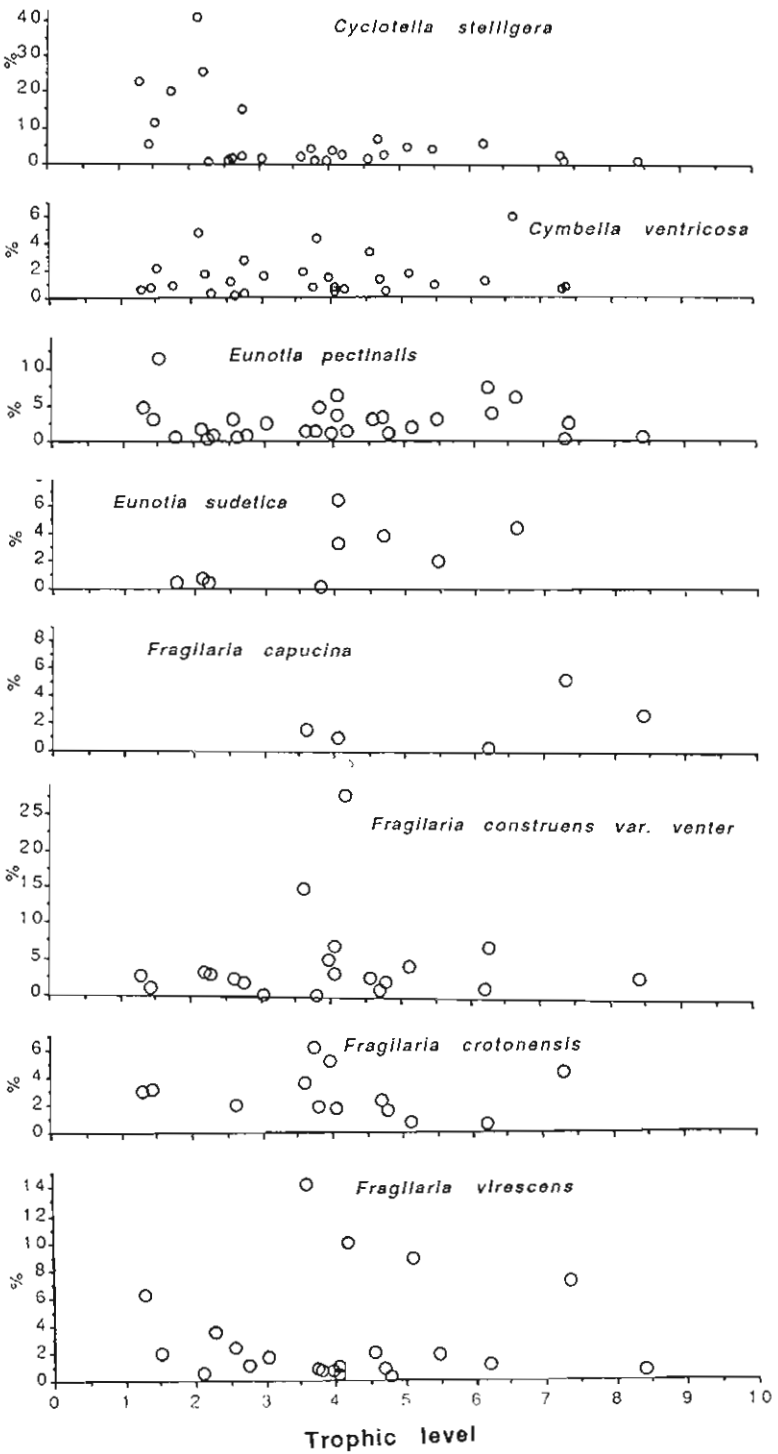
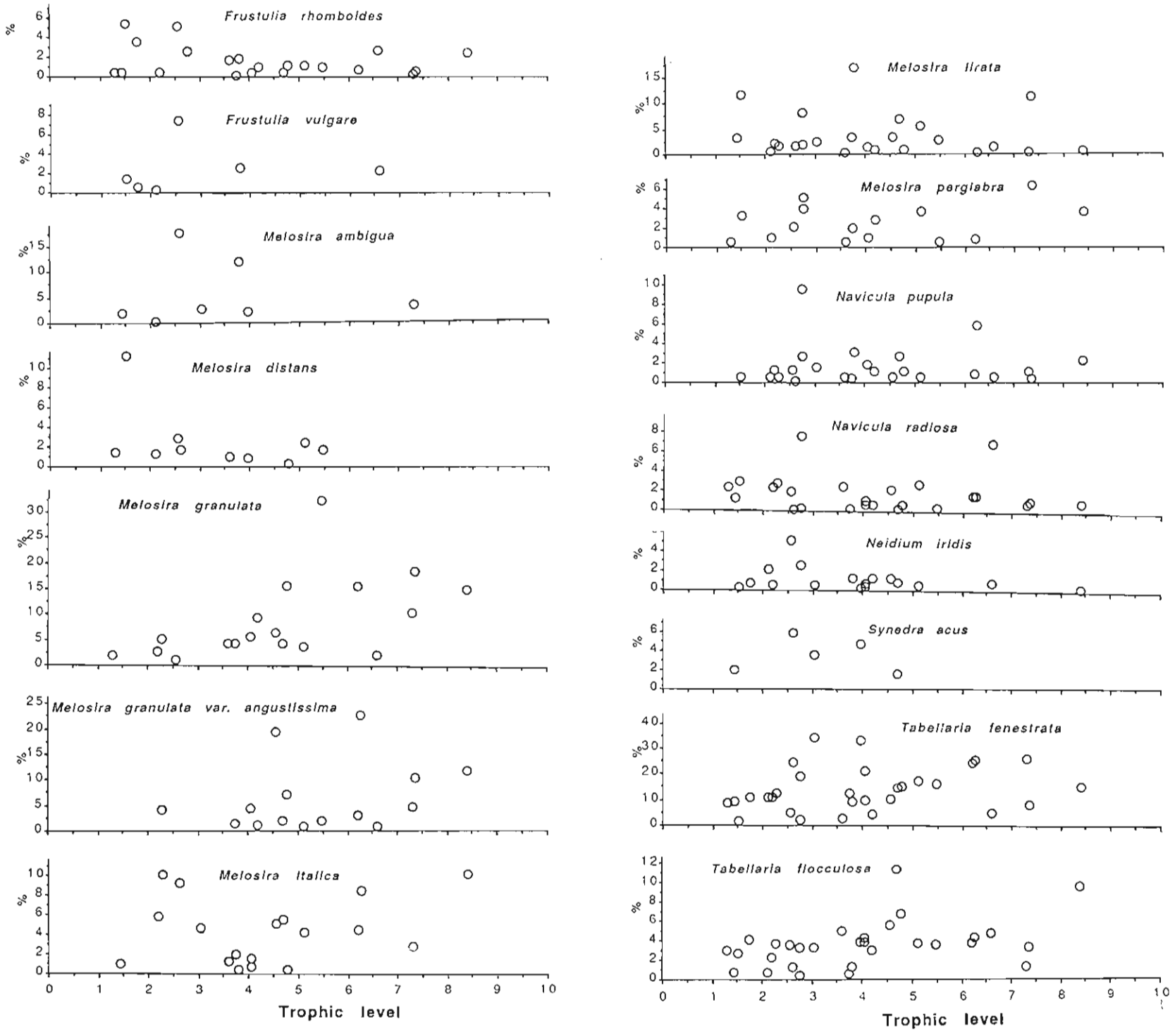

Cyclotella stelligera
Cymbella ventricosa
Eunotia pectinalis
Eunotia sudetica
Fragilaria capucina
Fragilaria construens var. venter
Fragilaria crotonensis
Fragilaria virescens
%
Trophic level

Fig. 12B. Trophic level vs. the relative abundance of 15 dominant diatom taxa.


Frustulia rhomboides
Frustulia vulgare
Melosira ambigua
Melosira distans
Melosira granulata
Melosira granulata var. angustissima
Melosira italica
Melosira lirata
Melosira perglabra
Navicula pupula
Navicula radiosa
Neidium iridis
Synedra acus
Tabellaria fenestrata
Tabellaria flocculosa
%
Trophic level

2. Diatom autecological features and lake trophic status

As an initial step in formulating predictive relationships, diatom taxa were assigned to the following trophic categories.

1). Ultraoligotrophic species (UO): weighted mean of TL below 0.24 (these taxa occur only in ultra-oligotrophic habitats);

2). Oligotrophic species (O): weighted mean of TL between 0.241 to 1.80 (distribution mainly in oligotrophic habitats);

3). Oligomesotrophic species (OM): weighted mean of TL between 1.81 to 3.00 (distribution mainly in oligomesotrophic habitats);

4). Mesotrophic species (M): weighted mean of TL between 3.01 to 4.20 (distribution mainly in mesotrophic habitats or eurytypic habitats);

5). Mesoeutrophic species (ME): weighted mean of TL between 4.21 to 5.40 (distribution mainly in mesoeutrophic habitats);

6). Eutrophic species (E): weighted mean of TL between 5.41 to 10.00 (distribution mainly in eutrophic habitats);

7). Hypereutrophic species (HE): weighted mean of TL above 10.00 (these taxa occur only in hypereutrophic habitats);

Assignment of trophic categories was based on the diatom species distribution in 30 of the study lakes (Lake #1-30, for the corresponding lake names see Table 9) and its distribution optimum (weighted average) value on the trophic level. For example, *Melosira granulata* was found in 18 study lakes displaying lake trophic level ranging from 1.3 to 8.4. Although *Melosira granulata* occurred also in oligotrophic lakes, it never

Table 11. The 86 common taxa of diatom observed in surface sediment samples taken from the profundal zone of 30 Muskoka lakes, their ranges and weight mean of total phosphorus (TP), chlorophyll-a (Chl-a), Secchi transparency depth (SD) and the trophic level for lakes in which they occurred.

Diatom Taxa	# of lakes in which taxa present	TP (μgl^{-1}) range	TP mean	Chl-a (μgl^{-1}) range	Chl-a mean	SD (m) range	SD mean	TL range	TL mean	Category
Achnanthes conspicua	9	6.0-17	11.56	1.4-4.7	2.41	1.75-7.2	4.24	1.43-4.56	2.3	OM
A. lanceolata	5	7.0-55	27.5	2.3-7.3	4.23	1.95-4.63	3.35	2.54-7.3	4.4	ME
A. linearis	17	5.0-55	14.14	1.6-12.7	3.35	1.75-5	3.46	1.30-7.3	3.29	M
A. marginulata	17	5.0-55	17.5	1.4-12.7	3.79	1.75-7.2	4.03	1.3-7.3	3.41	M
Amphicampa hemicyclus	6	5.0-43	12.53	1.7-7.8	3.59	1.5-4.5	3.83	1.5-7.4	3.16	M
Amphora nomanii	9	10.-35	14.16	1.6-6.2	3.67	1.9-7.2	3.81	1.75-5.48	3.65	M
A. ovalis	11	5.0-55	14.82	2.4-7.3	3.78	1.75-4.63	3.23	2.18-7.3	3.76	M
Anomoeoneis serians	8	8.0-17	12.21	1.6-6.2	2.81	1.75-6.1	4.06	1.75-4.77	3.33	M
A.serians v. brachysira	13	5.0-68	18.92	1.6-12.7	5.08	1.2-5	3.57	1.3-8.4	3.91	M
Asterionella formosa	30	5.0-68	18.18	1.4-12.7	3.76	1.2-7.2	3.59	1.3-8.4	3.82	M
A. ralfsii	10	6.0-17	11.5	1.4-6.2	2.58	2.3-7.2	5.11	1.43-4.77	2.58	OM
Cyclotella bodanica	27	5.0-68	15.6	1.4-8.7	3.27	1.2-7.2	3.88	1.3-8.4	3.29	M
C. glomerata	14	5.0-17	12.08	1.4-6.2	2.95	2-7.2	4.46	1.43-4.77	2.9	OM
C. kuetzingiana	5	5.0-14	6.86	1.4-3.9	1.59	3.25-7.2	5.03	1.3-3.6	1.52	O
C. stelligera	27	5.0-68	13.44	1.4-8.7	2.72	1.2-7.2	4.61	1.3-8.4	2.71	OM
Cymbell amphicephala	7	8.0-55	27.67	1.9-12.7	6.3	1.95-7.2	3.79	2.1-7.3	4.83	ME
C. naviculiformis	12	5.0-35	11.15	1.6-6.2	3.29	1.75-7.2	4.09	1.3-5.48	3.02	M
C. pusilla	7	8.0-14	10.79	1.6-5.6	3.2	2-7.2	4.72	1.75-4.69	2.81	OM
C. sotica	13	5.0-68	28.11	1.6-12.7	6.41	1.2-5	3.13	1.3-8.4	5	ME
C. ventricosa	28	5.0-56	18.58	1.4-12.7	4.86	1.5-7.2	3.88	1.3-97.36	3.93	M
Diploneis ovalis	7	5.0-13	8.1	1.4-6.2	3.36	1.75-4.5	3.7	1.43-4.77	2.77	OM
Eucocconeis flexella	8	5.0-47	17.01	2.4-12.7	3.86	1.75-4.63	3.67	2.18-6.6	3.64	M
Eunotia curvata	5	6.0-48	9.83	1.4-6.2	2.14	2.7-6.1	4.87	1.43-6.27	2.12	OM
E. exigua v.compacta	8	5.0-56	19.44	1.4-6.2	3.63	2.3-5	3.94	1.3-6.2	3.59	M
E. faba	8	5.0-47	22.52	1.7-12.7	6.42	1.5-4.63	3.44	1.5-7.36	4.62	ME
E. flexuosa	7	5.0-56	22.63	1.4-12.7	4.82	1.5-5	3.32	1.3-7.36	4.04	M
E. incisa	24	5.0-56	24.79	1.4-12.7	5.69	1.5-6.1	3.01	1.43-7.36	4.89	ME
E. kocheliensis	6	10.-68	44.14	2.6-8.7	7.05	1.2-4.63	1.99	2.6-8.4	6.8	E
E. lunaris	12	5.0-68	22.07	1.7-12.7	5.72	1.2-4.63	3.07	1.5-8.4	4.52	ME
E. pectinalis	29	5.0-68	20.99	1.4-12.7	4.25	1.2-7.2	3.41	1.3-8.4	3.99	M
E.pectinalis v.ventralis	14	5.0-68	23.9	1.4-8.7	4.16	1.2-5	3.13	1.3-8.4	4.18	M
E.praerupta v.inflata	7	5.0-35	25.66	1.7-12.7	6.49	1.75-4.2	2.77	1.5-6.6	5.13	ME
E. robusta	13	7.0-56	30.53	2.5-7.8	5.02	1.5-4.63	2.7	2.54-7.36	5.25	ME
E. sudetica	9	5.0-35	19.64	1.6-12.7	5.34	1.75-7.2	2.79	1.75-6.6	4.68	ME
E. tenella	8	6.0-68	16.09	1.4-8.7	4.39	1.2-4.5	3.74	1.43-8.4	3.69	M
E. trinacria	5	5.0-55	19.64	1.7-12.7	5.11	1.5-4.4	2.61	1.5-7.36	3.75	M
Fragilaia capucina	5	11.-68	48.5	2.5-8.7	6.67	1.2-3.25	1.94	3.6-8.4	6.74	M
F. construens	8	10.-47	18.7	1.6-7.8	4.05	1.5-7.2	3.99	1.75-7.36	3.91	M
F.construens v.binodis	6	5.0-55	20.33	2.6-7.3	4.9	1.95-4.5	3.22	2.18-7.3	4.22	ME
F.construens v.venter	20	5.0-68	17.62	1.4-8.7	4.63	1.2-5	3.11	1.3-8.4	4.13	M
F. crotonensis	13	5.0-56	17.86	1.4-7.3	4.23	1.75-5	3.5	1.3-7.3	3.9	M
F. pinnata	13	5.0-55	13.16	1.6-7.3	4.2	1.75-5	3.32	1.3-7.3	3.63	M
F. undata	11	5.0-68	33.31	1.7-8.7	5.73	1.2-4.63	2.48	1.5-8.4	5.64	E
F. virescens	22	5.0-68	20.2	1.6-8.7	3.41	1.2-7.2	3.42	1.3-8.4	4.07	M
Frustulia rhomboides	22	5.0-68	18.55	1.4-12.7	4.37	1.2-6.1	3.62	1.3-8.4	3.7	M

Table 11 continue

Diatom Taxa	# of lakes in which taxa present	TP (μgl^{-1}) range	TP mean	Chl-a (μgl^{-1}) range	Chl-a mean	SD (m) range	SD mean	TL range	TL mean	Category
F. vulgare	6	5.0-32	11.94	1.6-12.7	4.9	3.2-7.2	4.15	1.5-6.6	3.27	M
Gomphonema parvalum	15	5.0-68	30.08	1.4-12.7	5.71	1.2-4.5	2.65	1.43-8.4	5.25	ME
Melosira ambigua	7	6.0-55	14.56	1.4-7.3	3.87	1.95-7.2	4.18	1.43-7.3	3.38	M
M. distans	10	5.0-47	12.92	1.6-6.2	2.48	1.9-7.2	4.21	1.3-5.48	2.55	OM
M.distans v. alpigena	11	5.0-68	13.2	1.4-8.7	3.63	1.2-4.5	3.17	1.43-8.4	3.54	M
M. granulata	18	5.0-68	33.66	1.6-12.7	5.33	1.2-5	2.23	1.3-8.4	5.6	E
M.granulata v.angustissima	15	9.0-68	36.32	2.1-12.7	5.87	1.2-4.8	2.47	2.29-8.4	5.86	E
M. islandica	6	9.0-68	23.56	3.9-8.7	5.96	1.2-4.4	3.13	3.61-8.4	4.97	ME
M. italica	18	5.0-68	28.59	1.4-8.7	4.45	1.2-4.8	3.25	1.43-8.4	4.59	ME
M. lirata	24	5.0-68	18.2	1.4-12.7	4.36	1.2-7.2	3.41	1.43-8.4	3.95	M
M. perglabra	15	5.0-68	25.9	1.6-8.7	4.64	1.2-7.2	3.23	1.3-8.7	4.49	ME
Meridion circulare	8	12.-56	29.82	2.5-7.8	5.52	1.5-4.4	2.12	3.79-7.36	5.55	E
Navicula bacillum	5	5.0-17	12.12	2.4-6.2	3.64	2.7-3.9	3.41	2.18-4.56	3.48	M
N. cocconiformis	14	5.0-68	22.55	1.6-12.7	4.88	1.2-7.2	3.25	1.3-8.4	4.28	ME
N. cryptocephala	10	6.0-14	11.45	1.4-6.2	4.28	1.75-7.2	4.22	1.43-4.77	3.4	M
N. lanceolata	5	5.0-32	16.56	1.4-12.7	5.65	1.75-5	4.08	1.3-6.6	3.73	M
N. pupula	24	5.0-68	21.87	1.7-12.7	4.3	1.2-7.2	3.05	1.51-8.4	4.24	ME
N. radiosa	25	5.0-68	20.75	1.4-12.7	4.88	1.2-5	3.37	1.3-8.4	4.06	M
N. scutiformis	5	5.0-13	9.51	2.5-6.2	3.14	1.75-4.5	3.39	2.18-4.18	3.09	M
N.subhamulata v.undulata	9	5.0-43	14.08	1.4-12.7	5.6	1.5-4.5	3.48	1.43-7.36	3.81	M
Neidium affine	11	5.0-55	19.06	1.7-12.7	5.41	1.5-4.63	3.41	1.5-7.36	4.14	M
N. iridis	17	5.0-68	13.1	1.6-12.7	3.86	1.2-7.2	3.89	1.5-8.4	3.34	M
Nitzschia acuta	8	5.0-68	28.14	1.7-12.7	7	1.2-4.63	2.92	1.5-8.4	5.17	ME
N. dissipata	15	5.0-68	21.81	1.4-12.7	4.41	1.2-5	2.89	1.3-8.4	4.27	ME
N. linearis	8	6.0-68	26.56	1.4-8.7	3.92	1.2-6.1	3.71	1.43-8.4	4	M
N. palea	15	5.0-55	13.64	1.4-12.7	3.89	1.75-6.1	4.02	1.3-7.3	3.24	M
N. romana	19	5.0-68	15.76	1.4-12.7	4.04	1.2-6.1	3.8	1.3-8.4	3.47	M
Pinnularia braunii	14	5.0-55	24.02	1.4-12.7	4.25	1.9-5	3.51	1.3-6.6	4.18	M
P. gentlis	5	6.0-17	12.44	1.4-5.3	3.35	3.7-4.5	4.01	1.43-3.97	3.19	M
P. gibba	12	5.0-68	26.89	1.4-8.7	4.65	1.2-4.8	3.21	1.43-8.4	4.54	ME
P. interrupta	7	7.0-68	20.36	2.4-8.7	4.08	1.2-4.63	3.55	2.54-8.4	3.95	M
P. major	11	5.0-47	17.7	1.4-6.2	3.84	1.75-7.2	3.45	1.43-5.48	3.81	M
P. microstauron	16	5.0-68	16.38	1.6-12.7	4.33	1.2-7.2	3.37	1.3-8.4	3.72	M
P. viridis	19	5.0-68	20.58	1.4-12.7	4.99	1.2-5	3.46	1.3-8.4	4.1	M
Stauroneis anceps	26	5.0-68	17.67	1.4-12.7	4.65	1.2-7.2	3.53	1.3-8.4	3.87	M
S. phoenicenteron	16	5.0-68	21.88	1.6-12.7	5.37	1.2-6.1	3.56	1.5-8.4	4.3	ME
Surirella linearis	10	7.0-68	17.13	2.1-8.7	3.65	1.2-4.8	3.53	2.29-8.4	3.59	M
S. robusta	20	5.0-68	18.11	1.6-12.7	3.93	1.5-7.2	3.65	1.5-7.36	3.82	M
Syneda acus	5	6.0-17	12.28	1.4-4.7	2.93	2.4.5	3.92	1.43-4.69	3.1	M
Tabellaria fenestrata	30	5.0-68	24.58	1.4-12.7	4.16	1.2-7.2	3.39	1.3-8.4	4.32	ME
T. flocculosa	30	5.0-68	23.73	1.4-12.7	4.76	1.2-7.2	3.08	1.3-8.4	4.53	ME

: The boundary of taxa categories were same as lake categories on the value of the relative trophic level (see text). The trophic categories (E = eutrophic species, ME = mesoeutrophic species, M = mesotrophic species, OM = oligomesotrophic species, O = oligotrophic species) of these taxa were based on their weighted mean of TL values.(common taxa of diatom: those were present in at least 5 study lakes)

was as abundant as it was in eutrophic lakes. Its distribution optimum was found in lakes with a trophic level value of 5.6 (the numerical calculation of its WA value see appendix IV). Therefore, *Melosira granulata* was classified as a eutrophic species because its optimal lake abundance level was associated with the eutrophic category (i.e.,its trophic level was above 5.41, Table 9). In this way, the autecological features of the trophic categories of 86 common diatom species were assigned (Table 11).

After the assignment of the species trophic category was made, all species of identical trophic category were collected and placed into their respective trophic categories. For example, in the 30 study lakes, 9 of the 86 species were categorized as oligomesotrophic (OM) (Table 12). Only one taxa, *Cyclotella kuetzingiana* belonged to the Oligotrophic group (Table 11).

Trophic categories	Trophic level	No. of species falling into the trophic categories
Ultraoligotrophic species	< 0.24	0
Oligotrophic species	0.241-1.8	1
Oligomesotrophic species	1.81-3.0	9
Mesotrophic species	3.01-4.2	46
Mesoeutrophic species	4.21-5.4	22
Eutrophic species	5.41-10	6
Hyper-eutrophic species	> 10	0

Table 12. Number of species in 7 trophic level categories from the 30 study lakes

The 86 common taxa which were categorized into five trophic groups accounted for over 90% of the total count of assemblages observed in the 30 lakes (Table 13). The one exception being Gravenhurst Bay where some of the dominant taxa did not belong to the 86 diatoms noted above.

Lake name	% of O group	% of OM group	% of M group	% of ME group	% of E group	Sum of 5groups
Fawn	0	1.29	18.44	47.40	31.55	98.68
Moot	0	1.12	35.31	28.06	34.17	98.66
Brandy	0	2.83	32.2	35.99	22.96	93.98
Hesners	0	0	53.18	41.43	3.12	97.73
Riley	0	.16	24.78	48.37	23.71	97.02
Nine Mile	0	6.01	30.37	39.76	19.01	95.15
Long	0	5.04	43.14	40.00	7.07	95.25
Black	0	6.44	27.77	30.3	34.09	98.6
Leech	0	7.00	49.51	37.01	5.53	99.15
Bass	0	7.77	32.39	27.32	25.07	92.55
Ricketts	0	7.95	38.07	42.91	7.81	96.74
Gullfeather	0	7.99	35.38	28.69	26.74	98.80
Ril	0	3.5	67.72	16.24	11.19	96.65
Little Leech	0	.32	67.05	26.76	4.3	98.43
Long Turtle	0	12.56	46.47	38.38	0	97.41
Meddra	0	8.53	69.2	19.43	.36	97.52
Gravenhurst Bay	0	5.04	45.6	19.37	5.7	75.71
Spence	.62	3.37	64.21	18.08	7.24	96.52
North Muldew	0	8.93	44.60	45.00	0	98.59
prospect	0	11.38	52.27	34.72	0	98.37
Clearwater	0	18.14	48.52	24.99	0	91.65
Loon	0	12.29	49.12	35.95	.26	97.62
Little long	0	4.99	67.73	19.67	.97	93.36
Wood	0	7.01	52.48	28.97	9.35	97.81
Pine	0	28.31	43.81	24.6	2.7	99.42
Clear	3.53	54.44	22.55	15.1	0	95.62
Leonard	.97	42.3	34.8	17.57	0	95.64
Heeney	0	23.46	63.74	12.32	.3	99.82
Trading Bay	10.58	24.74	42.95	14.16	1.79	94.22
Muskoka	13.45	15.88	50.24	13.12	0	92.69

Table 13. The relative abundance of five diatom groups observed in the surface sediment samples taken from the profundal zone of 30 Muskoka lakes, and the percentage that these 5 groups represented as a portion of the total observed.

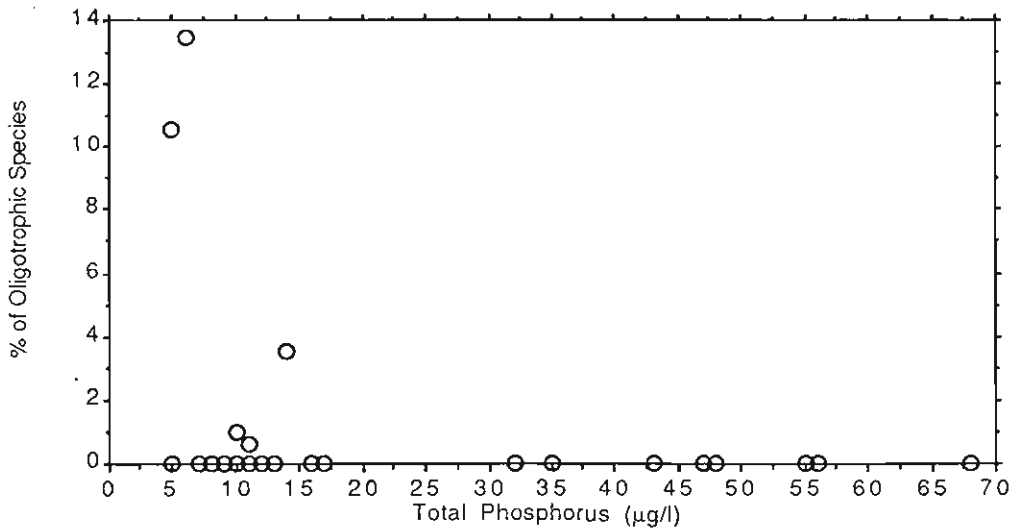
3). Distribution of the 5 diatom indicator groups

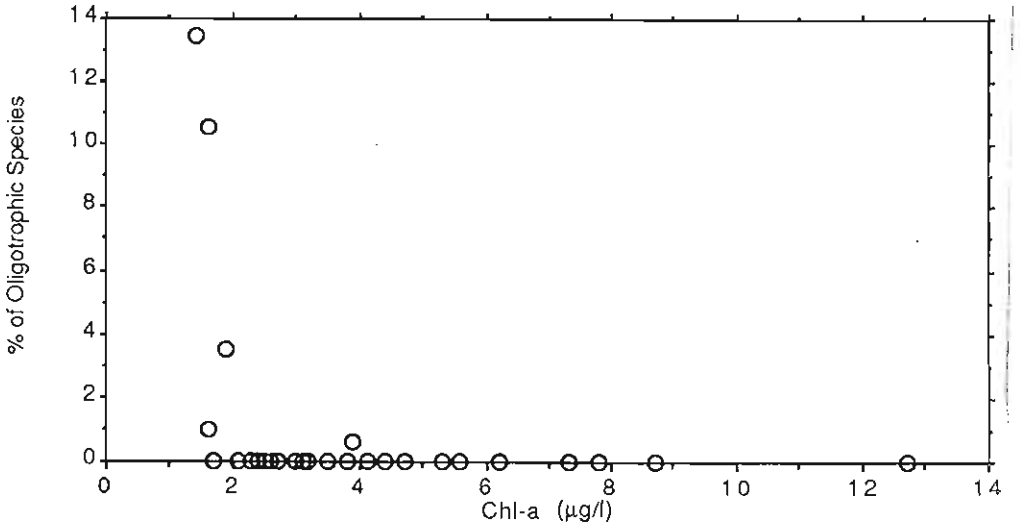
After the 86 common diatom taxa were categorized into the 5 diatom indicator groups, the relative abundance of each group was plotted against

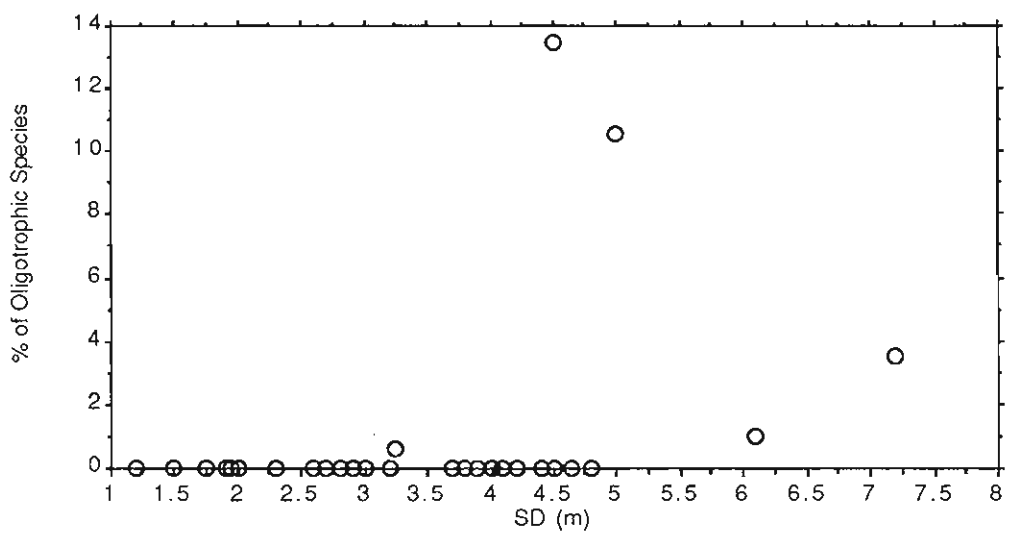
the values of TP, Chl-a, SD and TL to determine how the distribution of each group was influenced by these environmental variables (Figs 13-17).

The oligomesotrophic species were distributed mainly in oligomesotrophic habitats, their relative abundance increased with decreasing TP, Chl-a and TL, and with increasing SD (Fig. 14). The distribution pattern of eutrophic and mesoeutrophic species were just the reverse of this (Figs. 16-17). The distribution of mesotrophic species was more variable, this group of species can be abundant in both oligotrophic and eutrophic lakes (Fig. 15).

Fig. 13. The relative abundance of oligotrophic diatom group (O) versus trophic variables of 30 study lakes.


% of Oligotrophic Species
0
2
4
6
8
10
12
14
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Total Phosphorus (µg/l)


% of Oligotrophic Species
0
2
4
6
8
10
12
14
0 2 4 6 8 10 12 14
Chl-a (µg/l)


% of Oligotrophic Species
0
2
4
6
8
10
12
14
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8
SD (m)

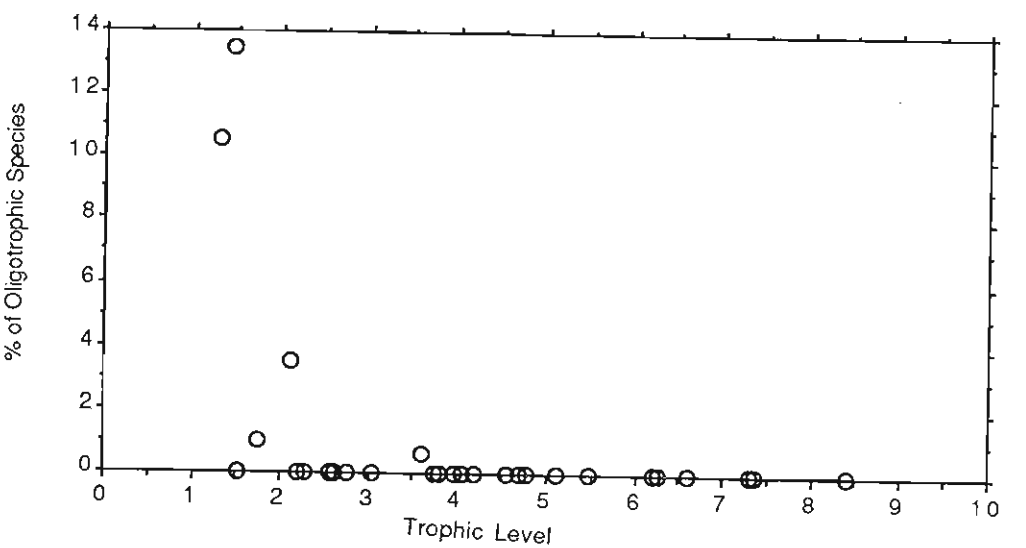
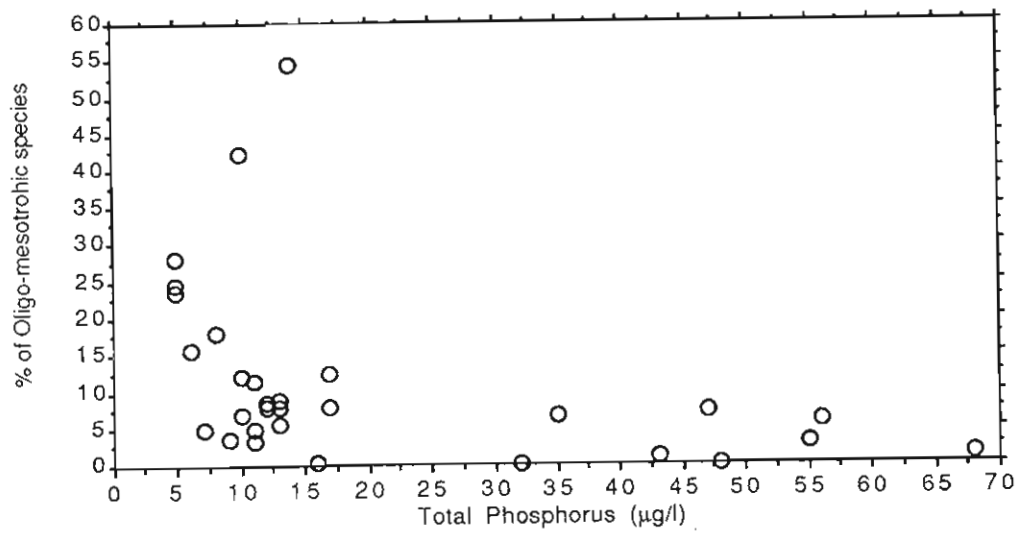
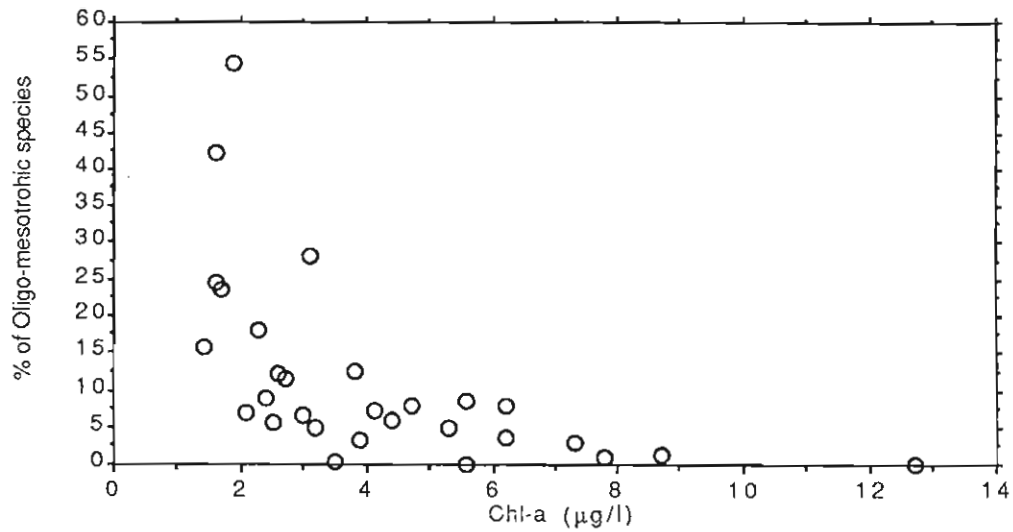
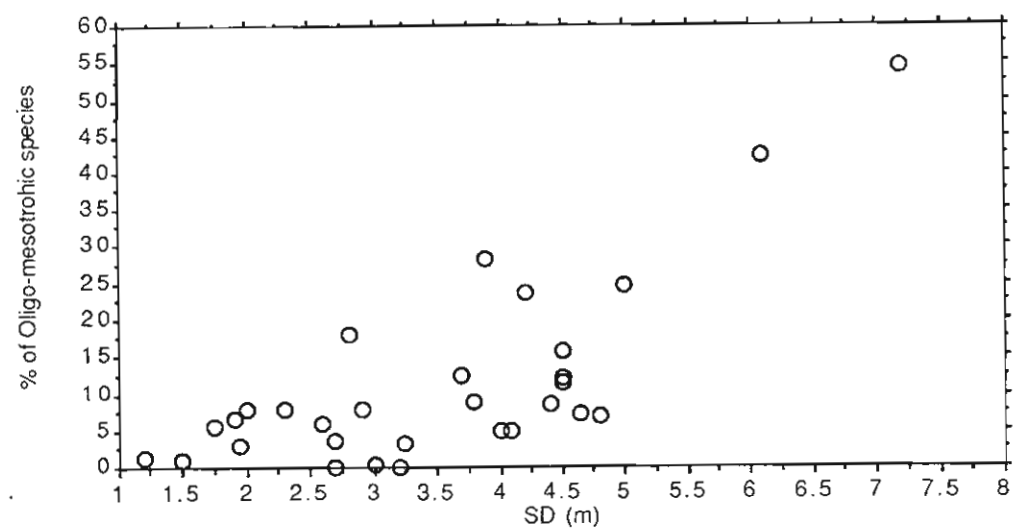

% of Oligotrophic Species
0
2
4
6
8
10
12
14
0 1 2 3 4 5 6 7 8 9 10
Trophic Level

Fig. 14. The relative abundance of oligomesotrophic diatom group (OM) versus trophic variables of 30 study lakes.


% of Oligo-mesotrohic species
Total Phosphorus (µg/l)


% of Oligo-mesotrohic species
Chl-a (µg/l)


% of Oligo-mesotrohic species
SD (m)

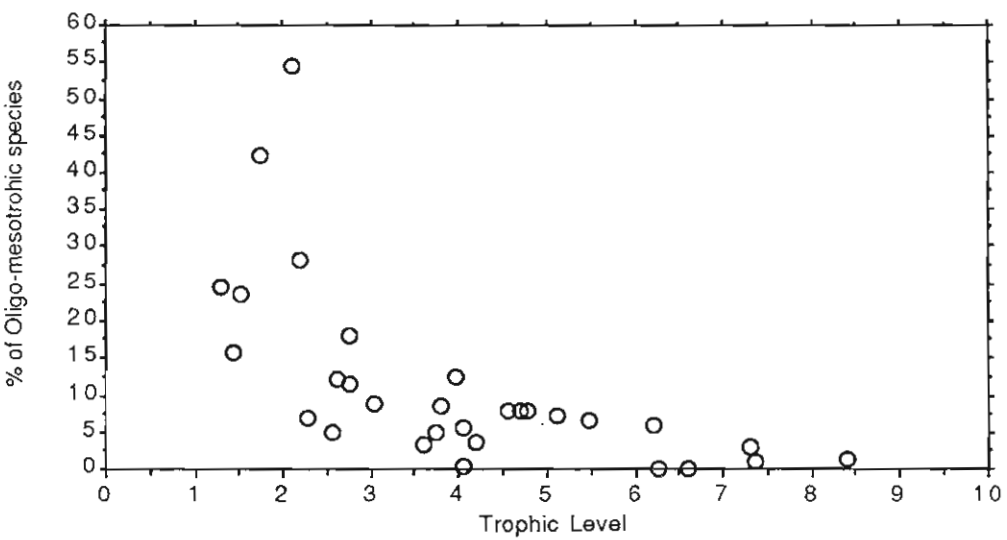
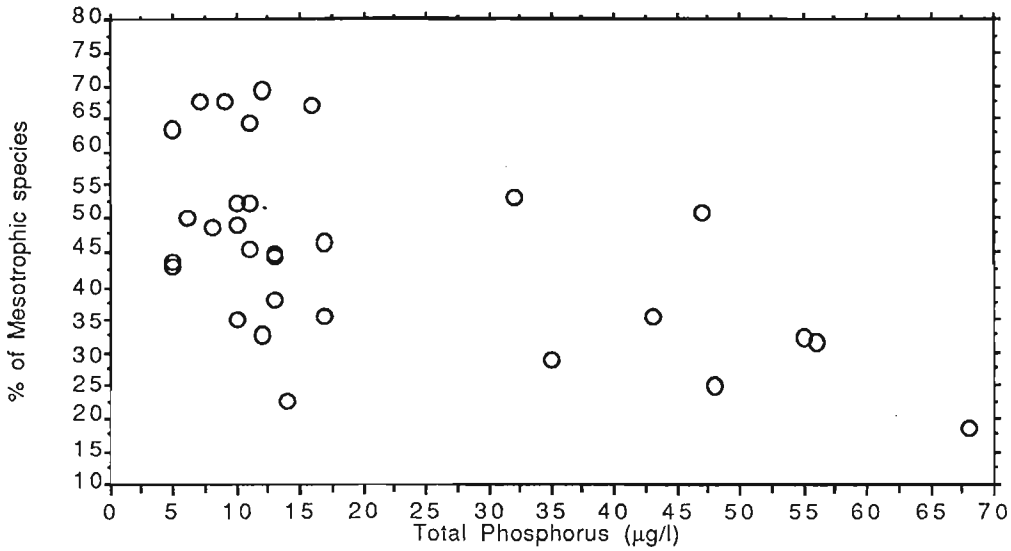
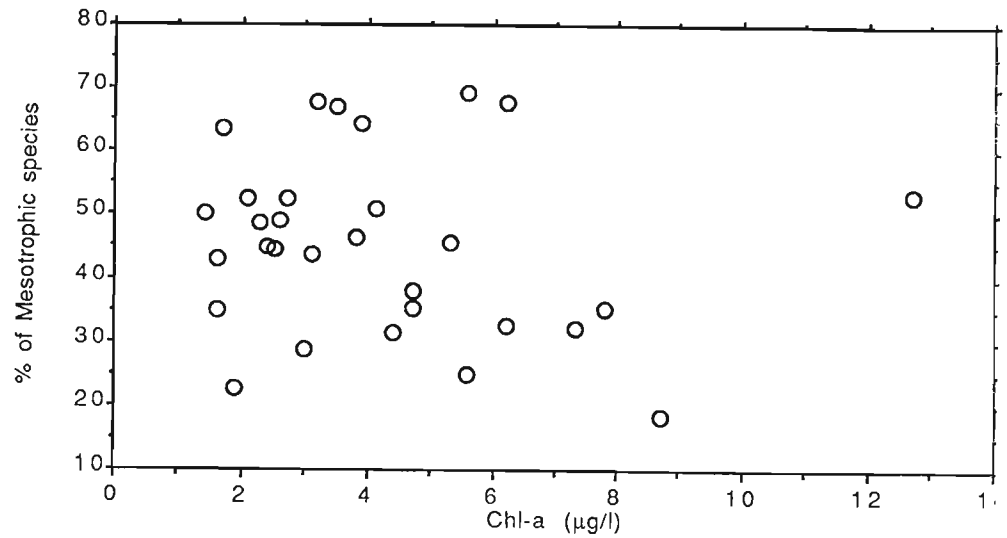
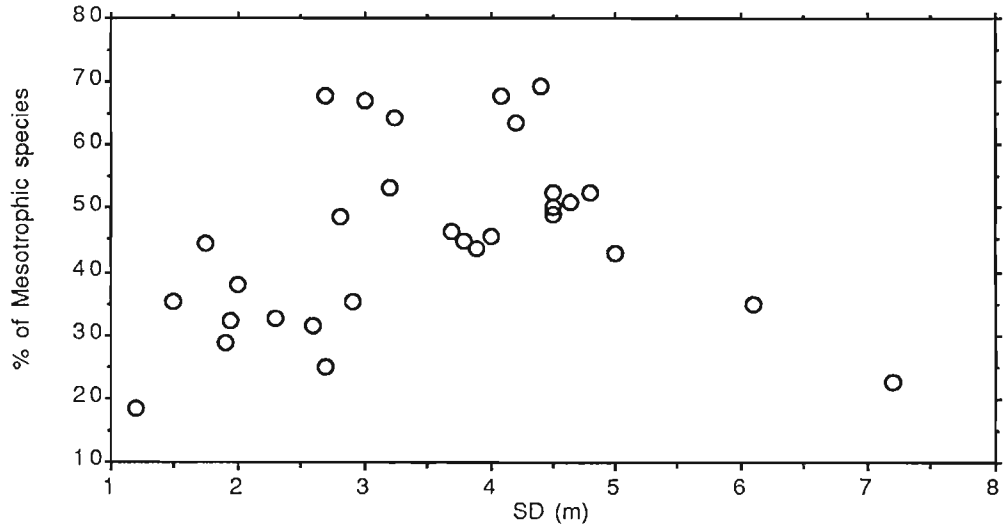

% of Oligo-mesotrohic species
Trophic Level

Fig. 15. The relative abundance of mesotrophic diatom group (M) versus trophic variables of 30 study lakes.


% of Mesotrophic species
Total Phosphorus (µg/l)


% of Mesotrophic species
Chl-a (µg/l)


% of Mesotrophic species
SD (m)

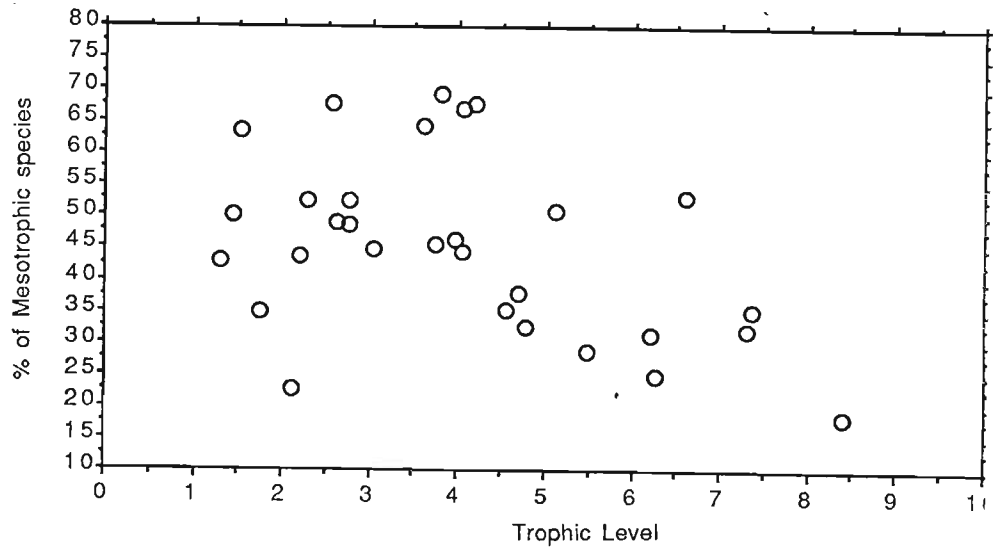
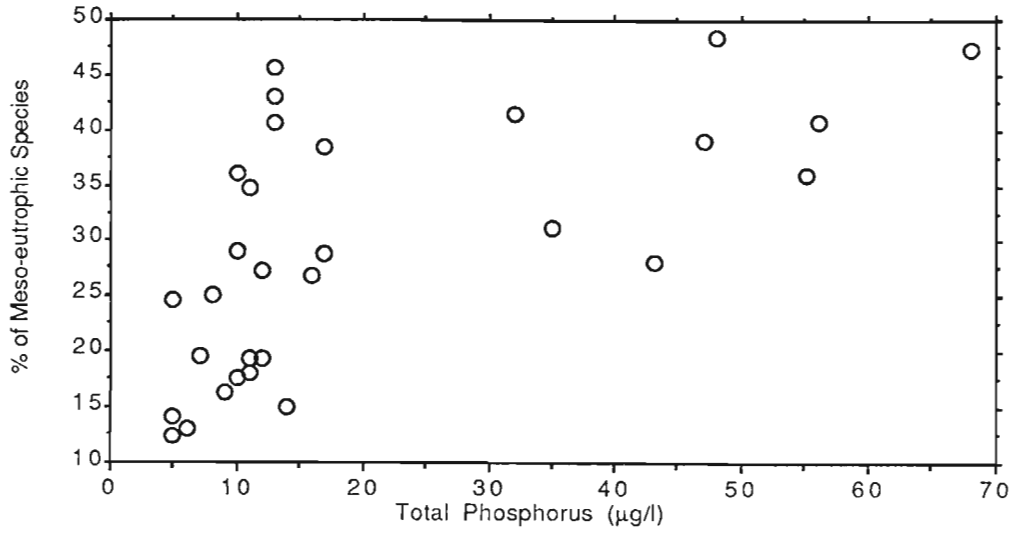
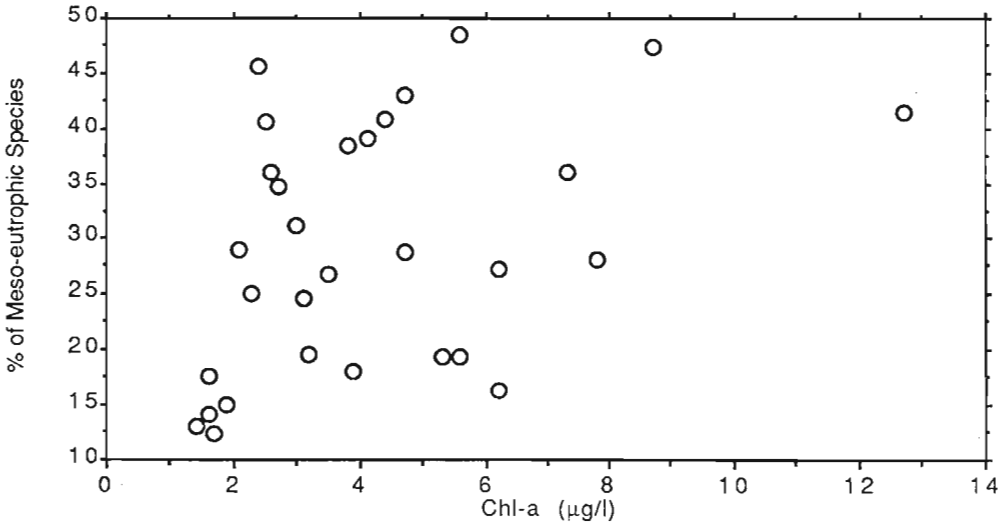
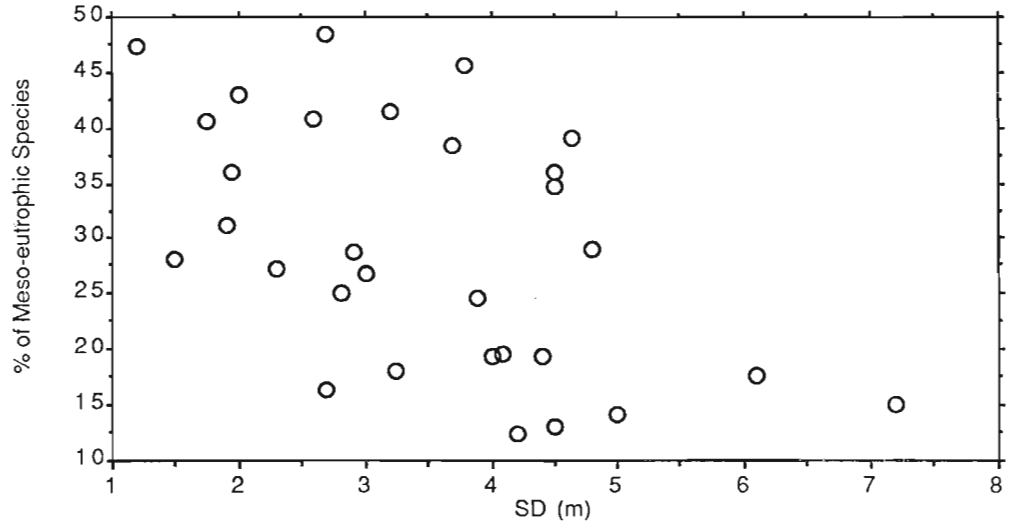

% of Mesotrophic species
Trophic Level

Fig. 16. The relative abundance of mesoeutrophic diatom group (ME) versus trophic variables for the 30 study lakes.


% of Meso-eutrophic Species
Total Phosphorus (µg/l)


% of Meso-eutrophic Species
Chl-a (µg/l)


% of Meso-eutrophic Species
SD (m)

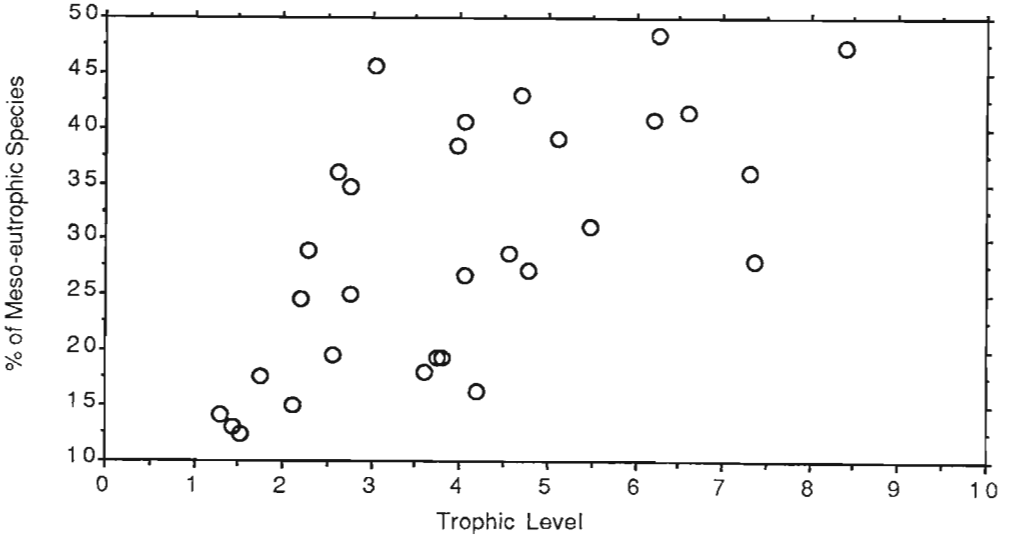
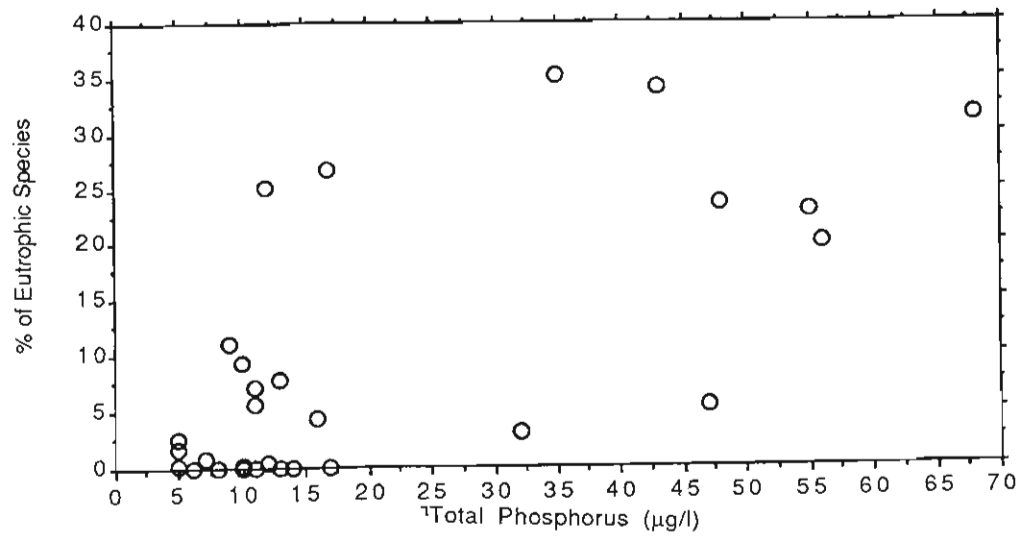
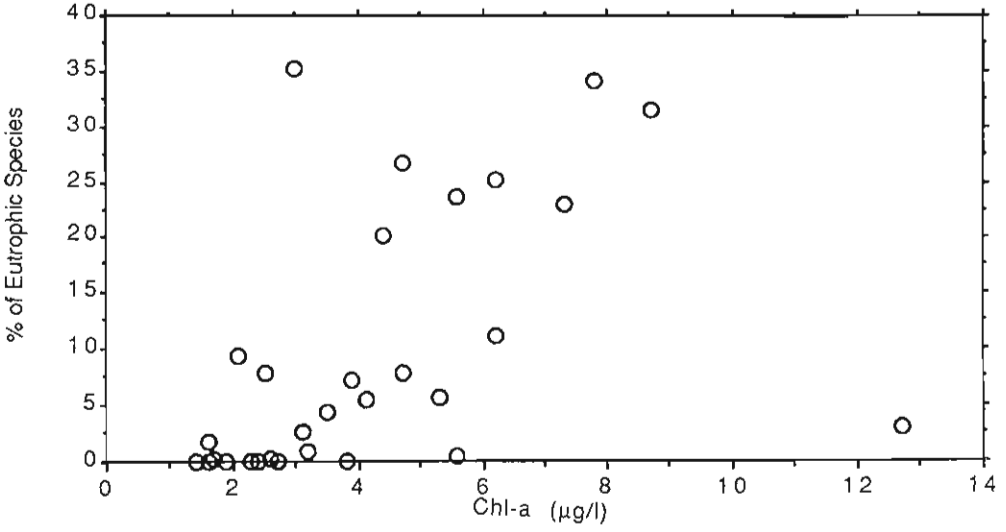
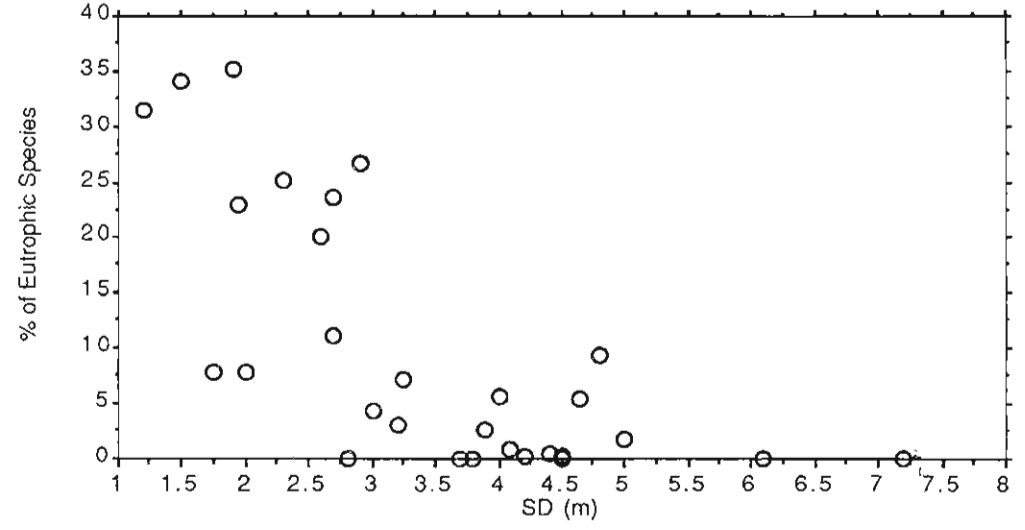
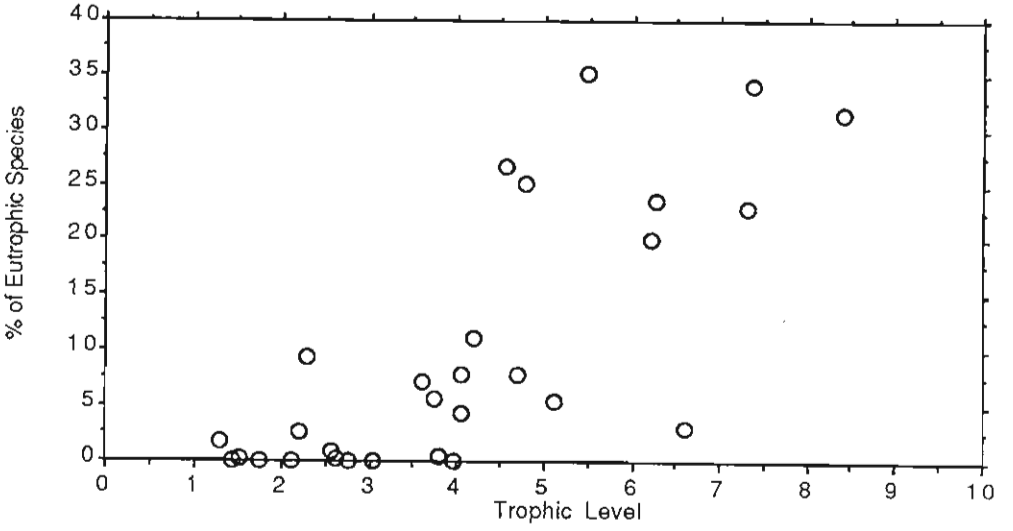

% of Meso-eutrophic Species
Trophic Level

Fig.17. The relative abundance of eutrophic diatom group (E) versus trophic variables for the 30 study lakes.


% of Eutrophic Species
0 5 10 15 20 25 30 35 40
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Total Phosphorus (µg/l)


% of Eutrophic Species
0 5 10 15 20 25 30 35 40
0 2 4 6 8 10 12 14
Chl-a (µg/l)


% of Eutrophic Species
0 5 10 15 20 25 30 35 40
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8
SD (m)


% of Eutrophic Species
0 5 10 15 20 25 30 35 40
0 1 2 3 4 5 6 7 8 9 10
Trophic Level

Part C: Regression analysis

1). Indirect single regression analysis with Index D

The values of Index D (see Materials and Methods) and Log Index D of 30 lakes were regressed against each of the trophic status indicator parameters (total phosphorus, chlorophyll-a, Secchi transparency depth and trophic level) (Fig. 18-25).

Although all regression equations were statistically significant ($P< 0.05$), the correlation coefficients ranged from 0.30 (Fig. 22) to 0.77 (Fig. 25).

In this study, lake trophic status was described by a new multiple trophic parameter called the trophic level (TL). The logarithmic transformation of the diatom trophic index (log Index D) regressed against TL was statistically significant ($P=0.0001$) and the correlation coefficient was relatively high ($r^2=0.77$). Thus, a statistical model of the relationship between the lake trophic status and the corresponding diatom assemblages for each of the 5 trophic levels was obtained (Fig. 25).

Based on Fig. 25, this model was expressed as:

Trophic level of lake = 2.643 - 7.575 log (Index D)

($r = 0.88$ $r^2 = 0.77$ $P = 0.0001$; $n = 30$)

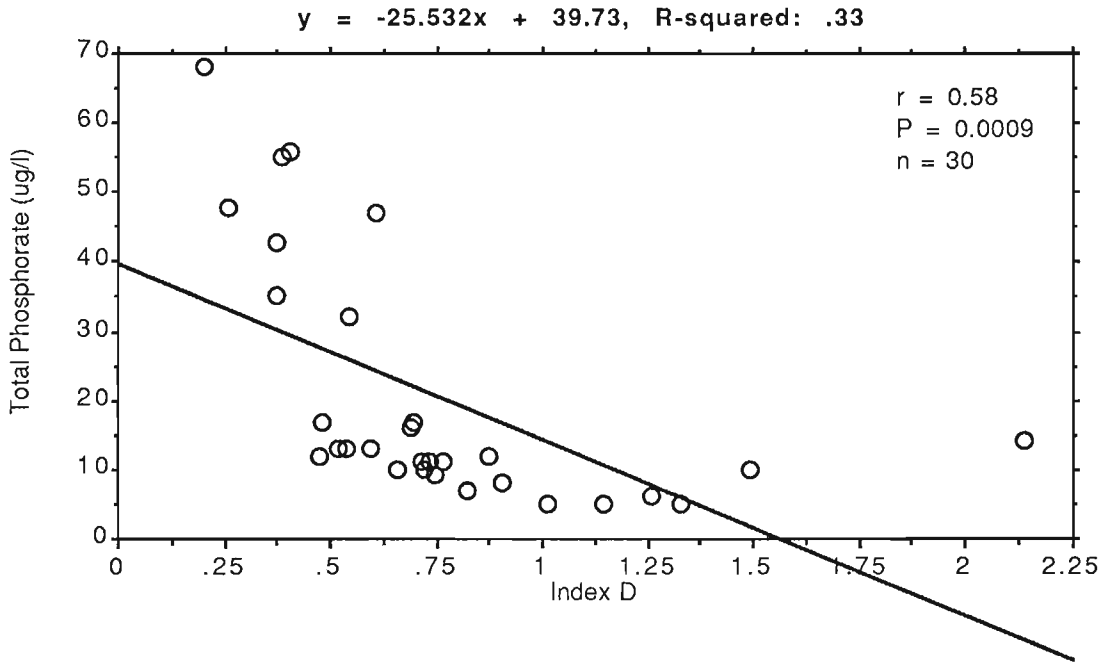


Fig. 18. Regression of total phosphorus (y=TP, $\mu g\ l^{-1}$) with diatom index ratio (x=Index D) of diatom assemblages in 30 study lakes.

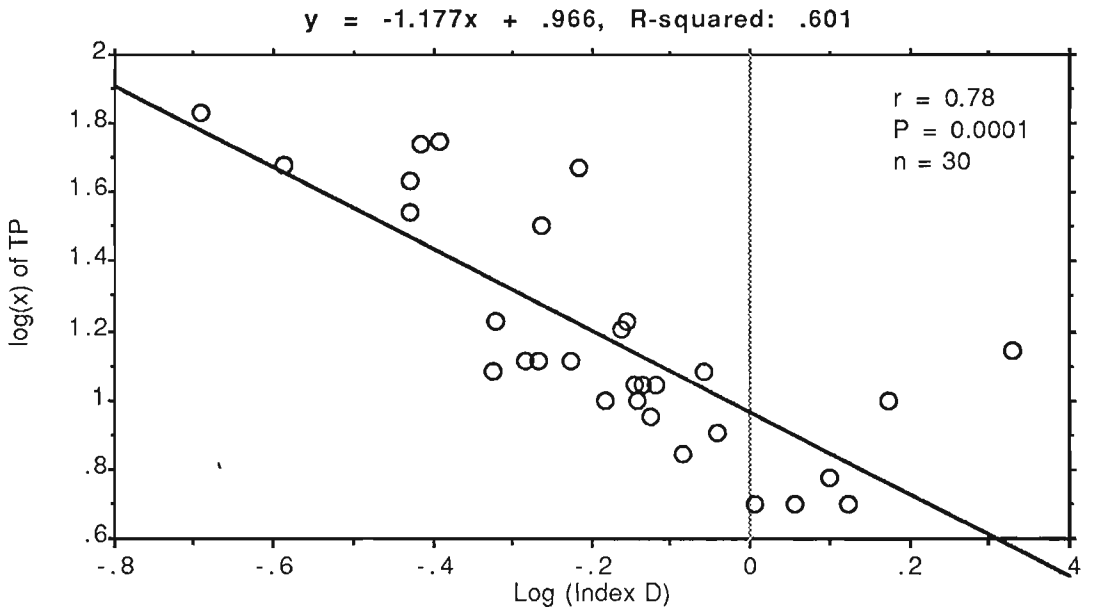


Fig. 19. Regression of logarithmic total phosphorus (y=logTP) with diatom index ratio [x=log(Index D] of diatom assemblages in 30 study lakes.

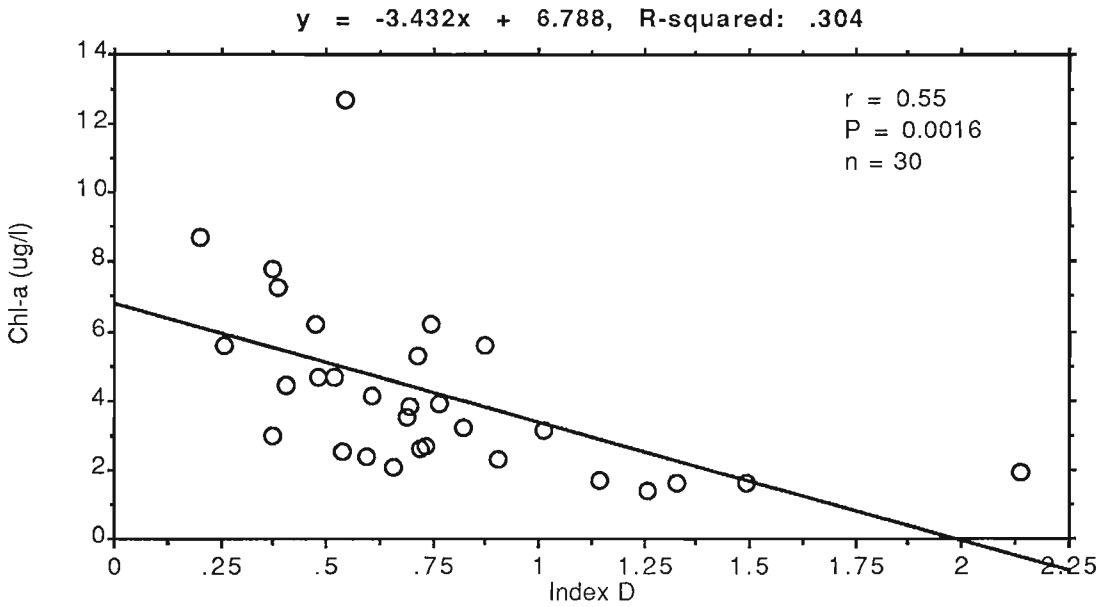


Fig. 20. Regression of chlorophyll-a (y=Chl-a, $\mu g\ l^{-1}$) with diatom index ratio x=Index D) of diatom assemblages in 30 study lakes.

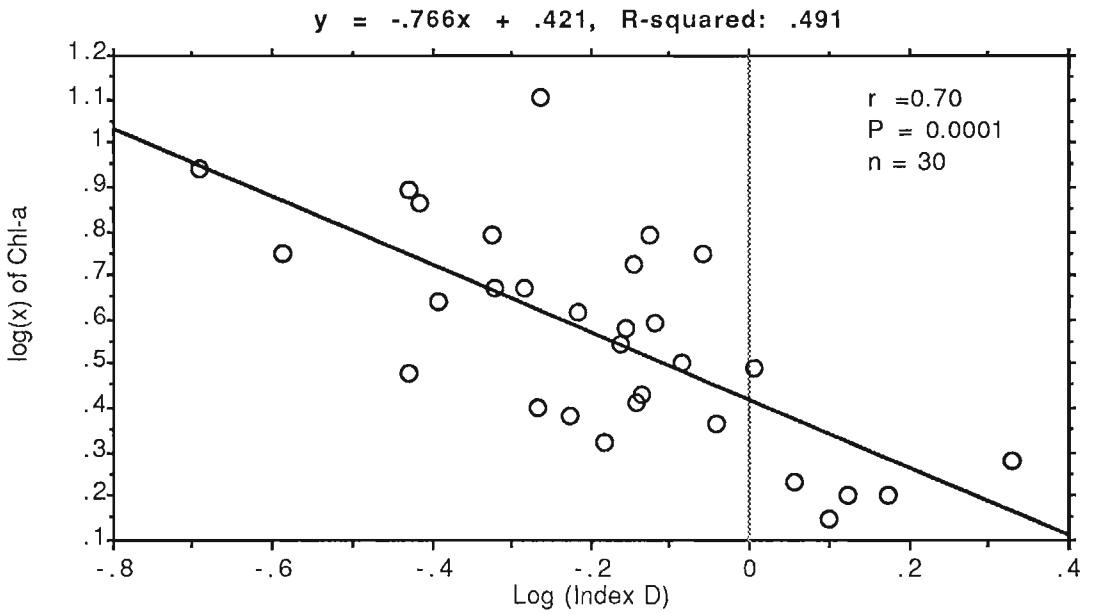


Fig. 21. Regression of logarithmic chlorophyll-a (y=logChl-a) with diatom index ratio [x=log(Index D] of diatom assemblages in 30 study lakes.

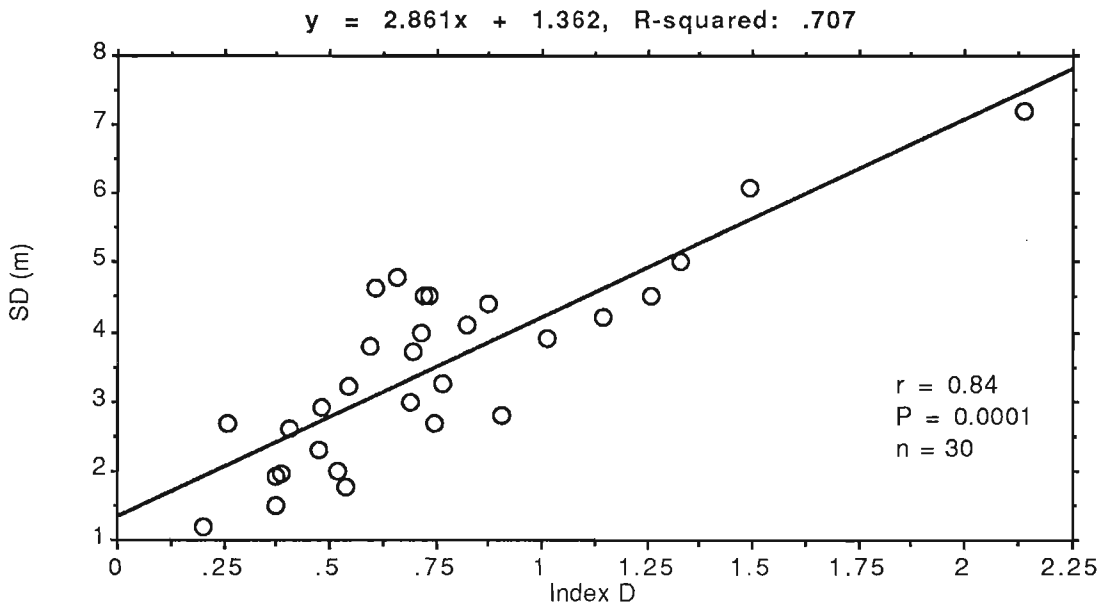


Fig. 22. Regression of Secchi depth (y=SD, m) with diatom index ratio (x=Index D) of diatom assemblages in 30 study lakes.

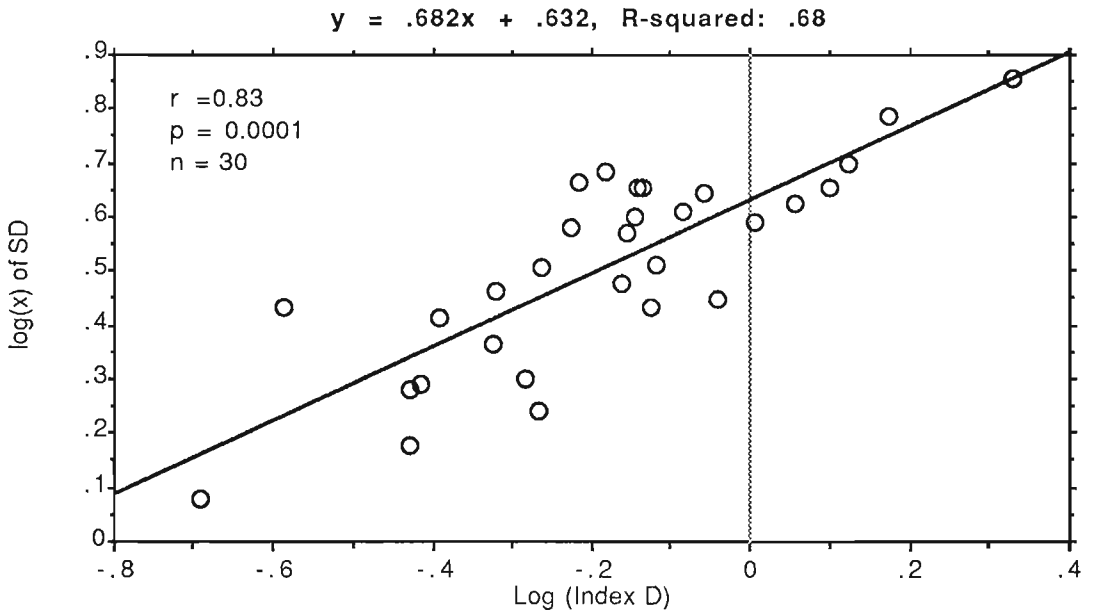


Fig. 23. Regression of logarithmic Secchi depth (y=logSD) with diatom index ratio [x=log(Index D] of diatom assemblages in 30 study lakes.

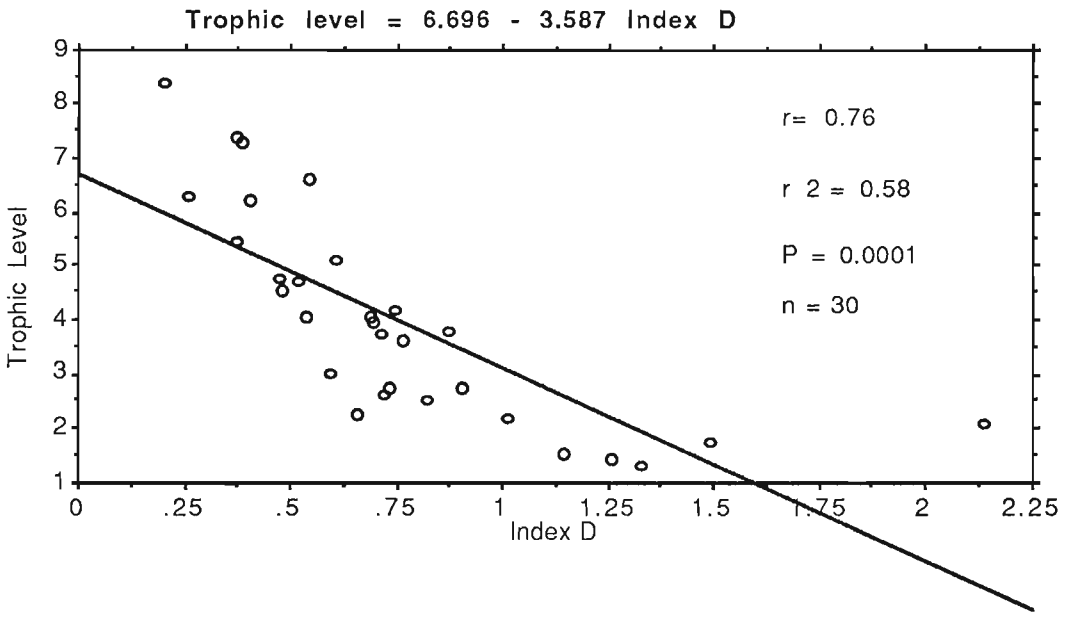


Fig. 24. Regression of trophic level (y=TL) with diatom index ratio (x=Index D) of diatom assemblages in 30 study lakes.

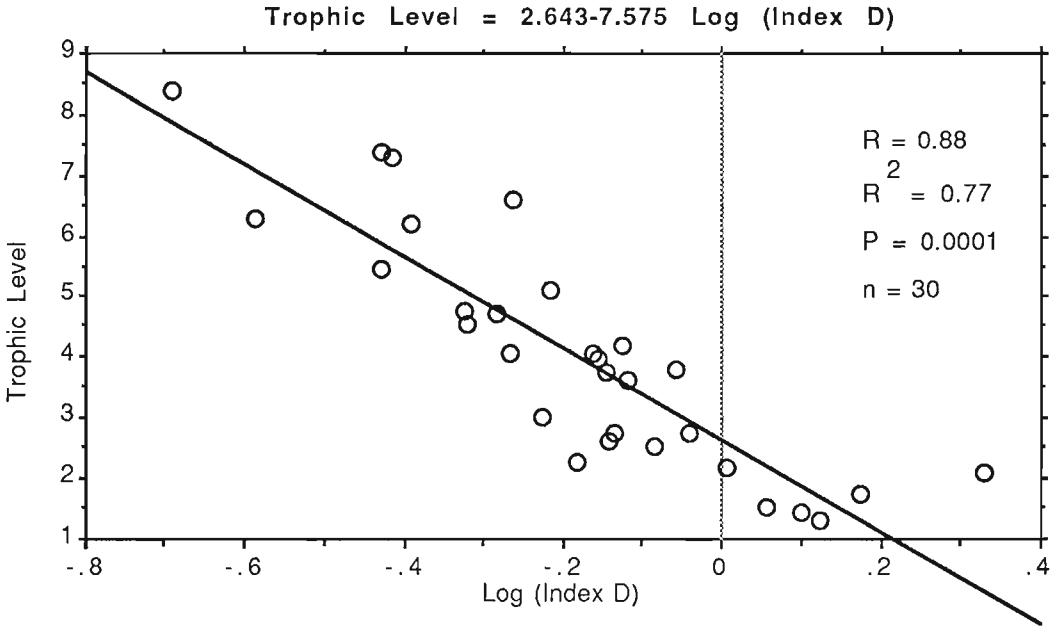


Fig. 25. Regression of logarithm of trophic level (y=log TL) versus diatom index ratio [x=log(Index D] of diatom assemblages in 30 study lakes.

2). Direct multiple regression analysis

The abundance of five trophic groups was regressed against each of the trophic status values for the 30 study lakes (total phosphorus, chlorophyll-a, Secchi transparency and trophic level). The regression equations obtained were:

A). Total phosphorus (TP)

TP = 0.549 **O**% + 0.112 **OM**%+0.003 **M**% + 0.826 **ME**% + 0.894 **E**% -15.262

(r=0.805, r^2=0.648, P=0.0001, n=30)

Log TP =1.041- 0.106 Log(**O**%) - 0.194 Log(**OM**%) - 0.544 Log(**M**%)

+ 0.783Log(**ME**%) + 0.091Log(**E**%)

(r=0.862, r^2=0.725, P=0.0003, n=30)

B). Chlorophyll-a (Chl-a)

Chl-a=10.617- 0.177 **O**% - 0.138 **OM**% - 0.073**M**% - 0.041 **ME**% - 0.016 **E**%

(r=0.634, r^2=0.402, P=0.0229, n=30)

LogChl-a = 0.957 - 0.252 Log(**O**%) - 0.161 Log(**OM**%) - 0.191 Log(**M**%)

+ 0.039 Log(**ME**%) + 0.048 Log(**E**%)

(r=0.661, r^2=0.438, P=0.0605, n=30)

C). Secchi transparancy depth (SD)

SD=3.469- 0.024 **O**% - 0.056 **OM**%-0.002 **M**%- 0.01 **ME**%- 0.05 **E**%

(r=0.868, r^2=0.737, P=0.0001, n=30)

LogSD=0.171 + 0.043 Log(**O**%) + 0.056 Log(**OM**%) + 0.514 Log(**M**%)
+ 0.058 Log(**ME**%) - 0.089Log(**E**%)
($r=0.793$, $r^2=0.628$, $P=0.0028$, $n=30$)

D). Trophic level (TL)

TL=4.286 - 0.076 **O**% - 0.055 **OM**% - 0.026 **M**% + 0.033 **ME**% + 0.065 **E**%
($r=0.89$, $r^2=0.792$, $P=0.0001$, $n=30$)

LogTL=0.315 - 0.243 Log(**O**%) - 0.11 Log(**OM**%) - 0,139 Log(**M**%)
+ 0.353 Log(**ME**%) + 0.108 Log(**E**%)
($r=0.887$, $r^2=0.787$, $P=0.0001$, $n=30$)

Except for the multiple regression equation of Log Chl-a ($P>0.05$), all the rest displayed regression equations that were statistically significant ($P< 0.05$). The correlation coefficient (r^2) ranged from 0.402 to 0.792. The highest regression coefficient was the trophic level multiple regression versus the five diatom trophic groups:

TL = 4.286 - 0.076 **O**% - 0.055 **OM**% - 0.026 **M**% + 0.033 **ME**% + 0.065 **E**%
($r=0.89$, $r^2=0.792$, $P=0.0001$, $n=30$)

DISCUSSION

I. A new multiparameter for lake trophic status

(a). Why develop a new trophic multiparameter?

In 1968, an agreement for the measurement of lake trophic status was made by the International Conference of Limnological Society in Wisconsin whereby the lake primary productivity was pointed to as a standard for the classification and measurement of lake trophic status (Personal communication with Dickman, 1990). However, numerous methodological and physical problems confront the application of the ^{14}C light and dark technique (Wetzel 1983). Vollenweider (1969) also mentioned that estimates of production rate by planktonic microflora from changes in biomass are much more difficult. In fact, the practical application of this method to determine the trophic status of every lake is not possible due to the expensive cost both in economy and time (Dickman, personal communications).

Thus, scientists began to search for a simpler parameter which would have a strong correlation with lake primary productivity instead of this standard parameter (e.g. OECD program in 1970s).

Lake trophic state is classified according to numerous diverse criteria which range from a single chemical measurement (e.g. total phosphorus and nitrogen in the water) to complex biological parameters such as the annual mean concentration of chlorophyll-a and the hypolimnetic oxygen depletion rates).

There are three drawbacks to these single parameter indices.

(1) Each parameter has an advantage but none is perfect. For example, total phosphorus concentration which was demonstrated to be a limiting factor in lake eutrophication does not show a good correlation with primary productivity in bog lakes (Wetzel 1983). Secchi disk transparency might be expected to give erroneous value in lakes containing high amounts of non algal particulate matter, and in highly colored lakes (Carlson 1977).

(2) The contradictions among these traditional single parameters are often quite substantial (Carlson 1977; Lambou et al. 1983; Yoshimi 1987; Henderson-sellers and Markland 1988). Some lakes may be considered oligotrophic by one criterion and mesotrophic or eutrophic by another. For example Clearwater Lake's mean chlorophyll-a concentration was 2.8 ug/liter (mesotrophic) in 1986 while it's mean summer Secchi depth was 6.3 m (oligotrophic by MOE criteria). This problem is sometimes circumvented by classifying lakes that show characteristics of oligotrophy and eutrophy as mesotrophic (Carlson 1977). Therefore, I felt that this was unacceptable.

(3) Contradictions regarding trophic classification are also present even when using the same single parameter due to differences between different regions or scientists. A mean chlorophyll-a concentration of 4 ug/liter was found in Black Lake. This value may be considered to show oligotrophy by the scheme of the US EPA and eutrophy by the MOE and mesotrophy by the OECD. These problems result in frustration in communicating to the public both the current nature or status of lakes and their past or future trophic status.

Carlson (1977) pointed out that the large number of criteria that have been used to determine trophic status has contributed to the

contention that the trophic concept is multidimensional, involving aspects of nutrient loading, nutrient concentration, productivity, faunal and floral quantity and quality, and it is even influenced by lake morphometry. As such, trophic status could not be evaluated by examining only one or two parameters. For these reasons, multiple parameters were developed (e.g. Michalski and Conroy 1973; U.S. EPA 1974; Bold 1976; Yoshimi 1987).

A multiple parameter of trophic status was established by the U.S. EPA program using a percentile ranking procedure (U.S. EPA 1974). The percentage of 250 lakes sampled in 1973 exceeding lake X for a given parameter was determined. The multiple parameter of trophic status is equal to the sum of the percentile ranks for each parameter used (annual medium TP, inorganic nitrogen, dissolved orthophosphorus; annual mean SD, chlorophyll-a, and minimum dissolved oxygen).

In 1976, Bold developed other multiple trophic indices (TSI_1 and TSI_2) using principal components analysis (Bold 1976). Variables used for Bold's TSI_1 are annual mean for chlorophyll-a, conductivity, inverse SD, TP, total organic nitrogen and algal assay control yield. Bold's TSI_2 is the same as his TSI_1, except that total kjeldahl nitrogen is used instead of total organic nitrogen and mean summer values are used instead of annual values.

More than three multivariate trophic status indices were examined for their relationship to each single parameter, and it was found that all three utilized ambient TP and one or more additional highly phorsphorus-correlated parameters. As a result there was a large degree of lack of independence between the "independent" variables employed in these multiple indices. All three multivariate trophic status indices included chlorophyll-a as a common component. The best relationship among these

TSIs with chlorophyll-a values yielded an r value of only 0.68 (Lambou et al. 1983).

In 1986, Yoshimi reviewed these previous approaches and commented that these multiple parameters are expected to increase understanding of comprehensive trophic levels and to make evaluations stable due to the effect of aggregation of several parameters. However, the contribution of each parameter to the comprehensive index number, which is important to the understanding of lake characteristics, cannot be directly estimated and used if the index is limited by whether the parameters are available (Yoshimi 1986). From this reason, Yoshimi developed a simpler multiple analysis so that the simultaneous construction of single-parameters and multiple parameter indices to evaluate trophic status for lakes would be possible by using principle component analyses (PCA) and data on total phosphorus, chl-a and SD (Yoshimi 1986). The equation obtained from the results of PCA was expressed as a linear combination of the three functions,

$$MTSI = (STSITP + STSIchl\text{-}a + STSISD)/3$$

Where,
$$STSITP = 7.67f(TP) + 7.21$$
$$STSIchl\text{-}a = 3.05f(Chl\text{-}a) + 0.95$$
$$STSISD = 4.82f(SD) + 5.66$$

Three single parameters (TP, Chl-a and SD) were chosen by Yoshimi in his multiple parameter approach because they were more sensitive to changes in lake trophic status than other single parameters that he tested and because they are widely considered to be important in the determinations of lake trophic level (Carlson 1977, Vollenweider and Kerekes 1980, Reckohow 1981, Yoshimi 1986).

The application of PCA to obtain the critical value of each single parameter such as STSITP, STSIchl-a, STSISD in Yoshimi's multiparameter approach requires high correlation coefficients among TP, Chl-a and SD (Yoshimi 1987). Such high correlation coefficients among these three single parameters, however, are not always to be found (Carlson 1977). Trophic variables in different regions and even different seasons in the same region may have different correlation coefficients (Table 5; Carlson 1977, Henderson-sellers and Markland 1988, Agbeti 1987, Christie 1988). The correlation coefficient value among these three parameters were also fairly low in my study's data set (TP vs. Chl-a, r^2=0.30,; SD vs. Chl-a, r^2=0.23; SD vs. TP, r^2=0.14).

Furthermore, the contribution of each of the three single parameters to the trophic status estimator is variable in different lakes (Carlson 1977). It is unlikely in the Yoshimi model that the contribution of TP, Chl-a and SD was equivalent. In Yoshimi model, MTSI = (STSITP + STSIChl-a + STSISD)/3. Because of this Yoshimi's multiparameter approach will be unstable and it is unlikely that it can be applied to evaluate lake trophic status over a broad range of lake types.

(b) Current approach

In this study, the new multiparameter lake trophic status index was also based on Yoshimi's same three single parameters (TP, Chl-a and SD). However, the combination of the three single parameters was based on the weighted relationship between lake trophic status and each of the single parameters. It has been demonstrated by many previous researchers that

the primary productivity or trophic level (TL) of a lake is positively correlated with TP and Chl-a and inversely correlated with SD. These principles could be described in a series of mathematical equations:

(a) Based on TP, $TL_1 = k_1TP$

(k_1 is variable in different regions or seasons)

(b) Based on Chl-a, $TL_2 = k_2$Chl-a

(k_2 is variable in different regions or seasons)

(c) Based on SD, $TL_3 = k_3/SD$

(k_3 is variable in different regions or seasons)

Then, the combination of these three principles will result in the development of a new multiple parameter index for lake trophic status (MTSI).

MTSI can be positively correlated with (TP x Chl-a / SD), or expressed as:

$$MTSI = TP \times Chl\text{-}a / SD$$

Because the MTSI index of lakes calculated from the above equation ranges from ultraoligotrophic to hypereutrophic its values range from decimal values into the hundreds. The trophic level (TL) index which I am proposing places most lakes into a simple range between 0 (for ultraoligotrophic lakes) and 10 for (hypereutrophic lakes) based on the mathematical calculation:

$$TL = 1.37 \ln[1 + MTSI]$$

$$= 1.37 \ln[1+(TP \times Chl\text{-}a / SD)]$$

The new trophic multiparameter index has the following advantages:

1. Because these three single parameters (TP x Chl-a and SD) were involved in the model of the new multiple parameter and the standard

boundary of the new multiple trophic category was calculated from standard boundaries of each single trophic parameter, the contradictions between these traditional single parameters are, therefore, avoided.

2. The relationship between trophic status and the three parameters TP x Chl-a / SD was based on the principle that in any region or lake in any season the contribution of each single parameter to trophic content is variable but the combination of all three is more stable. Thus, it is likely that the new multiparameter index can be applied to evaluate the lake trophic status over a broad range of lakes.

3. The new multiparameter index has clear boundary values between each of the trophic categories, and ranges from 0 (ultraoligotrophic) to 10 (hypereutrophic lake). This simplicity makes communication and management of lake trophic status more convenient.

4. As I discussed earlier, each parameter has its own advantage, but, none is perfect in quantifying lake trophic status. For example, Secchi disk transparency was influenced by humic particulate matter in highly colored lakes (Carlson 1977). If the new multiparameter was used, however, the disadvantage of any single parameter would be reduced. Due to the high content of humic color in my study lake, 34 lakes would be classified as eutrophic if trophic status was evaluated solely by using Secchi transparency. If the new multiparameter is used to indicate trophic level, the number of eutrophic lakes is reduced to 14 (Table 14).

trophic status	# of lakes evaluated by total phosphorus	# of lakes evaluated by chlorophyll-a	# of lakes evaluated by Secchi transparency	# of lakes evaluated by new multiparameter
ultra-oligotrophic	0	0	0	0
oligotrophic	18	20	7	10
oligo-mesotrophic	33	25	8	30
mesotrophic	17	24	21	18
eutro-mesotrophic	6	9	15	14
eutrophic	12	8	34	14
hyper-eutrophic	0	0	1	0
total	86	86	86	86

Table 14. Comparison of the trophic status of the 86 study lakes evaluated by application of the different trophic parameters.

Eighteen lakes would be classified as oligotrophic if trophic status was evaluated solely by total phosphorus. The number of oligotrophic lakes is reduced to 10 if the new multiparameter is used to indicate trophic level (Table 14). The chlorophyll-a concentration of these lakes was relatively high even though the total phosphorus of some of the study lakes was quite low (e.g. Wolfkin lake and Hard lake, Table 9). There was a reduction in the number of oligotrophic lakes from 20 determined by Chl-a to 10 when the MPI was used because Chl-a compensated for (balanced) their low phosphorus levels (e.g. Clear lake and Gull lake, Table 9).

Thus the new trophic multiparameter would appear to be a more reasonable approach for determining the true trophic status of a lake.

II. Diatom Autecological Research

The autecological analysis of the trophic characteristics of diatom species is an important aspect of this study.

In many previous diatom studies of lake trophic level, the trophic indicator value for each diatom species was taken from a compilation of autecological studies (Lowe 1974, Beaver 1981). The problem with this approach is that one species may be reported for example as eutrophic by one scientist and mesotrophic or oligotrophic by another. For example, *Cyclotella glomerata, Stephanodiscus hantzschii* and *S. tenuis* were referred to as indicators of oligotrophic waters by Stockner and as eutrophic indicators by Duthie and Sreenivasa (1971) and Brugam (1978). Such contradictions have been noted for nearly every species in autecological studies on lake trophic status (e.g. Beaver 1981). In addition, for many diatom species, there is still no information on the trophic status of a large number of taxa (Agbeti 1987). Thus, the autecological relationship of diatom species and lake trophic status has not been as well documented as their pH autecological relationships.

It is very important to separate diatom assemblages into several indicator groups which correspond to lake trophic level so that regression analysis between diatom assemblages and lake trophic status can be better interpreted.

To assign a trophic status to each diatom species in the study area, I analyzed each species' relative abundance in 30 lakes of known trophic status, and the optimum density for each species was determined by the weighted average method (Charles, 1985). On this basis I was able to

evaluate the trophic level status for each species in a more realistic manner than if I had not analyzed its abundance and distribution optimum, and made instead an arbitrary decision regarding the trophic status of each species based solely on the published literature.

The weighted average method is a new technique for determining species autecological features which have been applied to determine the optimum diatom distribution in an environment where numerous variables co-occur (Charles, 1985).

In the study of Christie (1988), the method of weighted average was utilized to determine ecological features of dominant diatom species on total phosphorus, chlorophyll-a and Secchi transparency. However, the five categories which she obtained did not give a clear definition of each group (Christie, 1988). These may have resulted because the boundary relationship between species' weighted average values and lake trophic categories was not well documented.

In the present study, a total of 251 diatom taxa were identified from the surface sediment samples of 50 study lakes (Table 10). The autecological trophic features of 86 common species which occurred in at least 5 of the 30 study lakes was investigated, along with their frequency of occurrence, their optimum (weighed average) and ranges of TP, Chl-a, SD and trophic level (Table 11). Taxa found in fewer than five lakes were assigned no trophic category because there was insufficient data for a decision re these species (Charles 1986). This was not a problem as the sum of the rare taxa accounted for less than 8.35% of the total observed in the 30 study lakes.

The most common species were those present in the majority of the study lakes. Assignment of the five indicator group trophic categories to

the 86 common taxa was based on the taxon's distribution optimum value (Table 11). The category boundaries of indicator species on trophic level were the same as these boundaries used in the study lakes (Table 8).

1. Oligotrophic indicator species

(Range of species autecological feature on trophic level: 0.24 ~ 1.80)

Cyclotella kutzingiana (Plate 3, Fig. A), was the only one species classified as an oligotrophic indicator in this study (Table 11). This taxon was only found in lakes which were characterized by low TP and Chl-a, and high SD (Fig.13). By using weight average formulae, its distribution optimum (WA value) on trophic level was 1.52 (Fig. 26). It was therefore classified as an oligotrophic indicator because its trophic status value did not exceed the 1.8 trophic index boundary value between oligotrophic and oligomesotrophic indicators as displayed above.

This taxon was reported as an oligotrophic indicator by Patrick (1960), Hutchinson (1967), Beaver (1981), and Christie (1987), but, as a mesotrophic indicator by Kling and Holmgren (1972). The autecological feature of this taxon determined from this study was consistent with most previous studies.

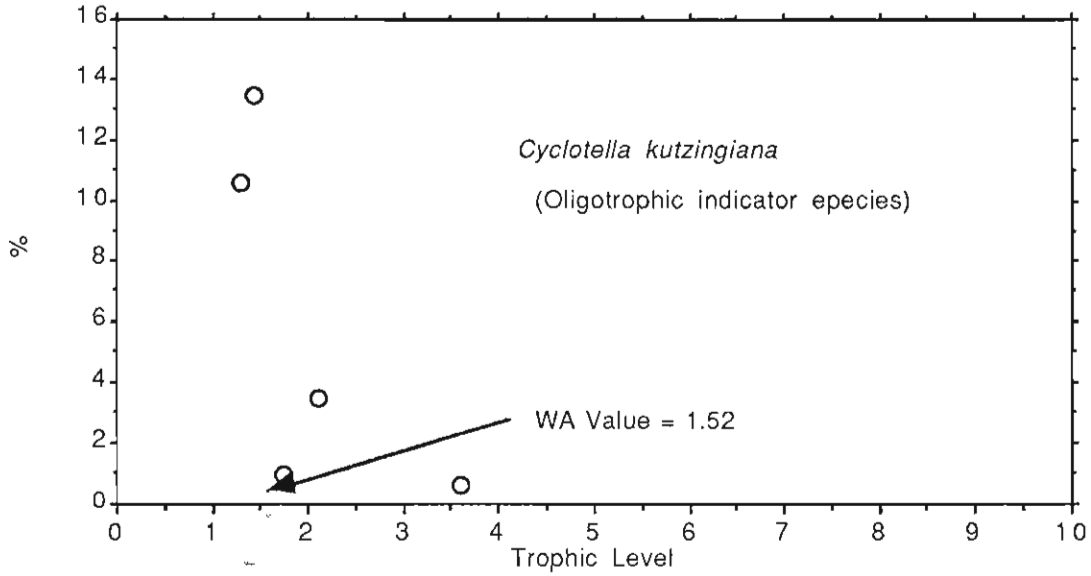


Fig. 26. The % abundance distribution and distribution optimum (WA Value) of *Cyclotella kutzingiana*, an oligotrophic indicator species, in 30 study lakes (for the numerical calculation of its WA value see appendix IV).

2. Oligomesotrophic indicator species

(Range of species autecological feature on trophic level: 1.81 ~ 3.0)

A total of 9 species from the 30 study lakes were determined to be oligomesotrophic (OM) indicators (Table 11). They were *Achnanthes conspicua, Asterionella ralfsii, Cyclotella glomerata, C. stelligera, Cymbella pusilla, Diploneis ovalis, Eunotia curvata* and *Melosira distans*.

Asterionella ralfsii (Plate 3, Fig. H) was reported to be a dystrophic species by Patrick and Reimer (1966). It was most abundant in my 30 study lakes that were characterized by low TP and Chl-a, and high SD (Figs. 9-12). Its distribution optimum was 2.58.

Cyclotella glomerata (Plate 2 Fig. E-F) was reported as oligotrophic by Hutchinson (1967), but was also found to be abundant in mesotrophic lakes by Kling and Holmgren (1972). It was found in 14 study lakes in which both TP and Chl-a values were low. Its distribution optimum on trophic level was 2.90.

The distribution pattern of *C. stelligera* (Plate 2 Fig. G) was wider than that of *Cyclotella glomerata*. It was found in 27 of the 30 study lakes. It was most abundant in oligomesotrophic lakes (Fig. 27). Its distribution optima on trophic level was 2.71. In previous studies, it was reported to be an oligotrophic indicator (Hutchinson 1967, Stockner 1971, Schindler and Holmgren 1977, Kling and Holmgren 1972) and reported as an eutrophic species (Cholnocky 1968).

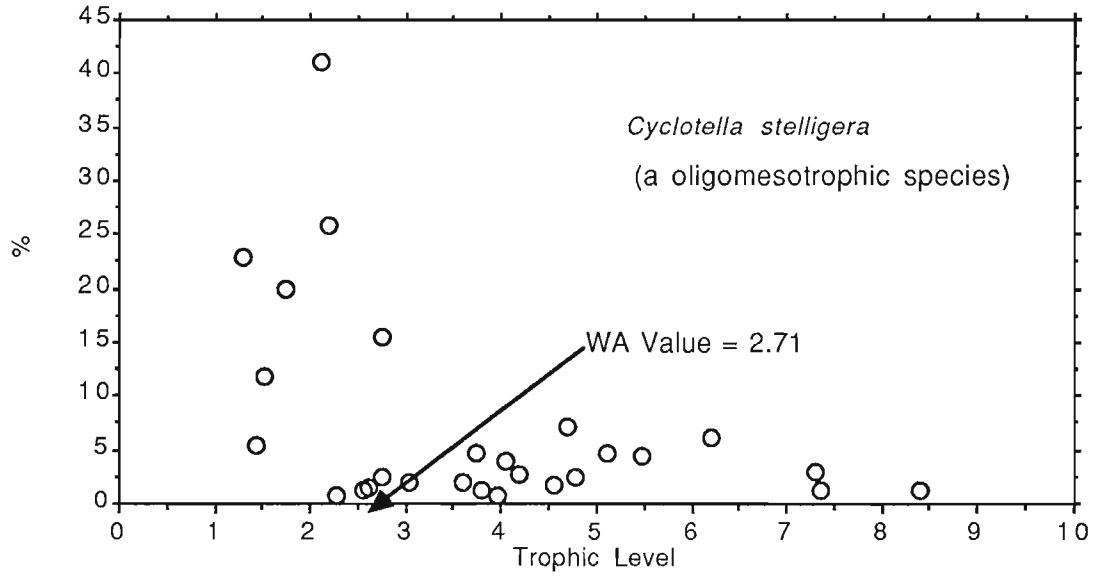


Fig. 27. The % abundance distribution and distribution optimum (WA Value) of *Cyclotella stelligera*, an example of oligomesotrophic indicator species, in 30 study lakes (for the numerical calculation of its WA value see appendix IV).

Eunotia curvata was found to be abundant both in oligotrophic and eutrophic lakes (Jorgenson 1948). It was found in only 5 of the study lakes and its percentage abundance was less than 5%. Its distribution optima on trophic level was 2.12.

In previous studies, *Melosira distans* ((Plate 1 Fig. D) was reported as oligotrophic (Foged 1964 and Hutchinson 1967) and mesotrophic (Kolkwitz 1915 and Patrick 1970). An abundant distribution was found only in oligotrophic lakes although it occurred in 10 of the study lakes which ranged from oligotrophic to eutrophic (Fig. 13). Its distribution optimum on trophic level was 2.55.

There was no trophic information available about *Achnanthes conspicua*, (Plate 5, Fig. D), *Cymbella pusilla* and *Diploneis ovalis* from previous studies. The percentage abundance of all three was less than 5% in study lakes for all three species. Their distribution optima on trophic level were 2.3, 2.81 and 2.71, respectively.

3. Mesotrophic indicator species

(Ranges of species autecological feature on trophic level: 3.01 ~ 4.20)

In 30 study lakes, 48 common species were classified as mesotrophic species based on their distribution optima on lake trophic level (Table 11).

Amphora ovalis (Plate 9 Fig. E-F) was found in 11 lakes with a distribution optimum of 3.76 on trophic level. Only Patrick (1970) reported this taxon as a mesotrophic species in previous studies.

Anomoeoneis serians was reported as an oligotrophic species by Stockner (1971). In this study, its abundance in the occurrence of 8 lakes was less than 5%. Its distribution optimum as a function of trophic level was 3.33.

Contradictory information of autecological features on trophic status about *Asterionella formosa* (Plate, Fig. G) was apparent in the literature. It was abundant in eutrophic lakes according to Hustedt (1930) and Haworth (1972); mesotrophic lakes according to Conroy et al. (1975), Kling and Holmgren (1972) and Patrick and Reimer (1966). This taxon is a very widely distributed species which is apparently tolerant of a wide range of trophic conditions (Stoermer et al. 1985). It occurred in all study lakes in this study, but it was most abundant in my oligomesotrophic and mesoeutrophic lakes (Fig. 13). Its distribution optimum as a function of trophic level was 3.82 (Table 11).

Cyclotella bodanica (Plate 2, Fig. A-C) was reported as an oligotrophic species in previous studies (Almer et al. 1974 and Hutchinson 1967). It was found in 27 lakes of this study and its distribution pattern was eurytypic. The most cases of abundant distribution were found from oligotrophic to mesotrophic lakes (Fig. 28). It was classified as a mesotrophic species in this study because its distribution optimum on trophic level was 3.29.

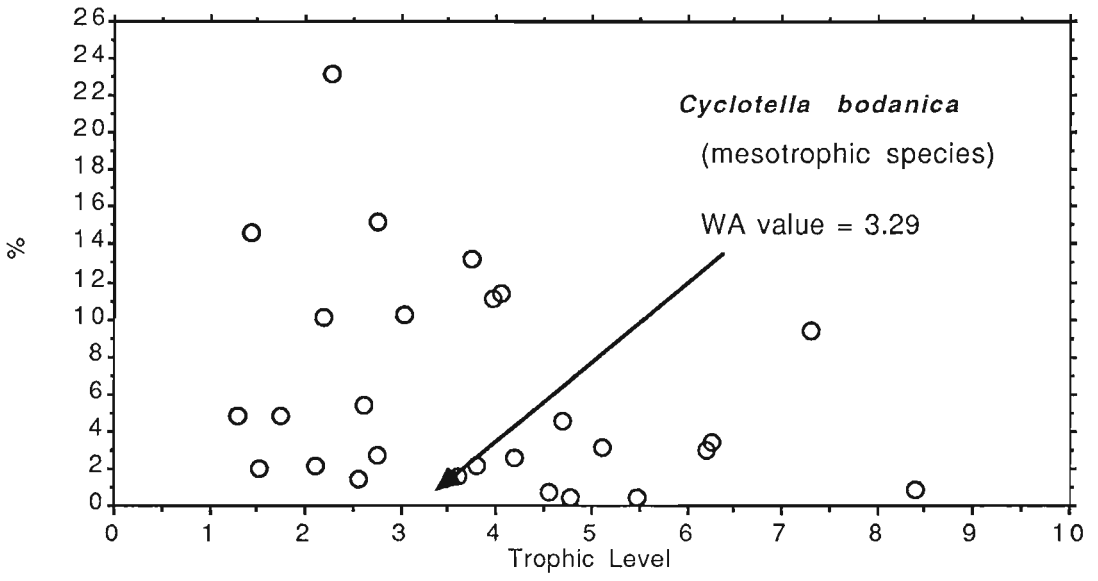


Fig. 28. The % abundance distribution and distribution optimum (WA Value) of *Cyclotella bodanica*, an example of mesotrophic indicator species, in 30 study lakes (for the numerical calculation of its WA value see appendix IV).

In previous studies, *Eunotia pectinalis* was found to be more abundant in oligotrophic lakes than in meso or eutrophic lakes (Jorgensen 1948, Patrick 1970). The distribution pattern of this species was also eurytypic in this study. However, it was classified as mesotrophic because its distribution optimum as a function of trophic level was 3.99 (Table 11).

Eunotia pectinalis var. ventricosa (Plate 5, Fig. B) was found abundant both in oligotrophic and eutrophic lakes (Patrick and Reimer 1966). In this study its abundance was less than 5% in 12 lakes and its distribution optimum as a function of trophic level was was 4.18 (Table 11).

From previous studies, *Fragilaria construens* was apparently tolerant of a wide range of trophic conditions and was classified as oligotrophic

(Patrick 1970), mesotrophic (Kling and Holmgren 1972) and eutrophic species (Hustedt 1938-1939). It was found in 8 of my study lakes (the relative abundance of its occurrence < 5%) and its Its distribution optimum as a function of trophic level was 3.91 (Table 11).

Fragilaria construens var. venter (Plate 3, Fig. E-F) was reported as an oligotrophic species (Reynolds and Allen 1968) and as a mesotrophic species by Patrick and Reimer (1966). It was found in 20 of my study lakes and was most abundant in my mesotrophic lakes (Fig. 13). Its distribution optimum as a function of trophic level was 3.29 (Table 11).

Fragilaria crotonensis in previous studies was found most often in oligotrophic lakes (Kolwitz 1914), mesotrophic lakes by Patrick and Reimer (1966) and eutrophic lakes by Hustedt (1930). It was found in 13 of my study lakes and its distribution optimum as a function of trophic level was 3.29 (Table 11).

Fragilaria pinnata (Plate 5, Fig. D) was reported as a mesotrophic species by Patrick (1970) and a eutrophic species by Hustedt (1938-1939) and Jorgensen (1948). In this study, it occurred in 8 lakes and its distribution optimum as a function of trophic level was 3.63.

Only one source of information on the trophic status of *Frustulia rhomboides* (Plate 7, Fig. E & G) was available (Jorgensen 1948). Jorgensen classified it as an oligotrophic species. It occurred in 22 of my study lakes and its distribution optimum as a function of trophic level was 3.7.

Melosira ambigua was found in both oligotrophic (Cholnocky 1968, Hustedt 1938-1939 and Patrick 1970) and eutrophic lakes (Hustedt 1930, 1949 and 1957). It was found in 7 of my study lakes and its distribution optimum as a function of trophic level was 3.38 (Table 11).

Previously published trophic information about *Navicula bacillum* and *N. lanceolata* reported them as eutrophic species (Jorgensen 1948). Both occurred in 5 of my study lakes and their distribution optima as a function of trophic level was 3.48 and 3.73, respectively.

In previous studies, *Navicula cryptocephala* (Plate 6, Fig. G) *N. radiosa, N. subhamulata, Pinnularia gentilis, P. viridis* (Plate 8, Fig. A-C) and *Synedra acus* were reported as mesotrophic species (Patrick 1970, Patrick and Reimer 1975, Kling and Holmgren 1972). The classification of the above species for their trophic categories in this study confirms the previous results.

Nitzschia linearis was reported as a eutrophic species (Jorgensen 1948). In this study its abundance was less than 5% in 8 of my study lakes and its distribution optimum as a function of trophic level was 4.0 (Table 11).

Nitzschia palea (Plate 10, Fig. B), *Pinnularia maior* (Plate 10, Fig. D) and *P. microstauron* (Plate 9, Fig. B) were found to be fairly abundant in both oligotrophic and eutrophic lakes (Hustedt 1938-1939, Jorgensen 1948, Cholnoky 1968, Patrick 1970 and Patrick and Reimer 1975). In this study, distribution optima as a function of trophic level was 3.24, 3.81 and 4.1, respectively (Table 11).

Stauroneis anceps (Plate 6, Fig. H) was tolerant both in oligotrophic (Cholnoky 1968, Hustedt 1938-1939 and Patrick 1970) and eutrophic conditions (Hustedt 1930, 1949 and 1957). It was found in 26 lakes and its distribution optimum as a function of trophic level was 3.87 (Table 11).

There was no trophic information from the literature available for 24 additional species which I identified. These were *Achnanthes linearis, A. marginulata* (Plate 5, Fig. E), *Amphicampa hemicyclus* (Plate 5, Fig. C),

Amphora nomanii (Plate 9, Fig. G), *Anomoeoneis serians var. branchysira* (Plate 7, Fig. C-D), *Cymbella naviculiformis* (Plate 9, Fig. D), *C. ventricosa* (Plate 9, Fig. C), *Eucocconeis flexella* (Plate 5, Fig. F-H), *Eunotia exigua, E. flexuosa, E. tenella, E. trinacria, Fragilaria virescens, Frustulia vulgare, Melosira distans var. alpigena, M. lirata* (Plate 2, Fig. D), *Navicula scutiformis, Neidium affine, N. iridis* (Plate 6, Fig. A-B), *Nitzschia romana* (Plate 10, Fig. A), *Pinnularia braunii, P. interrupta, Surirella linearis* (Plate 10, Fig. G) and *Surirella robusta* (Plate 10, Fig. E).

4. Mesoeutrophic indicator species

(Range of Mesoeutrophic indicator species autecological features as a function of trophic level: 4.21 ~ 5.40)

A total of 22 mesoeutrophic indicator species were classified as mesoeutrophic in this study. Trophic status from the literature was available for only 9 of these taxa.

In previous studies, both *Gomphonema parvulum* and *Nitzschia dissipata* were reported as eutrophic species (Patrick 1970 and Jorgensen 1948). In this study, their distribution optima as a function of trophic level were 5.25 and 4.27, respectively (Table 11).

Melosira islandica and *Pinnularia gibba* (Plate 9, Fig. A) were common both in oligotrophic (Hustedt 1930 and Cholnoky 1968) and eutrophic conditions (Kling and Holmgren 1972, Jorgensen 1948). *Melosira islandica* was found in 6 of my study lakes and *Pinnularia gibba* was found in 12 lakes. Their distribution optimum as a function of trophic level were 4.97 and 4.54, respectively (Table 11).

Melosira italica (Plate 1, Fig. G-H) was reported as a mesotrophic species by Patrick (1970) and an oligotrophic species by Kling and Holmgren (1972). In this study, it occurred in 18 of my study lakes and it was most abundant in my oligomesotrophic to eutrophic lakes (Fig. 13). Its distribution optimum as a function of trophic level was 4.59. .

Navicula pupula (Plate 6, Fig. A-B) was abundant both in mesotrophic lakes (Kling and Holmgren 1972) and eutrophic lakes (Patrick 1970). In this study, it occurred in 24 lakes and its distribution optimum as a function of its trophic level was 4.24 (Table 11).

Similar to *Navicula pupula, Stauroneis phoenicenteron* was also reported as a mesotrophic species by Hustedt (1938-1939) and Jorgensen (1948), and a eutrophic species by Patrick (1970). In this study, it occurred in 16 lakes and its distribution optimum as a function of its trophic level was 4.3 (Table 11).

Contradictions of autecological features as a function of trophic status for *Tabellaria fenestrata* (Plate 4, Fig. D-E) were apparent in the literature. It was reported both as a eutrophic species (Patrick and Reimer 1966) and as a mesotrophic species (Conroy et al. 1975, Kling and Holmgren 1972 and Schindler and Holmgren 1971). This taxon is a very widely distributed species which is apparently tolerant of a wide range of trophic conditions. It occurred in all of my study lakes, but was most abundant in mesotrophic to eutrophic lakes (Fig. 29). It was classified as a mesoeutrophic species because its distribution optimum as a function of its trophic level was 4.32.

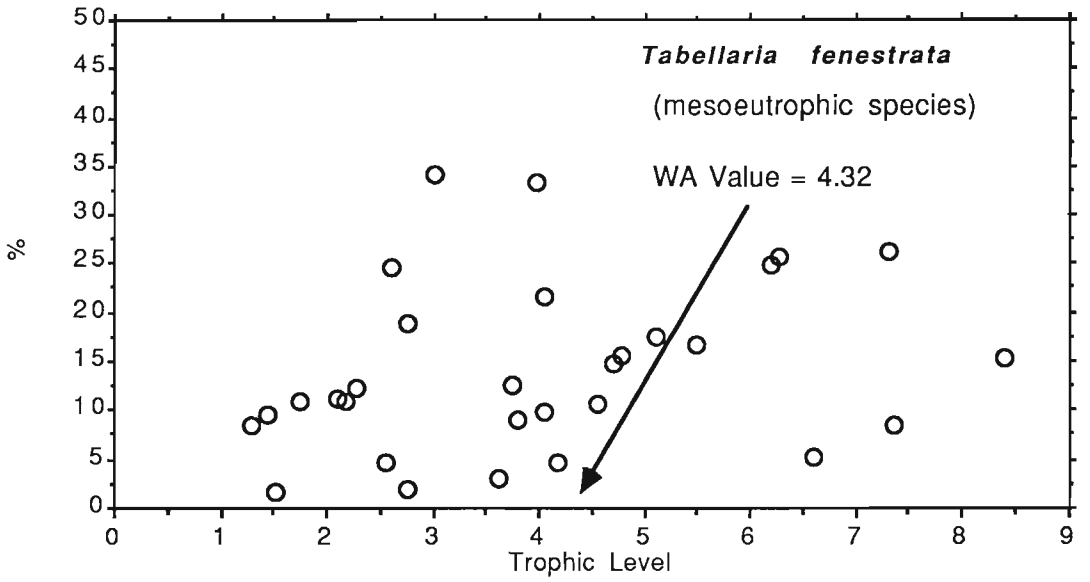


Fig. 29. The % abundance distribution and distribution optimum (WA Value) of *Tabellaria fenestrata*, an example of mesoeutrophic indicator species, in 30 study lakes (for the numerical calculation of its WA value see appendix IV).

Previous trophic information about *Tabellaria flocculosa* (Plate 4, Fig. A-C) classified it as occurring abundantly both in oligotrophic and mesotrophic lakes (Patrick and Reimer 1966, Schindler and Holmgren 1971, Kling and Holmgren 1972, Koppen 1978). The distribution pattern of this species in this study was characteristically eurytypic. It was most abundant in mesoeutrophic to eutrophic lakes although It occurred in all lakes in this study (Fig. 13). Its distribution optimum as a function of its trophic level was 4.32 (table 10).

The following species were classified as mesoeutrophic. However, there was no trophic information available from the literature about these 13 species. These were *Achnanthes lanceolata, Cymbella amphicephala, C. scotica, Eunotia faba, Eunotia incisa, E. lunaris, E. praerupta* (Plate 4, Fig. F-

G), *E. robusta, E. sudetica, Fragilaria construens var. binodis, M. perglabra* (Plate 1, Fig. F), *Navicula coccconiformis* (Plate 6, Fig. C) and *Nitzschia acuta.*

5. Eutrophic indicator species

(Range of eutrophic indicator species autecological features as a function of trophic level: 5.40 ~ 10.0).

Six species were classified as eutrophic species in this study. In published studies, four of these species *Fragilaria capucina, Melosira granulata* (Fig. 30 and Plate 1, Fig. A), *M. granulata var, angustissima*

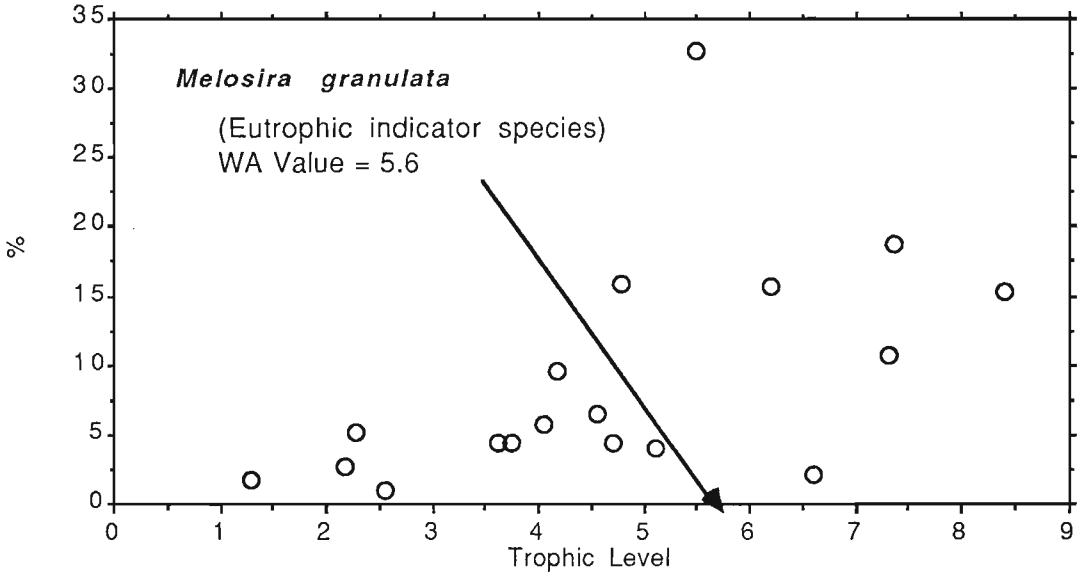


Fig. 30. The % abundance distribution and distribution optimum (WA Value) of *Melosira granulata*, an example of eutrophic indicator species, in 30 study lakes (for the numerical calculation of its WA value see appendix IV).

(Plate 1, Fig. B), *Pinnularia gentilis* and *Meridion circulata* were reported to be eutrophic species (Hustedt 1930, 1937-1938, 1957, Jorgensen 1948, Foged 1964, Hutchinson 1967, Patrick 1970, and Kling and Holmgren 1972). The classification of the above species as a function of their trophic categories in this study conformed to previous results. There was no trophic information available from the literature about *Eunotia kocheliensis* and *Fragilaria constricta*. The percent abundance of both were less than 5% in my study lakes. Their distribution optima as a function of trophic level was 6.8 and 5.64, respectively (Table 11).

III. Hypothesis test of two established models between diatom assemblages and lake trophic status

(a) The correlation between observed and diatom inferred tropic levels

After the relationship between diatom assemblages and lake trophic status from 30 study lakes was investigated, two statistical models which reflected this relationship were obtained by using the single and multiple regression methods:

(1). Single regression method

Trophic Level of lake = 2.643 - 7.575 log (Index D)

($r = 0.88$ $r^2 = 0.77$ $P = 0.0001$; $n = 30$)

(2). Multiple regression method

Trophic Level of lake = 4.286-0.076**O**%-0.055**OM**%-
0.026**IND**%+0.033**ME**%+0.065**E**%

($r=0.89$, $r^2=0.79$, $P=0.0001$, $n=30$)

Because the diatom inferred trophic status was developed from the TL of each of the 30 study lakes, it came as no surprise that the two indices of lake trophic level (TL and index D) were statistically correlated and that their correlation coefficient was relatively high. To really test the model, it was necessary to apply the two equations developed on the 30 study lakes (TL and index D) to another group of 20 new lakes in order to determine whether the diatom inferred trophic levels (index D) were correlated with the water chemistry calculated trophic levels (TL) as computed from TP, Chl-a and SD for the MOE data provided for the 20 new lakes.

To carry out this test, the surface sediment diatoms were counted in the new group of 20 lakes and the (Index D) equation (developed as described above from the initial 30 study lakes) was used to determine whether the 20 new lakes were eutrophic, mesotrophic or oligotrophic. Once this diatom inferred trophic information for the new study lakes was calculated (from Index D or directly multiple regression of 5 diatom trophic categories). It was possible to determine the trophic status of each of the 20 new lakes solely on the basis of their, Secchi, chlorophyll and phosphorus data. Once their TL was calculated it was possible to compare the TL value for each of the new lakes with their diatom inferred trophic status.

For this reason, the diatom assemblages from another 20 lakes were analyzed (Appendix 3-4). The autecological features of the 86 common diatom species which were determined from the previous 30 study lakes were also applied for these species occurring in 20 test lakes. The percentage abundance for five diatom trophic groups, value of Index D, and diatom predicted trophic level which both inferred by single and multiple regression methods were obtained for each of 20 test lakes (Table 15).

Lake Name	% of **O** species	% of **OM** species	% of **M** species	% of **ME** species	% of **E** species	sum of 5 groups	Index D	Inferred TL by sing. regr.	Inferred TL by mult. regr.	mea-sured TL
Kashe	0	8.99	34.11	29.29	14.15	86.54	.56	4.57	4.79	4.7
Ben	0	8.52	52.32	20.1	2.71	83.65	.81	3.34	3.3	3.5
Ryde	0	6.51	25.58	29.5	35.67	97.26	.35	6.06	6.55	6.2
Weismuller	0	7.51	25.77	32.69	17.38	83.35	.44	5.35	5.41	5.32
Pine	0	7.96	42.82	28.32	7.61	86.71	.64	4.09	4.16	3.9
Sosseau	9.1	0.9	48.06	31.95	0	90.01	.73	3.7	3.35	4.1
Ada	0	3.75	34.31	28.24	27.14	93.44	.42	5.46	5.88	5.8
Mckay	2.48	26.99	43.68	18.32	5.24	96.71	1.09	2.37	2.42	2.5
Gull	0	0	82.75	12.51	0.46	95.72	.86	3.12	2.58	2
Clear Water	0	9.68	49.84	17.58	19.42	96.52	.69	3.88	4.3	3.8
Menominee	0	8.86	41.91	21.23	26.99	98.98	.56	4.53	5.16	4.5
Wildcat	0	9.86	61.94	22.14	3.64	97.57	.82	3.3	3.1	2.8
Simoce	0.44	0	27.33	6.14	8.04	41.95	.67	3.96	4.27	4.2
Gold City	0	12.44	49.95	21.87	7.59	91.86	.79	3.44	3.52	5.94
Baxter	0	8.95	32.62	32.77	23.65	97.99	.47	5.15	5.56	5.12
Healey	0	10.56	39.69	25.86	17.4	93.51	.61	4.29	4.66	4.8
Henshaw	1.08	6.19	64.25	21.21	3.56	96.29	.8	3.36	3.12	3
Hammel Bay	0	5.8	43.31	21.59	23.07	93.77	.56	4.56	5.05	4.9
Waseosa	12.23	0.57	18.78	22.47	4.97	59.02	.68	3.9	3.9	3.8
Horseshoe	0	6.52	73.44	15.5	0.49	95.95	.89	3.01	2.56	2.2

Table 15. The relative (%) abundance of five diatom groups observed in the surface sediment samples from profound of 20 testing lakes, and the comparison of measured trophic level with diatom predicted trophic levels of these 20 lakes, which inferred by both single and multiple regression methods.

A strong relationship was found between the measured trophic level (TL) and the diatom inferred trophic level when these inferred trophic level values were plotted against the corresponding measured trophic level values (Figs. 25 & 26). Both correlations were statistically significant ($P < 0.0001$). The correlation coefficient (r^2) of the measured trophic level to diatom inferred trophic level by single and multiple regression methods were 0.68 and 0.73, respectively with 18 degrees of freedom (Figs. 25 & 26).

Although both correlation coefficients were not as high as expected, the variation in diatom assemblage reflected by correlation coefficients were not unreasonable. There are several possible reasons:

1. The environment of a lake is a very complicated ecosystem. The occurrence and abundance of any plant or animal species is affected by many environmental factors. Lake trophic status is not the only factor influencing diatom assemblages. The many previous studies had demonstrated that other environmental factors such as pH, water color, temperature and heavy metal were also correlated with the diatom species composition and abundance (e.g. Taylor et al. 1986, Smol 1989).

2. Diatom assemblages and water chemical values in lake ecosystems have spatial and temporal variability (Jones and Flower 1986, ter Braak and van Dam 1989). This variability would be problematical in very shallow and humic lakes such as Golden City Lake. As a result, the diatom inferred trophic level both by single and multiple regression methods of this lake was unrealistically low compared with other lakes. Both correlation coefficients were improved to above 0.9 (r^2) if Golden City Lake was excluded.

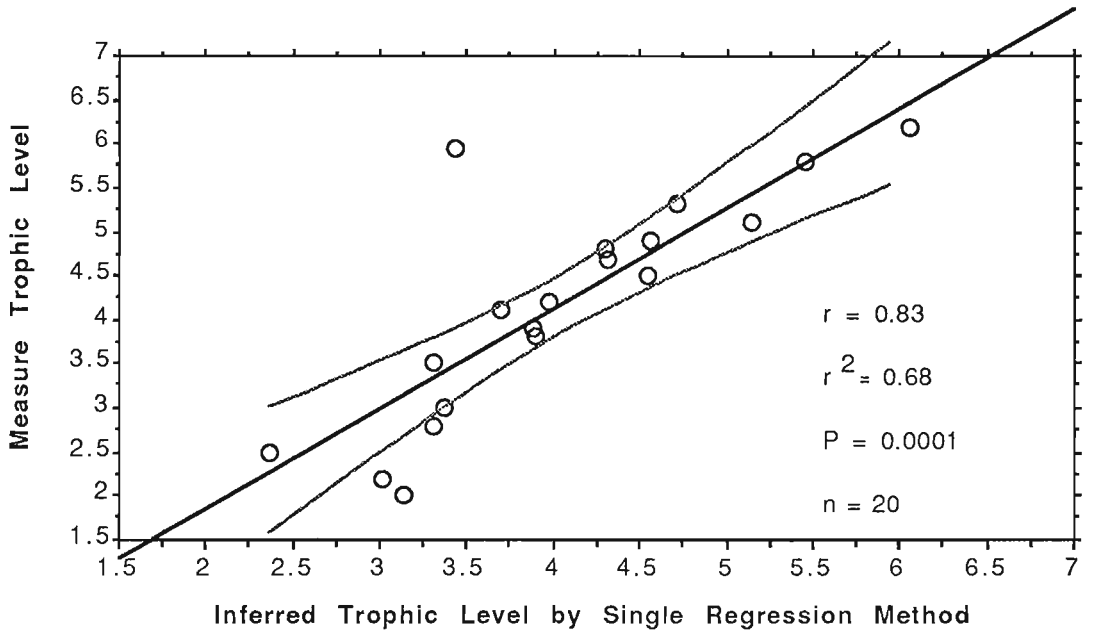


Fig. 25. Inferred lake trophic level, derived from the single regression method, vs. measured trophic level, computed from values of TP, Chl-a and SD of MOE data for 20 testing lakes, and two curves represented the boundary lines at 95% confidence level.

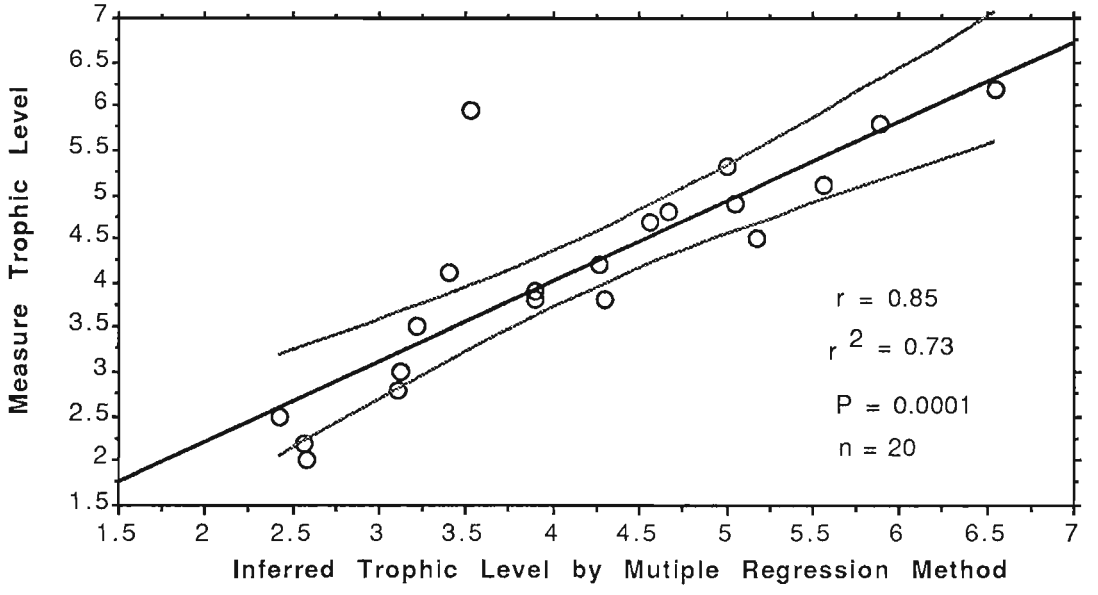


Fig. 26. Inferred lake trophic level which derived from multiple regression method vs. measured trophic level which computed from values

of TP, Chl-a and SD of MOE data for 20 testing lakes, and two curves represented the boundary lines at 95% confidence level.

3 The number of lakes used for testing the observed models was relative small (n=20). The testing correlation coefficient could be increased if time permitted me to study diatom assemblage from a few more lakes.

(b). Multiple versus single regression analysis comparisons

The correlation between measured trophic level and diatom inferred trophic level derived from multiple regression had a higher coefficient value (r^2=0.73) than the one derived by single regression (r^2=0.68). The possible reason for this was that surface sediment diatom samples contained the fossil diatoms which accumulated over several years. Therefore, the multiple regression analysis of five diatom trophic groups observed from surface sediment samples may reduce the regression variation which resulted for the above reason. An analogous situation was found in pH and diatom correlation studies in which multiple pH-readings were better than single pH-readings (Davis and Anderson 1986, ter Braak and van Dam 1989).

(c). A comparison this approach with previous studies

A detailed discussion of the four types of methodology using diatoms to indicate both present and past trophic status has been described in my literature review section. Those are: (1) Inferring trophic status by some indicator species; (2) by ratios of diatom taxonomic groups; (3) by trophic indexes with single regression and (4) by using multiple regressions.

Because the pattern of diatom distributions corresponding to lake trophic status does not appear at family or class taxonomic levels, reconstruction methods which are based on the ratios of diatom taxonomic groups such as C : P ratio (Nygaard 1949) and A : C ratio (Stockner and Benson 1967) were not as appealing in both theory and practice as those based on the autecology of the individual diatom species (e. g. Duthie and Sreenivasa 1971; Stockner 1972; Brugam 1979; Ennis et al. 1983; Wetzel 1983). Since a reliable quantitative model for diatom assemblages and lake trophic status is still not available, the traditional species-indicator method for tracing the trophic history of lakes, is still found in the most recent literature (Stoermer et al. 1988, Scherer 1988, Rawlence 1988. Earle et al 1988).

The multiple regression method for establishing the nature of the relationship between diatoms and lake trophic status is relatively new. Both single and multiple regression methods for the correlation between diatom assemblage and lake trophic status were developed only in recent years (Agbeti 1987, Christie 1988, Agbeti and Dickman 1989). Their approach pointed out the direction for further research although it appears to have had some disadvantages in terms of diatom autecology and hypothesis testing.

Comparison of this study to the previous approaches, indicated that the major differences were:

1. In this study, the lake trophic status was considered to be influenced by various physical, chemical and biological factors (Carlson 1977). Therefore, trophic status could not be evaluated by examining only one or two parameters. The trophic parameter was recognized as a multidimensional one (Brezonik and Shannon 1971; Michalski and Conroy 1973, Bold 1976, Yoshimi 1987). For this reason, new multiple parameters were developed and used to correlate with the diatom assemblages observed in this study. In the studies of Agbeti and Christie, lake trophic status was evaluated by an individual single parameter such as TP or Chl-a (Agbeti 1987, Christie 1988).

2. In this study, the autecological relationship of diatom species and lake trophic status was investigated. Such an investigation is an important basis for the establishment of a statistical model for the relationship between diatoms and lake trophic status. It is not reliable if the autecological features of diatom species were based on the contradictory information from the literature as was the case for Agbeti (1987). In the case of Christie, autecological research from 37 lakes of known trophic status was made. However, it was difficult to distinguish the boundary limit for each of the 5 diatom trophic groups (Christie 1988).

3. As was discussed previously, once the transfer functions were obtained from the diatom studies of one group of lakes it was possible to test the model using another group of lakes. Unfortunately, this was not done in Agbeti's approach (Agbeti 1987). In the case of Christie, the trophic level assignment for each diatom species was based on 37 study lakes. Unfortunately, the same 37 study lakes were then used a second

time to test the model which was generated by calculating the diatom inferred trophic levels (Christie 1988). This results in a circular argument (i.e. a tautology).

In this study, the close agreements between measured and diatom inferred trophic level both by single and multiple regression methods were examined in another 20 study lakes. As such, the two transfer function models between diatoms and lake trophic status were found to be statistically significant.

CONCLUSIONS

Surface sediment diatoms of 50 Muskoka-Haliberton lakes were analyzed in order to establish a relationship between the lake trophic status and their subfossil diatoms. To achieve this goal, additional investigations dealing with how to evaluate lake trophic status and how to determine the autecological feature of diatom species were carried out. The following main conclusions were obtained in this study:

1. When the trophic level values of the 30 lakes were regressed against their five corresponding diatom trophic groups, two mathematical equations for expressing the assumed linear relationship between the diatom assemblages composition were derived by

   (1) using a single regression technique:

   Trophic level of lake (TL) = 2.643 - 7.575 log (Index D)

   ($r = 0.88$ $r^2 = 0.77$ $P = 0.0001$; $n = 30$)

   Where, Index D = (O% + OM% + M%)/(E% + ME% + M%);

   (2) using a multiple regression technique:

   TL=4.285-0.076 O%- 0.055 OM% - 0.026 M% + 0.033 ME% + 0.065 E%

   ($r=0.89$, $r^2=0.792$, $P=0.0001$, $n=30$)

   There was a significant correlation between measured and diatom inferred trophic level both by single and multiple regression

methods were ($P < 0.0001$, n=20), when both models were applied in another 20 testing lakes. Their correlation coefficients (r^2) were also relatively high. As such, the two transfer function models between diatoms and lake trophic status were significantly correlated.

2. A new multiple index was proposed and used in the classification of 85 Ontario lakes for lake trophic status, by the computation of the physical, chemical and biological data, provided by OME. By using this new trophic parameter, the lake trophic level can be determined by:

$$TL = 1.37 \ln[1+(TP \times Chl\text{-}a / SD)].$$

The new trophic multiparameter is reasonable for a unifying determination of true trophic states of lakes. It is useful for understanding the characteristics of lakes and their comprehensive trophic states. The clear boundaries between 7 lake trophic categories (Ultraoligotrophic lake: 0-0.24; Oligotrophic lake: 0.241-1.8; Oligomesotrophic lake: 1.81-3.0; Mesotrophic lake: 3.01-4.20; Mesoeutrophic lake: 4.21-5.4; Eutrophic lake: 5.41-10; Hyper-eutrophic lake: above 10) make this new trophic parameter more convenient for management of water quality, communication to the public and comparison of trophic status in different lakes.

3. Based on the investigation of the diatom composition and the variety of its abundance in 30 study lakes, the distribution optima of diatom species were determined, by using a quantitative method called weight averaging (Charles 1985). The resulting documentation of diatom species autecological features made the regression

analysis between diatom assemblages and lake trophic status statistically significant.

This study indicated that the diatom assemblages were sensitive to the changes of lake trophic status. The two above models were significantly established after they were applied and tested in another group of 20 lakes. As indicators of lake trophic status, diatoms are especially useful in situations where no local trophic information is available and in studies of the paleotrophic history of lakes. From the above, a theory was developed in this study which refers to ecological knowledge of diatoms in reflecting and assessing water quality and lake trophic status.

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APPENDIX I: Photographs of some study lakes taken during field sampling.

A: Clear Lake, an oligomesotrophic lake.

B (below): Lake Simcoe, a mesoeutrophic lake.

C: Wildcat Lake, an oligomesotrophic lake

D: Gravenhurst Bay (mesotrophic) on Muskoka Lake

E: Heeney Lake, an oligotrophic lake

F: Hersners Lake, an eutrophic brown water lake

Appendix II: Abundance distribution (%) of diatom species observed from 30 study lakes. No. (1-30) correspond to the names of the study lakes (see Tab. 8).

Diatom Taxa	No. of study lake									
	1	2	3	4	5	6	7	8	9	10
Achnanthes biasolettiana	•	•	•	•	•	•	•	•	•	0.45
A. conspicua	•	•	•	•	•	•	1.1	•	•	•
A. exigua	•	•	1.73	•	•	•	•	•	•	•
A. gibberula	•	•	•	•	•	•	•	•	•	•
A. lanceolata	•	•	0.63	•	•	•	•	•	0.79	•
A.lanceolata v. elliptica	•	•	•	•	•	•	•	•	•	•
A. linearis	•	•	0.31	0.41	0.94	0.84	0.41	0.48	•	•
A. marginulata	•	•	0.79	0.81	1.57	•	0.18	•	0.63	•
A. oestrupii	•	•	•	•	•	•	0.35	•	•	•
A. peragallii	•	•	•	•	•	0.34	•	•	•	•
Actinella punctata	•	•	•	•	•	•	•	•	•	•
Amphicampa hemicyclus	•	0.28	•	•	•	•	•	0.48	•	•
Amphora nomanii	•	•	•	•	•	•	•	0.32	•	0.15
A. ovalis	•	•	0.31	•	•	•	0.7	•	0.06	0.3
Anomoeoneis exilis	•	•	•	•	•	1.34	1.19	•	0.38	•
A. follis	•	•	•	•	•	•	0.23	•	•	•
A. serians	•	•	•	•	•	•	0.37	•	•	0.3
A. serians v. brachysira	0.32	1.39	0.31	5.55	•	2.18	•	0.67	1.32	•
A. vitrea	•	•	•	•	•	•	•	•	•	•
Asterionella formosa	4.05	2.23	8.65	0.27	5.49	4.7	8.49	2.75	5.61	11.79
A. ralfsii	•	•	•	•	•	•	•	•	•	2.84
Caloneis bacillum	•	•	•	•	•	•	0.41	•	•	•
C. silicula	•	•	•	•	•	•	•	•	•	•
Ceratoeis arcus v.linearis	•	•	•	•	•	•	•	•	•	•
Cocconeis disculus	•	•	•	•	•	•	•	•	•	0.3
C. placentula	•	•	•	•	1.41	•	•	•	•	•
Cyclotella bodanica	0.81	•	9.43	•	3.45	3.02	11.43	0.49	3.17	0.45
C. comensis	•	•	•	•	•	•	•	•	•	•
C. glomerata	•	•	•	•	•	•	•	•	•	1.64
C. kuetzingiana	•	•	•	•	•	•	•	•	•	•
C. meneghiniana	•	•	•	•	•	•	•	•	•	•
C. michiganiana	•	•	•	•	•	•	•	•	•	0.3
C. ocellata	•	•	•	•	•	•	•	•	•	•
C. stelligera	1.29	1.12	2.83	•	•	6.04	3.98	4.49	4.67	2.54
Cyclostephanos dubius	•	•	•	•	•	•	•	•	•	•
Cymbella acuticuscula	•	•	•	•	•	•	•	•	•	•
C. amphicephala	•	•	0.31	1.76	•	•	•	•	1.31	•
C. brehmii	•	•	•	•	•	•	•	•	•	•
C. cesati	•	•	•	•	•	•	•	•	•	•
C. cistula	•	•	•	•	•	•	•	•	•	•
C. cuspidata	•	•	•	•	•	•	•	•	•	•
C. hauckii	•	•	•	•	•	•	•	•	•	•
C. hybridica	•	•	•	2.98	•	•	•	•	•	•
C. lunata	•	•	•	•	•	•	•	•	•	•
C. microcephala	•	•	•	•	•	•	0.21	•	•	•
C. naviculiformis	•	•	•	•	•	•	0.47	0.32	•	0.3
C. pusilla	•	•	•	•	•	•	•	•	•	•
C. sotica	1.13	0.98	•	4.06	•	1.34	0.51	0.65	1.11	•
C. ventricosa	•	0.7	0.63	5.82	•	1.17	0.65	0.92	1.74	0.45
Diploneis elliptica	•	•	0.31	•	0.31	•	•	•	•	•
D. oculata	•	•	•	•	•	•	•	•	•	•
D. ovalis	•	•	•	•	•	•	0.09	•	•	0.15

Appendix II continued

Diatom Taxa	No. of study lake									
	1	2	3	4	5	6	7	8	9	10
D. paella	•	•	•	•	•	•	•	•	•	•
Eucocconeis flexella	•	•	•	0.27	•	•	0.6	•	0.4	•
Eunotia alpina	•	•	•	•	•	•	•	•	•	•
E. arcus	•	•	•	•	•	•	•	•	•	•
E. bidentula	•	0.28	•	•	•	•	0.28	•	•	•
E.biggiba v. pumila	•	•	•	•	•	•	•	•	•	0.3
E. curvata	•	•	•	•	0.16	•	•	•	•	•
E. diodon	•	•	•	•	•	•	•	•	•	•
E. elegans	•	•	•	•	•	•	•	•	•	•
E.exigua v. compacta	•	•	•	•	•	0.67	•	•	0.77	1.04
E. faba	•	0.28	•	2.17	•	•	•	0.44	0.68	•
E. flexuosa	•	1.26	•	1.08	•	1.01	•	•	•	•
E. incisa	•	2.93	1.57	4.74	1.1	1.51	2.23	1.57	0.73	2.99
E. indica	•	•	•	•	•	•	•	•	•	•
E. kochielenensis	1.29	3.07	0.47	•	•	•	•	•	0.36	•
E. lunaris	0.32	•	0.31	2.17	•	•	0.7	0.32	0.57	•
E. lunaris v.capitata	•	•	•	•	•	•	•	•	•	•
E. leochelinensis	•	•	•	•	•	•	•	•	•	•
E. nalgelii	•	•	•	•	•	•	•	•	•	•
E. parallela	•	•	•	•	0.31	•	•	•	•	•
E. pectinalis	0.65	2.37	0.31	6.09	3.92	7.38	6.19	2.87	1.99	1.19
E.pectinalis v.ventralis	0.32	3.21	•	•	•	2.35	•	0.6	•	1.34
E.praerupta v.bidens	•	•	•	•	•	•	•	•	•	1.64
E.praerupta v.inflata	•	•	•	2.57	•	•	0.42	2.43	•	0.3
E. robusta	•	2.51	0.31	•	0.16	0.67	0.28	0.7	0.66	•
E. septenottrionalis	•	•	•	•	•	•	0.29	•	•	•
E. sudetica	•	•	•	4.47	•	•	3.29	1.94	•	•
E.sudetica v.bidens	•	•	•	•	•	•	•	•	•	•
E. tautoniensis	•	•	•	•	•	•	•	•	•	•
E. tenella	0.49	•	•	•	•	0.84	0.56	•	•	•
E. trinacria	•	0.56	0.31	1.49	•	•	•	0.65	•	•
E. valida	•	•	•	•	•	•	•	•	•	•
E.vanheurckii v.intermedia	•	•	•	•	•	•	•	•	•	•
Fragilaria brevistrata	•	•	•	•	•	•	•	•	•	0.15
F. capucina	2.75	•	5.19	•	•	0.34	0.94	•	•	•
F. construens	•	0.28	•	•	•	•	•	•	0.46	0.75
F.construens v.binodis	•	•	0.63	•	•	•	•	•	•	•
F.construens v.venter	3.07	•	•	•	7.06	1.34	3.36	•	4.25	2.24
F. crotonensis	•	•	4.25	•	•	0.5	1.71	•	0.73	1.49
F. magocsyi	•	•	•	•	0.31	•	•	•	•	•
F. pinnata	•	•	0.47	•	•	•	0.23	•	0.96	3.58
F. undata	0.65	1.67	•	•	•	0.5	•	0.48	0.41	0.15
F. vancheriae	•	•	•	•	•	•	•	•	•	0.15
F. virescens	0.65	7.11	•	•	•	1.17	0.47	1.9	8.88	0.3
Frustulia rhomboides	2.43	0.56	0.31	2.71	•	0.67	0.37	1.03	1.13	1.19
F. vulgare	•	•	•	2.3	•	•	•	•	•	•
Gomphonema acuminatum	•	•	•	•	•	•	•	•	•	•
G. angustatum	•	•	•	•	•	•	•	•	•	0.15
G. gracile	•	•	•	•	•	•	•	•	•	•
G. gravei	0.32	•	•	•	0.31	•	•	•	•	•
G. longiceps	•	•	•	•	•	•	0.41	•	•	•
G. parvulum	0.81	0.28	0.31	2.17	2.83	0.67	2.52	0.48	•	•
G.truncutum v.capitatum	•	•	•	•	•	•	•	•	•	•
Gyrosigma attenuatum	•	•	•	•	•	•	•	•	•	•
Hantzschia amphioxys	•	•	•	•	•	•	•	•	•	0.15
Melosira ambigua	•	•	3.14	•	•	•	•	•	•	•

Appendix II continued

Diatom Taxa	No. of study lake 1	2	3	4	5	6	7	8	9	10
Melosira distans	•	•	•	•	•	•	•	1.72	2.42	0.3
M.distans v.alpigena	0.65	•	•	•	•	•	1.42	•	•	1.34
M. granulata	15.21	18.83	10.69	2.17	•	15.77	5.68	32.72	3.95	15.82
M.granulata v.angustissima	11.65	10.32	4.72	0.95	22.61	3.02	•	1.89	0.81	7.01
M. islandica	0.65	1.12	•	•	•	•	•	•	•	•
M. italica	10.19	•	2.83	•	8.48	4.53	0.78	•	4.32	0.45
M. lirata	0.65	11.16	0.31	1.35	0.31	•	1.42	2.66	5.59	0.75
M. perglabra	3.72	6.42	•	•	•	0.84	•	0.54	3.67	•
Meridion circulare	•	0.28	1.89	•	1.1	0.5	1.25	•	•	2.09
Navicula amphibola	•	•	•	•	•	•	•	•	0.5	•
N. bacillum	•	•	•	•	•	•	•	•	•	•
N. bicapitallata	•	•	•	•	•	•	•	•	•	0.45
N. cocconiformis	1.13	•	•	2.3	•	0.67	1.28	1.03	0.68	•
N. cryptocephala	•	•	•	•	•	•	0.28	•	•	1.34
N. disjuncta	•	•	•	•	•	•	•	•	•	•
N. exigua	•	•	•	•	•	•	•	•	•	•
N. fragilarioides	•	•	•	•	•	•	•	•	•	•
N. gastrum	•	•	•	•	•	•	•	•	•	•
N. grimmei	•	•	•	•	•	•	•	•	•	•
N. gysingensis	•	•	•	•	•	•	•	•	•	•
N. hustedtii	•	•	•	•	•	•	•	•	•	•
N. lanceolata	•	•	•	1.89	•	•	0.2	•	•	•
N. lapidosa	•	•	•	•	•	•	•	•	•	•
N. laevissima	•	•	•	•	•	•	•	•	•	0.45
N. maculata	•	•	•	•	•	•	•	•	•	•
N. placentula	•	•	•	•	•	•	•	•	•	•
N. protracta	•	•	•	•	•	•	•	•	•	•
N. pseudoscutiformis	•	•	•	•	•	•	•	0.64	•	•
N. pupula	2.27	0.42	1.1	0.54	5.81	0.84	1.83	•	0.53	1.19
N. radiosa	0.97	1.12	0.79	7.17	1.73	1.68	0.7	0.43	2.84	0.75
N. scutiformis	•	•	•	•	•	•	0.56	•	•	•
N. simlex	•	•	•	•	•	•	•	•	•	•
N. sovereigae	•	•	•	•	•	•	•	•	•	•
N. subhamulata v.undulata	•	0.56	•	2.03	•	•	•	•	•	•
Neidium affine	•	0.56	0.31	2.03	•	•	•	0.86	1	•
N. alpinum	•	•	•	•	•	•	•	•	•	•
N.bisculcatum v.subundatum	•	•	•	•	•	•	•	•	•	•
N. dilatatum	•	0.42	•	•	•	•	•	•	•	•
N. iridis	0.32	•	•	0.81	•	•	0.78	•	0.52	•
N. productum	•	•	0.63	•	•	•	•	•	•	•
Nitzschia acuta	0.81	•	0.31	1.62	•	•	•	•	0.65	•
N. dissipata	1.29	0.56	•	0.68	•	•	0.64	0.33	0.4	0.15
N. frustulum	•	•	•	•	•	•	•	•	•	•
N. gracilis	•	•	•	•	•	•	•	•	•	0.3
N. hantzschia	•	•	•	•	•	•	•	•	•	•
N. ignorata	•	•	•	•	•	•	•	•	•	•
N. lacunarum	0.32	•	•	•	•	•	•	•	•	•
N. linearis	0.32	•	•	•	•	0.34	•	•	•	•
N. palea	•	•	0.31	0.95	•	•	0.27	0.48	•	0.6
N. romana	0.32	•	0.16	1.22	•	•	0.36	0.32	0.79	•
N. spectabilis	•	•	•	•	•	•	•	•	•	•
N. subtilis	•	•	•	0.41	•	•	•	•	•	•
N. vermiculare	•	•	•	•	•	•	•	0.32	•	•
Opephora martyi	•	•	•	•	•	•	•	•	•	•
Pinnularia abaujensis	•	•	•	•	•	•	•	•	•	•
P. acrosphaeria	•	•	•	•	•	•	•	•	•	0.3

Appendix II continued

Diatom Taxa	No. of study lake 1	2	3	4	5	6	7	8	9	10
P. accuminata	•	•	•	•	•	•	•	•	•	•
P. biceps	•	•	•	•	•	•	•	•	•	•
P. borealis	•	•	•	•	0.31	•	0.51	0.48	•	0.45
P. braunii	•	•	•	0.68	0.31	0.34	•	1.46	2.08	•
P. cardinalis	•	•	•	•	•	•	•	•	•	•
P. esoxe	•	•	•	•	•	•	•	•	•	0.15
P. formica	0.32	•	•	•	•	•	0.28	•	•	•
P. gentilis	•	•	•	•	•	•	•	•	•	•
P. gibba	0.32	0.42	•	•	•	1.17	0.23	•	0.94	•
P. interrupta	1.13	•	•	•	•	•	•	•	1.39	•
P. major	•	•	•	•	•	•	0.28	0.81	0.61	•
P. mesolepta	•	•	•	•	•	•	•	•	•	•
P. microstauron	0.49	•	0.79	2.03	•	•	•	2.59	•	•
P. polyonca	•	•	•	•	•	•	•	•	•	•
P. stomatophora	•	•	•	•	•	•	•	•	•	•
P. subcapitata	•	•	•	•	•	•	•	•	•	•
P. viridis	0.32	0.98	0.31	2.84	•	•	0.74	2	1.27	•
Stauroneis anceps	0.32	0.28	•	3.11	•	•	1.19	1.36	1.96	0.75
S. legumen	•	•	•	•	•	•	•	•	•	•
S. livingstonii	•	•	•	•	•	•	•	•	•	•
S. parvula	•	0.42	•	•	•	•	•	•	•	•
S. phoenicenteron	0.16	0.56	0.16	2.3	•	•	•	0.65	0.95	•
S. smith	•	•	•	0.95	•	•	•	•	•	•
S. staurolineata	•	•	•	•	•	•	•	•	•	•
Stenopterobia intermedia	•	0.28	•	•	•	•	•	•	•	•
Surirella angustata	•	•	•	•	•	•	•	•	•	•
Surerrilla biseriata	•	•	•	•	•	•	•	•	•	•
S. delicatissima	•	•	•	•	•	•	•	•	•	•
S. linearis	0.16	•	•	•	•	0.67	0.14	0.32	•	•
S. ovalis	•	•	•	•	•	•	•	•	•	•
S. ovata	•	•	0.47	•	•	•	•	•	•	•
S. robusta	•	0.7	•	0.27	•	0.5	0.43	2.32	0.96	0.3
Syneda acus	•	•	•	•	•	•	•	•	•	•
Synedra amphicephata	•	•	•	•	•	•	•	•	•	1.19
Synedra nana	•	•	2.2	•	•	•	•	•	•	•
S. parastica	•	•	•	•	•	•	•	•	•	•
S. tabulata	•	•	0.63	•	•	•	0.32	•	•	•
S. ulna	•	•	•	•	•	•	•	•	•	0.6
Tabellaria binalis	0.32	0.56	•	•	•	•	•	•	•	•
T. fenestrata	15.21	8.37	26.26	5.14	25.75	24.83	21.51	16.65	17.49	15.52
T. flocculosa	9.39	3.21	1.26	4.74	4.24	3.69	4.29	3.57	3.64	6.72

Appendix II continued

Diatom Taxa	No. of study lake									
	11	12	13	14	15	16	17	18	19	20
Achnanthes biasolettiana	•	•	•	•	•	•	•	•	•	•
A. conspicua	•	0.39	•	0.32	•	•	•	•	•	0.74
A. exigua	2.13	•	•	•	•	•	•	•	•	•
A. gibberula	•	•	•	•	•	•	•	•	•	•
A. lanceolata	•	•	•	•	•	•	•	0.75	•	•
A.lanceolata v.elliptica	•	•	1.54	•	•	•	•	•	•	•
A. linearis	1.85	0.26	0.98	•	1.38	•	1.4	0.5	0.67	0.89
A. marginulata	•	•	1.82	•	0.69	•	•	1	1.52	0.44
A. oestrupii	•	•	•	•	•	•	•	•	•	•
A. peragallii	•	•	•	•	•	•	•	0.25	•	•
Actinella punctata	•	•	•	•	•	•	•	•	•	•
Amphicampa hemicyclus	•	•	•	•	•	0.95	•	•	•	0.3
Amphora nomanii	0.99	•	•	•	•	0.47	•	0.5	0.34	•
A. ovalis	•	0.26	0.28	•	•	•	0.34	0.87	1.18	•
Anomoeoneis exilis	•	•	•	•	•	•	•	2.62	•	•
A. follis	•	•	•	•	•	•	•	•	•	•
A. serians	0.28	0.39	•	3.18	•	•	•	•	•	2.81
A.series v.brachysia	•	•	0.7	•	•	•	•	5.49	•	•
A. vitrea	•	•	•	•	•	•	•	•	•	•
Asterionella formosa	5.97	9.83	1.68	44.75	6.88	3.67	11.98	0.5	8.6	19.05
A. ralfsii	•	•	•	•	2.58	0.36	•	•	2.36	3.55
Caloneis bacillum	•	•	•	•	•	•	•	•	•	•
C silicula	•	•	•	•	•	•	•	•	0.34	•
Ceratoeis arcus v.linearis	•	•	•	•	•	•	•	•	•	•
Cocconeis disculus	•	•	•	•	•	•	•	•	•	•
C. placentula	•	•	•	•	•	•	0.55	•	•	•
Cyclotella bodanica	4.55	0.66	2.52	•	11.02	2.13	13.14	1.62	10.29	15.21
C. commensis	•	•	•	•	•	•	•	2.37	•	•
C. glomerata	0.43	5.64	•	•	8.09	3.55	•	•	4.72	0.3
C. kutzingiana	•	•	•	•	•	•	•	0.62	•	•
C. meneghiniana	•	•	•	•	•	•	•	•	•	•
C. michiganiana	•	•	•	•	•	•	•	•	•	•
C. ocellata	•	•	•	•	•	•	•	•	•	•
C. stelligera	7.24	1.83	2.66	•	0.86	1.18	4.62	2	1.85	2.36
Cyclostephanos dubius	•	•	•	•	•	•	•	•	•	•
Cymbella acuticuscula	•	•	•	•	0.34	•	•	•	•	•
C. amphicephala	•	1.05	•	•	•	•	•	0.25	•	•
C. brehmii	•	•	•	•	•	•	•	•	•	•
C. cesati	•	•	•	•	•	•	•	•	•	•
C. cistula	•	•	•	•	•	•	0.16	•	•	•
C. cuspidata	•	•	•	•	0.17	•	•	•	•	•
C. hauckii	•	•	0.7	•	•	•	•	•	•	•
C. hybridica	•	•	•	•	•	•	•	•	•	•
C. lunata	•	•	•	•	•	•	•	•	•	•
C. microcephala	•	•	•	•	•	•	•	•	•	•
C. naviculiformis	•	0.13	0.56	•	0.17	•	0.1	•	•	0.59
C. pusilla	0.28	•	•	•	•	3.44	•	•	•	2.66
C. sotica	•	•	0.84	0.8	•	•	•	1.25	•	•
C. ventricosa	1.28	3.28	0.56	0.48	1.38	4.27	0.65	1.87	1.52	0.3
Diploneis elliptica	•	•	•	•	•	•	•	•	•	•
D. oculata	0.14	•	•	•	•	•	•	•	•	•
D. ovalis	•	•	•	•	•	•	0.32	0.37	•	•
D. paella	•	•	•	•	•	•	•	•	•	•
Eucocconeis flexella	•	•	•	•	•	•	0.05	0.25	0.17	1.03

Appendix II continued

Diatom Taxa	No. of study lake									
	11	12	13	14	15	16	17	18	19	20
Eunotia alpina	•	0.13	•	1.59	•	•	•	•	•	•
E. arcus	0.28	•	•	•	•	•	•	•	•	•
E. bidentula	•	•	•	•	•	•	•	•	•	•
E.biggiba v. pumila	•	•	•	•	•	•	•	•	•	•
E. curvata	•	•	0.28	•	•	•	•	•	•	1.18
E. diodon	•	•	•	•	•	•	•	•	•	•
E. elegans	•	•	•	•	•	0.59	•	•	•	•
E.exigua v. compacta	•	•	•	•	0.17	0.47	•	•	•	2.22
E. faba	•	0.79	•	•	•	•	•	0.75	•	•
E. flexuosa	0.57	•	•	•	•	•	•	•	•	•
E. incisa	1.85	1.7	0.42	1.11	0.17	1.9	•	•	0.34	1.33
E. indica	•	•	•	•	0.17	•	•	•	•	•
E. kochielenensis	•	•	•	•	•	•	•	0.75	•	•
E. lunaris	•	1.57	•	•	•	•	0.49	•	0.17	•
E. lunaris v.capitata	•	•	•	•	•	•	•	•	•	•
E. leochelinensis	•	•	•	•	•	0.12	•	•	•	•
E. nalgelii	•	•	•	•	•	1.18	•	•	•	•
E. parallela	•	•	•	•	•	•	•	•	•	•
E. pectinalis	3.41	3.01	1.4	3.66	1.03	4.62	1.42	1.37	2.53	0.74
E.pectinalis v.ventralis	•	•	•	•	0.52	0.36	•	0.62	•	•
E.praerupta v.bidens	•	0.52	•	•	•	•	•	•	0.51	•
E.praerupta v.inflata	•	0.66	•	•	•	•	•	•	•	•
E. robusta	0.43	0.39	•	0.64	•	•	0.21	•	•	0.3
E. septenottrionalis	•	•	•	•	•	•	•	•	•	•
E. sudetica	3.84	•	•	6.37	•	0.12	•	•	•	•
E.sudetica v.bidens	•	•	•	•	•	•	•	•	•	•
E. tautoniensis	•	•	•	•	•	•	•	•	•	•
E. tenella	•	•	•	•	•	2.37	1.89	0.5	•	•
E. trinacria	•	•	•	•	•	0.36	•	•	•	•
E. valida	•	•	•	•	•	•	•	•	•	0.3
E.vanheurckii v.intermedia	•	•	•	•	0.17	•	•	•	•	•
Fragilaria brevistrata	•	•	•	•	•	•	•	•	•	•
F. capucina	•	•	•	•	•	•	•	1.5	•	•
F. construens	•	•	•	•	1.72	•	0.16	0.37	•	•
F.construens v.binodis	•	0.13	0.7	•	•	•	•	•	•	0.59
F.construens v.venter	0.99	2.75	28.25	7.01	5.16	0.36	•	14.96	0.34	•
F. crotonensis	2.27	•	•	•	5.16	1.78	6.04	3.49	•	•
F. magocsyi	•	•	•	•	•	•	•	•	•	•
F. pinnata	•	0.26	0.98	•	•	•	•	3.99	•	0.74
F. undata	•	0.92	0.56	•	•	0.24	•	0.5	•	•
F. vancheriae	•	•	•	•	•	•	•	•	•	•
F. virescens	0.85	1.97	9.93	0.96	0.69	0.71	0.86	14.21	1.69	•
Frustulia rhomboides	0.43	•	0.98	0.48	•	1.78	0.11	1.75	•	•
F. vulgare	•	•	•	•	•	2.49	•	•	•	•
Gomphonema acuminatum	•	•	•	•	•	•	•	0.25	•	•
G. angustatum	•	•	•	•	•	•	•	•	•	•
G. gracile	•	•	•	•	•	0.12	•	•	•	•
G. gravei	•	•	0.28	•	•	•	•	•	•	•
G. longiceps	•	•	•	•	•	•	•	•	•	•
G. parvulum	0.85	•	•	0.48	•	•	0.6	0.5	•	0.44
G.truncutum v.capitatum	•	•	•	•	•	•	•	•	•	•
Gyrosigma attenuatum	•	•	•	•	•	•	•	0.37	•	•
Hantzschia amphioxys	•	•	•	•	•	•	•	•	•	•

Appendix II continued

Diatom Taxa	No. of study lake									
	11	12	13	14	15	16	17	18	19	20
Melosira ambigua	•	•	•	•	2.24	12.09	•	•	2.87	•
Melosira distans	•	•	•	•	0.86	•	•	1	•	•
M.distans v.alpigena	1.56	•	•	3.66	0.86	1.18	•	•	•	•
M. granulata	4.4	6.55	9.51	•	•	•	4.35	4.49	•	•
M.granulata v.angustissima	1.99	19.27	1.12	4.3	•	•	1.35	•	•	•
M. islandica	•	0.52	0.28	•	•	2.49	•	1.12	•	•
M. italica	5.54	5.11	•	1.59	•	0.47	2	1.25	4.72	•
M. lirata	6.96	3.28	0.84	•	•	16.94	3.16	0.25	2.36	1.92
M. perglabra	•	•	2.8	0.96	•	•	1.95	0.5	•	5.17
Meridion circulare	1.42	•	•	•	•	0.12	•	•	•	•
Navicula amphibola	•	•	•	•	•	•	•	•	•	•
N. bacillum	•	0.26	0.14	•	•	•	•	0.25	0.51	•
N. bicapitallata	•	•	•	•	•	•	•	•	•	•
N. cocconiformis	0.85	•	•	0.64	•	•	•	0.62	•	2.07
N. cryptocephala	•	•	•	•	•	2.96	0.33	0.75	•	•
N. disjuncta	•	•	•	•	•	•	•	•	•	•
N. exigua	•	0.26	•	•	•	•	•	•	•	•
N. fragilarioides	•	•	•	•	•	•	•	•	•	•
N. gastrum	•	•	•	•	•	•	•	•	•	•
N. grimmei	•	•	•	•	•	•	•	•	•	•
N. gysingensis	•	•	•	•	•	•	•	•	•	•
N. hustedtii	•	•	•	•	•	•	•	•	•	•
N. lanceolata	•	•	•	•	•	•	•	•	•	2.66
N. lapidosa	•	•	•	•	•	•	•	•	•	•
N. laevissima	•	•	•	•	•	•	•	•	•	•
N. maculata	•	•	•	•	•	•	•	•	•	•
N. placentula	•	•	•	•	•	•	•	0.25	•	•
N. protracta	0.14	•	•	•	•	•	•	•	•	•
N. pseudoscutiformis	•	•	•	•	•	•	•	•	•	•
N. pupula	2.7	0.52	1.12	•	•	3.08	0.48	0.62	1.52	2.66
N. radiosa	0.28	2.23	0.7	1.11	•	•	0.22	2.62	•	0.3
N. scutiformis	•	•	0.14	•	•	•	•	0.25	•	0.59
N. simlex	•	•	•	•	•	•	•	•	•	•
N. sovereigae	•	•	•	•	•	•	•	•	•	•
N.subhamulata v.undulata	•	•	2.24	•	0.17	•	•	0.5	0.34	•
Neidium affine	•	•	2.24	•	0.17	•	•	0.5	0.34	•
N. alpinum	•	•	•	•	0.17	•	•	•	•	•
N.bisculcatum v.subundatum	•	•	•	•	0.34	•	•	•	•	•
N. dilatatum	•	•	•	•	•	•	•	•	•	•
N. iridis	0.85	1.31	1.26	0.48	0.34	1.3	•	•	0.51	•
N. productum	•	•	•	•	•	•	•	•	•	•
Nitzschia acuta	•	•	1.26	•	•	•	•	0.37	•	•
N. dissipata	0.57	•	•	•	0.34	•	•	1.62	1.01	•
N. frustulum	0.57	•	•	•	•	•	•	•	•	•
N. gracilis	•	•	•	•	•	•	•	•	•	•
N. hantzschii	•	•	•	•	•	•	•	•	•	•
N. ignorata	•	•	•	•	0.17	•	•	•	•	•
N. lacunarum	•	•	•	•	•	•	•	•	•	•
N. linearis	•	0.13	•	•	•	0.12	0.1	•	•	0.3
N. palea	•	•	•	•	•	2.13	•	0.87	1.18	0.3
N. romana	1.28	0.39	•	0.96	•	0.71	•	1.12	•	0.3
N. spectabilis	•	•	•	•	•	0.12	•	•	•	•
N. subtilis	•	•	•	•	•	•	•	•	•	•
N. vermiculare	•	•	•	•	•	•	•	•	•	•

Appendix II continued

Diatom Taxa	No. of study lake									
	11	12	13	14	15	16	17	18	19	20
Opephora martyi	•	•	•	•	•	•	0.21	•	•	•
Pinnularia abaujensis	•	•	•	•	•	•	•	•	•	•
P. acrosphaeria	•	•	•	◦	◦	•	•	•	•	•
P. accuminata	•	•	•	•	•	•	•	•	•	1.33
P. biceps	•	•	•	•	•	•	•	•	•	•
P. borealis	•	•	•	•	•	•	•	•	•	•
P. braunii	0.57	0.92	0.56	•	•	•	•	•	0.17	•
P. cardinalis	•	•	•	•	•	•	0.11	•	•	•
P. esoxe	•	•	•	•	•	•	•	•	•	•
P. formica	•	•	1.12	•	•	•	•	•	•	•
P. gentilis	•	•	•	•	0.34	•	0.22	•	0.17	•
P. gibba	0.43	•	1.26	•	•	•	0.45	•	•	•
P. interrupta	•	2.62	•	•	0.69	•	•	0.62	1.52	•
P. major	•	0.13	1.68	•	•	•	•	0.25	•	•
P. mesolepta	•	•	•	•	•	0.24	•	•	•	•
P. microstauron	0.43	•	3.64	•	•	•	0.77	0.5	•	1.92
P. polyonca	•	•	•	•	0.34	•	•	•	•	•
P. stomatophora	•	•	•	•	•	0.12	•	•	•	•
P. subcapitata	•	•	•	•	•	•	•	•	•	•
P. viridis	•	0.26	0.84	•	0.69	0.12	1.25	0.25	•	•
Stauroneis anceps	0.57	0.39	0.98	0.32	0.52	2.96	0.65	0.62	1.69	0.3
S. legumen	•	•	•	•	0.17	•	•	•	•	•
S. livingstonii	•	•	•	•	•	•	•	•	•	•
S. parvula	•	•	•	•	•	•	•	•	•	•
S. phoenicenteron	•	0.13	•	0.64	0.86	0.95	•	0.5	0.51	•
S. smith	•	•	•	•	0.17	•	•	•	•	•
S. staurolineata	•	•	•	•	0.17	•	•	•	•	•
Stenopterobia intermedia	•	0.26	•	•	•	•	•	•	•	•
Surirella angustata	•	•	•	•	•	•	•	•	•	•
Surerrilla biseriata	•	•	•	•	•	•	•	•	•	•
S. delicatissima	•	•	•	•	•	•	•	•	•	•
S. linearis	•	•	0.84	•	•	•	•	0.5	0.51	•
S. ovalis	•	•	•	•	0.34	•	•	•	•	•
S. ovata	•	•	•	•	•	•	•	0.37	•	•
S. robusta	0.57	0.79	1.54	•	•	1.9	0.86	0.5	0.34	•
Syneda acus	1.56	•	•	•	4.65	•	•	•	3.54	•
Synedra amphicephata	•	•	•	•	•	•	•	•	•	•
Synedra nana	•	•	•	•	•	•	23.04	0.5	•	•
S. parastica	•	•	•	•	•	•	•	•	•	•
S. tabulata	•	•	•	•	•	•	0.22	•	•	•
S. ulna	•	•	•	•	•	•	•	•	•	•
Tabellaria binalis	•	•	•	•	•	•	•	•	•	•
T. fenestrata	14.63	10.62	4.62	9.71	33.22	9.12	12.65	2.99	34.23	18.91
T. flocculosa	11.22	5.5	2.94	3.82	3.79	1.3	0.54	4.99	3.2	3.25

Appendix II continued

Diatom Taxa	No. of study lake									
	21	22	23	24	25	26	27	28	29	30
Achnanthes biasolettiana	•	•	•	•	•	•	•	•	•	0.16
A. conspicua	•	0.13	•	1.71	•	0.56	0.36	•	•	0.49
A. exigua	•	•	•	•	•	•	•	•	0.3	•
A. gibberula	0.72	•	•	•	•	•	•	•	•	•
A. lanceolata	0.6	•	0.42	•	•	•	•	•	•	•
A.lanceolata v.elliptica	•	•	•	•	•	•	•	•	1.04	•
A. linearis	5.17	•	•	•	•	•	•	0.9	4.92	•
A. marginulata	•	1.44	0.42	•	0.43	0.99	0.85	•	1.49	2.27
A. oestrupii	•	•	•	•	•	•	•	•	•	•
A. peragallii	•	•	•	0.62	•	•	•	•	•	•
Actinella punctata	•	•	0.97	•	•	•	•	•	•	•
Amphicampa hemicyclus	•	•	2.08	•	•	•	•	0.9	•	•
Amphora nomanii	•	0.26	•	•	•	0.56	0.24	•	•	•
A. ovalis	•	0.65	•	•	0.14	•	•	•	•	•
Anomoeoneis exilis	•	•	•	•	•	•	•	•	•	•
A. follis	•	•	•	•	•	•	•	•	•	•
A. serians	1.08	•	•	•	•	•	2.91	•	•	•
A.series v.brachysia	•	•	10.53	•	1.85	•	•	2.26	2.09	•
A. vitrea	•	•	•	•	•	•	•	•	•	0.32
Asterionella formosa	0.84	7.58	3.32	11.37	8.25	4.37	14.3	2.26	2.24	4.21
A. ralfsii	•	6.8	0.28	•	•	5.22	11.03	•	•	0.49
Caloneis bacillum	•	•	•	•	•	•	•	•	•	0.32
C. silicula	•	•	•	•	•	1.69	•	•	•	•
Ceratoeis arcus v.linearis	•	•	•	•	•	•	•	•	1.19	•
Cocconeis disculus	•	•	•	•	•	•	•	•	•	•
C. placentula	•	•	•	•	•	•	•	•	•	0.16
Cyclotella bodanica	2.64	5.36	1.39	23.21	10.1	2.12	4.85	1.95	4.77	14.59
C. commensis	•	•	•	•	•	•	•	•	•	•
C. glomerata	1.08	1.7	•	4.52	0.85	4.8	6.18	•	•	7.29
C. kutzingiana	•	•	•	•	•	3.53	0.97	•	10.58	13.45
C. meneghiniana	•	•	•	•	•	•	•	•	•	•
C. michiganiana	•	•	•	•	•	•	•	•	1.94	•
C. ocellata	•	•	•	•	•	•	•	•	•	•
C. stelligera	15.5	1.44	1.25	0.78	25.75	41.04	20	11.73	22.95	5.51
Cyclostephanos dubius	0.6	•	•	•	•	•	•	•	•	•
Cymbella acuticuscula	•	0.26	•	•	•	•	•	•	•	•
C. amphicephala	0.84	•	•	•	•	0.71	•	•	•	•
C. brehmii	•	•	•	•	•	•	1.45	•	•	0.32
C. cesati	•	•	•	•	•	•	•	•	•	0.16
C. cistula	•	•	•	•	•	•	•	•	•	•
C. cuspidata	•	0.26	•	•	•	•	•	•	•	•
C. hauckii	•	•	•	•	•	•	•	•	•	•
C. hybridica	•	•	•	•	•	•	•	•	•	•
C. lunata	4.45	•	•	•	•	•	•	•	•	•
C. microcephala	•	•	•	•	•	•	•	•	•	•
C. naviculiformis	•	•	0.55	•	1.28	0.99	•	•	0.3	•
C. pusilla	1.56	0.52	•	•	•	0.56	3.03	•	•	•
C. sotica	•	•	2.49	•	•	•	•	0.6	0.75	•
C. ventricosa	2.64	0.13	1.11	0.31	1.71	4.65	0.85	2.11	0.6	0.65
Diploneis elliptica	•	•	•	•	•	0.85	•	•	•	•
D. oculata	•	•	•	•	•	•	•	•	•	•
D. ovalis	•	•	•	•	0.43	•	•	0.45	•	0.16
D. paella	•	•	•	•	•	•	•	•	•	0.32
Eucocconeis flexella	•	•	•	•	0.43	•	•	•	•	•

Appendix II continued

Diatom Taxa	No. of study lake									
	21	22	23	24	25	26	27	28	29	30
Eunotia alpina	•	•	0.42	•	•	•	•	•	•	•
E. arcus	•	•	•	•	•	•	•	•	•	•
E. bidentula	•	•	0.28	•	•	•	•	•	•	•
E.biggiba v. pumila	•	•	•	•	•	•	•	•	•	•
E. curvata	•	•	•	•	•	•	1.7	•	•	1.94
E. diodon	0.6	•	•	•	•	•	•	•	•	•
E. elegans	•	•	0.55	•	•	•	•	•	•	•
E.exigua v. compacta	•	•	•	•	•	•	•	•	0.15	0.97
E. faba	•	•	1.94	•	•	•	•	0.3	•	•
E. flexuosa	•	•	•	•	•	•	•	2.26	0.6	0.81
E. incisa	0.24	0.39	•	1.87	0.28	•	1.21	0.45	•	0.32
E. indica	•	•	•	•	•	•	•	•	•	•
E. kochielenensis	•	0.26	•	•	•	•	•	•	•	•
E. lunaris	1.68	•	•	•	0.28	•	•	0.9	•	•
E. lunaris v.capitata	•	•	•	•	•	•	•	•	•	•
E. leochelinensis	•	•	•	•	•	•	•	•	•	•
E. nalgelii	•	•	•	•	•	•	•	•	•	•
E. parallela	•	•	•	•	•	•	•	•	•	•
E. pectinalis	•	0.65	2.91	0.93	0.14	1.69	0.61	11.58	4.62	2.92
E.pectinalis v.ventralis	0.24	0.39	0.97	•	•	•	•	3.01	0.6	1.78
E.praerupta v.bidens	•	•	•	•	•	•	•	•	•	0.49
E.praerupta v.inflata	•	•	•	•	0.71	•	•	0.45	•	•
E. robusta	•	•	1.52	•	•	•	•	•	•	•
E. septenottrionalis	•	•	•	•	•	•	•	•	•	•
E. sudetica	•	•	•	•	0.43	0.71	0.36	•	•	•
E.sudetica v.bidens	0.36	•	•	•	•	•	•	•	•	•
E. tautoniensis	•	•	0.14	•	•	•	•	•	•	•
E. tenella	•	•	3.32	•	•	•	•	•	•	0.49
E. trinacria	•	•	•	•	•	•	•	1.8	•	•
E. valida	0.48	•	•	•	•	•	•	•	0.3	•
E.vanheurckii v.intermedia	•	•	•	•	•	•	•	•	•	•
Fragilaria brevistrata	•	•	•	•	•	•	•	•	•	•
F. capucina	•	•	•	•	•	•	•	•	•	•
F. construens	•	•	•	•	•	0.28	0.73	•	•	•
F.construens v.binodis	•	0.13	•	•	0.43	•	•	•	•	•
F.construens v.venter	1.8	2.35	•	3.12	3.41	•	•	•	2.83	1.13
F. crotonensis	•	1.96	•	•	•	•	•	•	2.98	3.08
F. magocsyi	•	•	•	•	•	•	•	•	•	•
F. pinnata	0.72	0.39	•	0.47	2.7	•	•	•	0.75	•
F. undata	•	•	•	•	•	•	•	0.3	•	•
F. vancheriae	•	•	•	•	•	•	•	•	•	•
F. virescens	1.08	•	2.35	3.58	•	0.56	•	1.95	6.26	•
Frustulia rhomboides	2.52	•	5.12	•	0.43	•	3.52	5.41	0.45	0.49
F. vulgare	•	•	7.34	•	•	0.28	0.61	1.35	•	•
Gomphonema acuminatum	•	1.18	•	•	•	•	•	•	•	0.32
G. angustatum	•	•	•	•	•	•	•	•	•	•
G. gracile	•	•	0.55	•	•	•	•	•	0.3	•
G. gravei	•	•	•	•	•	•	•	•	•	•
G. longiceps	•	•	•	•	•	•	•	•	•	•
G. parvulum	•	•	•	•	0.28	•	•	•	•	0.65
G.truncutum v.capitatum	•	•	•	•	•	•	•	•	•	0.49
Gyrosigma attenuatum	•	•	•	•	•	•	•	•	•	•
Hantzschia amphioxys	•	•	•	•	•	•	1.09	•	•	•
Melosira ambigua	•	17.65	•	•	•	0.14	•	•	•	1.94
Melosira distans	•	1.7	2.91	•	•	1.27	•	11.28	1.49	•
M.distans v. alpigena	1.32	0.39	•	•	2.42	•	•	•	•	2.43
M. granulata	•	•	0.97	5.14	2.7	•	•	•	1.79	•

Appendix II continued

Diatom Taxa	No. of study lake									
	21	22	23	24	25	26	27	28	29	30
M. granulata v. angustissima	•	•	•	4.21	•	•	•	•	•	•
M. islandica	•	•	•	•	•	•	•	•	•	•
M. italica	•	9.28	•	10.12	5.83	•	•	•	•	0.97
M. lirata	8.17	1.57	•	1.71	2.13	0.42	•	11.88	•	3.4
M. perglabra	3.97	•	2.08	•	•	0.99	•	3.31	0.6	•
Meridion circulare	•	•	•	•	•	•	•	•	•	•
Navicula amphibola	•	•	•	•	•	•	•	•	•	•
N. bacillum	•	•	•	•	0.14	•	•	•	•	•
N. bicapitallata	•	•	•	•	•	•	•	•	•	•
N. cocconiformis	0.96	•	•	•	1.99	0.28	•	•	1.04	•
N. cryptocephala	0.24	0.39	•	•	•	1.13	0.12	•	•	0.65
N. disjuncta	•	•	•	•	•	•	•	•	•	0.32
N. exigua	•	•	•	•	•	•	•	•	•	•
N. fragilarioides	•	•	•	•	•	•	•	•	•	0.16
N. gastrum	•	•	•	•	•	•	•	•	•	•
N. grimmei	0.48	•	•	•	•	•	•	•	•	•
N. gysingensis	•	•	•	•	•	•	•	•	•	1.62
N. hustedtii	•	•	•	•	•	•	•	•	•	0.32
N. lanceolata	•	•	•	•	•	•	•	•	1.04	0.16
N. lapidosa	•	•	•	•	0.57	•	•	•	•	•
N. laevissima	•	•	•	•	•	•	•	•	•	•
N. maculata	0.24	•	•	•	•	•	•	•	•	•
N. placentula	•	•	•	•	•	•	•	•	•	•
N. protracta	•	•	•	•	•	•	•	•	•	•
N. pseudoscutiformis	•	•	•	0.31	•	•	•	•	•	0.16
N. pupula	9.5	0.13	1.25	0.62	1.28	0.56	•	0.6	•	•
N. radiosa	7.69	0.13	1.94	2.8	2.42	•	•	3.01	2.38	1.3
N. scutiformis	•	•	•	•	0.71	•	•	•	•	•
N. simlex	0.24	•	•	•	•	•	•	•	•	•
N. sovereigae	•	•	•	0.62	•	•	•	•	•	•
N.subhamulata v.undulata	•	•	3.88	•	•	•	•	1.2	•	0.16
Neidium affine	•	•	3.88	•	•	•	•	1.2	•	•
N. alpinum	•	•	•	•	•	•	•	•	•	•
N.bisculcatum v.subundatum	•	•	•	•	•	•	•	•	•	•
N. dilatatum	•	•	•	•	•	•	•	•	•	•
N. iridis	2.52	•	5.12	•	0.57	2.12	0.73	0.3	•	•
N. productum	•	•	•	•	•	•	•	•	•	•
Nitzschia acuta	1.08	•	•	•	•	•	•	0.3	•	•
N. dissipata	2.4	0.13	•	•	•	•	•	•	0.3	0.81
N. frustulum	•	•	•	•	•	•	•	•	•	•
N. gracilis	•	•	•	•	•	•	•	•	•	•
N. hantzschii	•	•	•	•	•	•	•	•	•	0.16
N. ignorata	•	•	•	•	•	•	•	•	•	•
N. lacunarum	•	•	•	•	•	•	•	•	•	•
N. linearis	•	•	•	•	•	•	0.24	•	•	0.49
N. palea	0.6	•	•	0.62	0.28	•	1.45	•	0.3	2.11
N. romana	•	•	0.28	1.09	1.85	•	1.33	1.2	0.6	0.49
N. spectabilis	•	•	•	•	•	•	•	•	•	•
N. subtilis	•	•	•	•	•	•	•	•	•	•
N. vermiculare	•	•	•	•	•	•	•	•	•	•
Opephora martyi	•	•	•	•	•	•	•	•	•	•
Pinnularia abaujensis	•	•	•	•	•	•	0.61	•	•	•
P. acrosphaeria	•	0.13	•	•	•	•	•	•	•	•
P. accuminata	•	•	•	•	•	•	•	•	•	•
P. biceps	•	•	•	•	•	0.85	•	•	•	•
P. borealis	•	•	•	•	•	•	•	•	•	•
P. braunii	•	0.39	1.66	•	0.85	•	•	•	0.3	0.49

Appendix II continued

Diatom Taxa	No. of study lake									
	21	22	23	24	25	26	27	28	29	30
P. cardinalis	•	•	•	•	•	•	•	•	•	•
P. esoxe	•	•	•	•	•	•	•	•	•	•
P. formica	•	•	•	•	•	•	•	•	•	•
P. gentilis	•	0.13	•	•	•	•	•	•	•	0.16
P. gibba	•	•	0.97	0.31	•	•	•	0.3	•	0.16
P. interrupta	•	•	4.71	•	•	•	•	•	•	•
P. major	0.36	•	•	0.47	•	0.42	•	0.3	•	0.16
P. mesolepta	•	•	•	•	•	•	•	•	•	•
P. microstauron	4.93	•	•	0.62	0.57	1.13	0.24	1.8	1.19	•
P. polyonca	•	0.13	•	•	•	•	•	•	•	•
P. stomatophora	•	•	•	•	•	•	•	•	•	•
P. subcapitata	•	•	5.68	•	•	0.71	•	•	•	•
P. viridis	•	•	1.52	1.4	1.85	•	•	1.5	1.04	0.32
Stauroneis anceps	2.64	0.13	0.83	•	0.43	0.14	0.61	2.26	0.75	0.65
S. legumen	•	•	•	•	•	•	•	•	•	•
S. livingstonii	0.96	•	•	•	•	•	•	•	•	•
S. parvula	•	•	•	•	•	•	•	•	•	1.46
S. phoenicenteron	1.2	•	0.69	•	•	•	0.85	0.9	•	•
S. smith	•	0.13	•	•	•	•	•	•	•	•
S. staurolineata	•	•	0.42	•	•	•	•	•	•	•
Stenopterobia intermedia	•	•	•	•	•	•	•	•	•	•
Surirella angustata	•	•	•	0.62	•	0.42	•	•	•	•
Surerrilla biseriata	•	•	•	•	•	•	0.73	•	•	•
S. delicatissima	•	•	•	•	•	•	•	0.6	•	•
S. linearis	•	0.52	1.8	0.78	•	•	•	•	•	•
S. ovalis	•	•	•	•	•	•	•	•	•	•
S. ovata	•	•	•	•	•	•	•	•	•	•
S. robusta	1.32	0.78	1.25	•	•	1.55	0.61	1.35	•	•
Syneda acus	•	5.88	•	•	•	•	•	•	•	1.94
Synedra amphicephata	•	•	•	•	•	0.28	0.24	•	•	•
Synedra nana	•	•	•	•	•	•	•	•	0.75	•
S. parastica	•	0.26	•	•	•	•	•	•	•	•
S. tabulata	•	•	•	•	•	•	•	•	•	•
S. ulna	•	•	•	•	•	•	•	•	•	•
Tabellaria binalis	•	•	0.55	•	•	•	•	•	•	•
T. fenestrata	2.04	24.58	4.71	12.31	10.81	11.14	11.03	1.5	8.49	9.56
T. flocculosa	0.48	1.31	3.6	3.74	2.28	0.71	4.12	2.71	2.98	0.65

Appendix III: Abundance distribution (%) of diatom species observed from 20 testing lakes. No. (31-50) correspond the names of the study lakes (see Tab. 8).

Diatom Taxa	No. of study lake									
	31	32	33	34	35	36	37	38	39	40
Achnanthes affinis	•	•	•	•	•	•	•	.28	•	•
Achnanthes biasolettiana	•	•	•	•	•	•	•	.14	•	•
A. conspicua	•	•	•	•	•	.3	.47	•	•	.9
A. dispar	•	•	•	•	•	•	•	•	•	•
A. exigua	•	•	.33	•	.35	•	•	•	•	•
A. lanceolata	•	•	.33	•	•	•	•	2.48	•	•
A. lanceolata v. elliptica	•	•	•	•	•	•	•	•	•	•
A. linearis	1.16	•	•	•	•	2.24	1.72	2.62	•	.66
A. marginulata	.33	•	•	•	.53	•	•	2.34	•	.21
A. peragallii	•	•	•	•	•	•	•	•	•	•
Actinella punctata	•	•	•	•	•	•	•	•	3.66	•
Amphicampa hemicyclus	•	•	•	•	•	•	•	•	•	•
A. ovalis	.17	3.8	•	.44	.18	1.94	•	•	•	.63
A. perpussila	•	•	•	•	•	•	•	•	•	•
Anomoeoneis exilis	•	•	•	•	•	•	.31	•	•	•
A. follis	•	•	•	•	•	•	•	•	•	•
A. serians	•	•	•	•	•	4.48	•	1.24	•	.12
A. serians v.brachysira	•	•	.49	1.47	•	•	.47	•	.76	•
Asterionella formosa	2.5	2.17	3.42	1.33	23.36	.3	11.54	6.75	43.21	.83
A. ralfsii	•	•	•	•	3.89	•	•	1.52	•	•
Caloneis alpestris	•	•	•	•	•	•	•	•	•	•
C. schumaniana	•	•	•	•	•	•	•	•	•	.18
C. silicula	•	•	•	.29	•	•	.16	•	•	•
Cocconeis disculus	•	•	•	•	•	•	•	•	•	•
C. pediculus	•	•	•	•	.35	•	•	•	•	•
C. placentula	.5	•	•	•	•	•	•	•	•	.34
Cyclotella bodanica	8.99	3.08	.16	15.32	10.09	11.79	6.24	7.58	.15	12.45
C. comensis	•	•	•	•	•	2.54	•	•	•	•
C. glomerata	.67	.91	•	4.57	3.01	•	•	11.98	•	•
C. kutzingiana	•	•	•	•	•	9.1	•	2.48	•	•
C. meneghiniana	•	•	.33	•	•	.3	•	•	•	•
C. stelligera	8.32	1.09	6.51	2.5	.53	•	2.81	12.53	•	7.06
Cymatopleura elliptica	•	•	•	•	•	•	•	•	•	•
Cymbella acuticuscula	•	•	•	•	•	•	•	•	•	.6
C. amphicephala	•	•	•	•	•	•	•	•	1.37	•
C. cistula	•	•	•	•	•	•	•	•	•	•
C. hybridica	•	•	•	•	.18	•	•	.28	•	•
C. hustedtii	•	•	•	•	•	•	•	•	•	•
C. lunata	.83	•	•	•	•	•	•	•	•	•
C. naviculiformis	•	.54	•	•	•	•	.16	•	•	.62
C. pusilla	•	4.35	•	•	•	•	•	.41	•	•
C. sotica	•	•	.33	•	•	.75	.16	•	•	.41
C. ventricosa	4.33	•	1.47	1.03	.35	2.24	.31	.14	•	.75
Diatoma elongatum	•	•	•	•	•	•	•	•	•	•
Diatoma vulgare	•	•	•	•	.18	•	•	•	•	•
Diploneis elliptica	.17	•	•	•	•	1.19	•	•	•	•
D. marginestriata	•	•	•	•	•	•	•	•	•	•
D. oculata	•	•	•	•	•	•	•	•	•	•
D. ovalis	•	•	•	•	•	.45	.31	•	•	.18
D. paella	•	•	•	•	•	•	•	.14	•	•
Epithemia argus	•	•	•	•	•	•	•	•	•	.23
E. intermedia	•	•	•	•	•	•	•	•	•	•
Eucocconeis flexella	•	•	•	.29	•	.6	•	•	•	.06

Appendix III continued

Diatom Taxa	No. of study lake									
	31	32	33	34	35	36	37	38	39	40
Eunotia alpina	•	•	.33	•	•	•	•	•	•	•
E. curvata	•	1.63	•	•	.53	•	•	.55	•	•
E. elegans	•	•	.49	•	•	•	•	•	•	•
E. exigua v. compacta	•	.18	•	.59	.71	•	•	.28	•	•
E. faba	•	•	1.3	•	•	•	•	•	•	•
E. flexuosa	•	1.63	1.79	•	•	•	.31	•	1.98	•
E. incisa	.67	2.17	7.82	1.03	1.59	•	•	.41	•	.58
E. kochielenensis	•	•	.98	•	•	•	•	•	•	•
E. lunaris	•	•	•	•	•	•	•	•	1.07	.06
E. monodon	•	•	•	•	•	•	•	•	•	•
E. pectinalis	6.16	2.17	2.44	.44	•	1.94	.31	.41	5.65	.84
E. pectinalis v. ventralis	•	•	2.61	.29	1.06	•	.47	.69	•	•
E. praerupta v. bidens	•	•	•	•	.35	•	•	•	•	•
E. praerupta v. inflata	•	•	•	•	•	•	•	•	•	•
E. robusta	.67	•	•	.59	.71	•	•	•	.31	.06
E. septenottrionalis	.5	•	•	•	•	•	•	.41	•	•
E. sudetica	•	•	•	•	•	•	•	•	4.27	•
E. tautoniensis	•	•	•	•	•	•	•	•	.31	•
E. tenella	•	•	•	.44	•	.15	.62	1.1	1.83	•
E. trinacria	.5	•	•	•	•	•	•	•	•	•
E. valida	•	•	•	•	•	•	•	•	•	•
Fragilaria affinis	.5	•	•	•	•	•	•	•	•	•
F. breviestrata	•	•	•	•	•	•	•	•	•	•
F. capucina	4.99	•	•	•	•	•	.62	•	•	•
F. construens	•	•	•	•	•	•	•	2.34	•	•
F. construens v. binodis	•	•	•	•	.18	1.64	.47	•	.61	.17
F. construens v. venter	3.49	•	.33	•	3.36	3.13	•	3.03	.92	7.83
F. crotonensis	•	•	•	•	.18	5.07	4.21	•	•	•
F. pinnata	8.15	•	•	•	.18	.45	•	.41	•	8.31
F. undata	•	•	•	.44	.18	•	•	.14	.46	.33
F. virescens	1.66	•	•	.88	•	1.64	•	•	3.05	•
Frustulia rhomboides	•	.72	1.63	.59	2.12	•	•	•	4.12	.22
F. vulgare	•	•	•	•	•	•	.16	.96	•	•
Gomphonema acuminatum	•	•	•	•	•	.6	.31	•	•	•
G. angustatum	•	•	•	•	•	•	•	•	•	•
G. bohemicum	•	•	•	•	•	.3	•	•	•	•
G. constricta v. capitata	•	•	•	•	•	•	.31	•	•	•
G. gracile	•	•	•	•	.35	2.54	•	•	•	.24
G. parvulum	.83	•	1.47	•	•	1.94	•	•	•	.06
G. subtile	•	•	•	•	•	•	•	•	•	•
Gyrosigma accuminatum	•	•	•	•	•	•	•	.14	•	•
Gyrosigma obscusum	•	•	•	•	•	•	•	•	•	•
G. strigile	•	•	•	•	•	•	•	•	•	•
G. wansbeckii	•	•	•	•	•	•	•	•	•	•
Mastogloia smithii	•	•	•	•	•	•	•	•	•	•
Melosira ambigua	•	•	•	•	8.5	.75	•	2.34	•	•
Melosira distans	•	•	•	.44	•	.15	•	•	•	.92
M. distans v. alpigena	•	•	•	•	.18	•	2.65	1.93	•	•
M. granulata	.67	•	33.06	13.11	6.37	•	18.88	5.1	•	15.3
M. granulata v. angustissima	7.82	1.99	.98	3.24	•	•	7.64	•	•	3.52
M. italica	3.16	•	1.47	6.48	4.6	2.84	5.62	1.79	•	•
M. lirata	•	.54	1.79	10.31	.53	•	•	4.55	4.73	.12
M. perglabra	•	•	•	2.65	•	•	•	•	1.07	3.15
Meridion circulata	.67	.72	.65	.59	1.06	•	•	•	•	.27
Navicula bacillum	•	1.63	•	•	•	•	•	•	•	1.54

Appendix III continued

Diatom Taxa	No. of study lake 31	32	33	34	35	36	37	38	39	40
N. cocconiformis	•	•	•	.44	•	.45	•	.55	•	.44
N. cryptocephala	•	•	•	•	•	•	•	1.24	•	•
N. cuspitata	•	•	•	•	•	•	•	•	•	•
N. gastrum	•	•	•	•	•	•	•	•	•	•
N. jarnefelti	•	•	•	•	•	•	•	.41	•	•
N. lanceolata	•	5.25	•	.15	•	•	•	•	•	•
N. pseudoscutiformis	•	•	•	•	•	•	•	.14	•	.06
N. pupula	2	10.87	•	•	.53	1.64	.62	1.1	•	4.24
N. radiosa	3.99	1.27	2.44	1.18	.35	3.43	1.09	•	1.83	3.2
N. scutiformis	•	•	•	•	•	.3	•	1.38	•	•
N. simula	•	•	•	•	•	•	•	•	•	•
Neidium affine	•	•	.49	.74	•	•	.78	•	4.58	.28
N. dilatatum	•	•	•	•	•	•	•	•	•	.34
N. iridis	•	•	.65	.44	.18	1.49	•	.28	2.44	.63
Nitzschia acuta	•	•	•	•	•	•	.62	•	•	.34
N. angustata	.83	•	•	•	•	•	•	•	•	•
N. apiculata	.33	•	•	•	•	•	•	•	•	•
N. dissipata	•	•	•	1.33	•	2.09	.31	•	•	.49
N. frustulum	•	•	•	•	•	.6	.31	•	•	•
N. lorenziana	•	•	•	•	•	•	•	•	•	•
N. nomanii	•	•	•	•	•	.6	•	•	•	•
N. obtusa	•	•	•	•	•	•	•	.28	•	•
N. palea	.67	.72	.33	•	.35	•	.16	.69	•	.78
N. recta	.17	•	•	•	•	•	•	•	•	•
N. romana	•	1.45	•	•	.35	2.09	•	.14	•	.23
N. vermiculare	•	•	•	•	•	•	•	•	•	•
Opephora martyi	•	•	•	•	•	•	•	•	•	•
Pinnularia appendiculata	•	6.7	•	•	•	•	•	•	•	•
P. biceps	•	1.63	•	•	•	•	•	•	•	•
P. braunii	•	1.81	.49	•	•	1.19	.16	•	.31	4.86
P. cardinalis	•	•	•	•	•	•	•	•	•	•
P. fasciata	•	•	•	•	•	.9	•	•	•	•
P. gentilis	•	•	•	•	•	•	•	.14	•	•
P. gibba	•	•	.33	.44	.18	•	.16	•	.61	.55
P. interrupta	•	•	.33	•	•	•	•	•	.46	•
P. macilenta	•	•	•	•	•	•	•	•	•	•
P. major	.67	5.43	.33	.59	•	•	.31	•	.31	.86
P. microstauron	•	8.15	1.79	2.21	•	•	1.56	•	2.6	1.3
P. nodosa	•	3.44	•	•	•	•	•	•	•	•
P. polyonca	•	•	•	•	.35	.45	•	•	•	1.42
P. subcapitata	•	•	•	•	•	•	•	.28	•	•
P. sublinearis	•	1.45	•	•	•	•	•	•	•	•
P. viridis	•	•	.16	.74	•	.3	.31	•	1.37	1.05
Repalodia gibba	•	•	•	•	•	•	•	•	•	•
Stauroneis anceps	•	11.78	1.3	.29	.35	2.54	•	•	•	2.08
S. phoenicenteron	•	•	.65	.29	•	•	•	•	•	.18
S. smith	•	•	•	•	•	•	•	•	•	•
Stenopterobia intermedia	•	•	•	•	•	•	•	•	•	•
Stephanodiscus hantzschia	•	•	•	•	•	•	•	•	•	•
S. niagarae	•	•	•	•	•	•	•	•	•	•
Surirella linearis	•	1.63	•	.59	•	•	.62	•	1.53	•
S. moelleriana	•	•	•	•	•	•	•	.14	•	•
S. ovata	•	•	•	•	•	•	•	•	•	•
S. robusta	.33	1.99	1.3	.74	•	•	.31	.41	.92	•
S. striatula	•	•	•	•	•	•	•	.28	•	•

Appendix III continued

	No. of study lake									
Diatom Taxa	31	32	33	34	35	36	37	38	39	40
S. tenera	•	•	•	•	•	•	•	.14	•	•
Syneda acus	•	•	•	•	•	•	•	.69	•	•
S. alpina	•	•	•	•	•	•	•	•	•	•
S. nana	•	•	1.14	1.03	•	•	5.15	•	•	•
S. rumpens	•	•	•	•	.35	•	•	•	•	•
S. tabulata	.67	•	•	•	•	•	•	•	•	•
S. ulna	•	•	•	•	.71	•	•	.28	•	•
T. fenestrata	20.13	3.8	10.75	16.64	18.23	18.06	19.34	10.06	2.44	6.86
T. flocculosa	1.83	3.26	5.05	2.8	2.3	2.54	.94	1.93	1.07	.05

Appendix III continued

Diatom Taxa	No. of study lake									
	41	42	43	44	45	46	47	48	49	50
Achnanthes affinis	•	•	•	•	•	•	•	•	•	•
Achnanthes biasolettiana	•	•	•	•	•	•	•	•	•	•
A. conspicua	.35	.52	•	•	•	•	•	•	•	•
A. dispar	•	•	3.36	•	•	•	•	•	•	•
A. exigua	•	•	•	•	•	•	.93	•	•	•
A. lanceolata	•	•	.73	•	•	•	•	•	7.11	•
A. lanceolata v. elliptica	•	•	5.99	•	•	•	•	.74	•	•
A. linearis	•	.88	•	1.37	•	2.44	3.1	.3	1.71	•
A. marginulata	.41	•	•	.61	1.18	•	•	•	•	3.32
A. peragallii	•	•	•	•	•	•	•	•	.57	•
Actinella punctata	.21	•	•	•	•	•	•	•	•	•
Amphicampa hemicyclus	.21	•	•	•	•	•	•	•	•	•
A. ovalis	•	.11	2.92	.46	•	.81	.31	.45	•	1.35
A. perpussila	•	•	9.21	•	•	•	•	•	•	•
Anomoeoneis exilis	•	•	•	.15	•	•	•	•	•	•
A. follis	•	•	•	•	•	•	.46	•	•	•
A. serians	.41	5.67	•	•	•	.65	.77	•	•	•
A. serians v. brachysira	.71	•	•	•	•	•	3.56	•	•	•
Asterionella formosa	1.93	1.77	2.78	1.06	6.42	•	6.19	11.9	1.28	3.69
A. ralfsii	•	•	•	•	5.41	.16	•	•	•	•
Caloneis alpestris	•	•	•	.15	•	1.3	•	•	•	•
C. schumaniana	•	•	•	•	•	•	•	•	•	•
C. silicula	•	•	•	•	•	•	•	•	•	•
Cocconeis disculus	•	•	3.65	•	•	•	•	•	•	•
C. pediculus	•	•	•	•	•	•	•	•	•	•
C. placentula	•	•	•	•	•	•	•	•	1.85	•
Cyclotella bodanica	1.77	1.17	•	27.47	5.24	2.28	21.83	21.88	4.27	3.2
C. commensis	•	•	1.9	•	•	•	•	•	•	•
C. glomerata	•	•	•	•	.34	•	•	•	•	3.69
C. kutzingiana	•	•	.44	•	•	•	1.08	•	12.23	•
C. meneghiniana	•	•	•	•	•	•	•	•	•	.12
C. stelligera	8.19	9.33	•	9.86	.84	8.94	6.19	1.93	.57	1.6
Cymatopleura elliptica	•	•	.44	•	•	•	•	•	•	•
Cymbella acuticuscula	•	•	•	•	•	•	•	•	•	•
C. amphicephala	•	5.07	•	•	•	•	•	•	•	•
C. cistula	•	•	•	•	•	•	.31	•	•	•
C. hybridica	•	•	•	•	•	•	•	•	•	•
C. hustedtii	•	•	•	•	•	•	•	•	•	.98
C. lunata	•	•	•	•	•	•	•	•	•	•
C. naviculiformis	•	•	•	•	•	•	•	•	•	.49
C. pusilla	•	•	•	•	1.52	•	•	•	•	.25
C. sotica	.46	2.7	•	.61	•	.98	2.32	.3	•	•
C. ventricosa	1.43	2.34	•	.3	.68	.33	.62	1.04	•	.98
Diatoma elongatum	•	•	•	•	•	•	•	•	4.98	•
Diatoma vulgare	•	•	•	•	•	•	•	•	•	•
Diploneis elliptica	•	•	•	1.37	.51	•	•	•	.57	•
D. marginestriata	•	•	•	•	•	•	.46	•	•	•
D. oculata	•	•	•	.76	•	•	•	•	•	•
D. ovalis	•	•	•	2.58	•	•	•	•	•	•
D. paella	•	•	•	•	•	•	•	•	•	•
Epithemia argus	•	•	•	•	•	•	•	•	.57	•
E. intermedia	•	•	.29	•	•	•	•	•	•	•
Eucocconeis flexella	•	•	•	•	•	•	•	•	.57	.49

Appendix III continued

Diatom Taxa	No. of study lake									
	41	42	43	44	45	46	47	48	49	50
Eunotia alpina	•	•	•	•	•	•	•	•	.28	•
E. curvata	•	•	•	•	.84	•	•	•	•	.49
E. elegans	•	•	•	•	•	•	•	•	•	•
E. exigua v. compacta	•	.52	•	•	•	•	•	•	•	.25
E. faba	.61	•	•	•	•	•	•	•	•	•
E. flexuosa	•	•	•	•	•	•	1.55	•	•	•
E. incisa	.71	1.37	•	.46	.34	.49	.62	.6	.85	3.2
E. kochielenensis	•	•	•	•	.17	•	•	•	•	•
E. lunaris	.76	.25	•	.91	•	.49	•	•	•	•
E. monodon	•	•	•	1.37	•	•	•	•	•	•
E. pectinalis	2.97	3.6	•	1.67	•	1.3	4.49	1.19	.57	.62
E. pectinalis v. ventralis	•	.76	•	•	•	•	•	•	•	•
E. praerupta v. bidens	•	•	•	•	•	•	•	•	•	•
E. praerupta v. inflata	3.26	•	•	•	•	•	•	•	•	•
E. robusta	.41	.3	•	•	.17	.16	•	•	•	•
E. septenottrionalis	•	•	•	•	•	•	•	•	•	•
E. sudetica	1.83	•	•	.3	•	.81	•	•	•	•
E. tautoniensis	•	•	•	•	•	•	•	•	•	•
E. tenella	•	•	•	•	•	•	•	•	•	•
E. trinacria	•	.3	•	•	•	•	•	•	•	•
E. valida	•	•	•	•	•	•	.31	•	•	.12
Fragilaria affinis	•	•	•	•	•	•	•	•	•	•
F. brevistrata	•	•	.29	•	•	•	•	•	•	•
F. capucina	•	•	•	•	•	•	•	•	2.13	•
F. construens	•	•	.73	•	•	•	•	•	•	1.6
F. construens v. binodis	•	•	.29	.46	•	.33	•	•	•	•
F. construens v. venter	.76	2.16	•	.3	2.36	4.07	1.55	.3	.57	17.59
F. crotonensis	•	•	7.75	6.53	•	.33	•	3.12	3.7	•
F. pinnata	2.07	•	12.13	.61	•	16.59	•	•	•	10.21
F. undata	.31	•	•	•	•	•	•	•	•	•
F. virescens	8.39	3.74	•	•	.34	•	1.08	•	.43	9.47
Frustulia rhomboides	1.53	4.49	•	•	1.35	•	3.1	.15	•	1.23
F. vulgare	•	3.12	•	•	•	•	•	•	•	.62
Gomphonema acuminatum	•	•	•	•	•	•	.46	1.49	•	•
G. angustatum	•	•	•	•	•	•	•	•	•	•
G. bohemicum	•	•	•	•	•	•	.31	•	•	•
G. constricta v. capitata	•	.16	•	•	•	•	•	•	•	•
G. gracile	•	•	•	•	•	•	•	•	•	.62
G. parvulum	•	.26	•	2.43	•	1.79	.46	•	•	.49
G. subtile	•	•	•	•	•	•	•	•	•	.49
Gyrosigma accuminatum	•	•	•	•	•	•	•	.89	•	•
Gyrosigma obscusum	•	•	•	•	•	4.23	•	•	•	•
G. strigile	•	•	.29	•	•	•	•	•	•	•
G. wansbeckii	•	•	•	•	•	•	•	•	.14	•
Mastogloia smithii	•	•	.29	•	•	•	•	•	•	•
Melosira ambigua	•	.62	•	•	1.86	•	•	•	•	9.47
Melosira distans	.31	•	•	•	•	1.46	•	3.87	•	•
M. distans v. alpigena	•	•	•	.46	•	•	•	•	•	•
M. granulata	24.66	3.64	8.04	7.13	23.48	12.52	.77	18.01	1.99	•
M. granulata v. angustissima	2.02	•	•	.46	•	4.88	2.48	4.61	.85	•
M. italica	•	•	•	2.58	9.46	2.93	•	13.69	1.42	•
M. lirata	14.82	•	•	•	2.2	.33	.62	•	.57	1.48
M. perglabra	1.49	2.67	•	•	•	•	•	•	•	•
Meridion circulare	•	•	•	•	•	•	.31	.45	•	.49

Appendix III continued

Diatom Taxa	No. of study lake									
	41	42	43	44	45	46	47	48	49	50
Navicula bacillum	•	•	•	•	•	•	•	•	.28	•
N. cocconiformis	.36	•	•	•	•	.65	•	•	•	•
N. cryptocephala	•	•	•	•	.68	•	•	•	•	.74
N. cuspitata	•	•	•	•	•	.49	•	•	•	.37
N. gastrum	.3	•	•	•	•	•	•	.6	•	•
N. jarnefelti	•	•	•	•	.34	•	•	•	•	•
N. lanceolata	•	.25	•	•	•	•	.93	•	•	•
N. pseudoscutiformis	•	•	•	•	•	•	•	•	•	•
N. pupula	•	3.46	•	1.97	•	3.09	1.55	•	.57	2.71
N. radiosa	.91	4.9	.29	2.88	.51	1.46	5.73	.3	.71	1.35
N. scutiformis	•	.11	.29	•	.17	•	.31	.74	2.13	•
N. simula	•	•	•	•	.34	•	•	•	•	•
Neidium affine	1.01	1.84	•	•	•	•	.15	•	•	•
N. dilatatum	•	•	•	•	•	•	•	•	•	•
N. iridis	.25	.39	•	•	•	1.95	•	•	•	.62
Nitzschia acuta	•	.26	•	•	•	•	•	•	•	•
N. angustata	•	•	•	•	•	•	•	•	•	•
N. apiculata	•	•	•	•	•	•	•	•	•	•
N. dissipata	•	1.06	•	3.19	•	.81	1.55	•	•	•
N. frustulum	.1	•	•	•	•	•	.46	•	•	•
N. lorenziana	•	•	•	•	•	•	•	•	•	.37
N. nomanii	•	•	•	•	•	•	•	•	•	•
N. obtusa	•	•	•	.46	•	•	•	•	•	•
N. palea	.1	•	•	•	2.7	•	.31	•	1.56	1.35
N. recta	•	•	•	•	•	•	•	•	•	•
N. romana	•	.71	.44	•	•	3.41	•	•	.43	.62
N. vermiculare	•	.35	•	•	•	•	•	•	•	•
Opephora martyi	•	•	11.26	•	•	•	•	.3	.28	•
Pinnularia appendiculata	•	•	•	•	•	•	•	•	•	•
P. biceps	•	•	•	•	•	•	•	•	•	•
P. braunii	•	.82	•	.91	•	•	.31	•	•	.49
P. cardinalis	•	•	•	•	.68	•	•	•	•	•
P. fasciata	•	•	•	•	•	•	•	•	•	•
P. gentlis	•	•	•	•	•	•	•	•	•	.49
P. gibba	.41	•	•	•	•	3.41	.31	•	•	•
P. interrupta	•	7.04	•	•	.68	•	.93	•	•	.49
P. macilenta	•	•	•	•	•	.33	•	•	•	•
P. major	.31	.57	•	•	•	1.46	•	•	•	•
P. microstauron	.8	6.52	•	•	•	•	1.7	•	•	•
P. nodosa	•	•	•	•	•	•	•	•	.28	•
P. polyonca	•	•	•	•	•	•	•	•	•	.49
P. subcapitata	•	•	•	•	•	•	•	•	•	•
P. sublinearis	•	•	•	•	•	•	•	•	•	•
P. viridis	.51	3.37	•	.61	.17	•	.62	.6	•	•
Repalodia gibba	•	•	1.32	•	•	•	•	.89	•	•
Stauroneis anceps	.1	2.89	•	4.1	•	.65	1.39	•	•	1.35
S. phoenicenteron	.21	1.27	•	1.52	•	•	1.24	.3	•	.98
S. smith	•	1.64	•	•	•	•	•	•	•	•
Stenopterobia intermedia	•	•	•	.15	•	•	•	•	•	•
Stephanodiscus hantzschia	•	•	1.46	•	•	•	•	•	9.53	•
S. niagarae	•	•	14.77	•	•	•	•	•	1.28	•
Surirella linearis	•	•	•	•	.17	•	3.1	.6	•	•
S. moelleriana	•	•	•	•	•	•	•	•	•	•
S. ovata	•	•	•	•	•	•	•	•	.28	.12
S. robusta	.51	1.28	•	.61	•	1.63	•	.74	•	.25

Appendix III continued

Diatom Taxa	No. of study lake									
	41	42	43	44	45	46	47	48	49	50
S. striatula	•	•	•	•	•	•	•	•	•	•
S. tenera	•	•	•	•	•	•	•	•	•	•
Syneda acus	•	•	•	•	5.91	•	•	•	•	.12
S. alpina	•	•	•	3.79	•	•	•	•	•	•
S. nana	•	•	3.51	•	•	•	•	•	17.07	•
S. rumpens	•	•	•	•	•	•	•	1.04	•	•
S. tabulata	•	•	•	•	•	•	•	.3	1.14	•
S. ulna	•	•	•	•	•	•	•	•	2.13	•
T. fenestrata	8.7	1.42	5.12	3.95	20.44	5.69	10.37	6.1	12.52	3.08
T. flocculosa	2.43	2.35	•	3.49	2.53	4.39	2.79	.6	•	5.04

Appendix IV. Five examples for numerical calculations of diatom species' distribution optima (weighted average)* on lake trophic leve from data of 30 syudy lakes.

Lake name	Tophic level	*C. kutzingiana*		*C. stelligera*		*C. bodanica*		*T. fenestrata*		*M. granulata*	
	(Xi)	%(Pi)	PiXi	%(Pi)	PiXi	%(Pi)	PiXi	%(Pi)	PiXi	%(Pi)	PiXi
Fawn	8.4	•	•	1.29	10.87	.81	6.8	15.21	127.77	15.21	127.77
Moot	7.36	•	•	1.12	8.22	•	•	8.37	61.62	18.83	138.64
Brandy	7.3	•	•	2.83	20.66	9.43	68.87	26.26	191.68	10.69	78.05
Hesners	6.6	•	•	•	•	•	•	5.14	33.93	2.17	14.29
Riley	6.27	•	•	•	•	3.45	21.66	25.75	161.44	•	•
Nine Mile	6.2	•	•	6.04	37.48	3.02	18.74	24.83	154.07	15.77	97.85
Long	4.04	•	•	3.98	16.11	11.43	46.22	21.51	87.01	5.68	22.99
Black	5.48	•	•	4.49	24.63	.49	2.68	16.65	91.28	32.72	179.35
Leech	5.11	•	•	4.67	23.88	3.17	16.18	17.49	89.42	3.95	20.22
Bass	4.77	•	•	2.54	12.1	.45	2.14	15.52	74.03	15.82	75.46
Ricketts	4.69	•	•	7.24	34.01	4.55	21.34	14.63	68.68	4.4	20.67
Gullfeather	4.56	•	•	1.83	8.36	.66	2.99	10.62	48.39	6.55	29.87
Ril	4.18	•	•	2.66	11.12	2.52	10.53	4.62	19.31	9.51	39.78
Little Leech	4.05	•	•	•	•	•	•	9.71	39.35	•	•
Long Turtle	3.97	•	•	.86	3.41	11.02	43.68	33.22	131.72	•	•
Medora	3.79	•	•	1.18	4.49	2.13	8.09	9.12	34.61	•	•
Grevenhurst Bay	3.73	•	•	4.62	17.24	13.14	49.08	12.65	47.22	4.35	16.25
Spence	3.61	.62	2.25	2	7.2	1.62	5.85	2.99	10.8	4.49	16.2
North Muldew	3.02	•	•	1.85	5.6	10.29	31.06	34.23	103.37	•	•
Prospect	2.76	•	•	2.36	6.52	15.21	41.96	18.91	52.15	•	•
Clearwater	2.75	•	•	15.5	42.69	2.64	7.28	2.04	5.63	•	•
Loon	2.6	•	•	1.44	3.74	5.36	13.95	24.58	63.96	•	•
Little long	2.54	•	•	1.25	3.17	1.39	3.52	4.71	11.98	.97	2.47
Wood	2.29	•	•	.78	1.78	23.21	53.08	12.31	28.14	5.14	11.76
Pine	2.18	•	•	25.75	56.18	10.1	22.04	10.81	23.59	2.7	5.9
Clear	2.1	3.53	7.42	41.04	86.32	2.12	4.45	11.14	23.43	•	•
Leonard	1.75	.97	1.7	20	35.01	4.85	8.49	11.03	19.31	•	•
Heeney	1.5	•	•	11.73	17.65	1.95	2.94	1.5	2.26	•	•
Trading Bay	1.3	10.58	13.75	22.95	29.82	4.77	6.2	8.49	11.04	1.79	2.32
Muskoka	1.43	13.45	19.27	5.51	7.89	14.59	20.89	9.56	13.7	•	•
Sum (Σ)	(n=30)	29.15	44.38	197.53	536.17	164.35	540.7	423.61	1830.9	160.76	899.84
Weighted Average		1.52		2.71		3.29		4.32		5.6	

*: The weighted mean of diatom species characteristics was determined from the following formula; $X = \Sigma P_i (X_i) / \Sigma P_i$ Where:

X = the weighted average of the relative trophic status of each diatom species

P_i = the percentage occurrence of the diatom species in sediment of lake i

X_i = the value of the relative trophic status in lake i (Charles 1985).

(In the case of *Cyclotella kuetzingiana*, its WA value $= \Sigma P_i (X_i) / \Sigma P_i$

$= 44.39/29.15 = 1.52$)

Plate 1: Scanning photographies of some diatom species.

A: *Melosira granulata*, bar scale = 1μm.

B: *Melosira granulata var. angustissima*, bar scale = 10μm.

C: *Melosira lirata f. biseriata*, bar scale = 1μm.

D: *Melosira distans*, bar scale = 10μm.

E: *Cyclotella stelligera*, bar scale = 1μm.

F: *Melosira perglabera*, bar scale = 1μm.

G: *Melosira ilalica*, bar scale = 1μm.

H: *Melosira ilalica*, bar scale = 10μm.

Plate 1

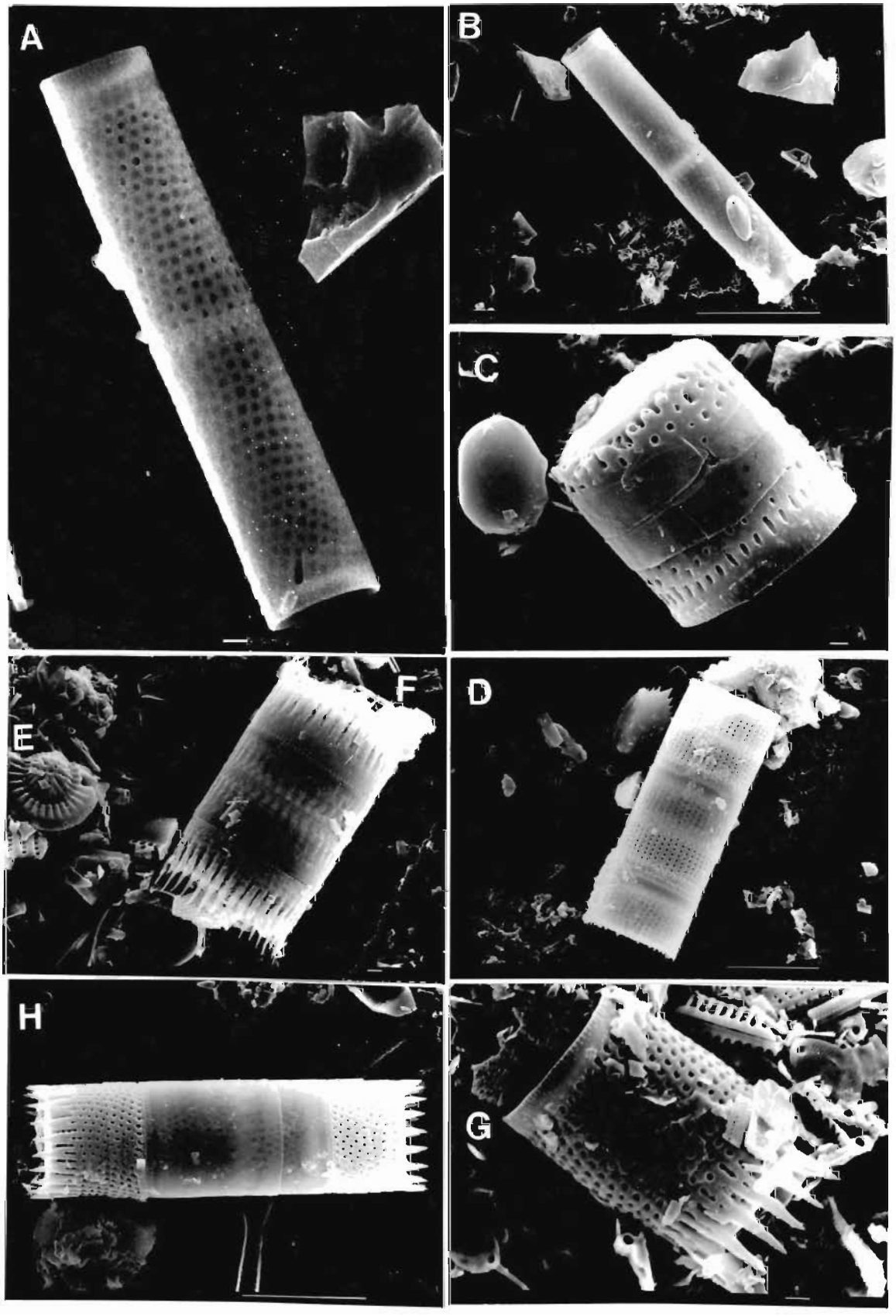

Plate 2: Scanning photographies of some diatom species.

A: *Cyclotella bodanica*, bar scale = 1μm.

B: *Cyclotella bodanica*, bar scale = 10μm.

C: *Cyclotella bodanica*, bar scale = 10μm.

D: *Melosira lirata*, bar scale = 1μm.

E: *Cyclotella glomerata*, bar scale = 1μm.

F: *Cyclotella glomerata*, bar scale = 1μm.

G: *Cyclotella stelligera*, bar scale = 1μm.

H: *Cyclotella stelligeroides*, bar scale = 1μm.

Plate 2

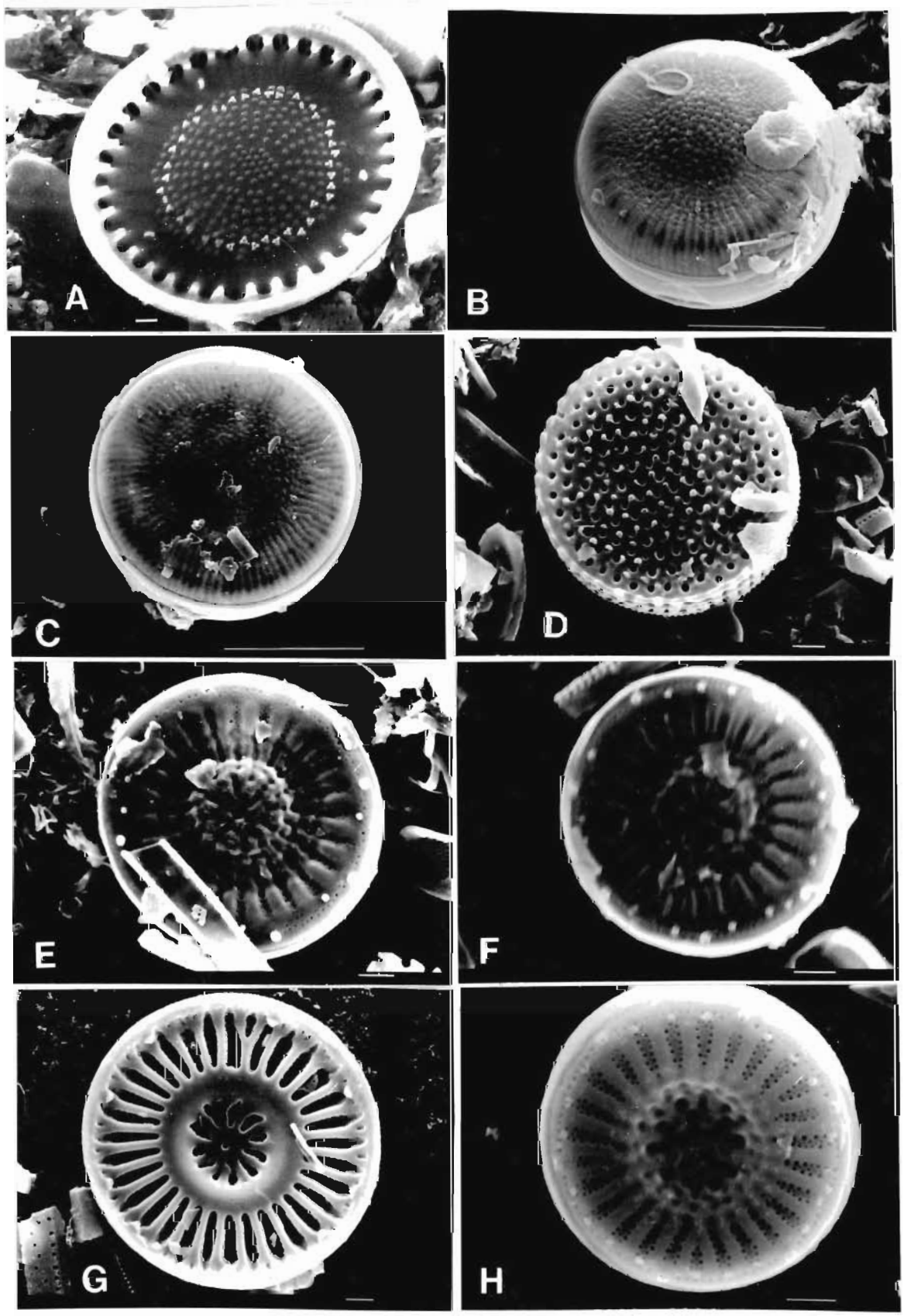

Plate 3: Scanning photographies of some diatom species.

A: *Cyclotella cf. kuetzingiana,* bar scale = 10µm.

B: *Cyclostephanos dubis,* bar scale = 1µm.

C: *Stephanodiscus niagarae,* bar scale = 10µm.

D: *Fragilaria pinnata,* bar scale = 10µm.

E: *Fragilaria construens var. venter,* bar scale = 10µm.

F: *Fragilaria construens var. venter,* bar scale = 10µm.

G: *Asterionella formosa,* bar scale = 10µm.

H: *Asterionella ralfsii,* bar scale = 10µm.

Plate 3

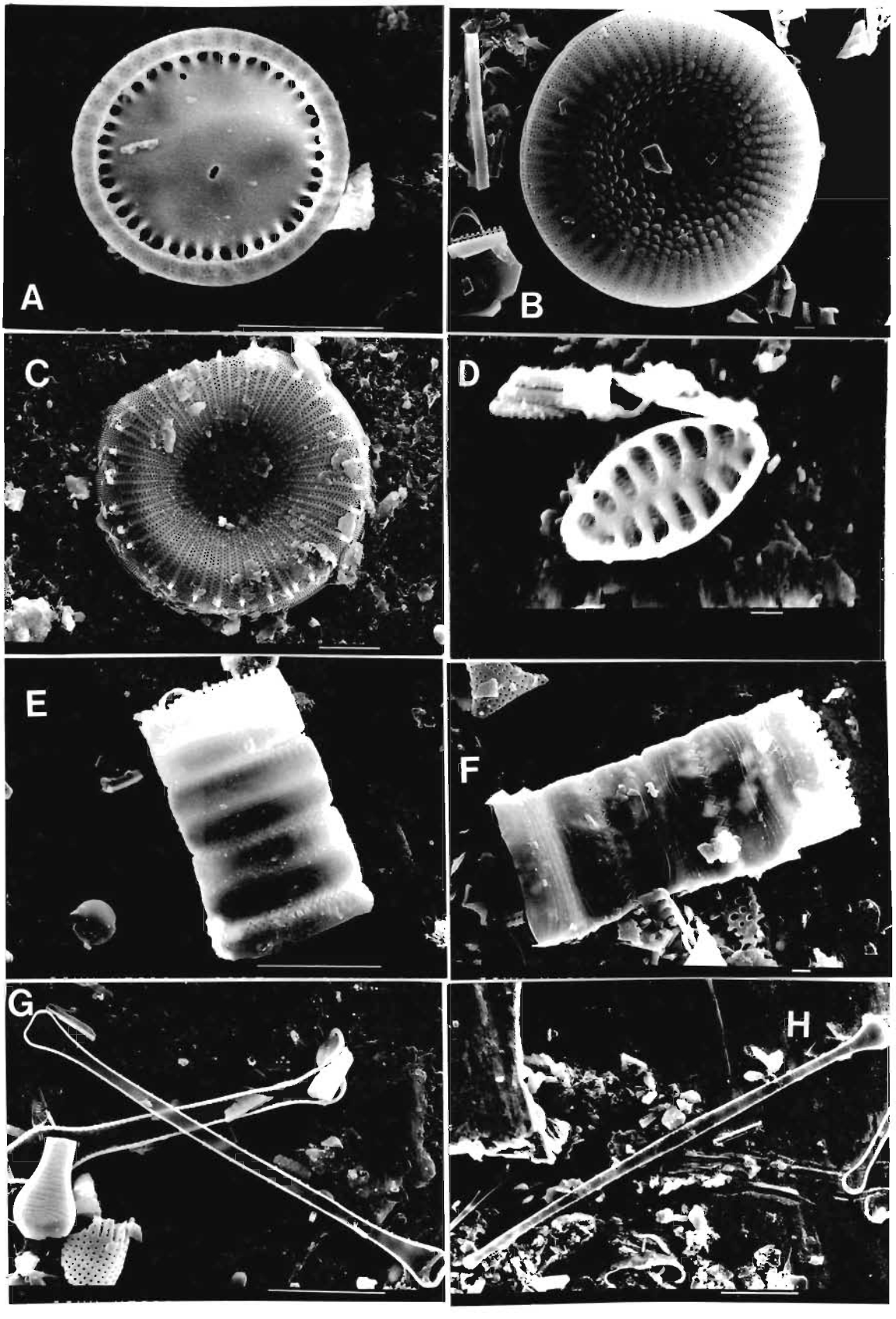

Plate 4: Scanning photographies of some diatom species.

A: *Tabellaria flocculosa,* bar scale = 1μm.

B: *Tabellaria flocculosa,* bar scale = 1μm.

C: *Tabellaria flocculosa,* bar scale = 1μm.

D: *Tabellaria fenestrata,* bar scale = 10μm.

E: *Tabellaria fenestrata,* bar scale = 10μm.

F: *Eunotia praerupta,* bar scale = 10μm.

G: *Eunotia praerupta,* bar scale = 10μm.

H: *Eunotia alpina,* bar scale = 10μm.

Plate 4

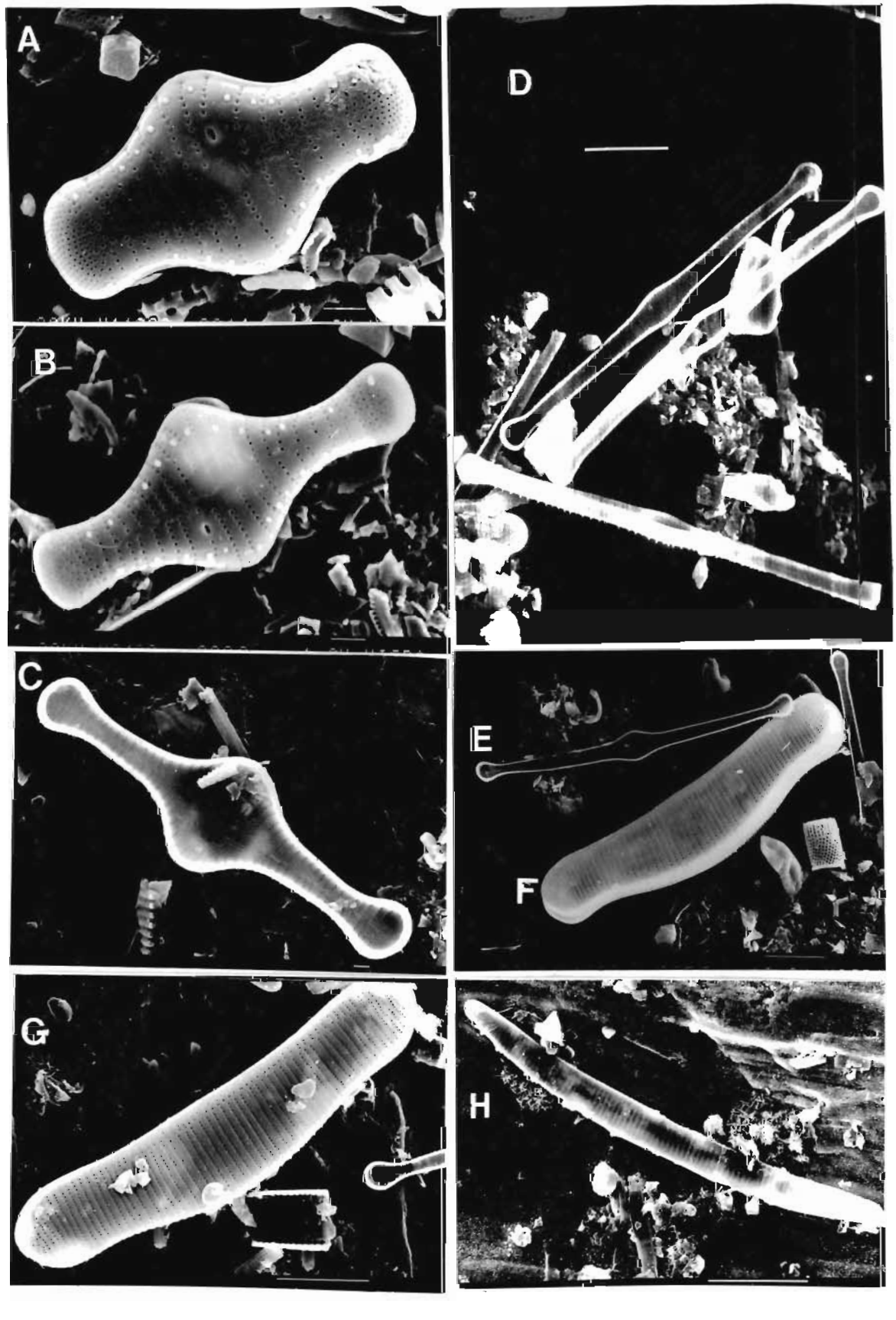

Plate 5: Scanning photographies of some diatom species.

A: *Eunotia gracilis*, bar scale = 10µm.

B: *Eunotia pectinalis var. ventralis*, bar scale = 10µm.

C: *Amphicampa hemicyclus*, bar scale = 10µm.

D: *Achnanthes conspicua*, bar scale = 1µm.

E: *Achnanthes marginulata*, bar scale = 1µm.

F: *Eucoccuneis flexella*, bar scale = 1µm.

G: *Eucoccuneis flexella*, bar scale = 10µm.

H: *Eucoccuneis flexella*, bar scale = 1µm.

Plate 5

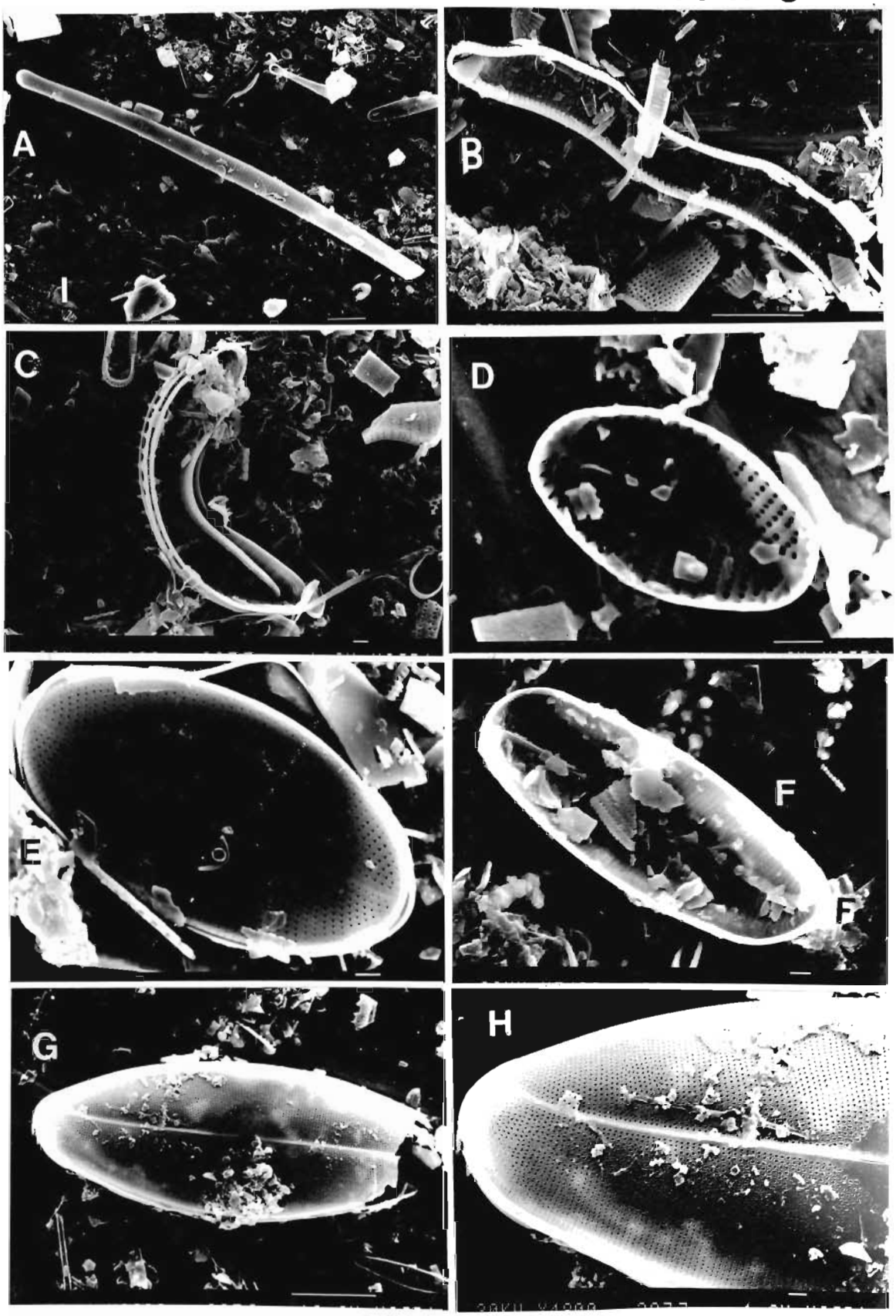

Plate 6: Scanning photographies of some diatom species.

A: *Navicula pupula*, bar scale = 10μm.

B: *Navicula pupula*, bar scale = 1μm.

C: *Navicula cocconeiformis*, bar scale = 1μm.

D: *Navicula dicephala*, bar scale = 1μm.

E: *Navicula pupula var. elliptica*, bar scale = 1μm.

F: *Navicula mutica*, bar scale = 1μm.

G: *Navicula cryptocephala*, bar scale = 1μm.

H: *Stauroneis anceps*, bar scale = 10μm.

Plate 6

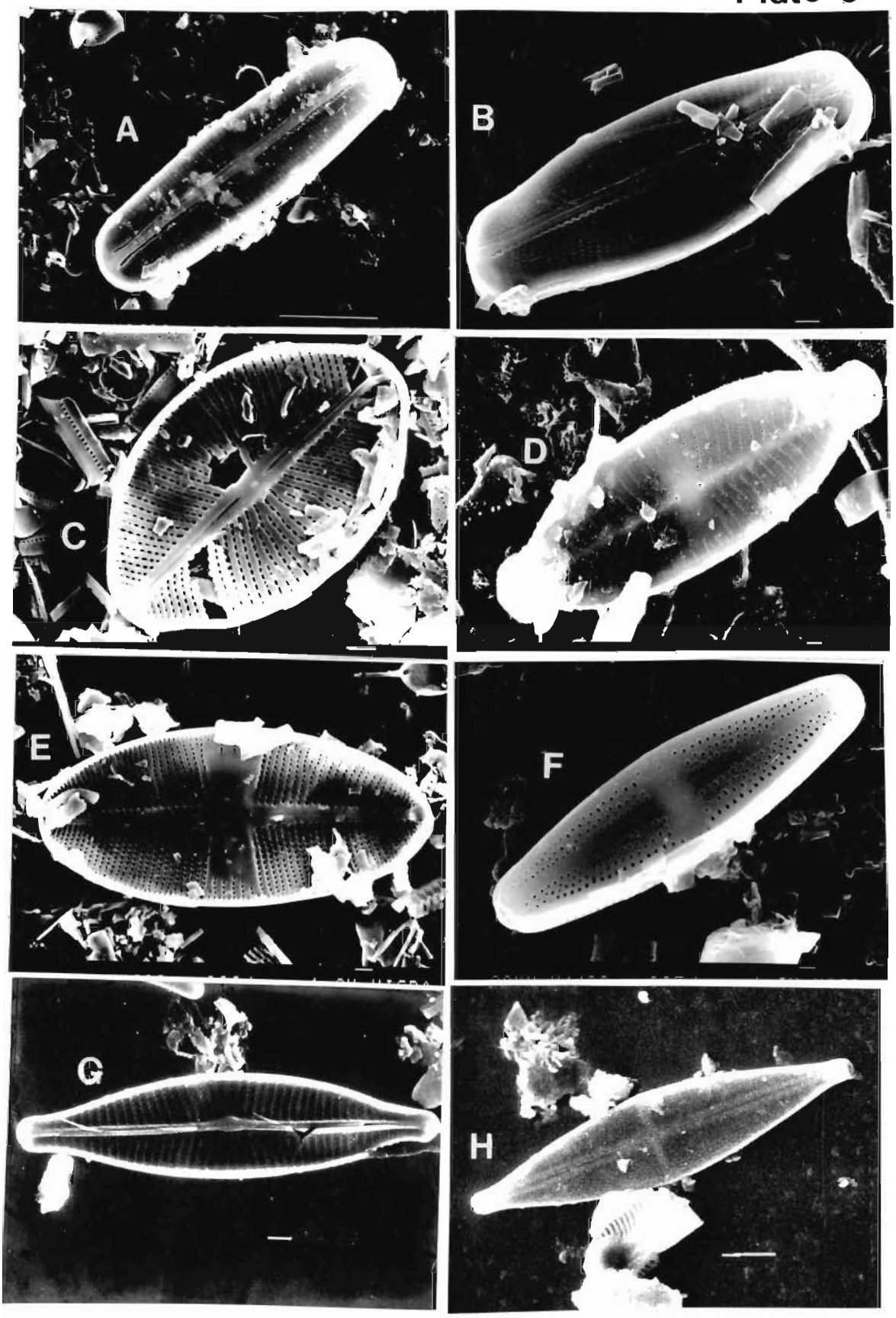

Plate 7: Scanning photographies of some diatom species.

A: *Neidium iridis*, bar scale = 10μm.

B: *Neidium iridis*, bar scale = 10μm.

C: *Anomoeoneis serians var, brachysira*, bar scale = 1μm.

D: *Anomoeoneis serians var, brachysira*, bar scale = 1μm.

E: *Frustulia rhomboides*, bar scale = 10μm.

F: *Surirella linearis*, bar scale = 10μm.

G: *Frustulia rhomboides*, bar scale = 10μm.

H: *Frustulia rhomboides var. saxonica*, bar scale = 10μm.

I: *Frustulia rhomboides var. saxonica*, bar scale = 10μm.

Plate 7

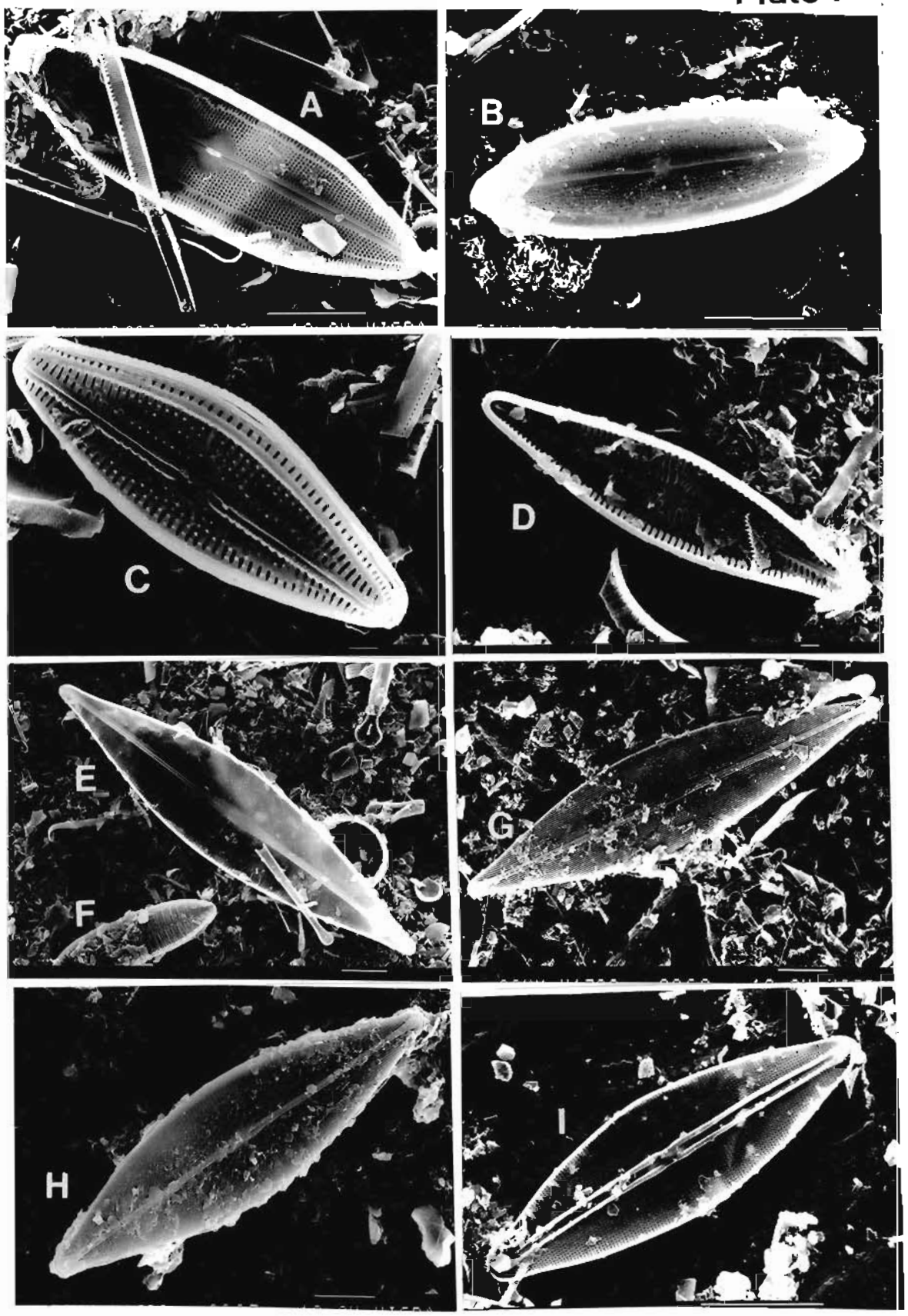

Plate 8: Scanning photographies of some diatom species.

A: *Pinnularia viridis*, bar scale = 10µm.

B: *Pinnularia viridis*, bar scale = 10µm.

C: *Pinnularia viridis*, bar scale = 10µm.

D: *Pinnularia major*, bar scale = 10µm.

E: *Pinnularia nodosa*, bar scale = 10µm.

F: *Pinnularia formica*, bar scale = 1µm.

Plate 8

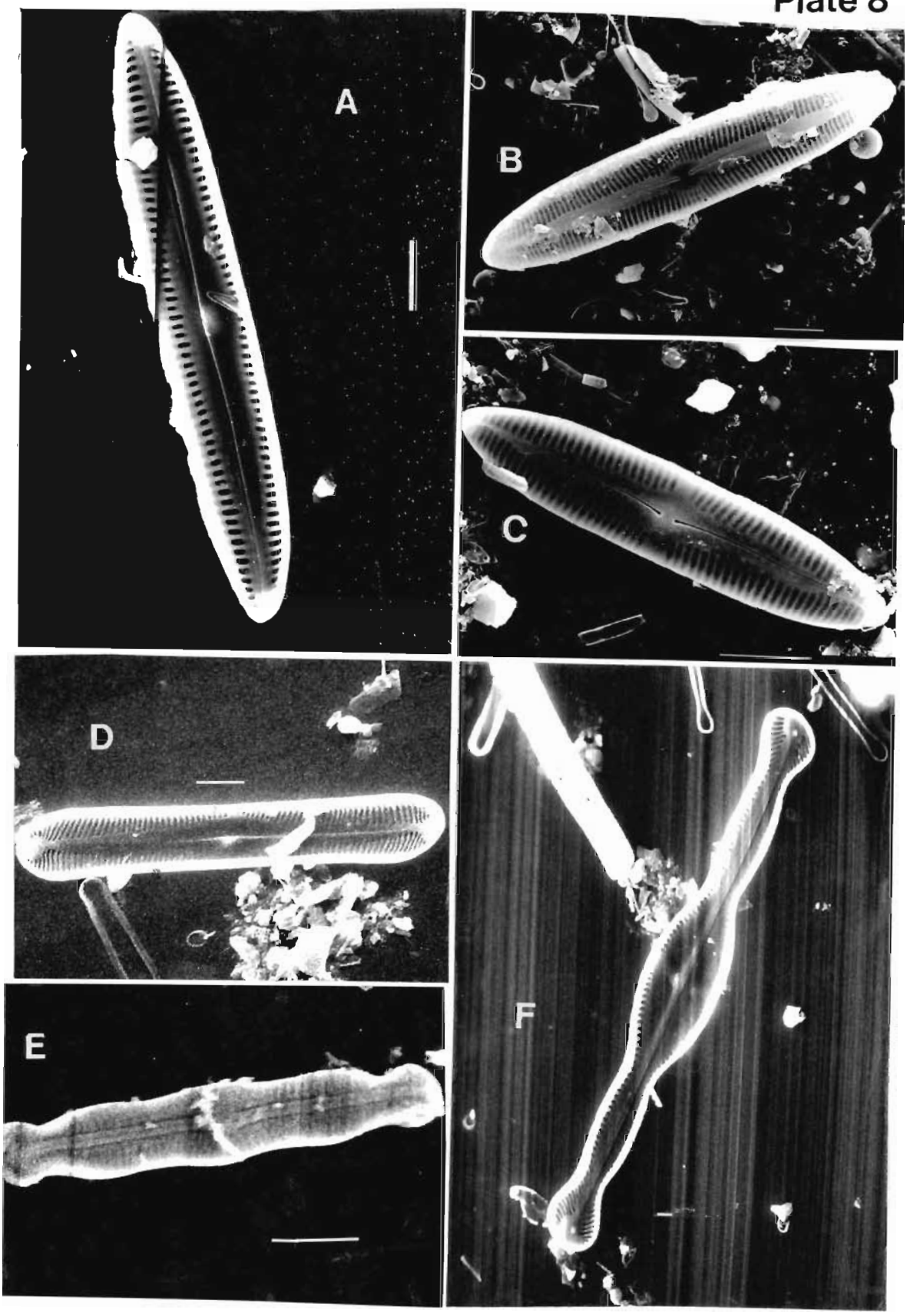

Plate 9: Scanning photographies of some diatom species.

A: *Pinnularia gibba,* bar scale = 10µm.

B: *Pinnularia microstaron,* bar scale = 10µm.

C: *Cymbella ventricosa,* bar scale = 10µm.

D: *Cymbella naviculifomis,* bar scale = 10µm.

E: *Amphora ovalis,* bar scale = 10µm.

F: *Amphora ovalis,* bar scale = 10µm.

G: *Amphora nomanii,* bar scale = 10µm.

H: *Gomphonema gracilis,* bar scale = 10µm.

Plate 9

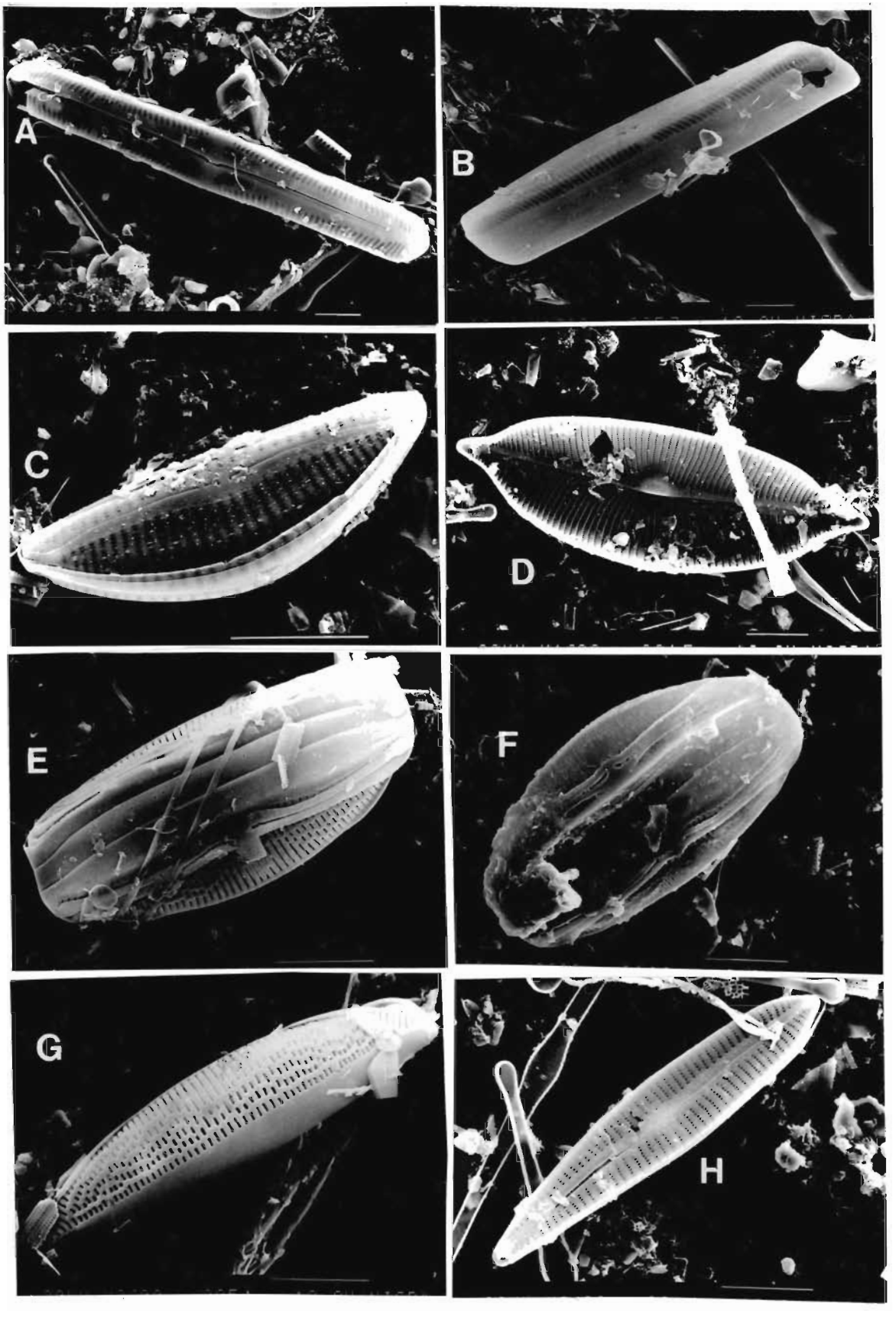

Plate 10: Scanning photographies of some diatom species.

A: *Nitzschia romana*, bar scale = 1μm.

B: *Nitzschia palea*, bar scale = 10μm.

C: *Nitzschia sublinearis*, bar scale = 10μm.

D: *Nitzschia sublinearis*, bar scale = 10μm.

E: *Surirella robusta*, bar scale = 10μm.

F: *Surirella biseriata var. bifrons*, bar scale = 1μm.

G: *Surirella linearis*, bar scale = 1μm.

H: *Cymatopleura solea*, bar scale = 10μm.

Plate 10