

POSTGLACIAL HISTORY OF LAKE GEORGE  
BASED ON DIATOMS IN SEDIMENT CORES

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ABSTRACT

Quantitative analyses of diatom distributions in sediment cores from Lake George indicate that the lake has experienced a postglacial successional history similar to that of other large temperate lakes. Analyses utilizing indicator species and groups of species suggest that Lake George passed from an early postglacial, nutrient-poor oligotrophic stage to an oligotrophic-mesotrophic stage, back to an oligotrophic stage, followed by a progression toward a more mesotrophic stage--all prior to 3,000 B.P.; however, there has been a marked increase in eutrophic diatom species in post-colonial time. Although Lake George is a large lake known for its natural beauty, there is no place in the lake at the present time where the water quality is as good (nutrient-poor) as it was in primeval times.

INTRODUCTION

Limnologists have used diatoms as indicators of environmental change in numerous lakes (for example, Conger, 1939; Patrick, 1943, 1954; Pennington, 1943; Round, 1957, 1961; Evans, 1970; Sreenivasa, 1970; Haworth, 1972). Generally such studies have dealt with long-term trends and have not been concerned with recent historical events. They have also dealt with the diatoms in detailed descriptive fashion and have not used multivariate analytical techniques. A few studies have correlated changes in the diatom population with recent historical trends (Stockner and Benson, 1967; Stockner, 1970) and have tried further to classify the lakes as to nutrient enrichment by using a simple Araphidineae/Centrales (A/C) ratio.

This study, which was part of an integrated, multidisciplinary study of Lake George, had as its aim the interpretation of the postglacial history of Lake George, including recent trends. Quantitative analysis of the diatom death assemblages is used to derive an objective classification of biotopes, groups of samples from similar environments, and to determine environmental gradients among these samples.

The two objectives of this study are 1) to see if Lake George has followed a simple trend from an oligotrophic to an eutrophic state, or if it has oscillated back and forth in response to climatic or other environmental changes as has been suggested for other mid-latitude lakes (Goulden, 1964; Livingstone, 1972); and 2) to be able to separate cultural eutrophication due to human activity from natural eutrophication in order to obtain a base-line for studies of nutrient enrichment and ecosystem perturbations. The latter objective is particularly timely because actions taken to retard eutrophication may be inappropriate if the process is principally due to natural causes. A lake may have been naturally eutrophic for many years before man occupied its drainage basin; therefore, attempts to curb cultural eutrophication beyond the natural base-line enrichment may have little or no effect.

#### METHODS

During the summer of 1970, several cores were obtained by SCUBA divers inserting 1-1/2" diameter plastic tubes as far as possible into the sediment; an expansion plug in the top maintained suction as the tube was removed. A core taken at a depth of 75 feet (26 m) from near Tea Island in the southern part of the lake was the longest and serves as the basis for this study.

The core was sampled for diatoms at 1-centimeter intervals by drilling small holes into the tube. By starting at the bottom and keeping the expansion plug in the top, none of the material leaked out. The sediment was removed by inserting a plastic straw on a hypodermic needle into the hole and withdrawing a small cylinder of material. Slides were prepared and multivariate analyses were performed as described by Bloomfield and Park in this volume.

#### RESULTS

##### BIOFACIES

R-mode (variable) cluster analysis of percentage data distinguished six biofacies (Fig. 1). Each of these biofacies was named after the dominant diatom. The Fragilaria construens biofacies includes F. pinnata, F. brevisstrata, Navicula spp., and Achnanthes lanceolata. These are all benthic or littoral forms that could grow in shallow water. The Tabellaria fenestrata biofacies consists of that species and Melosira granulata, both being planktonic. The Gyrosigma biofacies includes both Gyrosigma spp. and Cocconeis spp.; these are benthic forms. The Cymbella biofacies is also benthic, with Cymbella spp., Diploneis spp., and Synedra spp. The Synedra radians biofacies includes Synedra ulna, Asterionella formosa, Fragilaria crotonensis, Cyclotella meneghiniana, and C.

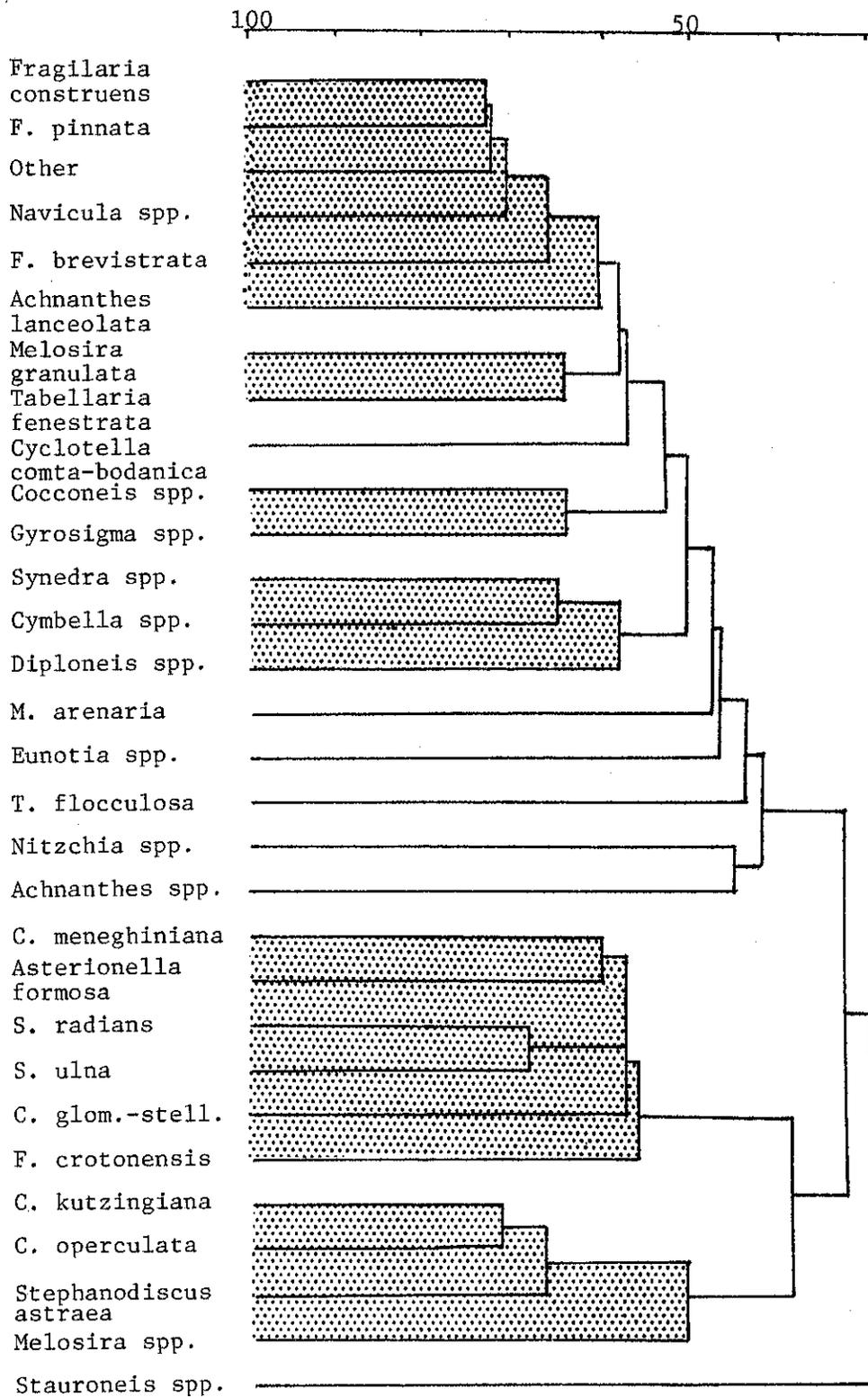


Figure 1. R-mode cluster dendrogram.

glomerata-stelligera. Most of these are planktonic and indicate eutrophic conditions. The Cyclotella operculata biofacies also consists of planktonic species. It includes Cyclotella operculata, C. kutzinghiana, Stephanodiscus astrae, and Melosira spp. (possibly M. italica or M. islandica).

#### BIOTOPES

Q-mode (sample) cluster analysis yielded four major biotopes and seven sub-biotopes (Fig. 2):

1) Sub-biotope A1 extends from the surface to a depth of 3 cm. It is dominated by Cyclotella glomerata-stelligera, Tabellaria fenestrata, Cyclotella operculata, C. meneghiniana, C. kutzinghiana, and Synedra ulna. The Synedra radians biofacies is most abundant in this sub-biotope.

2) Sub-biotope A2 extends from 4 cm to 17 cm and is dominated by Achnanthes lanceolata, C. operculata, Tabellaria fenestrata, Melosira granulata, C. comta, Fragilaria brevisstrata, C. kutzinghiana, and Fragilaria construens. The Cyclotella operculata biofacies is most abundant in this sub-biotope and is virtually absent below.

3) Biotope B extends from 18 cm to 24 cm, and is dominated by F. construens, F. pinnata, Tabellaria fenestrata, and Epithemia spp. The centric forms disappear almost completely in this sub-biotope. The common forms are almost all benthic.

4) Biotope C extends from 25 cm to 39 cm. It is dominated by Fragilaria construens, F. pinnata, and Achnanthes lanceolata. Gyrosigma accuminatum, which is alkalibiontic, is abundant at the lower part of the biotope. The centric and planktonic diatoms are almost nonexistent in this biotope.

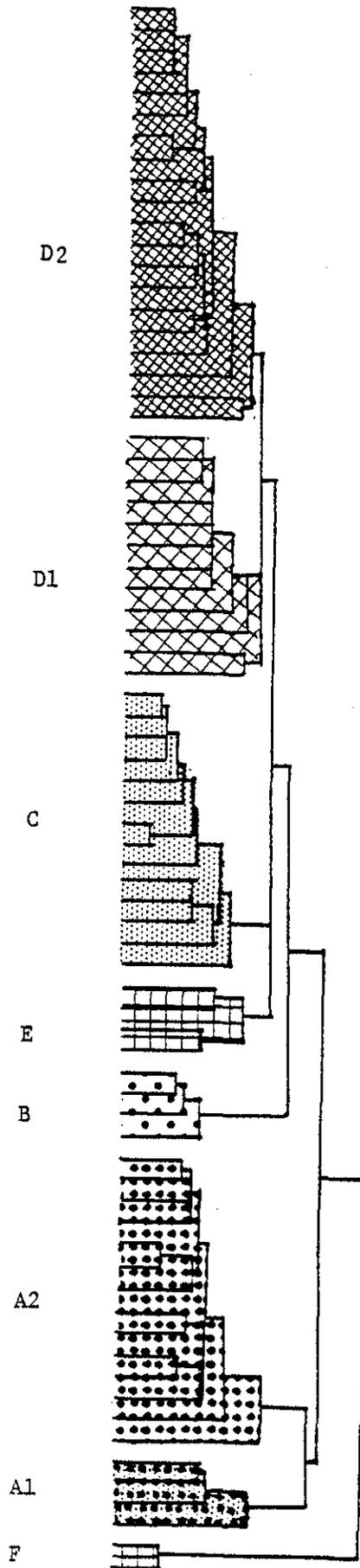
5) Sub-biotope D1 extends from 40 cm to 52 cm and is dominated by Fragilaria pinnata, F. construens, Melosira granulata, Tabellaria fenestrata, Cocconeis spp., and Achnanthes spp. Gyrosigma accuminatum is abundant at the top of this sub-biotope. The centric and planktonic diatoms start to increase again at this level.

6) Sub-biotope D2 extends from 53 cm to 72 cm, and is dominated by Cyclotella comta, Fragilaria construens, and F. pinnata. Most of the forms are benthic, but the planktonic and centric diatoms are moderately abundant. The Synedra radians biofacies shows a slight increase in this sub-biotope.

7) Biotope E extends from 73 cm to 74 cm. It is dominated by Fragilaria pinnata, Achnanthes spp., Gyrosigma spp., and Gomphonema spp. Biotope E is characterized by the virtual absence of centric, planktonic and eutrophic diatoms.

8) Biotope F extends from 75 cm to 76 cm, and is dominated by

Figure 2.  
Q-mode cluster dendrogram.



Achnanthes spp., A. lanceolata, Cymbella spp., and Fragilaria pinnata.

The data were also compared with surface-sediment samples (see paper by Bloomfield and Park in this volume). Because most of the surface-sediment samples were only identified to genera, the core data were converted to genera also. The top three core samples clustered with the surface-sediment samples.

#### ORDINATION

Figures 3a and 3b show the disposition of the biotopes in the ordination model, which accounts for 74.8% of the dissimilarity among all the core samples. The left endpoint of the first axis is in biotope A, with 74.4% planktonic diatoms dominated by Cyclotella glomerata-stelligera, Synedra ulna, and Tabellaria fenestrata. Six eutrophic indicator species make up 47.5% of the sample. The right endpoint is in biotope C and is dominated by Fragilaria construens, Fragilaria pinnata, and Achnanthes lanceolata, with no planktonic or eutrophic diatoms present.

The top endpoint of the second axis is in biotope C and is dominated by Fragilaria construens, Fragilaria pinnata, and Achnanthes lanceolata, with 12% planktonic diatoms. Eutrophic indicator species make up only 1% of the sample. The bottom endpoint is in biotope E and is dominated by Cyclotella comta, Fragilaria construens, and Fragilaria pinnata, with 26.9% planktonic diatoms. Eutrophic indicator species make up 4.2% of the sample.

The top endpoint of the third axis (Fig. 3b) is in biotope E and is dominated by Achnanthes lanceolata, Achnanthes spp., Cymbella spp., and Fragilaria pinnata. There are no eutrophic indicator species and the planktonic diatoms comprise only 1.8% of the sample. The bottom sample is in biotope D2 and is dominated by Fragilaria pinnata, Fragilaria construens, Melosira granulata, Navicula spp., and Cocconeis spp. The eutrophic indicator species are absent, but the planktonic diatoms make up 19% of this sample.

Figure 3c shows the distribution of relative percentages of the planktonic diatoms in the ordination model, indicating an increase from right to left. Polynomial regression was run on the plankton data and the trend is plotted on the model. The linear trend accounted for 88% of the variation. The trend for the relative percentages of centric diatoms also was plotted on the ordination model; it had a fit of 73%. The depth trend is assumed to lie between the centric and planktonic diatom trends as observed in ordination of the surface-sediment samples.

Figure 3d shows the distribution of relative percentages of six eutrophic indicator species. The linear trend accounted for 72% of the variation. The six eutrophic indicators also increase from right

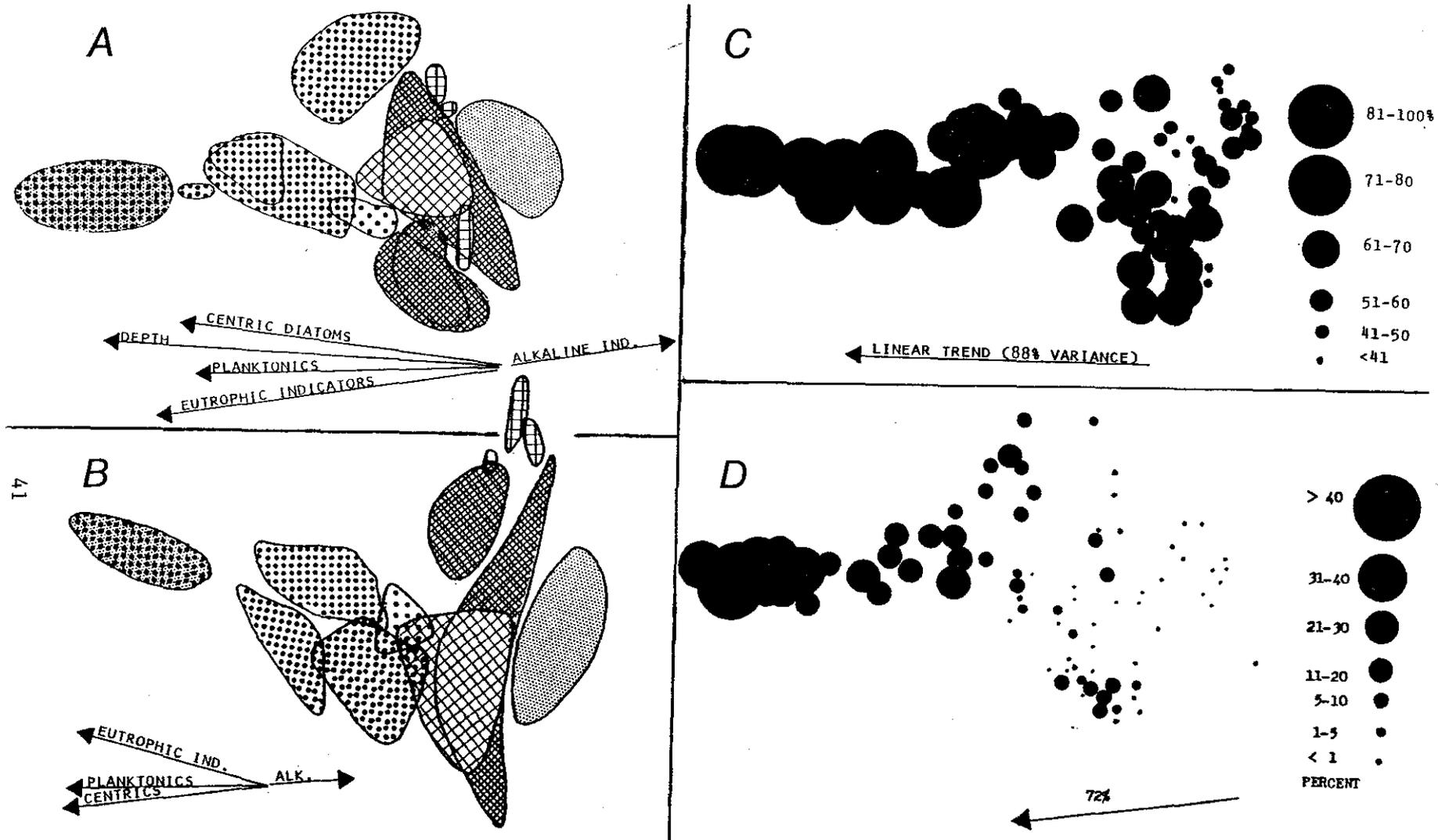


Figure 3. Q-mode ordination model. A-axes 1 and 2; patterns correspond to those in Fig. 2. B-axes 1 and 3. C-distribution of plankton diatoms along axes 1 and 2. D-distribution of eutrophic indicator species along axes 1 and 2.

to left, as does the depth.

#### TIME-TREND ANALYSES

The planktonic diatoms, which include all of the centric diatoms plus Asterionella formosa, Fragilaria crotonensis, Tabellaria fenestrata, and T. flocculosa, increase from only a few percentage to around 40% between 45 and 60 cm. They then decrease again to almost zero at 30 cm and increase greatly to 80% in the top few centimeters (Fig. 4). This seems to indicate a change in either water depth or turbidity of the water. Shallow water and clearer water would both favor the growth of the benthic diatoms which require light penetration to the bottom; however, deep water of great clarity could still be expected to contain planktonic diatoms.

The six eutrophic indicator diatoms, Cyclotella glomerata-stelligera, C. kutzingiana, Asterionella formosa, Fragilaria crotonensis, Synedra ulna, and Stephanodiscus astrae, show a general trend similar to the centric and planktonic diatoms (Fig. 5). However, at 5 cm they increase sharply to 45% of the total diatom population.

#### DISCUSSION AND CONCLUSIONS

The six diatom biofacies appear to have environmental significance. The Fragilaria construens, Gyrosigma, and Cymbella biofacies are comprised of benthic diatoms, including both oligotrophic and eutrophic forms. The Synedra radians biofacies is comprised of planktonic diatoms characteristic of eutrophic conditions; the Cyclotella operculata biofacies is dominated by planktonic diatoms characteristic of oligotrophic conditions; and the Tabellaria fenestrata biofacies is dominated by planktonic species that may represent mesotrophic-eutrophic conditions.

Nutrient enrichment, water depth, and possibly water clarity are the principal environmental factors that have affected the distributions of postglacial diatoms, as determined from the ordination model. Alkalinity may have been a secondary factor. Diatom biotopes, derived from Q-mode cluster analysis, indicate that there were nutrient-poor conditions initially, followed by a change to slightly enriched conditions; this trend was followed by a return to nutrient-poor conditions, which then gradually gave way to more enriched conditions, with a sharp increase in nutrient enrichment beginning at the 5 cm level in the reference core.

The recent sedimentation rate is approximately 0.48 mm/year as indicated by data from sediment traps (Williams, 1972), which suggests that the accelerated nutrient-enrichment trend<sup>14</sup> coincides closely with the period of settlement of the basin. A C<sup>14</sup> date of 3100 BP from the 13 cm level indicates that the initial stages of natural eutrophication were in evidence in the southern basin of Lake

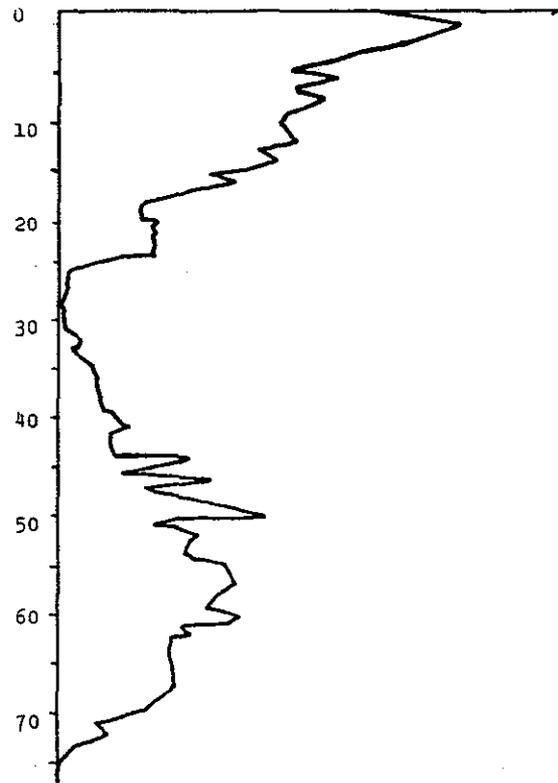


Figure 4. Distribution of relative abundance of planktonic diatoms in core; depth in cm.

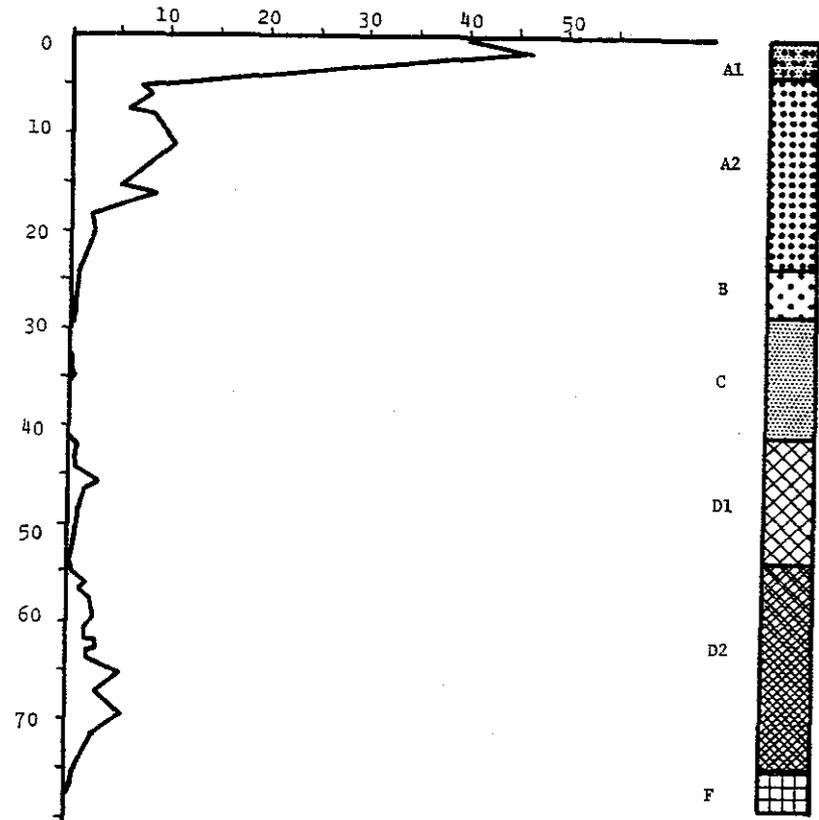


Figure 5. Distribution of relative abundance of eutrophic indicator species in core; depth in cm; biotopes shown at right.

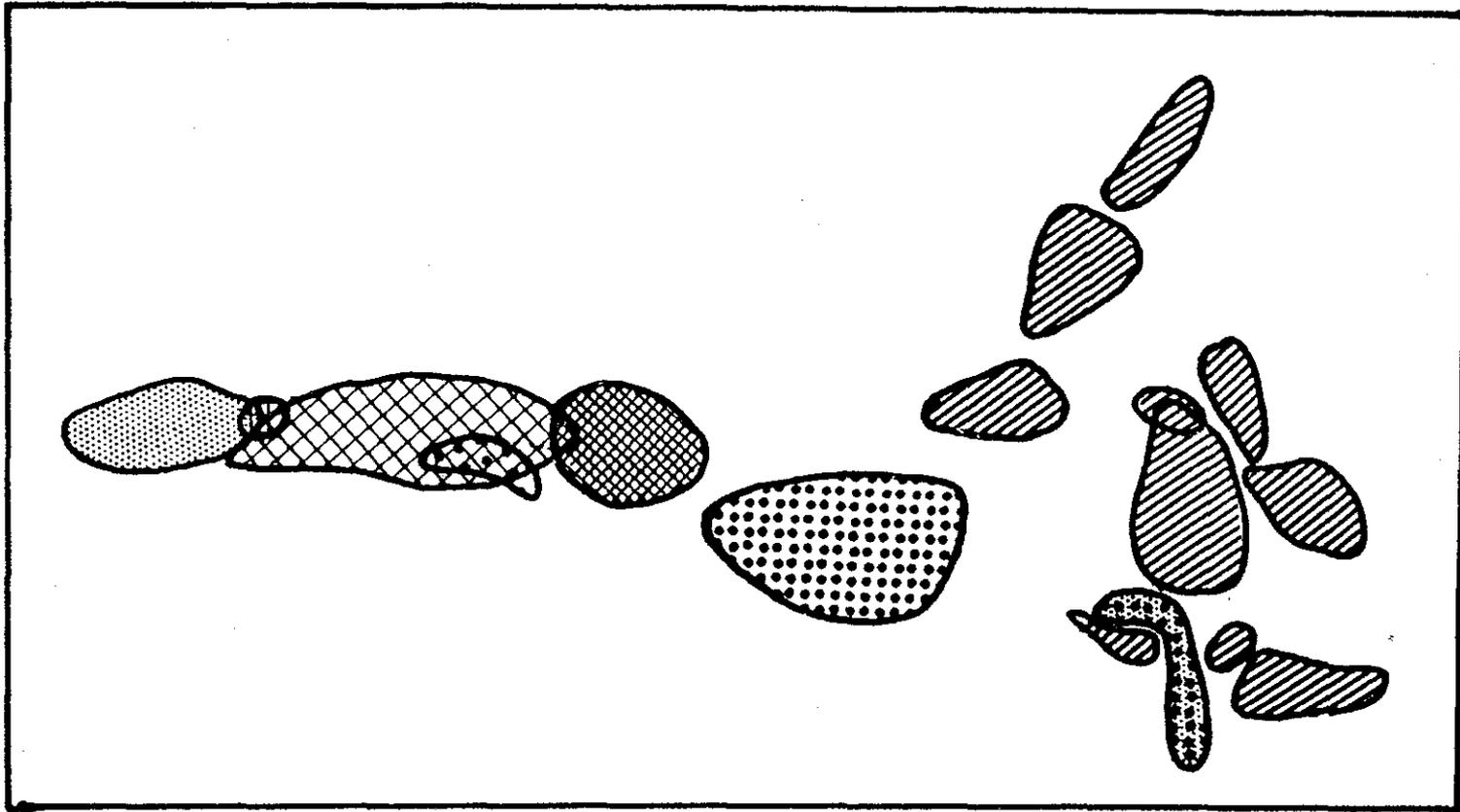


Figure 6. Q-mode ordination of combined core and surface-sediment samples; patterns correspond to those in other figures; eutrophic samples on the right.

George well before settlement (see Fig. 5). The prehistoric fluctuations in nutrient enrichment correspond to those observed in other large temperate-climate lakes and probably reflect the effects of postglacial climate on both the lake and the associated drainage basin.

The changes noted in the distribution of biotopes in the cores are also manifested in the trends of indicator groups. However, examination of the planktonic-diatom and eutrophic-indicator curves (Figs. 4 and 5) suggests that biotope C, which is dominated by benthic species, may be more an indication of low water level (or possibly extreme water clarity) than of nutrient-poor conditions.

The core data were compared with the surface sediment data (Bloomfield and Park, this volume) by combining both in a single ordination model (Fig. 6). All the surface-sediment samples plot in the right side of the model, which represents relatively nutrient-rich conditions. This indicates that nowhere in the lake at the present time is the water quality as good as that which prevailed in prehistoric times.

#### ACKNOWLEDGMENTS

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