HISTORICAL WATER QUALITY AND ECOLOGICAL CHANGE OF THREE LAKES IN THE RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT, MN

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SUMMARY

1. In this project, paleolimnological techniques were used to reconstruct the trophic and sedimentation history of Mitchell, Lotus, and Round Lakes in Hennepin and Carver Counties, Minnesota.

2. Sediment cores were collected from each lake and lead-210 activity was analyzed to develop dating models and determine sediment accumulation rates. Sediments were analyzed for inorganic, organic, and carbonate components using loss-on-ignition analysis, and subfossil diatoms in the sediments were analyzed for reconstruction of changes in lake ecology and trophic state.

3. Sedimentation rates increased dramatically in all three lakes during the 1900s. Peak sedimentation occurred in the 1940s in Mitchell Lake, Lotus Lake had peaks in 1966 and 1993, and the peak in Round Lake was in the 1980s.

4. In all three lakes, sedimentation rates have decreased in recent decades and are currently slightly elevated over sedimentation rates prior to European settlement.

5. Diatom community assemblages and diatom-inferred total phosphorus (TP) histories in all three lakes suggest that these systems have been in the meso- to eutrophic range during the past 150-200 years. Nutrient levels in Mitchell Lake have historically been highly variable, fluctuating between eutrophic and hypereutrophic levels. Lotus Lake was a mesotrophic system until the 1940s with diatom-inferred TP levels generally below 30 µg/l. Total phosphorus levels in Lotus Lake increased to eutrophic levels after the 1940s; recent changes in diatom communities hint at declining nutrient levels although alternative ecological drivers may be driving the recent community shifts. Round Lake had mesotrophic nutrient levels (<40 µg/l TP) prior to European settlement; diatom-inferred TP values since the 1960s have been steady in the slightly eutrophic range (40-60 µg/l TP).

INTRODUCTION

Within the glaciated regions of the Upper Midwest, lakes feature prominently in the landscape and are a valued resource for tourism, municipalities, home and cabin owners, recreational enthusiasts, and wildlife. Current and historical land and resource uses around the lakes in Hennepin and Carver Counties, including shoreline development, transportation development, sport fisheries, stormwater runoff, water level management, aquatic invasives, grazing, and agriculture, have raised concerns about the state of the lakes and how to best manage them in a future certain to bring change. To effectively develop management plans, knowledge of the natural state of a lake and an understanding of the timing and magnitude of historical ecological changes become critical components. In this project, paleolimnological techniques were used to reconstruct the trophic and sedimentation history of Lotus, Mitchell, and Round Lakes in Hennepin and Carver Counties, Minnesota. Results provide a management foundation through the determination of the natural or reference condition of these lakes and the reconstruction of ecological changes that have occurred in the lakes during the last 150-200 years.

With any lake management plan it is important to have a basic understanding of natural fluctuations within the system. Reliable long-term data sets, on the order of 30 - 50 years, are generally not available for most regions of the country. Through the use of paleolimnological techniques and quantitative environmental reconstruction, we can estimate past conditions, natural variability, timing of changes, and determine rates of change and recovery. This type of information allows managers and researchers to put present environmental stresses into perspective with the natural variability of the system. It can also be used to identify response to and recovery from short-term disturbances.

Lotus and Mitchell Lakes have been determined to be impaired for nutrients, particularly total phosphorus (TP). Lotus Lake is located near the ecotone of the Central Hardwood Forests and Western Corn Belt Plains ecoregions, near the town of Chanhassen, in Carver County, MN. Lotus Lake has a median depth of 10.5 feet, with a maximum depth of 29 feet at a deep hole; it is currently classified as eutrophic, with an average TP value of 56 µg/l (http://www.pca.state.mn.us/water/clmp/lkwqReadFull.cfm?lakeid=10-0006; February 2011). Mitchell Lake is located near the town of Eden Prairie in Hennepin County, also near the ecotone of the Central Hardwood Forests and Western Corn Belt Plains ecoregions of MN. It has a maximum depth of 18 feet and is currently classified as hypereutrophic, with an average total phosphorus (TP) value of 90 µg/l (http://www.pca.state.mn.us/water/clmp/lkwqReadFull.cfm?lakeid=27-0070; February 2011). Round Lake is also in Hennepin County, it is the deepest lake of the three with a maximum depth of approximately 45 feet. Unlike Lotus and Mitchell Lakes, Round Lake has been mesotrophic throughout most of its monitoring history (David Austin, personal communication).

The primary aim of this project was to use paleolimnological analysis of dated sediment cores from the three lakes to reconstruct ecological histories using biogeochemistry, sediment accumulation, diatom-inferred total phosphorus (DI-TP), and diatoms as biological indicators. The lakes currently have marginal to poor water quality and are the subject of local and state concern to develop management plans that include an understanding of presettlement conditions, historical lake response to landuse and past management, and development of management targets. These goals are well-suited to a paleolimnological study. Analytical tools included radioisotopic dating of the cores, geochemical analyses to determine local sediment accumulation rates, and analysis of subfossil algal communities. Multivariate analyses, diatom-based transfer functions, and comparison of algal assemblages with an 89 Minnesota lake data set were used to relate changes in trophic conditions and algal communities to human impacts in the local watershed.

Diatoms have been widely used to interpret environmental conditions in lakes (Dixit et al., 1994). Many species are sensitive to specific water conditions and are useful as bioindicators. Over the past 20 years, statistical methods have been developed to estimate quantitative environmental parameters from diatom assemblages. These methods are statistically robust and environmentally sound (Birks 1998). They have been used successfully in reconstructing a wide variety of environmental parameters including pH, total phosphorus (TP), and salinity (e.g. Fritz et al., 1991, 1999, Dixit et al. 1992; Hall and Smol 1992. In the state of Minnesota, diatom analysis has been used as one line of evidence for developing lake nutrient criteria (Heiskary and Wilson 2008) and lake specific nutrient standards (Edlund and Ramstack 2007).

METHODS – SEDIMENT CORING

Sediment cores were collected in March of 2009 by LacCore (National Lacustrine Core Repository), Department of Geology and Geophysics, University of Minnesota-Twin Cities. Coring date, location, and water depth are provided in Table 1.

METHODS – BIOGEOCHEMISTRY

Weighed subsamples were taken from regular intervals throughout the cores for loss-on-ignition (LOI) analysis to determine bulk and dry density and dry weight percent of organic, carbonate, and inorganic matter. Sediment subsamples were heated at 105°C to determine dry density, then sequentially heated at 550°C and 1000°C to determine organic and carbonate content from post-ignition weight loss, respectively. LOI analysis was performed by LacCore.

METHODS – LEAD-210 DATING

Sediments from each lake were analyzed for lead-210 activity to determine age and sediment accumulation rates for the past 150-200 years. Lead-210 was measured at numerous depth intervals by lead-210 distillation and alpha spectrometry methods, and dates and sedimentation rates were determined according to the c.r.s. (constant rate of supply) model (Appleby and Oldfield 1978). Dating and sedimentation errors were determined by first-order propagation of counting uncertainty (Binford 1990).

METHODS – DIATOM AND NUMERICAL ANALYSES

Fifteen downcore samples from each lake were analyzed for diatoms. See Table 2 for a list of samples prepared for diatom analysis from each core.

Diatoms samples were prepared by placing approximately 0.25 cm^3 of homogenized sediment in a 50 cm^3 polycarbonate centrifuge tube, and adding 2-5 drops of 10% v/v HCl solution to dissolve carbonates. Organic material was subsequently oxidized by adding 10 ml of 30% hydrogen peroxide and heating for 3 hours in an 85°C water bath. After cooling, the samples were rinsed with distilled deionized water to remove oxidation biproducts. Aliquots of the remaining material, which contains the diatoms, were dried onto 22x22 mm #1 coverglasses, which were then permanently attached to microscope slides using Zrax mounting medium. Diatoms were identified along random transects to the lowest taxonomic level under 1250X magnification (full immersion optics of NA 1.4). A minimum of 400 valves was counted in each sample. Abundances are reported as percentage abundance relative to total diatom counts. Identification of diatoms used regional floras (e.g. Patrick and Reimer 1966, 1975, Edlund 1994, Camburn and Charles 2000) and primary literature to achieve consistent taxonomy.

Stratigraphies of predominant diatoms (species with greater than or equal to 5% relative abundance in one or more core depths) were plotted against core date. Relationships among diatom communities within a sediment core were explored using the ordination methods of Correspondence Analysis (CA) or Detrended Correspondence Analysis (DCA) depending on the gradient lengths in the cores, both of which are available in the software package R (Ihaka &

Gentleman 1996). Core depths/dates were plotted in ordinate space and their relationships and variability used to identify periods of change, sample groups, and ecological variability among core samples. A general rule for interpreting a CA or DCA is that samples that plot closer to one another have more similar diatom assemblages.

Downcore diatom communties were also used to reconstruct historical epilimnetic phosphorus levels. A transfer function for reconstructing historical logTP was earlier developed based on the relationship between modern diatom communities and modern environmental variables in 89 Minnesota lakes (Ramstack et al. 2003, Edlund and Ramstack 2006) using weighted averaging (WA) regression with inverse deshrinking and bootstrap error estimation (C2 software; Juggins 2003). The strength of the transfer function was evaluated by calculating the squared correlation coefficient (r^2=0.83) and the root mean square error (RMSE=0.181) between the observed logTP with the model estimates of logTP for all samples. Bootstrapping was used in model validation to provide a more realistic error estimate (RMSEP, the root mean square error of prediction=0.208) because the same data are used to both generate and test the WA model (Fritz et al. 1999). Reconstructed estimates of logTP (diatom-inferred TP, or DI-TP) for each downcore sample were determined by taking the logTP optimum of each species, weighting it by its abundance in that sample, and determining the average of the combined weighted species optima. Data are presented as both logTP values and as backtransformed values, to TP in µg/l.

RESULTS AND DISCUSSION – BIOGEOCHEMISTRY

Mitchell Lake: There are two major changes in sediment composition in the core from Mitchell Lake (Figure 1). The first is a gradual rise in inorganic matter, with a corresponding decrease in organic matter from approximately 122 cm to 105 cm depth. The second is more abrupt increase in inorganic matter and decrease in organic matter from 48 cm to 38 cm; during this transition inorganic matter rises from approximately 50% to 68% dry weight. The amount of carbonate in the Mitchell Lake sediments remains low and relatively constant throughout the length of the core.

Lotus Lake: The changes in sediment composition in the Lotus Lake core are less pronounced; the sharpest change is a rise in inorganic matter and decrease in organic matter at approximately 140 cm depth (Figure 2). The amount of carbonate in the core is low, but begins to rise gradually at about 60 cm. From 60 cm to 26 cm the amount of carbonate increases from 10% to 17% dry weight; at 25 cm the carbonate abruptly increases to 22% and remains elevated to the top of the core.

Round Lake: The amount of carbonate in the Round Lake core remains low and relatively constant throughout the length of the core (Figure 3). However, there are large shifts in both inorganic and organic matter throughout the core. Inorganic matter shows a steady increase and organic matter a steady decrease from the bottom of the core up to approximately 100 cm depth; there is an inverse of this trend in the top 10 cm of the core, and large fluctuations in inorganic and organic matter in between.

RESULTS AND DISCUSSION – DATING AND SEDIMENTATION

Mitchell Lake: The unsupported lead-210 activity, the resulting lead-210 dating model, and the sediment accumulation rate for Mitchell Lake are shown in Figure 4. In Mitchell Lake, the sedimentation rate prior to European settlement ranges from 0.02 to 0.04 g/cm^2 yr (Figure 4c). The sedimentation rate gradually rises in the early 1900s, and sharply peaks at 0.39 g/cm^2 yr in the 1940s. After this sharp rise in the 1940s, sedimentation in Mitchell Lake has decreased, although at the core top it remains slightly elevated over pre-European settlement levels.

The distinct peak in sedimentation rate in the 1940s corresponds with the sharp increase in inorganic matter in the core (Figure 1), both suggesting that there was a large influx of sediment from the watershed during this time.

Lotus Lake: The unsupported lead-210 activity, the resulting lead-210 dating model, and the sediment accumulation rate for Lotus Lake are shown in Figure 5. Prior to European settlement the sedimentation rate in Lotus Lake ranges from 0.08 to 0.10 g/cm^2 yr (Figure 5c). As in Mitchell Lake, the sedimentation rate begins to increase in the early 1900s, but unlike Mitchell the rise continues until the 1980s, where it peaks at 0.21 g/cm^2 yr. After the early 1980s, the sedimentation rate declines; however as in Mitchell Lake the present day rate remains slightly elevated over pre-European settlement levels.

Round Lake: Figure 6 illustrates the unsupported lead-210 activity, the resulting lead-210 dating model, and the sediment accumulation rate for Round Lake. The sedimentation rate prior to European settlement ranged from 0.04 to 0.06 g/cm^2 yr, with a slight rise to 0.06 to 0.08 g/cm^2 yr beginning around the time of European settlement in the late 1800s/early 1900s (Figure 6c). The sedimentation rate sharply increases in the 1920s and remains elevated until the early 1990s, with a peak of 0.37 g/cm^2 yr in 1966 and another peak at 0.37 g/cm^2 yr in 1993. In the past decade the sedimentation rate has rapidly declined and is presently just slightly elevated over pre-European settlement levels.

RESULTS AND DISCUSSION – DIATOM STRATIGRAPHY AND ORDINATIONS

Mitchell Lake: A correspondence analysis (CA) of the Mitchell Lake diatom data shows two major shifts in the diatom community assemblage since the mid-1800s (Figure 7). The first shift took place in the late 1800s/early 1900s, and the second in the most recent decades. The stratigraphic diagram from Mitchell Lake shows the predominant diatoms whose abundances are driving the shifts in the community assemblage (Figure 8). The bottommost core samples (1847-1883) are dominated by *Aulacoseira ambigua*; this is a planktonic species that thrives in well-mixed or windswept lakes. From the early 1900s to the 1980s, the abundance of *A. ambigua* drops off and the dominant diatoms are small planktonic species such as *Stephanodiscus minutulus* and *Cyclostephanos tholiformis*. These small centric diatoms decrease in abundance in recent decades and are replaced by a flora dominated by *Aulacoseira granulata*, *Asterionella formosa*, *Fragilaria capucina* var. *mesolepta*, and *Fragilaria crotonensis*.

Overall, the abundant species throughout this core are planktonic diatoms that are indicative of eutrophic conditions, although some can be found in mesotrophic systems (e.g. *A. ambigua, A. formosa*, and *F. crotonensis*). This indicates that, although there have been some shifts in the diatom community assemblage, Mitchell Lake has been a productive system since the mid 1800s.

Lotus Lake: A detrended correspondence analysis (DCA) of the diatom data from the Lotus Lake core shows one prominent shift in the diatom community assemblage between 1940 and 1950 (Figure 9). There is a secondary shift at the top of the core, with the 2009 sample showing a large change from the rest of the core. The changes in relative abundances of major diatom species driving the shifts in the community assemblage are illustrated on the stratigraphic diagram (Figure 10). Prior to 1940 the diatom community was dominated *Fragilaria construens* var. *venter* and *Fragilaria pinnata*; these small *Fragilaria* species are tychoplanktonic, which means they can live either attached to the benthos or suspended in the plankton. After 1940, these diatoms are replaced by more of a true planktonic assemblage, such as *Stephanodiscus niagarae*, and *S. minutulus*, as well as *Aulacoseira ambigua* and *A. granulata*. The uppermost sample is distinguished by a sharp rise in *Fragilaria crotonensis*, a species often found in mesotrophic systems.

Round Lake: A correspondence analysis (CA) of the Round Lake core shows two major shifts in the diatom community assemblage, the first between 1911 and 1920, and the second between 1969 and 1980 (Figure 11). The sample from 1940 is a bit of an anomaly in that it is more similar to the core bottom than to the cluster of samples from 1920 to 1969.

The diatom species whose changes in abundance are driving the shifts in the CA are shown in the stratigraphic diagram of Round Lake (Figure 12). Prior to 1920 there are multiple species that dominate the assemblage, such as the planktonic species *Asterionella formosa*, *Stephanodiscus minutulus*, and *Fragilaria crotonensis*; several benthic species also appear in abundance, such as *Achnanthes minutissima*, and *Navicula minima*. From 1920 to 1969 the assemblage is characterized by the small planktonic diatoms *Cyclostephanos tholiformis*, *C. invisitatus*, and *Stephanodiscus hantzschii*; *A. minutissima* also increases in abundance at this time. The exception during this time period is the 1940 sample, which is characterized by a large increase in *Fragilaria crotonensis*. From 1980 to the present *Stephanodiscus minutulus* and *Fragilaria capucina* var. *mesolepta* increase in abundance and *Achnanthes minutissima* remains abundant. The most recent sample has an abundance of the epiphytic taxon *Cocconeis placentula*.

RESULTS AND DISCUSSION – PHOSPHORUS RECONSTRUCTIONS

Mitchell Lake: The total phosphorus (TP) reconstruction from Mitchell Lake shows large fluctuations in TP values, from 42 µg/l to over 100 µg/l, but overall indicates that this lake has been productive since the mid-1800s (Figure 13). Although the diatom-inferred TP concentration at the top of the core (66 µg/l) is lower than the current monitored value of 90 µg/l, both indicate highly eutrophic conditions.

Lotus Lake: The Lotus Lake TP reconstruction indicates that this was a mesotrophic lake from the mid-1800s through 1940; after 1940 TP levels rise sharply to over 60 µg/l (Figure 14). Since the 1980s, the TP reconstruction suggests that TP levels have been declining in Lotus Lake, and diatom-inferred TP at the core top is 25 µg/l. Current monitored TP values are in the eutrophic range, suggesting that ecological drivers other than nutrients may be driving the recent diatom community shifts.

Round Lake: The Round Lake TP reconstruction shows that the lake was mesotrophic at the bottom of the core (Figure 15). Since then the lake has been eutrophic, with fluctuations from 30 µg/l to nearly 100 µg/l. The diatom-inferred TP indicates that the TP concentrations in Round Lake have remained relatively constant since the 1980s, although the values exceed the recent monitoring values which indicate the lake is mesotrophic.

Diatom-based weighted averaging reconstructions have worked well to infer past TP concentrations in deep lakes; however, shallow lakes can challenge these traditional methods (Sayer 2001; SCWRS unpublished data). One of the problems with diatom-inferred nutrient reconstructions in shallow lakes is that in these systems there is often a decoupling of nutrient levels with variables that are normally correlated, such as chlorophyll a and Secchi depth (Heiskary and Lindon 2005). Therefore, a given TP concentration may support a large range of chlorophyll a levels. Similarly, the relationship between TP and diatoms is not as strong in shallow lakes, which can make diatom-based TP reconstructions less reliable (Ramstack and Edlund, unpublished data). In addition, we find that some shallow lakes are dominated by generalist species; these species are adapted to living in wind-swept shallow systems, so the species turnover in these lakes is less dependent on nutrient levels (Bennion et al. 2001; Sayer 2001). The diatom community changes in shallow lakes are quite informative as to changes in habitat and overall ecology of the lake. Therefore, it is important to interpret the TP reconstructions cautiously, and in conjunction with diatom species changes and changes in the geochemical properties of the sediments.

CONCLUSIONS

Sedimentation rates in all three lakes increased dramatically during the 1900s, with the rise beginning just after 1900 in Mitchell and Lotus Lakes and in the 1920s in Round Lake. The dramatic increase in sedimentation rate in Round Lake in the 1920 corresponds to a large shift in the diatom community assemblage, with small planktonic species also increasing in abundance as sedimentation rates increased.

The timing of peak sedimentation rate varied by lake, with Mitchell Lake peaking in the 1940s, Lotus Lake showing peaks in 1966 and 1993, and the peak in Round Lake occurring in the 1980s. Sedimentation rates in all three lakes have decreased in recent decades and are currently only slightly elevated over pre-European settlement levels.

Diatom community assemblages in all three lakes suggest that these have been productive systems (in the meso- to eutrophic range) throughout the period of study. This has been found in other lakes in this region; recent paleolimnological studies in the Minnehaha Creek Watershed District (Hennepin and Carver Counties) showed that of 15 bays and lakes within the Lake Minnetonka watershed, ten were found to be mesotrophic prior to European settlement, and five were eutrophic before settlement (Edlund and Ramstack 2006, Edlund et al. 2009).

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Table 1. Coring locations and water depth at the core site.

Lake	Date Cored	Coring Coordinates	Water Depth at Core Site (m)
Mitchell	March 2, 2009	44.85930°N, 93.49790°W	4.85
Lotus	March 12, 2009	44.87955°N, 93.52813°W	5.63
Round	March 20, 2009	44.868068°N, 93.492319°W	9.78

Table 2. Samples prepped for diatom analysis from each lake.

Core	Sample Depth (cm)	Lead-210 Date
Mitchell Lake	0-1	2009
Mitchell Lake	9-10	2000
Mitchell Lake	17-18	1990
Mitchell Lake	22-23	1980
Mitchell Lake	28-29	1970
Mitchell Lake	34-35	1960
Mitchell Lake	42-43	1950
Mitchell Lake	64-65	1940
Mitchell Lake	82-83	1930
Mitchell Lake	92-93	1921
Mitchell Lake	98-99	1911
Mitchell Lake	102-103	1901
Mitchell Lake	107-108	1883
Mitchell Lake	111-112	1867
Mitchell Lake	116-117	1847
Lotus Lake	0-1	2009
Lotus Lake	13-14	2001
Lotus Lake	22-23	1990
Lotus Lake	33-34	1979
Lotus Lake	41-42	1971
Lotus Lake	49-50	1961
Lotus Lake	58-59	1950
Lotus Lake	67-68	1940
Lotus Lake	77-78	1930
Lotus Lake	87-88	1921
Lotus Lake	98-99	1910
Lotus Lake	106-108	1900
Lotus Lake	118-120	1884
Lotus Lake	126-128	1872
Lotus Lake	134-136	1860
Round Lake	1-2	2008
Round Lake	7-8	2001
Round Lake	14-15	1990
Round Lake	21-22	1980
Round Lake	29-30	1969
Round Lake	41-42	1959
Round Lake	51-52	1950
Round Lake	66-67	1940
Round Lake	83-84	1930
Round Lake	91-92	1920
Round Lake	97-98	1911
Round Lake	100-102	1899
Round Lake	106-108	1884
Round Lake	110-112	1874
Round Lake	116-118	1862

Figure 1. Percent dry weight of organic, $CaCO_3$, and inorganic matter in the Mitchell Lake core.

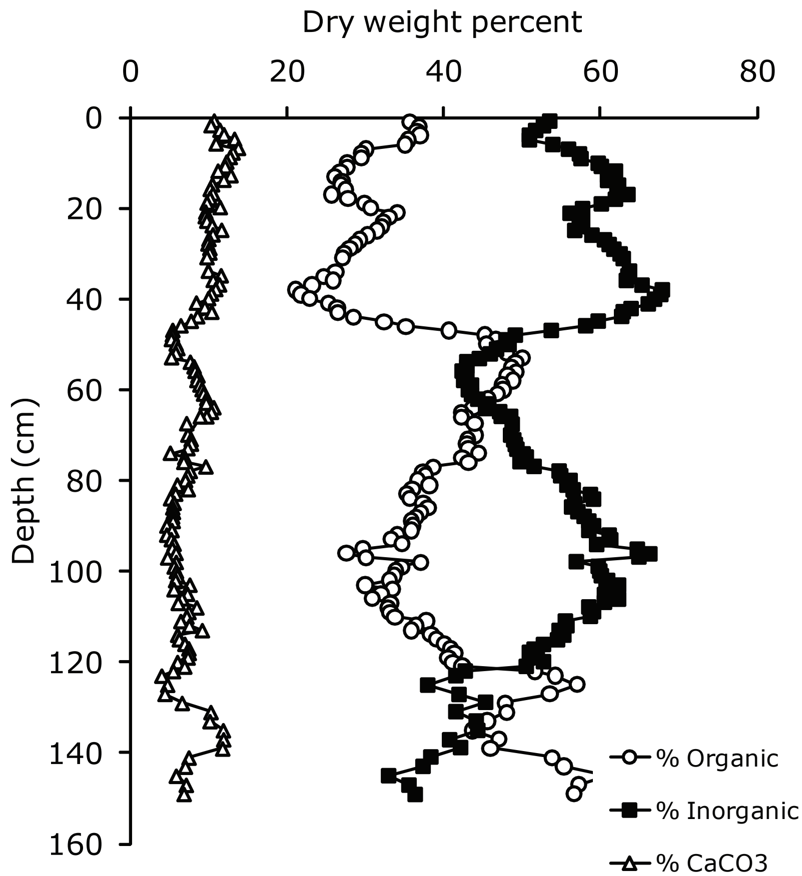

Figure 2. Percent dry weight of organic, $CaCO_3$, and inorganic matter in the Lotus Lake core.

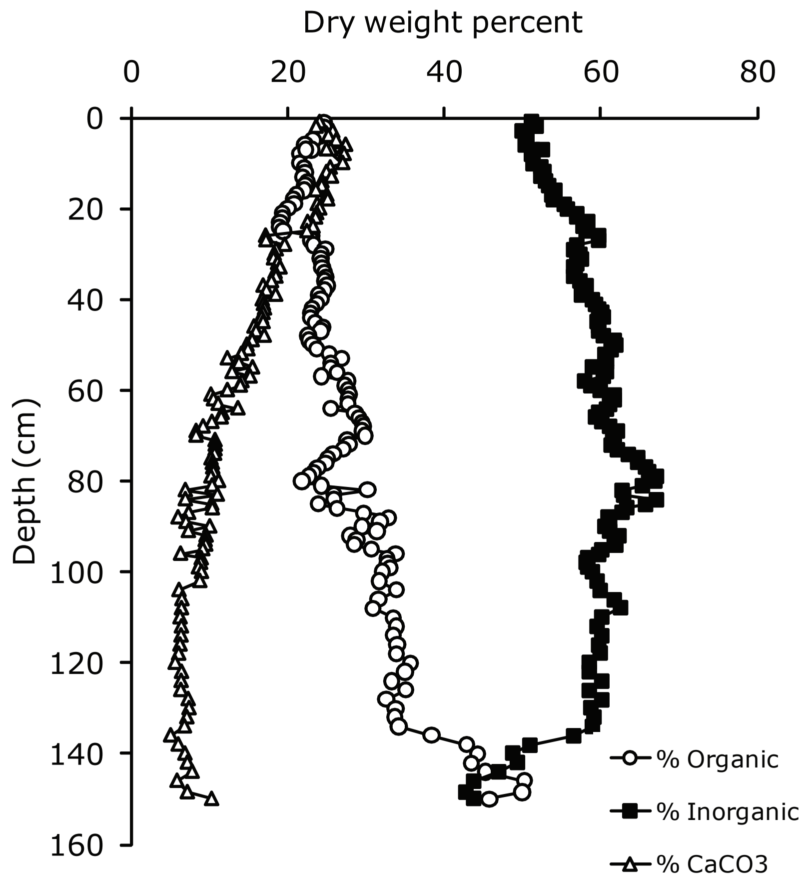

Figure 3. Percent dry weight of organic, $CaCO_3$, and inorganic matter in the Round Lake core.

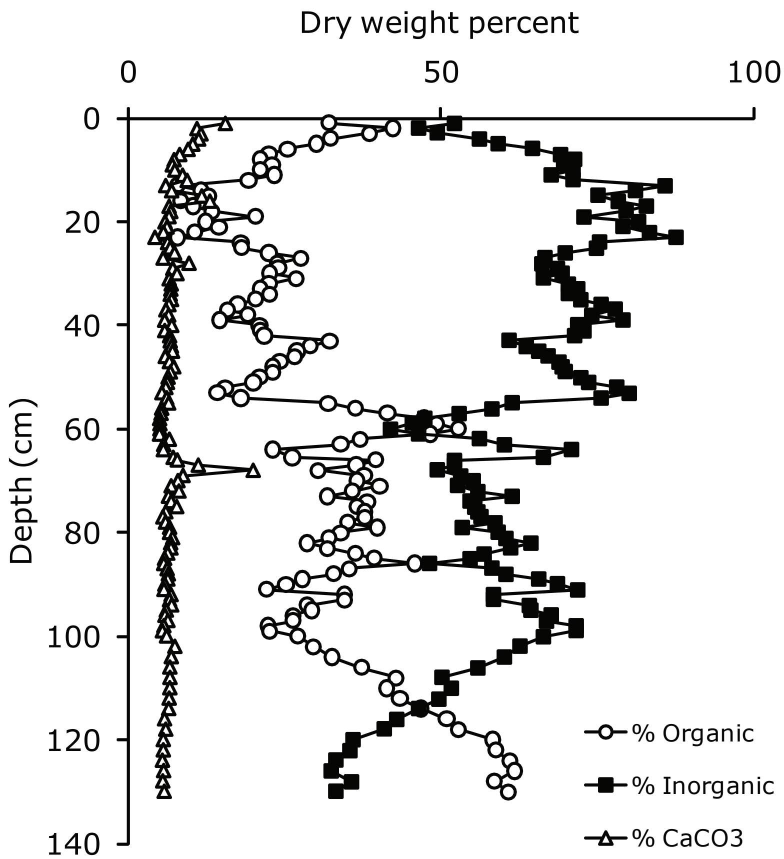

Figure 4. Unsupported lead-210 activity (a), lead-210 dating model (b), and sediment accumulation rate (c) for Mitchell Lake.

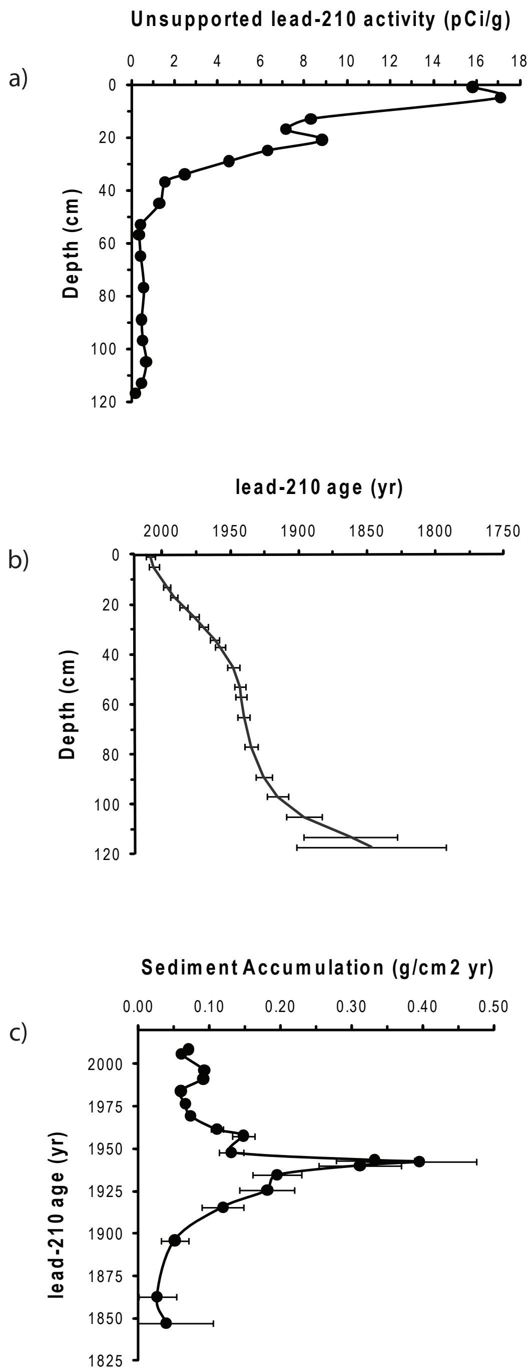

Figure 5. Unsupported lead-210 activity (a), lead-210 dating model (b), and sediment accumulation rate (c) for Lotus Lake.

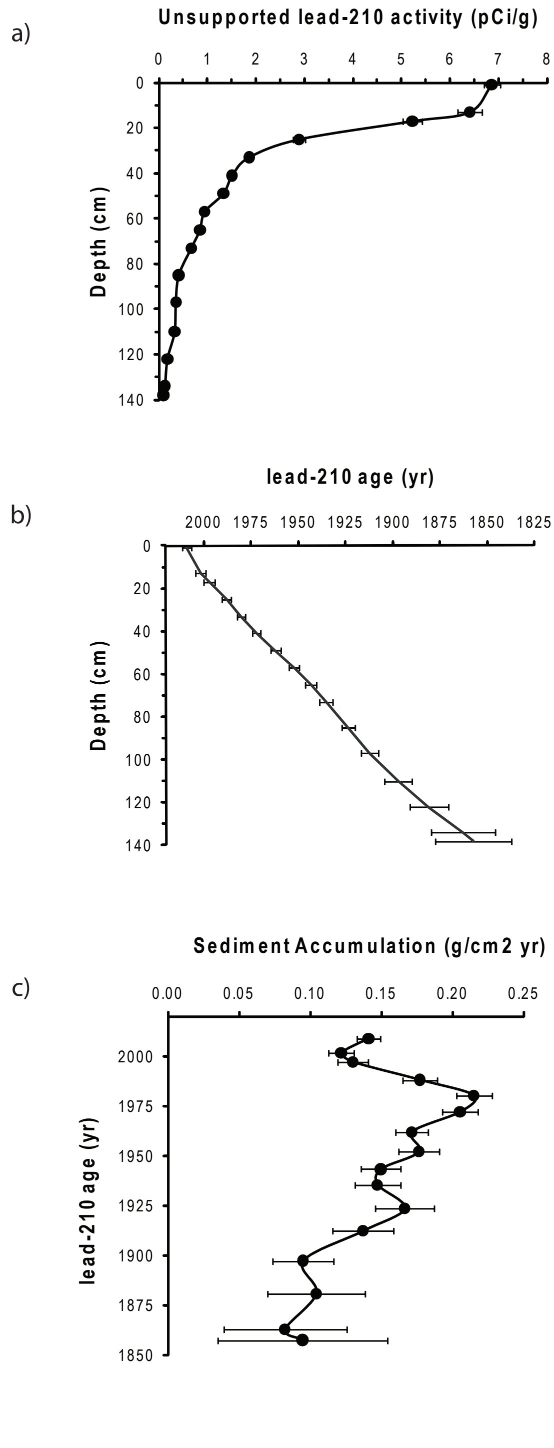

Figure 6. Unsupported lead-210 activity (a), lead-210 dating model (b), and sediment accumulation rate (c) for Round Lake.

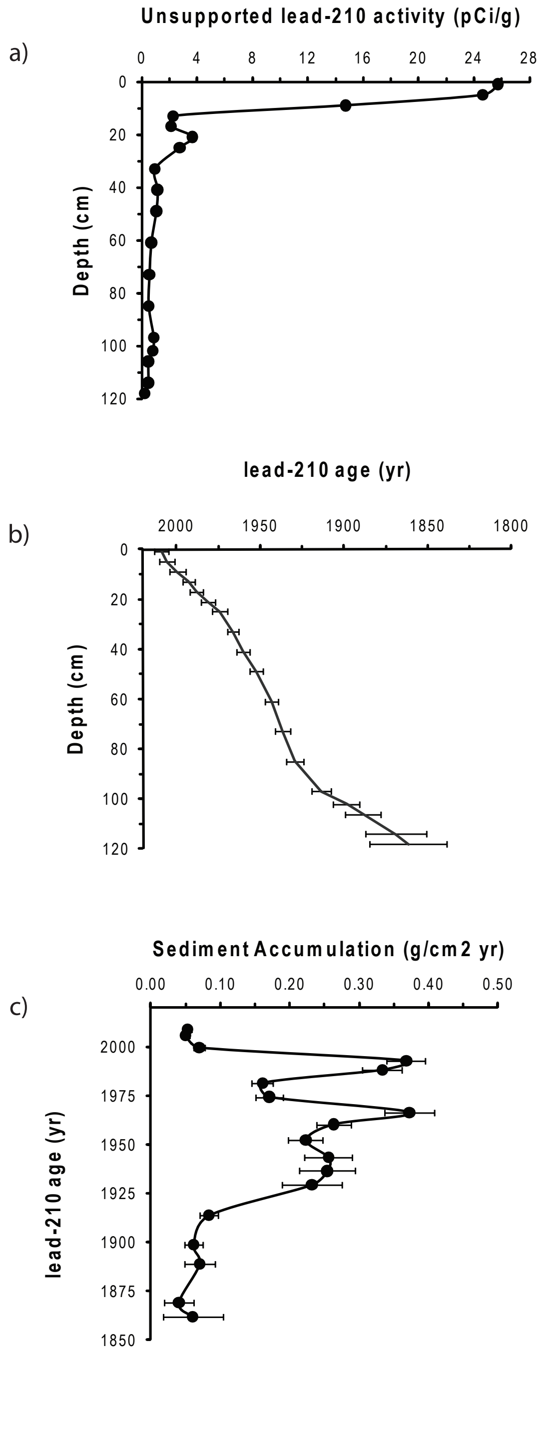

Figure 7. Correspondence analysis (CA) of diatom communities from Mitchell Lake. Lines illustrate the trajectory through time.

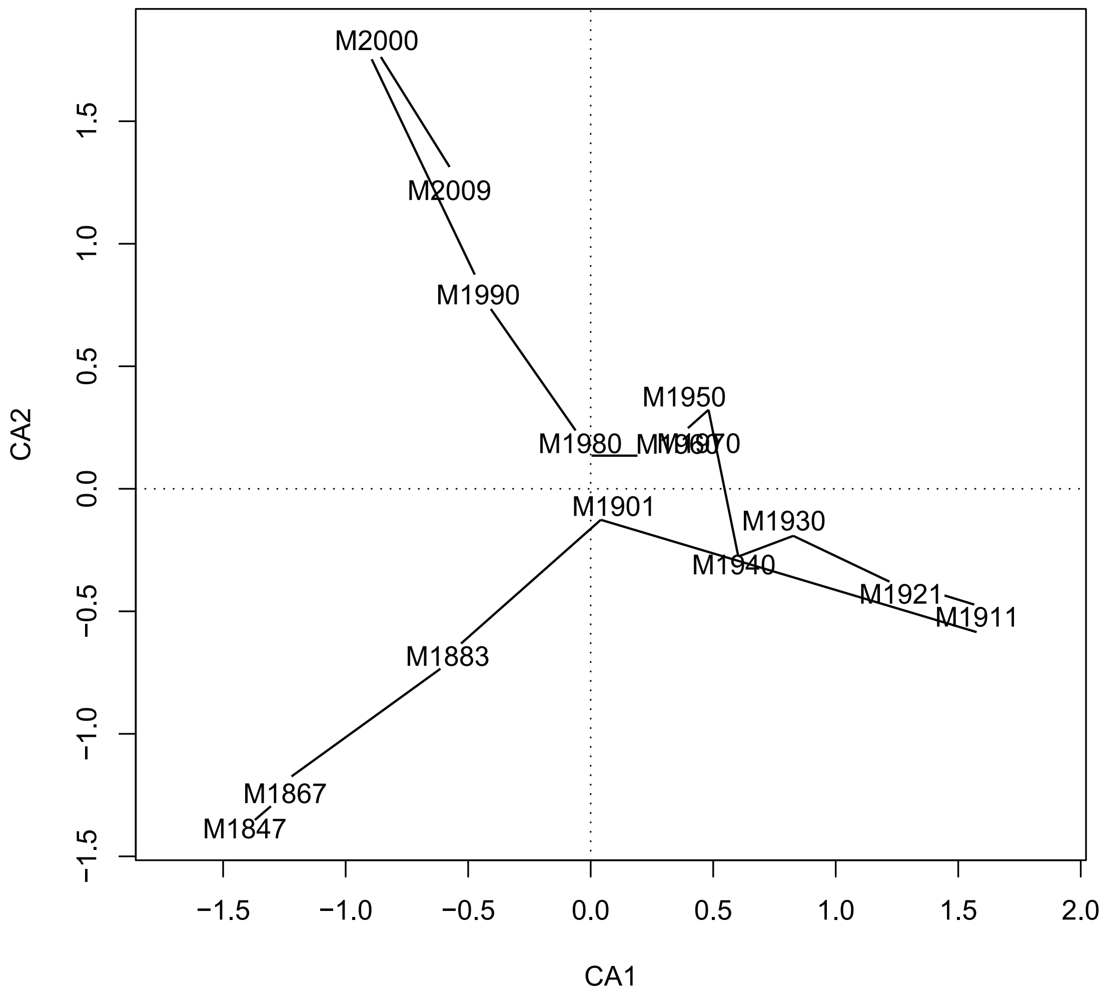

Figure 8. Downcore stratigraphy for predominant diatom taxa (greater than or equal to 5% relative abundance) in Mitchell Lake (1847-2009). Horizontal lines indicate the predominant grouping of samples based on a constrained cluster analysis.

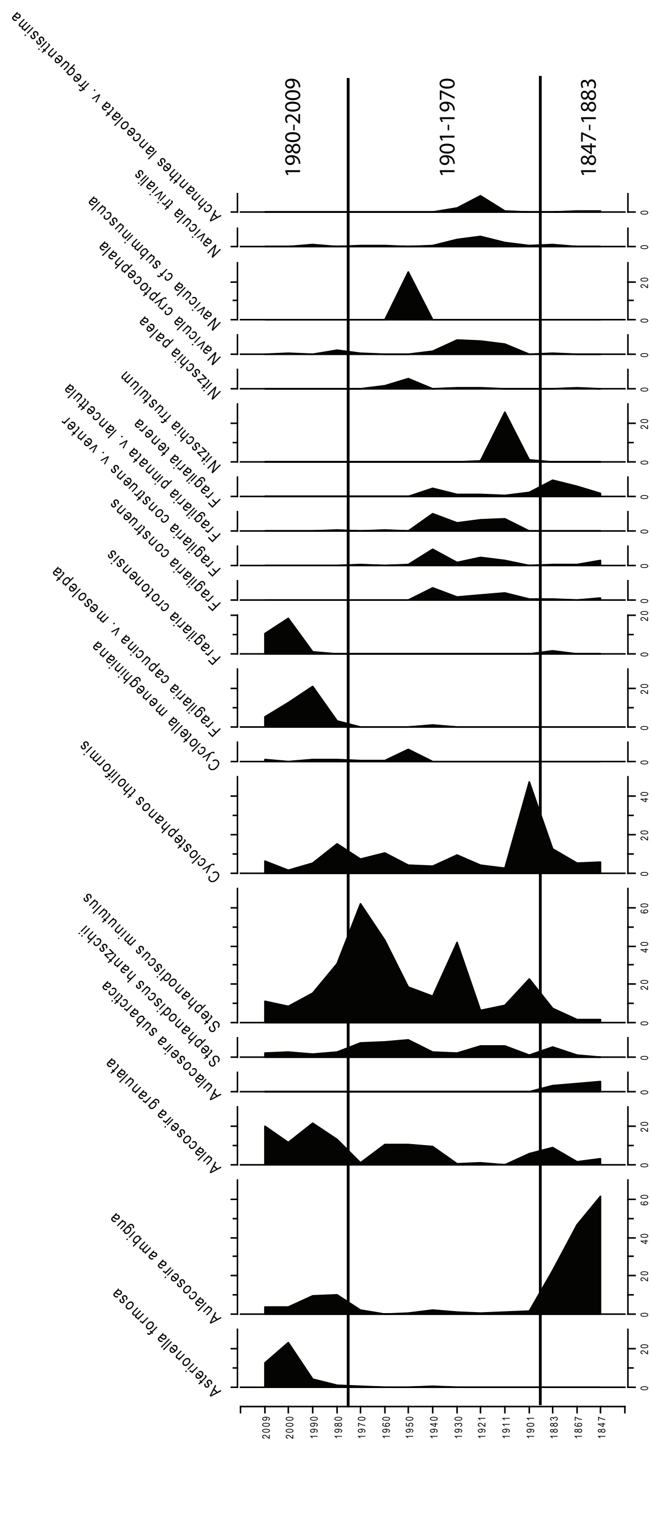

Figure 9. Detrended correspondence analysis (DCA) of diatom communities from Lotus Lake. Lines illustrate the trajectory through time.

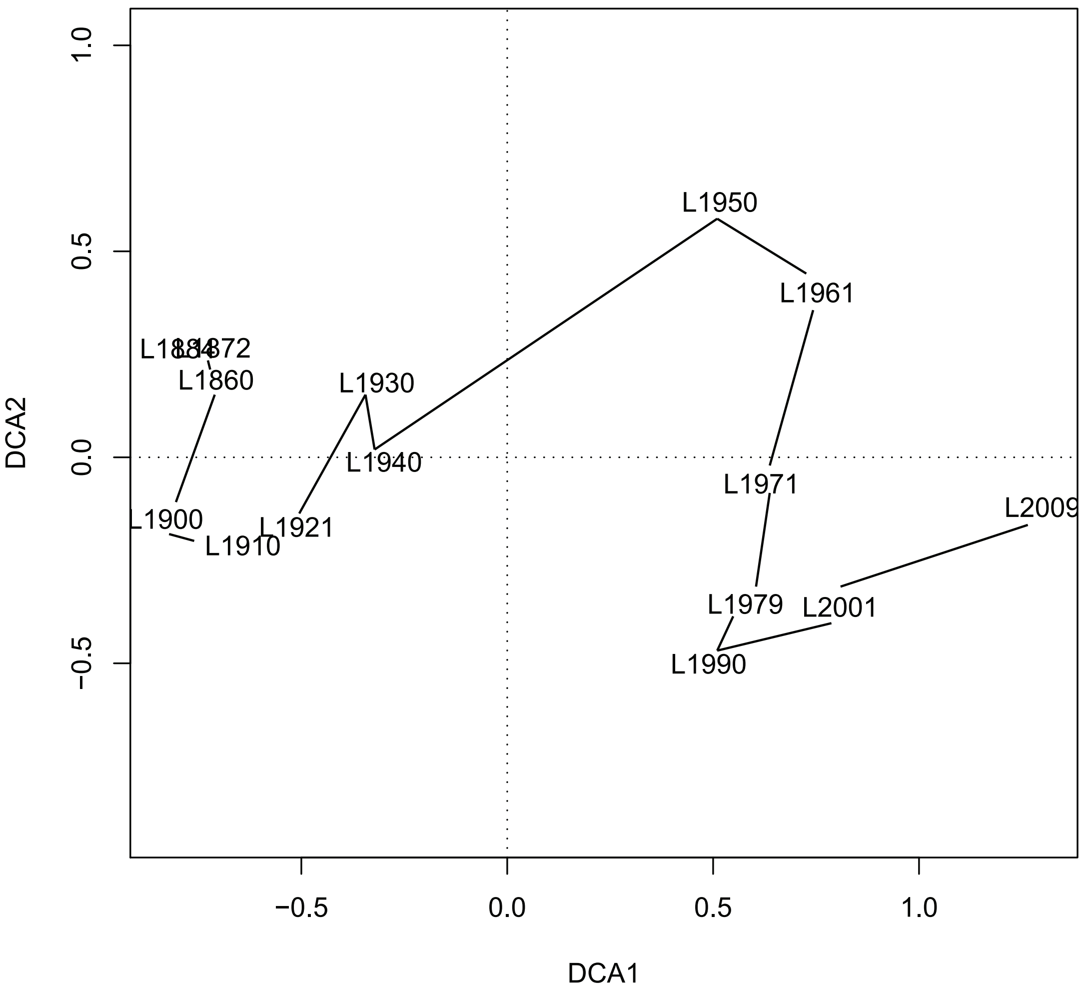

Figure 10. Downcore stratigraphy for predominant diatom taxa (greater than or equal to 5% relative abundance) in Lotus Lake (1860-2009). Horizontal line indicates the predominant grouping of samples based on a constrained cluster analysis.

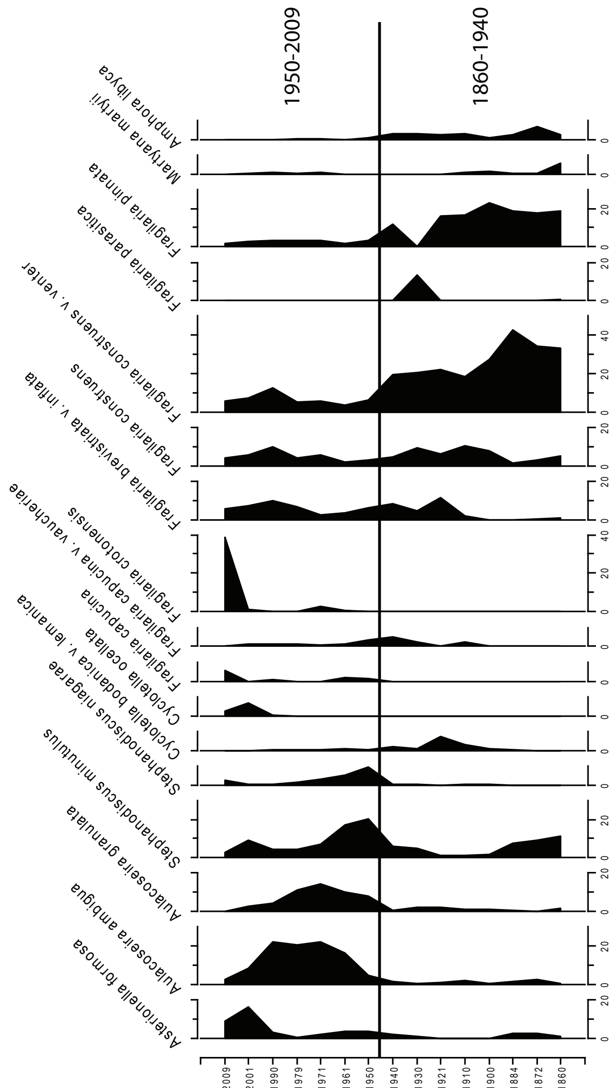

Figure 11. Correspondence analysis (CA) of diatom communities from Round Lake. Lines illustrate the trajectory through time.

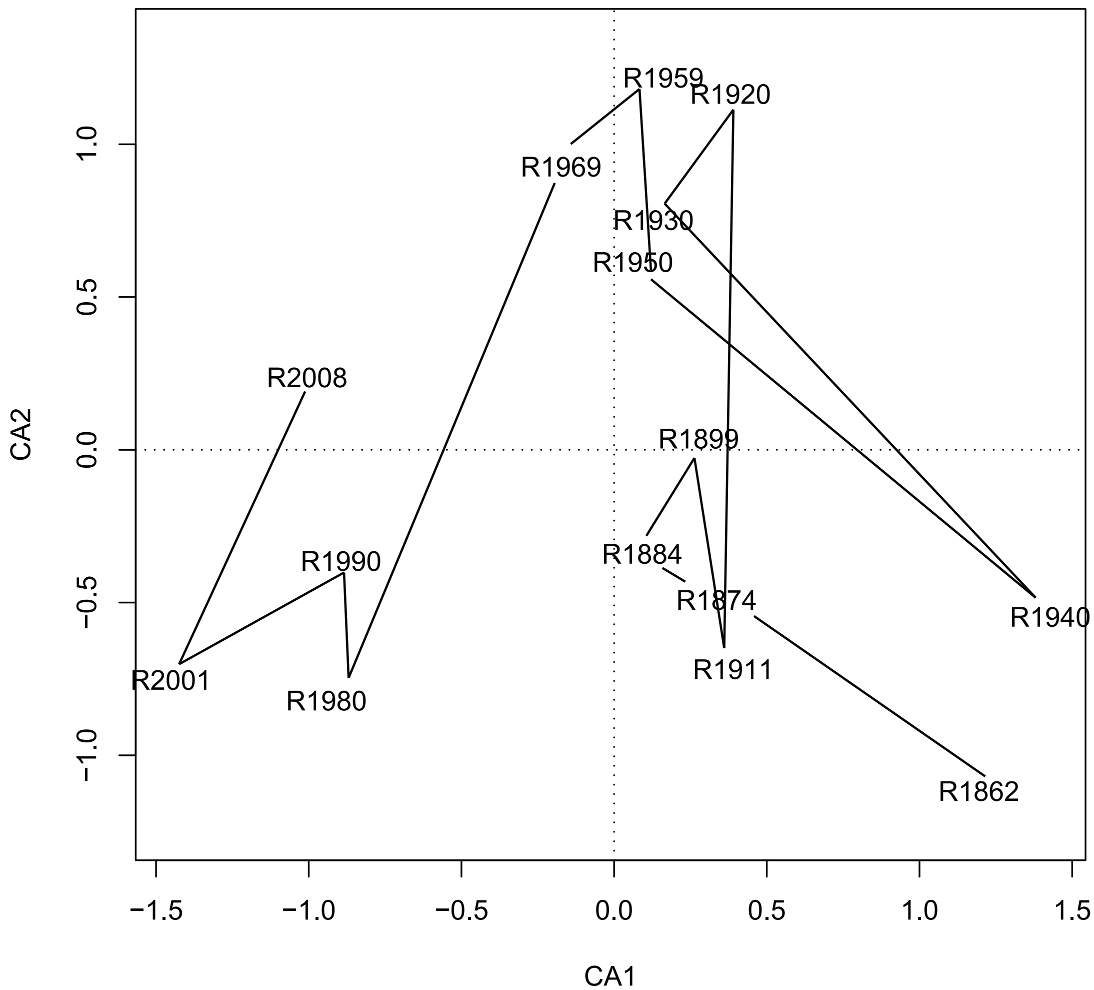

Figure 12. Downcore stratigraphy for predominant diatom taxa (greater than or equal to 5% relative abundance) in Round Lake (1862-2008). Horizontal lines indicate the predominant grouping of samples based on a constrained cluster analysis.

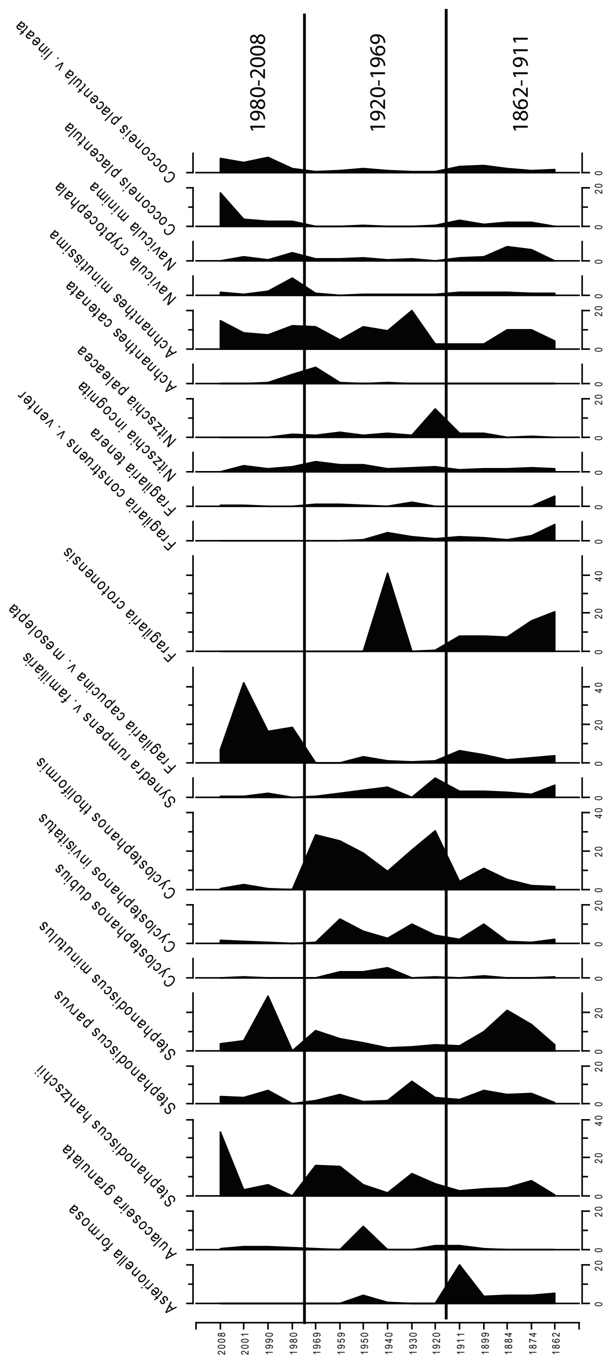

Figure 13. Diatom-inferred total phosphorus (TP) reconstruction for Mitchell Lake. Reconstruction is shown as log TP (right panel) and as backtransformed values in micrograms per liter (left panel).

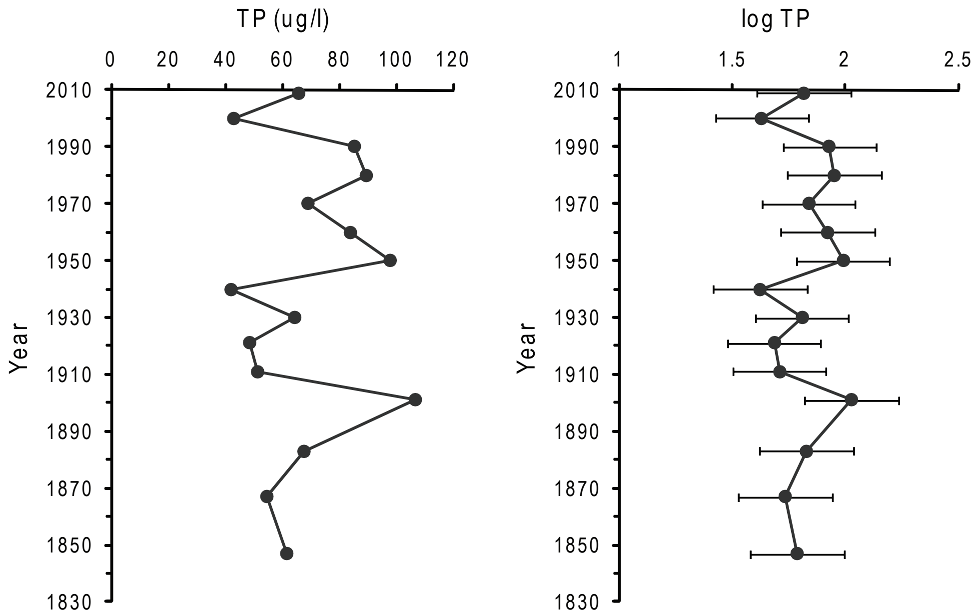

Figure 14. Diatom-inferred total phosphorus (TP) reconstruction for Lotus Lake. Reconstruction is shown as log TP (right panel) and as backtransformed values in micrograms per liter (left panel).

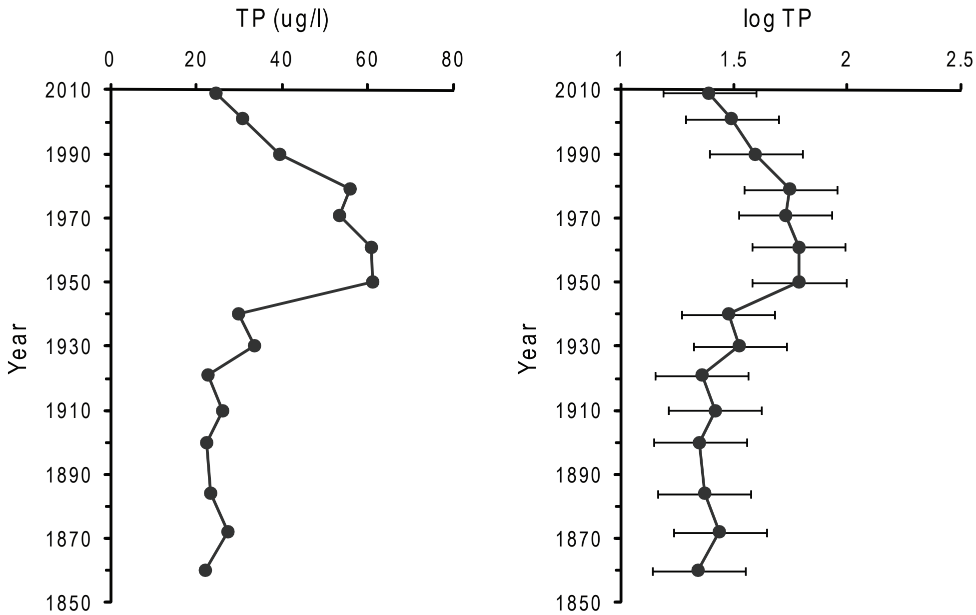

Figure 15. Diatom-inferred total phosphorus (TP) reconstruction for Round Lake. Reconstruction is shown as log TP (right panel) and as backtransformed values in micrograms per liter (left panel).